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Master Thesis

The commodity market's volatility through Covid-19 and the war in Ukraine

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Abstract

In early 2020 a pandemic quickly led to major shutdowns of production and travel to prevent the spread of the Covid-19 virus, and lockdowns affecting the supply chain stopping the flow of materials and goods. Because of this the demand for energy shifted downwards leading to a fall in several commodity prices. This is due to energy being used for both production and transport, so a decrease in energy demand will lead to a decrease in price. Further the invasion of Ukraine led to another major shift in several markets as the war affected the supply of some major commodities, as Europe, United States, and other nations sanctioned Russia, leading to long term consequences on the commodity markets. The commodity prices increased rapidly, especially for commodity groups as energy, fertilizers, grains, and metals, where Ukraine and Russia are big exporters. Both events have led to higher volatility and uncertainty in the commodity market and have made the basis to investigate the research question on how the commodity market and the volatility revolving commodities have been impacted. By using a moving standard deviation this analysis explores how volatility has changed from the start of 2015 until the end of 2022. Further by using a moving beta and Sharpe ratio the relative risk is analyzed for the same interval, comparing each commodity to gold, as gold often is seen as a safe-haven by investors.

The empirical data shows that the energy commodities are the ones with highest volatility in the pre-covid period. As the pandemic hits crude oil is the only commodity making a big immediate leap as soon as society locks down. It is then quickly followed by an increase in volatility from gold, natural gas, and copper. Later into 2020 wheat and coal volatility starts to increase as well, while Nickel already had a relatively high volatility and see some variations. Further into 2021 we see most commodity volatilities starting to fall again, except for coal and natural gas who make large jumps. As the war in Ukraine starts in early 2022 other commodities like crude oil, nickel and wheat make large leaps in volatility as well, later followed by copper. Gold does not show any change in volatility during the period. Looking at the beta and the relative risk, for the pre-covid period it is shown that the commodities are mostly less volatile relative to gold, except for natural gas that often exceeds gold volatility. This is the case until the war starts in 2022 when we see a large leap in all commodities beta. Overall gold is shown to be riskier than the other commodities before the war, and after the war starts the other commodities show a larger level of risk compared to gold. Furthermore, the Sharpe ratio shows that the commodities follow mostly the same pattern where gold is the better investment in the first 3 quarters of 2016, as well as from 2019 until 2021. However, the commodities are better investments from late 2016 until late 2018, as well as from 2021 until mid- to late-2022, where gold becomes a better investment option than most of the commodities by the end of 2022.

Preface

This analