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Optimal Portfolio Allocation of Commodities for the Swedish Investor

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Abstract

Commodities have historically been seen as great diversifiers to stocks and bonds. Following the financialization in late 1990s and early 2000s this began to be questioned by previous research due to increasing correlations with the stock market, which has created a need for further research with in the field. This thesis does therefore seek to analyze the correlation among commodities and to determine the optimal commodity allocation from the perspective of a Swedish investor through studying the OMXS30GI and Bloomberg's Commodity Indices during the period 2002-2021. The results indicate no tendency of change in the correlations due to macroeconomic or financial changes, as indicated by previous studies. We can therefore not conclude that the alleged commodity benefits have been challenged. Additionally, the result also indicates that utilizing a sub-sector allocation strategy is more beneficial compared to investing in an aggregated commodity index, in this case the Bloomberg Commodity Index (BCOM), when only allowing long positions in the assets. During the sub-sector optimization, the results continuously found that an allocation in the Precious Metal sector and OMXS30GI is most beneficial for the Swedish investors. When allowing for short positions as well, all commodity sectors are a valuable contribution to the portfolio.

Keywords: *Optimal Portfolio Allocation into Commodities, OMXS30GI, Bloomberg Commodity Index (BCOM), Sub-Sectors, Sharpe Ratio, Swedish Investor, Financialization, Diversification, Hedge, Precious Metals, Inflation, Råvaror, Optimal Allokering, Ädelmetaller.*

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1. Introduction

Commodity investing has a long history that goes back for more than a century. They have traditionally been seen as risky instruments for hedging or speculation rather than as an asset class for strategic allocation and have thus played a minor role in the investment decisions of institutional asset managers and private investors (Demidova-Menzel & Heidhorn, 2007; Till, 2006). Starting with Keynes's writings on commodity futures trading in the early 1930s, and as further developments within the area have been done, the interest in commodities have increased significantly since then. Prior to the 2000s, precious metals along with other commodities were praised for being great assets for diversification as they showed hedging properties by being uncorrelated, or negatively correlated, with equities and bonds on average (Greer, 2000). Some previous research ascribe this increase in interest as a result of recent academic findings promoting strategic portfolio allocations into commodities and thus creating a new trend among investors, while others think that a rise of emerging markets as a new source of demand and the increase in financialization[1] following the 1990s, is the reason behind the significant increase in commodity holdings (Demidova-Menzel & Heidorn, 2007; Filiptchuk & Lindholm, 2011; Silvennoinen & Thorp, 2012). Consequently, the spotlight is being brought on commodities, changing the investor's views on the role of commodities in their portfolios after investors witnessed extreme price movements. These price movements were present in especially energy, precious and industrial metals, that most likely comes from the underinvestment in commodity production during the past years resulting in insufficient supply according to Demidova-Menzel and Heidorn (2007). This has led to commodities becoming highly relevant as an asset class worth conducting further research into.

This thesis has been inspired by the ongoing debate present in previous research within the commodity investing field. Several studies, such as Gorton and Rouwenhorst (2006), Erb and Harvey (2006) and Bodie and Rosansky (1980), among others, have shown promising investment characteristics of commodity futures in the years before the dot-com bubble in the early 2000s. Their papers all found that commodities had both higher returns and lower volatility, and thus outperforming stocks. They also found that commodities tended to have a negative correlation with stocks and bonds and a positive correlation with inflation,

[1] ***Financialization*** is the phenomenon of the quantitative and qualitative evolution of the financial sector and the role of finance during economic growth. The term can also be explained in forms of that a new epoch of capitalism has emerged, which has become more dominant than before. - Sawyer (2013).

especially unexpected inflation, and thus performing well when stocks and bonds did not. The overall implication of these findings is that it would be beneficial for the investor to include commodity futures in a traditional portfolio, previously consisting of only stocks and bonds, as it would result in a higher risk-adjusted return and greatly improve the portfolio. Jensen, Mercer, and Johnson (2002) found that precious and industrial metals, as well as agricultural futures contracts, offer the biggest diversification benefits for the investors. In addition, numerous studies, by Demidova-Menzel and Heidhorn (2007), Bodie and Rosansky (1980) and Tang and Xiong (2010), also showed that commodities have always exhibited low correlation among themselves historically. Since then, these alleged benefits and properties of commodities have been questioned by some researchers, causing a debate on the subject. These more recent studies, particularly by Silvennoinen and Thorp (2012) and Filiptchuk and Lindholm (2011), have found implications that the previously low, or even negative, correlation between commodity prices and stock or bond prices have deteriorated, as well as the correlations between commodity prices themselves. Filiptchuk and Lindholm (2011) also pondered if this was a temporary or permanent shift in the asset characteristics, and if the change would continue. This, along with the changing economic environment from the start of the 2000s, has been one of the inspirational sources for writing this thesis and wanting to update the literature with more recent data and expand the research within the field of commodity allocation.

This thesis will look at commodity investing from the perspective of portfolio optimization for the Swedish investor. The evaluation will be done through a strategic allocation strategy to commodities based on dividing the total asset class into sub-sectors. This due to the fact that previous studies have found individual commodities and commodity sub-sectors to be heterogeneous and therefore more beneficial rather than to invest in an aggregated index such as the Bloomberg Commodity Index (BCOM). The chosen sub-sectors are the following: Energy, Precious Metals, Industrial Metals, Agriculture and Livestock. This thesis expects to find an improved optimal allocation by investing in accordance with the sub-sector strategy.

2. Background

This section will explain why it's beneficial for the investor to invest in commodities and then carry on to describe the most common ways the investor could get exposure to the commodity markets, where the chosen and most beneficial alternative being commodity future indices.

Benefits of Investing into Commodities

There are several studies that conclude that there are numerous benefits of including commodities into a traditional portfolio that consists of only stocks and bonds. Research done by Greer (1978) suggested that a portfolio with a moderate use of collateralized[2] commodity futures earned higher and less volatile returns than an equity-only portfolio. Further research done by Bodie and Rosansky (1980), as well as Gorton and Rouwenhorst (2006) and Filiptchuk and Lindholm (2011), found that commodity futures also had equity-like returns. However, research by Demidova-Menzel and Heidorn (2007) and Cheung and Miu (2010) find that these commodity benefits only were evident in shorter and isolated time periods, while Erb and Harvey's study from 2006 found that the composition of the commodity index played a big part for the type of returns the index experienced.

Another common reason for the investor to add commodities to their portfolio is the diversification benefits that the commodities offer. These diversification benefits arise from commodities having negative or a low positive correlation with stocks and bonds, and can thus be classified as safe haven, hedge or diversifier respectively.[3] The precious metal gold, for example, has been known to show properties of being regarded as a safe haven, during market turmoil, but has in later years instead been characterized as a hedge due to increased correlation with the market (Li & Lucey, 2014). There has also been evidence to prove that investment into commodities, spread over different commodity sectors, includes allocation benefits that could otherwise not be retrieved by a stock or bond portfolio as there is a low correlation between the commodities themselves (Erb & Harvey, 2006). The reason behind this is that there are different demand and supply factors affecting the price behaviour for the

[2] A ***collateralized*** position in futures is a portfolio where the investor takes a long position in futures and simultaneously invests the same amount in government securities, for example Treasury bills. - Filiptchuk & Lindholm (2011).

[3] ***Hedge*** as an asset that is uncorrelated or negatively correlated with the comparable asset on average. While a ***diversifier*** is defined as an asset that is positively correlated but not completely correlated with the comparable asset on average. ***Safe haven*** is similar to the definition of hedge but during time periods of market turmoil. - Li & Lucey (2010).

individual commodities, so while one commodity underperforms another will outperform, which greatly improves the portfolio risk-adjusted return for the investor.

Regardless of the correlation level with equities, commodity futures have several other beneficial characteristics as well. Commodities futures have been known to have a positive skewed return distribution (while stocks showed a negative skewness) and tend to adjust with inflation, therefore demonstrating inflation hedging properties (Bodie & Rosansky, 1980; Erb & Harvey, 2006, Kazemi et al., 2009). Kazemi et al. (2009) later argue that the Energy sector has the greatest correlation with inflation. In addition, studies by Gorton and Rouwenhorst (2006), as well as by Greer (2005), demonstrates that commodities also hedge against unexpected inflation and changes in expected inflation. They explain it as when the inflation rises, bond prices tend to increase as a consequence of the increase in interest which, in turn, increases the company's cost of capital. This typically results in declines in stocks and bond valuations while being positive for the commodity sector due to the positive correlation with inflation, and the commodity valuation increases (Greer, 2000). Greer (2000), as well as Cheung and Miu (2010), claims that these inflation hedging properties that commodities possess are the most valuable characteristics of commodities in a portfolio.

Investing into Commodities

Although the term "commodities" include a vast majority of different goods, there are only a small number of them that are investable. The range of the different investable commodities available reflects the nature of the commodity itself as well as the market demand and supply for the commodities (Demidova-Menzel & Heidhorn, 2007). The type of access to the different commodities also depends on the market size of the specific commodity according to Pulvermacher (2005a).

The following paragraphs aims to mention the three main ways of gaining exposure to commodities: direct investment into the physical commodity itself, through investment into commodity related companies and investment into other commodity related investments, with a focus on commodity futures.

Physical Commodities

There are few commodities that allow direct exposure into the commodity itself as the possibility depends on the feasibility of the commodity storing. Demidova-Menzel and Heidorn (2007) explain that physical investments are more common within the sector of precious metals and agricultural products, while other commodities such as coal and uranium offer no possibility for physical investments due to storage difficulties. Pulvermacher (2005a) points out that direct investment into the physical commodity becomes less efficient from an optimal allocation perspective as a result of taking physical possession of the commodity is associated with high transaction costs combined with costs for storage and insurance.

Commodity Related Companies

A common alternative to get exposure to the commodity markets is to invest in commodity-related companies, either through stocks or bonds. This usually includes exploration and production companies, such as power plants, refineries or oil & gas exploration companies (Filiptchuk & Lindholm, 2011). However, according to the article by Kazemi et al. in 2009 investments into equity companies that specialize in particular commodity sectors generally only have moderate correlations with the commodity sector. They therefore concluded that this type of indirect commodity investment did not provide direct exposure to commodity price changes. Demidova-Menzel and Heidorn (2007) claims that the reason behind this was that the correlation between commodity-related companies and the overall equity market was much stronger compared to the relationship between the commodity-related companies and the actual commodity prices. On top of that, Demidova-Menzel and Heidorn (2007), together with Gorton and Rouwenhorst (2006), explain that the performance of a single company, in addition to the commodity price risk itself, is also sensitive to other types of risks and directly linked to the overall state of the economy and the managerial decisions of the companies. With all this combined, the commodity-related companies were unable to replicate the unique price-return behaviour of direct investment into commodities and the companies were therefore a weak substitute for their underlying commodity (Demidova-Menzel & Heidorn, 2007; Gorton & Rouwenhorst, 2006).

Commodity Futures

Commodity futures are the most common financial instruments in commodity markets. The futures are highly liquid exchange-traded standardized contracts that oblige the investor to buy or sell a definite amount of a specific commodity at a predetermined price and date

(Filiptchuk & Lindholm, 2011). They have the advantage of offering the investor exposure to the commodity price movements whilst also having low transaction costs at the same time. Consequently, commodity futures are commonly used as both a hedge against the products' or raw materials' price fluctuations and to lock in the prices for the products (Filiptchuk & Lindholm, 2011). Since the futures are allowing both long and short positions, depending on the investors market expectation, the future market is also a large market for speculators, who use the contracts to bet on the future spot price movements in hope of having a positive payoff without the inconvenience of taking physical delivery of the underlying commodity at the contract's expiration date (Demidova-Menzel & Heidhorn, 2007).

The exposure to commodities through the future market is quite different than investing through corporate securities according to Gorton and Rouwenhorst (2006). The economic function of stocks and bonds is to raise external wealth for the firm, making the risk the investor bears different from the risk the investor gets from commodity futures, since it's affected by the managerial decisions. The investor therefore bears the risk that the firm's cash flows might be low and are compensated for this by receiving a risk premium (which exceeds the risk-free rate). The purpose with commodity futures, in contrast, is not to raise external wealth for the company but to offer insurance for the future value of their outputs or inputs. The investor is hence compensated for the risk throughout the short-term price fluctuations (Gorton & Rouwenhorst, 2006).

Commodity Indices

Investment in a pre-designed commodity index, which is a basket of commodity future contracts, is a convenient way of getting exposure to the commodity futures without having to take physical delivery of the underlying commodity as the indices are rolled[4] on a regular basis. In addition, the investor also receives the benefits in form of the diversification return[5] that is obtained from investing into a diversified portfolio of commodity futures. By combining the returns of two, or more, portfolio constituents the variance can be reduced and

[4] The ***roll return*** is the change in the price of the nearby futures contract and arises from the rolling long futures positions forward through time, where the future price converges to the spot price. Typically, the current spot price is the futures contract with the shortest time to maturity. - Demidova-Menzel & Heidorn (2007).

[5] ***Diversification return*** is the difference between a portfolio's geometric return and the weighted average geometric return of the portfolio's constituents. "A positive diversification return means that the compound return of the portfolio will be greater than the weighted-average compound return of the individual portfolio constituents. The geometric average return of a portfolio will be positively affected by the reduction in variance." - Erb & Harvey (2006).

the portfolio obtains a diversification return. This gives the rebalanced portfolio a higher compounded return and thus a higher so-called Sharpe Ratio (Erb & Harvey, 2006).

As interest for commodity investment has grown, the number of available commodity indices has grown with it and many more have been introduced in the recent years. However, this thesis will focus on the Bloomberg Commodity Index (BCOM), which is among the most commonly used commodity future indexes in the market, and widely accepted as a benchmark according to Filiptchuk and Lindholm (2011). In 2021, the index held 23 commodity futures, spread over five sectors, of which nine are agricultural products, six are energy products, four are industrial metals, two are precious metals, and two are livestock products (Bloomberg, 2021).[6]

Each commodity index has its unique characteristics in terms of components, weightings, rolling methodology and rebalancing features. The Bloomberg Commodity Index is a passive long-only investment where the weights in the index are based on production and liquidity. Kazemi et al. (2009) write that the use of production data has the ability to underweight and underestimate the economic significance of storable commodities (e.g. gold) at the expense of relatively non-storable commodities (e.g. live cattle). It also underestimates the investment value that financial market participants place on certain commodities, according to Demidova-Menzel and Heidhorn (2007). For that reason, liquidity has twice as much influence as production data in deciding the overall weights in BCOM.

The Bloomberg Commodity Index is rebalanced[7] annually, although allowing for fluctuations outside the limits between the rebalancing, to restrict that no sub-sector constitutes more than 33% and no single commodity constitutes more than 15% of the total index. This ensures that the index remains diversified. The biggest individual commodity is therefore gold, which makes up 12,39% of the index, while the sub-sector Energy takes up 32,64% of the BCOM index (Bloomberg, 2021). The concept of re-weighting and rebalancing helps the index to smoothly respond to evolve to accommodate the changes in the markets according to Demidova-Menzel and Heidhorn (2007).

[6] A full composition of the sub-sectors can be seen in Appendix III.
[7] ***Annual rebalancing*** is when the index weights are adjusted to remain the same despite the change in price developments for the different individual commodities or sub-sectors.

3. Research Discussion

Section three describes the problem area and analysis. It will start by explaining the recent change in the economic environment that has been emerging since the early 2000s and then give an explanation as to why it might be more beneficial to invest with the sub-sector strategy.

Problem Description & Analysis

Since the dot-com bubble in 2001, the market conditions have been changed by the macroeconomic and financial environment. The market integration has increased, where emerging markets, especially China and India, have become prominent (Demidova-Menzel & Heidhorn, 2007). The definition of what is considered to be normal financial and monetary policies have also changed dramatically in recent years. Central banks have continued to grow their balance sheets through quantitative easing and as a result pushed interest rates down to historically low levels, in some cases even negative. This will substantially affect the value of the asset prices and the underlying risk of the financial markets.

After the emergence of financialization in the early 2000s, investors' methods for exposure towards commodities changed significantly, according to Greer (2000). It was previously common to invest in commodity related companies as means for exposure into the commodity sector since the commodity future market was not common amongst average investors and not many available commodity indices existed. But the creation of the Goldman Sachs Commodity Index (GSCI) and Bloomberg Commodity Index (BCOM), in the early 1990s led to significant changes in the commodity markets and more indices were created (Greer, 2000; Kazemi et al., 2009). The index providers also created indices with commodities futures as the underlying asset as well as introducing Exchange Traded Funds (ETFs) based on these indices. This, combined with earlier research on the many benefits of commodity investing, made for the perfect opportunity for commodities. The research done by Tang and Xiong (2010) expands on the effects of index investing in commodities, where their study is based on the Commodity Futures Trading Commission (CFTC) staff report (2008) and Masters (2008), which both concluded that investing in commodities through indices became very popular, finally catching the attention of investors, following the early 2000s recession. As interest for commodity investments grew so did the financialization of the markets. The increase in financialization resulted in significantly higher access for all types of investors to invest in commodities which led to more capital being allocated in commodities (Tang & Xiong, 2010). However, recent research has found that the large inflow of funds into commodity markets has also resulted in spillover effects from the stock and bond markets, and has especially affected the prices of the non-energy sectors to become increasingly more exposed to different economic shocks (Tang & Xiong, 2010). This in turn has led to commodity prices being gradually more positively correlated with other asset classes, such as equities or bonds and the US dollar exchange rate, than they were prior to the 2000s, thus losing the properties that are associated with being a hedge or safe haven (Baur & Lucey, 2010; Greer, 2000; Tang & Xiong, 2010).

Silvennoinen and Thorp (2012) showed that this increase in correlation was especially significant during high market stress, for example during the dot-com bubble in early 2000 and during the great financial crisis in the late 2000s. They argue that this partly can be explained by the increased asset integration in the market and the changing economic and financial environment. For this reason, it is therefore highly relevant to investigate commodities as an asset class, but also divided into different sub-sectors, to see how the change in the macroeconomic and financial environment has affected commodities and the investment into commodities.

The Theory of Sub-Sectors

Previous research is mostly positive to include commodities in a traditional portfolio. Research done by Erb and Harvey (2006), Gorton and Rouwenhorst (2006) and Filiptchuk and Lindholm (2011), as opposed to looking at the total asset class, also evaluated the properties of individual commodities and in sub-sectors. They concluded that the investor must look at the individual constituent parts of the portfolio and the correlation between the aggregated BCOM index and the different sub-sectors to understand where the aggregated index's returns were coming from. They also indicated that it might be more beneficial to invest into the different sub-indices rather than in the total BCOM index as the aggregated commodity index gives no possibility for the investor to impact the allocation weights in the different commodities, to ensure that the index remains diversified. However, this inability to impact the weights could have a major impact on the investor's optimal allocation.

Previous research by Filiptchuk and Lindholm (2011) indicates large diversification benefits when using commodity sub-sectors in portfolio optimization instead of a total commodity index. They found that the optimal allocation was 20% when utilizing sub-indices compared to only 8% when using an all-included index. This supports the suggested sub-sector strategy. This has given us the inspiration to divide the commodities into five sub-sectors and apply this approach on the portfolio optimization problem and compare this scenario to portfolio optimizations of the total asset class.

The chosen sub-sectors are the following: Energy, Precious Metals, Industrial Metals, Agricultural products and Livestock. The reasoning behind these chosen sub-sectors is the apparent differences between the commodities in terms of the physical characteristics and different factors driving the demand and supply for each commodity. A physical characteristic can be the storage possibilities for the commodity, where metals can be stored conveniently and over long periods of time, whereas livestock has a finite lifespan and cannot be stored in the same manner as metals. Furthermore, agricultural commodities are often sensitive to the pattern of harvests, while the demand for energy related commodities increases as the weather gets colder, which affects the spot and future prices of the commodity (Filiptchuk &Lindholm, 2011; Li & Lucey, 2014). It is therefore vital to understand the underlying key factors that drive the commodity's performance, since they in turn affect the demand and supply and result in very different price and correlation behaviours for the commodities as argued by Demidova-Menzel and Heidhorn (2007) and Greer (2000). The above mentioned reasons do therefore suggest that there are many benefits for an investor who is looking to find an optimal portfolio with commodities to look at the sub-sector strategy.

4. Purpose & Research Question

Section four describes the purpose, research questions and the limitations of the thesis.

Purpose

The aim of this paper is twofold. First, to update previous research by including more recent data. Second, to analyze how different commodities and sub-sectors can be used in portfolio optimization from a Swedish investor's standpoint within this new macroeconomic and financial setting which has minted the years since the start of the twenty-first century. Our goal is to find the optimal portfolio allocation of commodities measured by Sharpe Ratio and to analyze how commodity diversification of a standard portfolio can increase the Sharpe Ratio. The thesis will also analyze if commodities, as indicated from previous studies following the great financial crisis, have lost some of their low correlation characteristics as well as testing if it is more efficient to invest in different sub-sectors rather than to invest in the aggregated BCOM index by itself.

Research Questions

The thesis aims to answer the following research questions:

- Are commodities beneficial for optimal portfolio allocation from the perspective of a Swedish investor and what is the optimal allocation in BCOM respective the sub-indices in that case?
- Can we, as suggested from previous research, see results that point towards the fact that it is more beneficial to invest according to the sub-sector strategy rather than to invest into the aggregated commodity index?
- Has the correlation between commodities and stocks/bonds, and between the different commodities themselves, changed since the emergence of the new economic setting by the start of the twenty-first century?

Limits of the Thesis

This thesis will not consider macroeconomic cycles as means for adjusting the optimal allocation. Seasonal or inflation effects for the commodities will also not be considered in the optimal allocation. The reader should keep in mind that the thesis is written from the perspective of a Swedish investor and is thus not fully applicable for non-Swedish investors due to currency and instrument differences.

5. Theoretical Framework

Section five aims to give an overview of the different theoretical frameworks that the thesis builds upon. The different theories presented, the Modern Portfolio Theory, the Efficient Frontier and the Sharpe Ratio, are the core parts of portfolio optimization theory.

Modern Portfolio Theory and Diversification

It has long been known that investors need to diversify their investments to reduce the risk in their portfolios, but a formal framework on how this could be done did not exist until 1952 when Harry M. Markowitz published his theory on "Portfolio Selection" in the Journal of Finance. He is the main creator behind Modern Portfolio Theory and Mean Variance Analysis, although the theory has been reinforced and improved further by several other econometricians later. The Mean-Variance Portfolio Theory explains how rational investors can reduce their risk through diversification while still maximizing their returns at this given level of risk. The fundamentals of the theory build on the concept that the mean is a good measure for the expected return, and that the variance, or rather the standard deviation, is a good measure for the risk for the different investments (Markowitz, 1952).

In his paper, Markowitz assumes that investors are risk-averse, meaning that when choosing which financial assets to invest in, between two otherwise identical investments, the investor will prefer the asset with the lowest risk (variance). Consequently, investors expect higher returns when they invest in riskier investments. Markowitz (1952) showed that individual assets might fluctuate more in price, indicating increased risk, but by adding several investments together in a portfolio the investor could reduce this volatility due to lower correlation between the different investments, and thus create a more preferable return. He also suggests that the investor should hold assets in different industries since these stocks are less correlated with one another and a fall in the price of one investment would, hence, be compensated by a rise in another. Markowitz calls this risk idiosyncratic risk since it is connected to an individual security and the volatility could thus be diversified away by adding it to a portfolio together with other securities. But when all idiosyncratic risk has been diversified away there is still so-called systematic risk left, which is associated with the entire market, as in the event of temporary market shocks, and hence can't be diversified away.

The Efficient Frontier and Capital Market Line

The theory could further be explained by the concept of the Efficient Frontier, also developed by Markowitz in his article from 1952, which is a set of portfolios that offers the lowest risk for a given level of return or the highest expected return for a given level of risk, making these portfolios the most optimal investments. The Efficient Frontier line is a curved line due to diminishing marginal returns by taking on more risk. The rational investor should always pick a portfolio on this Efficient Frontier curve since these portfolios are the most optimal choice in the matter of maximizing the expected returns while taking the investors risk-aversion into consideration. If the chosen portfolio is not on the line, then the investor could always find a more efficient portfolio offering either the same return, but with lower risk, or the same risk but with higher return. Later on, the concept of the Capital Market Line was added to the Efficient Frontier. The Capital Market Line is a straight line, originating from the expected return of the risk-free rate on the y-axis, and that combines the risk-free interest rate with Markowitz's set of efficient portfolios. Including the risk-free investment is preferable since its variance is zero, and the security will therefore be uncorrelated with the other risky securities and would hence result in a slightly more diversified portfolio.

The point where the Capital Market Line tangents the Efficient Frontier the investor could find a portfolio consisting of both the risk-free investment and a well-diversified combination of risky assets called the Market Portfolio. This Market Portfolio would, according to Markowitz (1952), be the absolute most efficient portfolio due to the fact that the relationship between risk and return would be the biggest.

Sharpe Ratio

William Sharpe published an article 1966, in which he classified the inclination of the Capital Market Line, which is measured by the Sharpe Ratio. A steeper line, indicated by a higher Sharpe Ratio for the portfolio, would be more profitable due to the fact that the return would be bigger in relation to the risk. In other words, the Sharpe Ratio represents the additional amount of return the investor receives per unit of increased risk, or how well the investor is compensated for taking on the additional risk above the risk-free security, by measuring the excess return for the investment, dividing it with the risk. The Sharpe Ratio does therefore make it easier for the investor to compare different portfolios in order to choose the most optimal one (Sharpe, 1966).

6. Data

The following section will describe the process of the data collection, the chosen securities and why they were chosen as proxies for the corresponding portfolio.

Data Collection

In their study from 2006, Gorton and Rouwenhorst evaluated the performance of indices consisting of spot and future prices. They showed that during the period 1959-2004 an equally-weighted total return index of commodity futures outperformed an equally-weighted portfolio of spot commodities, which both were adjusted for inflation. Thus, commodity future markets offered higher returns than the spot markets during the period. The retrieved data does therefore consist of the closing price of the total return index for BCOM and each of its sub-indices on a monthly basis over the time period 1st of January 2002 until 31st of March 2021 to estimate the performance of the chosen variables. The total return index includes both dividend and coupon payments of the assets. The data for the different indices and the exchange rates for the corresponding months were collected from Bloomberg, while the data for the risk-free rate[8] was retrieved from the Swedish Riksbank in the form of a 10-year government bond.

Table 1: General Information about the Chosen Securities

OMXS30GI	OMX Stockholm 30 GI Index contains the 30 most liquid stocks traded on NASDAQ Stockholm and their total return. Due to the constraint on the number of included companies, the index has maintained perfect liquidity which has led to it being recognized as the leading index reflecting the Swedish stock market. The prices are in SEK.
BCOM	Launched in 1998, Bloomberg Commodity Index Total Return (*BCOMTR*) is one of the leading indices tracking the global commodity markets. The index tracks future prices on the largest 23 physical commodities spread over five sub-sectors with the objective of maintaining weights which reflect each commodity's global financial significance and liquidity. The index has unique diversification compared with comparable commodity indices, which usually have large stakes in oil.
Precious Metals	Bloomberg's Precious Metals Total Return Index (*BCOMPRTR*) tracks the total return of future prices for gold and silver and is quoted in USD. This index is meant to give a fair representation of the precious metal sector yield.
Industrial Metals	Bloomberg's Industrial Metals Total Return Index (*BCOMINTR*) consists of and tracks the future prices on aluminum, copper, nickel and zinc with the purpose of displaying the sector's return. The prices are quoted in USD.

[8] The ***risk-free rate*** is defined as the expected rate of return for the 10-year Swedish government bond.
- Damodaran (2008).

Agriculture	Bloomberg's Agriculture Total Return Index (*BCOMAGTR*) includes future contract prices of coffee, corn, cotton, several different soybeans, sugar and wheat with the purpose of portraying the total return of the agricultural commodity sector in USD.
Energy	Bloomberg's Energy Group Total Return Index (*BCOMENTR*) contains prices on future contracts of oil, gasoline and natural gases to represent developments in the energy sector. The prices are quoted in USD.
Livestock	Bloomberg's Livestock Total Return Index (*BCOMLITR*), is a sub-index to the *BCOMTR* much like previous sub-indices. The livestock index contains future contract prices on lean hogs and live cattle to represent the livestock commodity sector. The prices are quoted in USD.

Choice of Proxies

Standard Portfolio Benchmark

The OMXS30GI Index was chosen as it is the index that would most accurately reflect the average Swedish investor's portfolio holdings in the Swedish stock market. The choice is also supported by the domestic home bias as described by Gehrig (1993). Furthermore, due to its established dominance, numerous financial products are based on the index such as derivatives, warrants, mutual funds and exchange traded funds (ETFs). Launched in 2006 the index is similar to OMXS30, the most traded index on the Swedish Stock Exchange. The difference between the two indices is that OMXS30GI includes reinvested dividends for the stocks, which OMXS30 does not. OMXS30GI is therefore a realistic and fair choice for the Swedish standard portfolio without any considerable large assumptions of the average Swedish investor's portfolio holdings. This makes the thesis more practically feasible.

Commodity Benchmark

As indicated by previous research, there is a large spread in choice for the commodity benchmark, where some have created their own equally-weighted index while others have used the S&P Goldman Sachs Commodity Index (GSCI) or Bloomberg Commodity Index.

Originally launched in 1998 as Dow Jones-AIG Commodity Index and later renamed to its current name in 2014, Bloomberg Commodity Index (BCOM) is one of the most established of its kind. Due to its constraints on exposure for individual sectors and commodities, the index is overall more diversified than the S&P Goldman Sachs Commodity Index (GSCI), which is significantly more exposed to the energy sector than BCOM is (Bloomberg, 2021).

This thesis uses BCOM as a benchmark for commodity markets due to the fact that it has been a prominent proxy for commodities in previous studies and the fact that the choice of using commodity indices results in a wider range of commodities that are otherwise not easily accessible by investing in each commodity by itself. BCOM will be used as a benchmark when comparing the two big indexes OMXS30GI and BCOM in Portfolio 2, while the different sub-sector indices will be used in the sub-sector strategy in Portfolio 3, where a comparison between OMXS30GI and the sub-sectors will be made.

Sub-Sector Benchmark

The use of a sub-sector strategy is inspired by the master thesis done by Filiptchuk and Lindholm (2011). It's also in alignment with previously aggregated research which has indicated that investments in total commodity indices are typically not optimal. The reason for this is the apparent differences between the commodities, as mentioned previously, and as these core differences in the commodities results in different demand and supply and hence affects the spot and future prices for each commodity. It is therefore of great importance to understand the ulterior key factors that drive the demand and supply for the commodities. This thesis does therefore seek to analyze the different characteristics of the sub-sectors Precious Metals, Industrial Metals, Energy, Agriculture and Livestock that can be seen in Table 1.

Unlike the master thesis by Filiptchuk and Lindholm (2011), this thesis will not include Bloomberg's Softs Commodity Index since this is a sub-index to the Bloomberg's Agriculture Index. The inclusion of the sub-sector Softs would lead to significantly high correlation between the Soft Index and Agriculture Index and would therefore give misleading results. If one would include the Softs Index, then one should exclude the BCOM sub-index Agriculture, and instead also include the Bloomberg's Grains Index as well as the individual commodities of Soybean Meal Index and Soybean Oil Index, since these together could replace the entire Agriculture Index.

By choosing indices that are possible to invest in through products tracking the indices, in this case the OMXS30GI Index and Bloomberg's Commodity Index and its sub-indices, the results will be more practically applicable and not only theoretical as it would be if an own index were to be constructed.

Risk-free Rate Benchmark

In his article, Damodaran (2008) argues what kind of instrument that can be used as a risk-free rate. According to Damodaran, the risk-free rate has to be unbiased and without the risk of default in order to be classified and accepted as a risk-free interest rate. If the risk-free rate is both unbiased and default free it gives results that can be compared with both other instruments as well as over time, which is crucial. The risk-free rate is unbiased if it is not subject to any macroeconomic views of the investor. If it is biased, then Damodaran explains that the final results will be interwoven with the investor's macroeconomic views and it would be impossible to distinguish the results of each effect. In addition, if the risk-free rate includes any type of default risk, which he points out often is the case for many local currency government bond rates in many emerging markets, per definition it cannot be classified as a risk-free rate. After stating this, he concludes that a long-term local government bond should be used as a measure for the risk-free rate if such a long-term government bond in the local currency, in which the valuation wishes to be done in (in this case Swedish kronor), exists and if the local government can be considered default free. This is why the use of a 10-year Swedish government bond is chosen as a proxy for the risk-free rate in the calculations of the thesis, instead of a government bond with a shorter time to maturity or another instrument.

7. Methodology

This section will start by giving a description of the sub-sector strategy, the applied method for portfolio optimization and performance evaluation in order to determine the optimal portfolio allocation for each asset. It will then carry on to describe the different robust tests that will be done in order to test the sensitivity of the results.

Sub-Sector Strategy

In the sub-sector optimization strategy, the Bloomberg Commodity Index is divided into sub-indices that together constitute the complete Bloomberg Commodity Index. A comparison between three different portfolios will be made. The first portfolio consists of the standard portfolio OMXS30GI. By adding the total commodity index BCOM in Portfolio 2, a comparison between the two can be made to see if adding commodities as a group is beneficial. By then replacing BCOM with its underlying sub-indices in Portfolio 3, a conclusion can be drawn to see if it's more beneficial to invest in commodities according to the sub-sector strategy. The rationale behind this stems from previous research which has found that it is more optimal to include subindices or commodities themselves instead of a large all-included index such as Bloomberg Commodity Index (Filiptchuk & Lindholm, 2011).

Below is a visual demonstration over the three different portfolios which will be used in the portfolio optimizations to show how the comparisons will be made:

Portfolio 1:	***Portfolio 2:***	***Portfolio 3:***
Standard portfolio	Standard portfolio + BCOM Index	Standard portfolio + BCOM Sub-Indices

Portfolio Optimization and Mean-Variance Analysis

The retrieved monthly closing prices are collected and converted to Swedish kronor (SEK) to account for the exchange rate risk. Then geometric monthly returns are calculated, and later annualized, to be used in the portfolio optimization calculations of the assets. Based on these geometric monthly returns, necessary statistical parameters can be calculated through a Mean-Variance analysis. These include the expected return, standard deviation, or volatility, correlation and covariances for each asset, along with other needed parameters such as the risk-free rate. The risk-free rate has been calculated from a 10-year government bond, where the average over the yearly risk-free rate has been calculated for each time period. [9]

By using Mean-Variance Analysis (MVA) by Markowitz, this thesis gains two advantages. First, by using the chosen method, which is widely established within the field of finance, together with the securities chosen from the Swedish investor's perspective the thesis becomes more practicable instead of being purely theoretical. Second, the MVA method can uniquely incorporate policy and budget constraints, which is one of the greatest advantages of using the method. By altering the budget constraint of $\sum w_i = 1$ and the portfolio weights, which are given by $w_i (i = 1, 2,...,N)$, the unique policy constraints can be found (Klabbers, 2017).

Based on the Swedish investor's preferences and in accordance with previously studies by Klabbers (2017) and Hernvall and Härnestav (2018), the following two conditions have been included to limit the optimization problem:

1. *Allowing no short-selling*
   By setting $w_i > 0$, which limits the weights to be positive, only long positions in the assets are allowed. This is due to the fact that short sales often are difficult and risky. Short selling is typically not common amongst the average investor, even if it occurs.

2. *A budget constraint of* $\sum w_i = 1$
   This budget constraint ensures that the weights of all assets in the portfolio sums up to one, which implies that all wealth has to be invested into some security, and is not allowed to be kept in cash or invested in the risk-free rate. With the constraint of $\sum w_i < 1$ not all wealth has to be invested in the different securities. With $\sum w_i > 1$ more than the initial wealth is invested, meaning that the investor borrows capital to invest in the different securities.

All the previous mentioned variables and constraints are then used to find the most optimal allocation for each risky portfolio through portfolio optimization and construction of the Efficient Frontier in order to maximize the Sharpe Ratio. The optimizations are performed for

[9] The calculations for the different necessary parameters and the MVA equation can be seen in Appendix I and Appendix II.

the standard portfolio, as well as for the two suggested strategies over the time period 2002-2021. The first strategy compares the standard portfolio, OMXS30GI, with the aggregated Bloomberg Commodity Index. The second strategy, the sub-sector strategy, divides the commodities in BCOM into its underlying sub-sectors, which replaces the aggregated BCOM index, expecting to find an improved strategic allocation to the commodities. The portfolio optimizations for each portfolio will also be performed on smaller six-year sub-periods, and compared with the total time period, as previous research by Demidova-Menzel and Heidorn (2007) and Cheung and Miu (2010) indicate that the benefits will be larger in shorter periods.

Assumptions of the Chosen Method

The Mean Variance Optimization Method is based on the assumption that all investors are risk averse, meaning that they prefer the lowest risk given a return. Furthermore, the method also assumes a normal return-distribution and perfect and efficient markets without any taxes or transaction costs. The approach is viewed as a single-period approach, where the objective of the investor is utility maximization at the end of the single holding period. Even perfect competition is assumed for the capital markets, which hinders the investor from influencing the price and hence the return distribution. The advantage with this assumption is that the only two decision parameters that need to be considered to characterize the distribution is the return (expected return) and the risk (variance, or rather the standard deviation) (Demidova-Menzel & Heidorn, 2007). However, Silvennoinen and Thorp (2012) argues that this is far from the truth, especially in commodity markets. The model has furthermore been exposed to some critics as the model makes assumptions that in many ways do not match the reality. For example, the calculated parameters used in the model are based on the expected values of that parameter, calculated from historical data. Due to this aspect the expected values might fail to incorporate important aspect, such as the new macroeconomic and financial changes that the world economies exhibit. The reader should therefore keep in mind that the thesis is based on historical data, and that results are thus only completely accurate for the chosen time period, and does not guarantee the same future outcome as these expectations don’t necessarily gives the correct forecast. Another critique against the model is that the mathematical risk measurement might not reflect the investor’s true risk-preferences. The model assumes that abnormally high returns are as risky as the abnormally low returns since the variance is a systematic measure. But in reality, investors are often described as being more concerned with losses than with gains, as originated in the loss-aversion theory by Kahneman and Tversky (1979), making the concept of risk asymmetric in nature. Despite the critique, Modern Portfolio Theory is still a widely accepted model that are frequently used in optimal portfolio allocation calculations. The thesis does therefore not see any problem with using this model to determine the optimal allocation.

Robust test

By conducting robustness tests, in addition to the original portfolio optimization simulation, the sensitivity of the given results is tested as the fundamental assumptions change. It also tests whether the final results are constant for investors with other investment preferences. This is done by changing the given policy and budget constraints previously assumed in hope that the Sharpe Ratio will increase, indicating that a more optimal portfolio can be obtained. Two different robust tests will be conducted to see if the results are in alignment for investors with other preferences.

Firstly, the policy constraint of only allowing long positions in the assets is removed. This means that short-selling now is permitted and the weights are allowed to be negative in the optimal portfolio allocation as opposed to before. This could be a valuable insight for the investor who wants to engage in short-selling. Research by Erb and Harvey (2006) indicates that a portfolio consisting of both long and short positions will have a higher return, and hence also a higher Sharpe Ratio, provided that the investor follows the trend, than a portfolio otherwise consisting of only long positions.

$$-1 < w_i < 1$$

The second robust test aims to see the effect on the portfolio weights when leverage is introduced. This will be done by allowing the investor to borrow, or allowing the use of credit, up to 15% of the portfolio value. This is due to the fact that leverage has increased in popularity in recent years for average investors as they want to utilize the low interest rates and new types of brokers. The value of 15% is a chosen arbitrary level. It is large enough to give room for alternative allocation without being unreasonable and involves too much additional risk so that the results remain applicable in practice for a Swedish investor. The level of 15% leverage is also a reasonable level as the method focuses on long-term investing and that long term investors are assumed to be risk averse and would not utilize a substantially higher level of leverage for longer periods of time.

$$0 < \sum w_i < 1{,}15$$

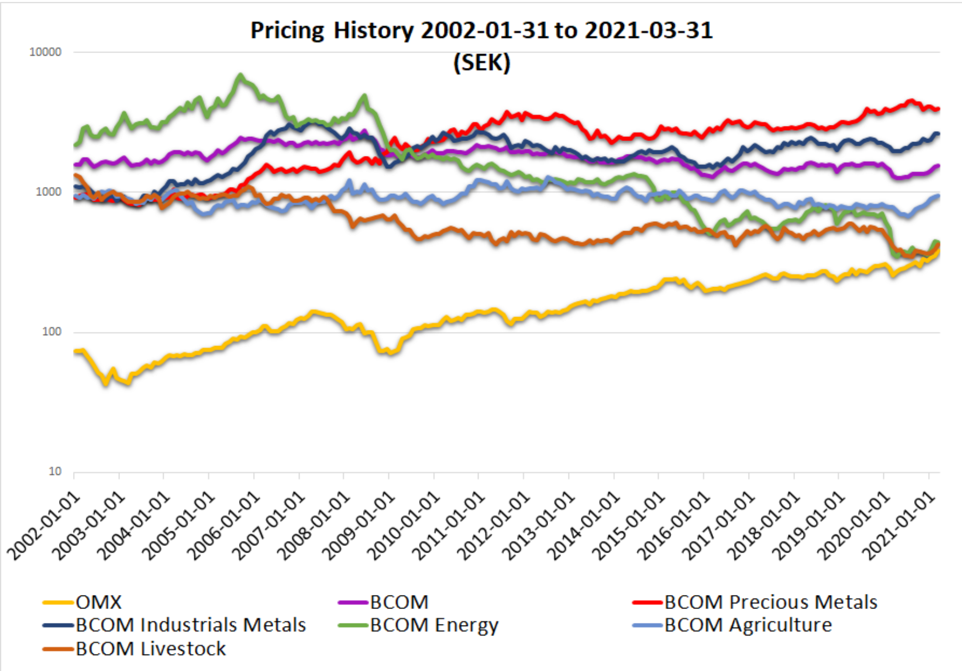
8. Empirical Findings & Analysis

The following section analyzes the dataset and compares the findings to literature on the subject. It both updates the previous research by testing the persistence of the alleged commodity benefits and evaluates whether the results from the suggested approaches are feasible, and are thus useful for future applications. It also states the optimal weights in each asset class for the three different commodity allocation scenarios.

Commodity Properties

Figure 1 below displays the index's historical prices for the commodities as a total asset class, but also divided into the sub-sectors. The different commodity indices are adjusted for the USD/SEK exchange rate for the corresponding period so that they might be compared with the historical prices for the standard portfolio, OMXS30GI. During the observed time period, the Swedish SEK has appreciated its value towards the US dollar which the Bloomberg instruments are denominated in. This implies that the commodity allocation has not been increased due to the depreciation effect on the analyzed currency.

Figure 1: Indexed Historical Prices of the Standard Portfolio and Commodities (Jan 2002 - Mar 2021) - Risk free rate: 2,435%



Comment: *Important to note is that the y-axis in the chart is logarithmic to demonstrate relative price developments to make the comparison easier.*

The intuition behind dividing the commodity benchmark, BCOM, into smaller sectors is due to the fundamental differences between the sub-sectors, as mentioned previously. Looking at the price developments, although the different sub-sectors perform quite similarly, there are some discrepancies in performance. Especially the Energy sector stands out as being very volatile, even though the volatility had its peak in the earlier years of the studied period and around the great financial crisis of 2008, and has since then decreased tremendously in both price and volatility. The prices of Precious Metals, on the other hand, have increased significantly since the great recession without exhibiting too much volatility in comparison to the other sub-sectors. Whereas, the sub-sectors Livestock and Agriculture come across as having much less varied price movements and the prices remaining at around the same levels during the entire studied period. With this in mind, the performance of the various sub-sectors is not necessarily captured by the aggregated BCOM index, although it has performed as an average for the different sub-sectors over the period. This suggests that there might be substantial advantages to a portfolio where the commodity allocation is based on each sub-sectors individual performance, rather than a portfolio consisting of pre-determined weights of each sub-sector and individual commodity. Even the descriptive statistics below in Table 2 reinforces the substantial differences between the sub-sectors.

Table 2: Descriptive Statistics for Standard Portfolio and Commodities, both as the Total Asset Class and the Sub-Sectors (Jan 2002 - Mar 2021) - Risk free rate: 2,435%

Descriptive Statistics	OMXS30GI	BCOM	Precious	Industrial	Energy	Agriculture	Livestock
Average return	9,04%	-0,06%	7,84%	4,68%	-8,02%	0,04%	-5,83%
STD	18,02%	13,47%	18,52%	18,54%	28,28%	17,99%	19,31%
Skewness (Adj. to SEK)	-0,624	-0,327	-0,057	-0,103	-0,692	-0,107	-0,203
Skewness (USD)		-0,883	-0,366	-0,536	-0,753	-0,197	-0,408

Comment: *The calculations are performed on annualized monthly returns over the entire time period. The skewness calculations are however performed on monthly returns and are not annualized.*

As can be seen, Precious and Industrial Metals significantly outperformed Agriculture and especially Energy and Livestock, which both have had immoderate standard deviations and a negative average return. They have thus been unprofitable investments for the given time period of 2002-2021. Since the Energy sub-sector is one of the largest allocations within the aggregated BCOM index, it has impacted BCOM’s return significantly. Nevertheless, the standard deviation for BCOM is lower than compared to the individual sub-sectors. This is probably due to the composition of the BCOM index, causing internal diversification.

The stock index OMXS30GI has performed the best during the studied time period with a clear positive trend and an average standard deviation among the alternatives. The similarity in the average return and volatility between OMXS30GI and Precious Metals index is worth noting and should lead to positive diversification effects by combining the two. Furthermore, the sub-sector Precious Metals qualifies of being a hedge due to the negative correlation with OMXS30GI as seen in Table 3. Another thing worth noting is that the skewness of the distributions is negative for all securities, even if they become less negative when adjusted for the exchange rate. These results differ from previous research, which states that commodities are especially attractive due to their positive skewness and low correlations (Gorton & Rouwenhorst, 2006). However, a direct comparison between our results and previous studies is somewhat difficult since our calculations focus on the Swedish investor, and have thus been adjusted for the exchange rate. The results are further incomparable due to the chosen time periods differing and/or some previous research is conducted on either differently constructed sub-sectors or on individual commodities. The closest sub-sector study in literature is the one conducted by Lindholm and Filiptchuk (2011), who analyze similar sub-sectors over the period 1991 to 2011. They have, however, chosen to include the sub-sector Softs which we have excluded due to the fact that it is a sub-sector to Agriculture. Our results are similar with theirs in terms of the standard deviations for the assets, with just minor differences, but differ substantially in terms of the average return during the period, where our results are lower.

Table 3: Correlation Matrix for OMXS30GI with BCOM and between Sub-Sectors (Jan 2002 - Mar 2021)

Correlation Matrix	OMXS30GI	BCOM	Precious	Industrial	Energy	Agriculture	Livestock
OMXS30GI	**1,00**	0,17	-0,07	0,37	0,12	0,04	0,06
BCOM	0,17	**1,00**	0,40	0,57	0,81	0,54	0,26
Precious Metals	-0,07	0,40	**1,00**	0,24	0,10	0,20	0,05
Industrial Metals	0,37	0,57	0,24	**1,00**	0,30	0,19	0,09
Energy	0,12	0,81	0,10	0,30	**1,00**	0,09	0,17
Agriculture	0,04	0,54	0,20	0,19	0,09	**1,00**	0,08
Livestock	0,06	0,26	0,05	0,09	0,17	0,08	**1,00**

Comment: *The correlations[10] are performed on monthly returns over the entire time period.*

[10] A ***correlation*** coefficient = +1 means that the single investments are perfectly positively correlated and the prices of the investment develop in the same direction. In this case, no diversification effects exist. A correlation coefficient = 0 means that the single investments are absolutely independent from each other. Therefore, a risk reduction through diversification is possible (risk spreading). A correlation coefficient = -1 means a completely negative correlation. The prices of the investments always develop in the opposite direction from each other. As a result, maximal diversification effects are possible (risk compensation, hedging).
- Demidova-Menzel & Heidorn (2007)

The correlations matrix that can be seen in Table 3 depicts the correlation between all chosen variables. As can be seen, BCOM and the different sub-sectors are highly correlated, while they exhibit lower correlations on average with the stock benchmark OMXS30GI and within the different sub-sectors. Important to note is the lack of negatively correlated assets. In the chosen time period only one asset, Precious Metals, is on average negatively correlated with the standard portfolio during the period 2002-2021. This means that precious metals, in this case gold and silver, can still be considered as a hedge since it fulfills the definition of being negatively or uncorrelated with the market on average. The rest of the assets are slightly positively correlated with the market on average, and can thus still be great diversifiers for the portfolio. In addition, the correlation between the individual sub-sectors is still relatively low, and has decreased on average in comparison with Lindholm and Filiptchuk correlations from 2011, which further justifies the sub-sector strategy. The only sub-sector that stands out is Livestock which has remained exactly the same or increased somewhat on average, in accordance to Lindholm and Filiptchuk's results.

Sub-Period Analysis

In attempts to further explain the given results, and with implications from previous studies, an additional study of the correlation and descriptive statistics over six-year periods will be conducted to see the developments throughout the years for all five sub-sectors. The last three months, Jan-March of 2021, have however been removed in the sub-periods to get more fair and consistent results across the different sub-periods.

Table 4: Average Return and Standard Deviation for OMXS30GI, BCOM and the Subsectors for 6-year Periods (Jan 2002 - Mar 2021)

Average return	2002-2007	2008-2013	2014-2020	2002-2021	*Average STD*	2002-2007	2008-2013	2014-2020	2002-2021
OMXS30GI	8,57%	7,35%	8,66%	**9,04%**	**OMXS30GI**	19,72%	20,00%	14,56%	**18,02%**
BCOM	7,07%	-6,01%	-2,45%	**-0,06%**	**BCOM**	13,89%	14,19%	12,20%	**13,47%**
Precious	10,62%	5,16%	8,72%	**7,84%**	**Precious**	15,72%	24,25%	15,15%	**18,52%**
Industrial	14,17%	-5,57%	4,40%	**4,68%**	**Industrial**	18,93%	20,79%	15,75%	**18,54%**
Energy	7,69%	-15,93%	-16,12%	**-8,02%**	**Energy**	32,17%	22,81%	28,53%	**28,28%**
Agriculture	1,46%	-2,34%	-0,88%	**0,04%**	**Agriculture**	17,76%	20,61%	15,94%	**17,99%**
Livestock	-9,72%	-8,16%	-2,77%	**-5,83%**	**Livestock**	19,84%	18,78%	19,36%	**19,31%**

Comment: *The calculations are performed on annualized monthly returns over the entire time period.*

The first six-year period, 2002-2007, and especially the year 2002 and 2003, experienced the reminiscence of the dot-com bubble, the 9/11 attacks and the fall from Enron and other internet companies from the years before. This crested major instability and investor confidence suffered, which especially affected indices. The remainder of the period is characterized by emerging markets and an increase in the demand for commodities, low interest rates and quantitative easing by banks leading to a bull run, encouraging high risk lending and borrowing (Sands, 2016). The results of these macroeconomic impacts can also be seen in the average return for the different securities as most of them are positive, and much higher than the remaining two time periods. During these years the 2000s energy crisis was also present, which started in 2003 and had its peak in 2008. The effects of this can be seen in the standard deviation of Energy, which is substantially higher than the remaining standard deviations for the other sub-sectors. The high volatility of the Energy sector throughout the years could also be due to that the demand for energy can’t be foreseen when the commodity is produced, resulting in the demand and supply for the commodity usually being out of balance as the commodity is difficult to store (Demidova-Menzel & Heidorn, 2007). The same can be said for the sub-sector Livestock.

The second six-year period is characterized by the global financial crisis in 2008-2009, with the American housing bubble and the banking crisis, which affected the entire world economy. The crisis sparked a global recession for many years with increased unemployment and decreased general trusts in institutions and their solvency (Evans-Pritchard, 2007; Williams, 2010; Wolfers, 2011). This ultimately contributed to the Eurozone debt crisis which started in late 2009, where several European countries were unable to repay their government debt which led to a balance of payment crisis. Several countries had to be bailed out in the following years, with the last one receiving its bailout program in 2012 (Copelovitch et al., 2016; Frieden & Walter, 2017; Kenton & Boyle, 2020). The influence of these crises is ever so present in the results as most of the securities exhibit negative average returns during this period, with only OMXS30GI and Precious Metals demonstrating positive returns on average. The standard deviation has increased, in most cases, in the corresponding period. However, the standard deviation for Energy and Livestock has instead decreased. This can also be explained by the fact that the correlation between the two sub-sectors have increased throughout the years.

Most of these European countries were able to regain market access and exit their bailout programs in 2014 as their economies had improved. After this, and in the last six-year period, the market conditions recovered to their original stable levels. The economy was once again blooming, with just some minor market declines throughout the years of 2014 to 2019 such as Brexit and the China-US trade war slowing the economy, making the period on average less volatile with less negative average returns and lower standard deviations than the previous period. Only Energy and Livestock moves in the opposite direction as the rest, and has thus increased during the years 2014-2020.

The last year of this six-year period, 2020, the Covid-19 pandemic broke out which contributed to the 2020 Stock Market Crash between February until April. The crash followed a decade of economic prosperity and sustained global growth after recovery from the financial crisis of 2007-2008, with global unemployment at its historically lowest levels and the degree of wealth and material comfort generally increasing around the world. This crash was a result of the lockdowns, and in conjunction with the introduction of the US Federal Reserve’s fourth round of quantitative easing in 2019 (The Federal Reserve, 2021). This might be the reason why the results are in conflict with one another, where some of the average returns are increasing while others have decreased in comparison to the last six-year period. This crash also brought a drastic fall in the oil prices and destabilization and collapse of the energy industry, which can be seen in both the average return for the sub-sector and in Figure 1 during the period.

Table 5: OMXS30GI Correlation with BCOM and the Subsectors for 6-year Periods (Jan 2002 - Mar 2021)

Corr OMXS30GI	**2002-2007**	**2008-2013**	**2014-2020**	**2002-2021**
BCOM	0,04	0,12	0,38	**0,17**
Precious	0,04	-0,18	0,00	**-0,07**
Industrial	0,45	0,36	0,30	**0,37**
Energy	-0,16	0,14	0,45	**0,12**
Agriculture	0,14	-0,02	-0,02	**0,04**
Livestock	0,15	-0,22	0,22	**0,06**

Corr BCOM	**2002-2007**	**2008-2013**	**2014-2020**	**2002-2021**
OMXS30GI	0,04	0,12	0,38	**0,17**
Precious	0,40	0,48	0,46	**0,28**
Industrial	0,57	0,43	0,61	**0,63**
Energy	0,81	0,83	0,77	**0,83**
Agriculture	0,54	0,34	0,72	**0,53**
Livestock	0,26	0,25	0,11	**0,39**

Corr Precious	**2002-2007**	**2008-2013**	**2014-2020**	**2002-2021**
Industrial	0,35	0,19	0,27	**0,24**
Energy	0,26	0,11	-0,02	**0,10**
Agriculture	0,25	0,28	0,04	**0,20**
Livestock	0,06	0,13	-0,03	**0,05**

Corr Industrial	**2002-2007**	**2008-2013**	**2014-2020**	**2002-2021**
Precious	0,35	0,19	0,27	**0,24**
Energy	0,14	0,33	0,42	**0,30**
Agriculture	0,08	0,28	0,15	**0,19**
Livestock	0,15	-0,05	0,18	**0,09**

Corr Energy	**2002-2007**	**2008-2013**	**2014-2020**	**2002-2021**
Precious	0,26	0,11	-0,02	**0,10**
Industrial	0,14	0,33	0,42	**0,30**
Agriculture	-0,12	0,27	0,12	**0,09**
Livestock	0,02	0,13	0,33	**0,17**

Corr Agriculture	**2002-2007**	**2008-2013**	**2014-2020**	**2002-2021**
Precious	0,25	0,28	0,04	**0,20**
Industrial	0,08	0,28	0,15	**0,19**
Energy	-0,12	0,27	0,12	**0,09**
Livestock	0,19	-0,10	0,13	**0,08**

Corr Livestock	**2002-2007**	**2008-2013**	**2014-2020**	**2002-2021**
Precious	0,06	0,13	-0,03	**0,05**
Industrial	0,15	-0,05	0,18	**0,09**
Energy	0,02	0,13	0,33	**0,17**
Agriculture	0,19	-0,10	0,13	**0,08**

Comment: *The correlations are performed on monthly returns.*

The previously mentioned results can be seen in the correlation as well. By looking at OMXS30GI correlation with the different commodities, both BCOM and the different sub-sectors, it can be seen that the results are inconsistent with each other. While OMXS30GI correlation with the sub-sectors Industrial Metals and Agriculture has decreased, its correlation with the Energy sector and BCOM increased. The major increase in correlation between OMXS30GI and BCOM is most likely due to the increased correlation between OMXS30GI and Energy, as this sub-sector is one of the largest allocations in BCOM and has hence a much higher influence on BCOM than the other sub-sectors. This could give somewhat deceptive results in the portfolio optimizations as this skews the results.

Furthermore, OMXS30GI correlation with Precious Metals and Livestock has experienced a rather big downturn in the years 2008-2013 to later increase during the bull run of 2014-2020. Precious Metals is the only sub-sector that has had a negative average correlation over the whole time period, indicating that Precious Metals is the only sub-sector that can be classified as a hedge during the period 2002-2021, while the other still can be classified as effective diversifiers to varying degrees.

The same inconsistent results can be seen in the correlation between BCOM with the rest of the securities, as well as in the correlation between the different sub-sectors. BCOM's correlation with Precious Metals, and the correlation between the Energy sub-sector and Livestock and Industrial Metals has increased. Whereas BCOM's correlation with Livestock and the correlation between Energy and Precious Metals has decreased. However, most of the correlations between the commodities are ambiguous as they move in opposite directions throughout the years.

The research done by Lindholm and Filipthuck (2011) found a noticeable increase in the correlations between all sub-sectors and stocks, where their last period of 2006-2011 showed substantially higher correlations than in previous periods. They refer to research done by Tang and Xiong (2010) and Krugman (2008), where Tang and Xiong (2010) explains this development is due to increased financialization, where Krugman (2008) instead argues that that the rise in correlations occurred due to a universal increased demand for all commodities from emerging markets rather than the financialization during the period. Lindholm and Filipthuck (2011) continue by also referring to Silvennoinen and Thorp (2012) who wrote that the increase in correlations could be due to the financial crisis in 2008-2009, and could thus be temporary, before drawing the conclusion that the correlations over the entire period are rather low, still making commodities a valuable contribution to the portfolio. By looking at our results, we can't see any of these tendencies as the correlations mostly are in conflict with each other, where many of them increase in one period to later decrease in the next, or the other way around. We can therefore not conclude that there has been a permanent increase in the correlations as Lindholm and Filipthuck (2011) suggested. We can, however, conclude that the correlations between the different sub-sectors and with the standard portfolio are still overall rather low, and would therefore be effective in diversifying a portfolio to obtain a more optimal allocation with higher return and less risk. We can also conclude that some of them could work as a hedge in selected periods due to their negative correlation. Moreover, the results and the composition of the BCOM index also might suggest that a sub-sector strategy is more successful than an aggregate index strategy. This confirms the findings of Lindholm and Filipthuck (2011), as well as Erb and Harvey (2006) and Gorton and Rouwenhorst (2006) before them, even after including the most recent data.

Portfolio Optimization

Above, the thesis concludes that the sub-sectors show properties that suggest significant diversification benefits, and some even hedging properties in selected time periods, when dividing the total commodity index into sub-sectors. Table 6 to Table 8 will therefore present the optimal allocation weights for the three different portfolios from the portfolio optimizations over the period 2002 to 2021. However, as previously mentioned, Demidova-Menzel and Heidorn (2007) and Cheung and Miu (2010) claims that the alleged benefits of commodities mostly come from short and isolated periods of extraordinarily strong commodity performance, which is why the 2002-2021 time period also will be broken-down into shorter six-year sub-periods that will be presented along the original time period of the portfolio optimizations.

The portfolio optimization results will be presented in the form of each portfolio, starting with the standard portfolio consisting of only OMXS30GI; to then continue by presenting the portfolio consisting of OMXS30GI and BCOM in Portfolio 2; and then lastly Portfolio 3 will present the sub-sector portfolio along with the standard portfolio. By presenting the results in this way, it is easier for the reader to compare the results throughout the different years and across the portfolios. Each portfolio, Portfolio 1-3, will be presented in the form of three different scenarios. First, Panel A will present the original simulation, where only long positions are allowed and the entire wealth has to be invested. Panel B will then demonstrate the first robust test where the short selling constraint has been removed, allowing the investor to take short positions in the asset. The last panel, Panel C, shows the optimal allocation into the risky portfolios if the investor were to be allowed to use 15% leverage while investing. All of the different simulations have been constructed to maximize the Sharpe Ratio, given the other constraints.

Portfolio 1 - 100% OMXS30GI

Table 6: Descriptive Statistics and Asset Weights for the Standard Portfolio over time

Panel A: Optimal Portfolios - Original Simulation

Descriptive Statistics					**Portfolio Weights**
Year	**Average Return**	**STD**	**Risk Free**	**Sharpe Ratio**	**OMXS30GI**
2002-2021	9,04%	18,02%	2,44%	0,37	100%
2002-2007	8,57%	19,72%	4,27%	0,22	100%
2008-2013	7,35%	20,00%	2,72%	0,23	100%
2014-2020	8,66%	14,56%	0,62%	0,55	100%

To be able to make a fair comparison between the different time periods the risk-free rate has to be adjusted. By not adjusting for the appropriate risk-free rate for each sub-period, and by using the calculated risk-free rate of 2,44% for the entire time period of 2002-2021, the method would have been inconsistent and the results would have been misleading. This, due to the fact that the risk-free rate affects both the Sharpe Ratio which, in turn, affects the optimal allocation weights for each portfolio scenario. This can be demonstrated above where Panel A shows different Sharpe Ratios despite the portfolio being 100% invested in OMXS30GI. This is a result of the average return, standard deviation and risk-free rate differing throughout the years.

It can also be seen that the average risk-free rate decreases for each sub-period. One, among many reasons, for this could be due to quantitative easing and the expansionary monetary policy by the governments. It can be observed that the Sharpe Ratio increases as the risk-free rate decreases, which is not surprising since the Sharpe Ratio measures the excess return of the portfolio in its calculations.[11]

Since both robust tests for Portfolio 1 will show the same results as Panel A above, despite robust test two will show a higher Sharpe Ratio due to the constraint that the investor can invest 115% but otherwise the same results, there's no need to include these in the text.

Portfolio 2 - OMXS30GI and BCOM

Table 7: Descriptive Statistics and Asset Weights for Standard Portfolio over time

Panel A: Optimal Portfolios - Original Simulation

Descriptive Statistics					Portfolio Weights	
Year	**Average Return**	**STD**	**Risk Free**	**Sharpe Ratio**	**OMXS30GI**	**BCOM**
2002-2021	9,04%	18,02%	2,44%	0,37	100%	0%
2002-2007	7,72%	11,87%	4,27%	0,29	43,47%	56,53%
2008-2013	7,35%	20,00%	2,72%	0,23	100%	0%
2014-2020	8,66%	14,56%	0,62%	0,55	100%	0%

Comment: *Panel A demonstrates the portfolios, consisting of only the standard portfolio and the total commodity index, with highest Sharpe Ratio for the different time periods.*

During the original optimization, which consists of only the standard portfolio OMXS30GI and BCOM, the optimal allocation weights can be seen allocated in only the OMXS30GI,

[11] The calculations of the Sharpe Ratio can be seen in Appendix II.

with the exception of the time period 2002-2007. During this sub-period the optimal portfolio consists of a majority of the weights allocated in BCOM. This could be due to Energy deviating from its norm by yielding a positive return, in contrast to the remaining two sub-periods and affecting BCOM due to its large allocation into the Energy sector. During this period Energy and OMXS30GI had a negative correlation of 0.16, lowering BCOM's correlation with OMXS30GI which further favored the allocation. Energy's negative correlation and average return might partly be explained by the bull market in oil prices during the 2000s energy crisis.

Another contributing factor could be the bull market in industrial metals during the same period, 2002-2007. The period begins with industrial metals bottoming out following the dot-com crisis in the early 2000s and was one of the commodities that moved aggressively during this 2000 Commodities Boom. The sub-sector Industrial Metals consists of the industrial metals aluminum, copper, nickel and zinc. During this period, both aluminum and copper experienced extreme price growths as a result of the increasing demands in global markets due to the strong economic growth. Implications of this could also be seen in Table 4 as Industrial Metals experienced the highest average return during the period, followed by Precious Metals, but with only a relative average standard deviation.

Panel B: Optimal Portfolios - Robust Test 1 (Short Selling Allowed)

Descriptive Statistics					Portfolio Weights	
Year	**Average Return**	**STD**	**Risk Free**	**Sharpe Ratio**	**OMXS30GI**	**BCOM**
2002-2021	9,04%	18,02%	2,44%	0,37	100%	0%
2002-2007	7,72%	11,87%	4,27%	0,29	43,47%	56,53%
2008-2013	6,56%	11,03%	2,72%	0,35	41,49%	-58,51%
2014-2020	6,10%	8,13%	0,62%	0,67	58,76%	-41,24%

Comment: *Panel B demonstrates the portfolios, consisting of only the standard portfolio and the total commodity index, where short selling is allowed in each time period.*

When allowing the investor to include short positions in their portfolio the outcome changes somewhat. The optimal portfolio weight for the entire time period 2002-2021 still remains the same as in the original simulation, as does the optimal portfolio weight for the first six-year sub-period, 2002-2007. However, the results change in the last two sub-periods where a relatively larger part of the weights is allocated towards a short position in BCOM. The reason, again, could be due to the decreasing energy prices and the negative average return and relative high volatility that the sub-sector has demonstrated during the last two sub-periods of 2008-2020. It can also be seen that the allocation weight in BCOM is bigger during the period 2008-2013. This could be explained by that all sub-sectors, except for Precious Metals, had negative returns during the period and higher negative returns than during the next period of 2014-2020. This made it more profitable to (indirectly) short these commodities through taking a short position in BCOM.

It can also be demonstrated that by allowing the investor to utilize short positions in the assets, the Sharpe Ratio increases substantially in comparison to the other scenarios. This could also be demonstrated in Panel B in Table 8 where short selling is allowed in the sub-sectors. This follows Erb and Harvey (2006)'s reasoning that a portfolio consisting of both long and short positions will have a higher return and thus higher Sharpe Ratio.

Panel C: Optimal Portfolios - Robust Test 2 (15% Leverage)

Descriptive Statistics					**Portfolio Weights**	
Year	**Average Return**	**STD**	**Risk Free**	**Sharpe Ratio**	**OMXS30GI**	**BCOM**
2002-2021	10,39%	20,72%	2,44%	0,38	115%	0%
2002-2007	8,85%	13,56%	4,27%	0,34	48,16%	66,84%
2008-2013	8,45%	23,00%	2,72%	0,25	115%	0%
2014-2020	9,96%	16,74%	0,62%	0,56	115%	0%

Comment: *Panel C demonstrates the portfolios, consisting of only the standard portfolio and the total commodity index, where the investor can use 15% leverage for each time period.*

Robust test 2 has no results that deviate from the original simulation. It only differs in the allocated weights due to that the investor can utilize leverage which increases the Sharpe Ratio marginally. This is most likely due to that the investor isn't allowed to take short positions in the assets in the scenario, making it more optimal to mainly invest in just OMXS30GI throughout the time periods, with the expectation of 2002-2007 with the Commodity's Boom and the 2000s Energy crisis.

Portfolio 3 - OMXS30GI and the Sub-Sectors

Table 8: Descriptive Statistics and Asset Weights for Standard Portfolio over time

Panel A: Optimal Portfolios - Original Simulation

Descriptive Statistics					Portfolio Weights					
Year	**Average Return**	**STD**	**Risk Free**	**Sharpe Ratio**	**OMXS30GI**	**Precious**	**Industrial**	**Energy**	**Agriculture**	**Livestock**
2002-2021	8,50%	12,50%	2,44%	0,49	55,58%	44,42%	0%	0%	0%	0%
2002-2007	14,17%	12,58%	4,27%	0,79	0%	0%	100%	0%	0%	0%
2008-2013	6,65%	14,38%	2,72%	0,27	67,97%	32,03%	0%	0%	0%	0%
2014-2020	8,69%	10,52%	0,62%	0,77	51,81%	48,19%	0%	0%	0%	0%

Comment: *Panel A demonstrates the portfolios, consisting of the standard portfolio and the commodity sub-sector indices, with highest Sharpe Ratio for the different time periods.*

The sub-sector optimization provides some even more interesting results. For the full time period, 2002-2021, the optimal portfolio allocation is roughly 56% in the standard portfolio and the remaining 44% is allocated in the sub-sector Precious Metals. This index consists of almost 76% Gold and 24% Silver. By allocating the corresponding weights in the two indices, the Sharpe Ratio increases from 0.37 to 0.49 if compared with the same time period and the original optimizations for Portfolio 2 and 3. This demonstrates the diversification effect of precious metals since the sub-sector is the only commodity sector to show positive returns on average across all three sub-periods. It is furthermore the sub-sector with the lowest standard deviation in two out of the three sub-periods. Precious Metals is therefore the only commodity sub-sector that can compete with OMXS30GI in terms of return and risk. This is most likely the reason why a large part of the allocation is allocated in Precious Metals. Furthermore, the correlation between the two assets have been very favorable as the correlation between OMXS30GI and Precious Metals has been among the lowest correlation across the different sub-periods and demonstrated a negative correlation of -0,07 for the total time period. Table 5 shows that Precious Metals is the only sub-sector to exhibit a negative correlation for the aggregated time period of 2002-2021.

The only period that differs from the optimal allocation being placed in Precious Metals and OMXS30GI is the first six-year period. It further highlights the previously mentioned boom market in industrial metals. This resulted in Industrial Metals having higher return, with the highest return among the alternatives during the period, and with marginally lower volatility. However, OMXS30GI exhibits the highest correlation with Industrial Metals for the corresponding period resulting in only a weak, or no, diversification benefits. The 100% allocation in Industrial Metals should therefore be seen as an outlier, despite demonstrating the highest Sharpe Ratio for the scenario, and is only due to the boom period in industrial metals.

Panel B: Optimal Portfolios - Robust Test 1 (Short Selling Allowed)

Descriptive Statistics					Portfolio Weights					
Year	**Average Return**	**STD**	**Risk Free**	**Sharpe Ratio**	**OMXS30GI**	**Precious**	**Industrial**	**Energy**	**Agriculture**	**Livestock**
2002-2021	8%	9,48%	2,44%	0,59	38,62%	31,59%	0,00%	-13,80%	-0,16%	-15,83%
2002-2007	11,65%	10,86%	4,27%	0,68	4,59%	26,64%	39,07%	0,02%	0%	-29,68%
2008-2013	10,02%	10,03%	2,72%	0,73	26,15%	16,08%	-9,16%	-35,97%	0%	-12,64%
2014-2020	10,03%	7,90%	0,62%	1,19	43,53%	19,09%	12,10%	-25,22%	0%	-0,06%

Comment: *Panel B demonstrates the portfolios, consisting of the standard portfolio and the commodity sub-sector indices, where short selling is allowed for each different time period.*

Panel B provides some interesting results when allowing for short selling in the sub-sectors. Similar to when the investor is allowed to have short positions in Panel B in Table 7, this scenario demonstrates the highest Sharpe Ratio across all portfolio optimizations. The results do therefore indicate that the highest Sharpe Ratio can be reached when the investor is allowed to have both long and short positions in the assets, which reinforces Erb and Harvey's theory from 2006. As can be seen in Panel B, when the investor is allowed to short, and to invest in accordance with the sub-sector strategy, the wealth is spread more evenly across the different alternatives compared to what they have been in previous scenarios.

The first six-year period, 2002 to 2007, results in a very low OMXS30GI allocation of not even 5% while the largest allocation is in Industrial Metals, although a rather large part is allocated in Precious Metals as well. The distinctive allocation is the significant short position in Livestock. This is probably due to the very weak price development of the Livestock index, as it is the only index showing a negative return in all time periods. The index had a closing price of 126$ at 2002-01-31, which had declined to a closing price of just 49$ per 2021-01-31.

The second sub-period, 2008-2013, shows again a large part of the wealth allocated in OMXS30GI and Precious Metals, which are the only indices to have gone well during the period. The largest allocation this period is in the Energy sector. This is probably due to the sector experiencing the worst returns, making it the most optimal asset to short due to the 2008 peak in the oil prices. The large short positions in Industrial Metals and Livestock are a result of the sub-sectors showing the worst return, after Energy, during the period, earning them an allocation.

The last sub-period shows a large allocation in OMXS30GI and Precious and Industrial Metals as they are the only indices having positive returns during 2014-2020 as showed in Table 4. The rather large short position in Energy is due to its large negative return and high volatility for the period. Agriculture, on the other hand, has not been dealt an allocation in either optimization due to it being more or less flat during the entire period while maintaining considerable volatility throughout the entire period and all six-year periods.

Panel C: Optimal Portfolios - Robust Test 2 (15% Leverage)

Descriptive Statistics					Portfolio Weights					
Year	**Average Return**	**STD**	**Risk free**	**Sharpe Ratio**	**OMXS30GI**	**Precious**	**Industrial**	**Energy**	**Agriculture**	**Livestock**
2002-2021	9,78%	14,37%	2,44%	0,51	63,67%	51,33%	0%	0%	0%	0%
2002-2007	14,28%	16,32%	4,27%	0,61	5,26%	48,53%	61,21%	0%	0%	0%
2008-2013	7,62%	16,46%	2,72%	0,30	77,17%	37,83%	0%	0%	0%	0%
2014-2020	9,99%	12,10%	0,62%	0,77	59,59%	55,41%	0%	0%	0%	0%

Comment: *Panel C demonstrates the portfolios, consisting of the standard portfolio and the commodity sub-sector indices, where the investor can use 15% leverage for each time period.*

Robust Test 2 does not result in any larger deviation from the original simulation in Portfolio 3 when regarding the proportion invested in each asset. The only difference is the 5,26% allocation in OMXS30GI and the 48,53% allocation in Precious Metals throughout the years of 2002-2007, which were both 0% in the original allocation.

As a concluding remark, although the sub-sector strategy has demonstrated superiority in terms of the highest achieved Sharpe Ratio and the allocation being more evenly spread across the different commodities, the strategy also has some flaws. One major flaw is that the impression that the utilization of a commodity index or sub-indices as used in this thesis can represent commodities as a whole might be given. This is not true. The reader should therefore be aware that these indices only include certain commodities and far from all commodities are included as many core commodities are missing. Examples of missing commodities are iron or steal from the Industrial Metals sector or uranium and coal from the Energy sub-sector. This is partly due to the high requirements that a large index such as BCOM has on the securities which results in a trade-off for investors between number of securities and ease of access.

9. Conclusion

The allocations into commodity instruments have increased dramatically over the last decades. The view of adding commodities to a portfolio have suggested significant diversification benefits by literature and previous studies. Recent years have, however, been contradictory to the alleged benefits and argue that they seem to appear and vanish over time depending on the analyzed commodity index composition and the time period studied. This thesis aimed to update previous research on commodities with recent data to evaluate the strategic commodity allocation of dividing the total commodity index into sub-sectors.

The studied time period of commodity performance ranges from 2002 to 2021. The thesis has analyzed commodities on an aggregated level, as well as on a sub-sector basis, and found that the performance of the commodity sub-sectors has varied throughout the years. Our results indicate that commodities behave similarly to what the previous studies indicated in the late 2000s, even from the perspective of a Swedish investor. Although this study has resulted in some differences. Where previous studies found that it was more optimal to utilize a minor allocation towards an aggregated commodity index, such as Bloomberg Commodity Index, we have found it to only be optimal for the 2002-2007 sub-period, where this outcome can be attributed to the index's significant dependability with the Energy sub-sector which had high volatility and low returns during the time period. But otherwise not optimal at all when only allowing long positions in the assets. This, combined with the findings by Erb and Harvey (2006), who found that the composition of an aggregate commodity index plays an important role is also shown in the results as the Energy sector has a large influence on the optimal allocation of BCOM.

The thesis also confirms previous studies theory on sub-sector allocation which is significantly more optimal, where the sub-sector Precious Metal sector being dominant in our results. Both the aggregated BCOM index and the sub-sector indices simply follow a boom-and-bust allocation when combined with the standard portfolio, with the exception (again) of Precious Metals. The majority of sub-sectors do not indicate any diversification effect when only allowing long positions due to them only being optimal to allocate during their boom periods but not long term, as this paper assumes. The only allocation which indicates being beneficial is the Precious Metals sector, which continuously adds a diversification benefit, even if the sector has a flat or both boom & bust period. This might be due to the value preservation characteristics that gold and silver is considered to have. These characteristics shine bright in a time period which has quantitative easing while still being less volatile than the standard portfolio when only allowing for long positions in the securities. The results of only finding Precious Metals to be overall a beneficial allocation can be explained by Demidova-Menzel and Heidhorn (2007) and Cheung and Miu (2010) which found that including all types of commodities is only beneficial during short and specific time periods.

In the case where both long and short positions are allowed, all commodity sectors, both in terms of the aggregated BCOM index as well as the sub-sectors, are a valuable contribution to the portfolio as the wealth is more evenly distributed and these scenarios exhibit the highest Sharpe Ratio when comparing all scenarios across the portfolios.

Moreover, despite the increased correlation found by some previous research we cannot see any of these tendencies and can therefore not conclude that there has been a permanent increase in the correlation in more recent years due to financialization, increased demand for commodities from emerging markets and the effects of the recent financial crisis, as indicated by several studies. We can therefore neither conclude that commodities' reputation as a good hedge or diversifier in a portfolio has been challenged as the correlation with the standard portfolio and within the different sub-indices remain relatively low.

Finally, the thesis continues to motivate risk avert long term Swedish private investors who seek to reduce their portfolio volatility to include Precious Metals or allowing both long and short positions in their portfolio and thus increasing the Sharpe Ratio. Important to note is that the level of allocation into the different indices are heavily influenced by the time period of choice and the chosen instruments. The results are furthermore based on historical values and do not guarantee similar future results.

10. Further Research

During the writing of this thesis some aspects arose which could be grounds for further research. As mentioned in the thesis, the sub-index Agriculture consists of the Bloomberg sub-sub-indices Softs and Grains. An interesting topic for further research could therefore be to replace the Bloomberg sub-index Agriculture with its respective sub-index, as well as replacing the other sub-indices used in this thesis with their corresponding sub-sub-indices, and to analyze how the results are affected. The positive effect of including for example precious metals could also be analyzed from the standpoint of monetary policy and alternative securities for allocation such as investment into ETFs of the physical commodity and how this alters the result.

Commodities overall could be further analyzed based on seasonal patterns or inflation, as well as different kinds of inflation, as this is something frequently mentioned in several studies. It would therefore be interesting to analyze how the optimal allocation change throughout the years by seasonal patterns or during periods of high inflation vs low inflation, and also how changes in the inflation expectations affects the result.

Furthermore, several papers of the previous research claim to find that commodities tend to have a positive skewed return-distribution which therefore motivates the commodity allocations. Although the thesis only briefly touches upon this, our results find indications of the opposite result in comparison to previous studies and instead finds evidence that most of the commodities have a negative skewed return-distribution regardless of the currency used, despite our results finding a less negative skewed distribution when converted to SEK. A suggestion for further research is therefore to investigate this relationship deeper. The thesis has also not analyzed the impact of exchange rate on the optimal allocation in commodities extensively which could also be grounds for further research as the relationship between the reserve currency USD and the Swedish SEK is interesting. Although this thesis does not indicate any significant impact overall, further research could analyze the exchange rate impact during short time periods.

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Appendix

Appendix I – Statistical Basics in Portfolio Theory

Geometric returns for each asset are calculated using monthly historical prices:

$$r_{i,t} = \mathrm{LN}\left(\frac{P_{i,t}}{P_{i,t-1}}\right)$$

$r_{i,t}$ = continuous return of asset *i* in period *t-1* till *t*
$P_{i,t}$ = price of asset *i* in period *t*
$P_{i,t-1}$ = price of asset *i* in period *t-1*

Expected return of a single asset is computed using continuous returns:

$$E(r_i) = \overline{r_i} = \frac{1}{n}\sum_{n=1}^{N} r_{i,t}$$

$E(r_i)$ = expected return of asset *i*
$\overline{r_i}$ = average return (mean) of asset *i*
n = number of observations in the sample

Standard deviation of a single asset:

$$\sigma(r_i) = \sqrt{Var(r_i)} = \sqrt{\frac{1}{N-1}\sum_{n=1}^{N}\left(r_{i,t}-\overline{r_i}\right)^2}$$

$\sigma(r_i)$ = standard deviation of asset *i*
$Var(r_i)$ = variance of asset *i*

To annualize the calculated parameters the monthly expected returns are multiplied by

$$\left(1+E(r_i)\right)^{12}-1$$

and the monthly standard deviations are multiplied by $\sqrt{12}$.

Correlation between two assets:

$$\rho(r_i, r_j) = \frac{\sum_{n=1}^{N}\left(r_{i,t}-\overline{r_i}\right)\left(r_{j,t}-\overline{r_j}\right)}{(n-1)\sigma(r_i)\sigma(r_j)}$$

$\rho(r_i, r_j)$ = correlation between asset *i* and asset *j*
(r_j) = standard deviation of the asset *j*
$r_{j,t}$ = continuous return of asset *j* in period *t-1* till *t*
$\overline{r_j}$ = average return (mean) of asset *j*
$\sigma(r_j)$ = standard deviation of asset *j*

Covariance between two assets:

$$Cov(r_i, r_j) = \sigma(r_i)\sigma(r_j)\rho(r_i, r_j)$$

$Cov(r_i, r_j)$ = covariance between asset *i* and asset *j*

Expected return of a portfolio:

$$E(r_p) = \sum_{i=1}^{n} w_i E(r_i)$$

$E(r_p)$ = expected return of a portfolio
w_i = weight in asset *i*

Standard deviation of a portfolio:

$$\sigma(r_p) = \sqrt{\sum_{i=1}^{n} w_i^2 Var(r_i) + 2 \sum_{i=1}^{n} \sum_{\substack{j=1 \\ j \neq i}}^{n} w_i w_j Cov(r_i, r_j)}$$

$\sigma(r_p)$ = standard deviation of a portfolio
w_j = weight in asset *j*

Appendix II – Portfolio Optimization Problem

The Optimization Problem:

$$Minimize\ \sigma(r_p) = \sqrt{\sum_{i=1}^{n} w_i^2 Var(r_i) + 2 \sum_{i=1}^{n} \sum_{\substack{j=1 \\ j \neq i}}^{n} w_i w_j Cov(r_i, r_j)}$$

Sharpe Ratio for the Portfolio:

$$Sharpe\ Ratio = \frac{E(r_p) - r_f}{\sigma(r_p)}$$

r_f = risk-free asset
$E(r_p) - r_f$ = excess return of a portfolio
$\sigma(r_p)$ = risk of a portfolio

Appendix III – Composition of Commodity Sub-Sectors

Table A1: Underlying Commodities in BCOM and the Allocation Weights as of February 2021

Energy (32,64%)	**Precious Metals (16,34%)**	**Industrial Metals (15,31%)**	**Agricultures (29,91%)**	**Livestock (5,80%)**
Brent Crude Oil (7,60%) (23,29%)	***Gold*** (12,39%) (75,81%)	***Aluminium*** (4,17%) (27,24%)	***Chicago Wheat*** (2,78%) (9,29%)	***Live Cattle*** (3,76%) (64,84%)
ULS Diesel (2,32%) (7,12%)	***Silver*** (3,95%) (24,19%)	***Copper*** (5,59%) (36,52%)	***Coffee*** (2,91%) (9,73%)	***Lean Hogs*** (2,04%) (35,16%)
Low Sulphur Gas Oil (2,98%) (9,13%)		***Nickel*** (2,61%) (17,03%)	***Kansas City Wheat*** (1,56%) (5,21%)	
Natural Gas (7,89%) (24,17%)		***Zink*** (2,94%) (19,21%)	***Cotton*** (1,58%) (5,27%)	
RBOB Gasoline (2,67%) (8,17%)			***Corn*** (5,80%) (19,38%)	
WTI Crude Oil (9,18%) (28,12%)			***Soybean Meal*** (3,29%) (10,98%)	
			Soybean Oil (3,41%) (11,41%)	
			Soybeans (5,64%) (18,87%)	
			Sugar (2,95%) (9,86%)	

Comment: *The top numbers demonstrate the sub-sector weights in the aggregated index BCOM. The weights after each commodity demonstrates the individual commodity weights, where the first is the individual commodity's weight in the aggregated index BCOM, and the latter is the individual commodity's weight in the corresponding BCOM sub-index. The weights have been retrieved from Bloomberg (2021).*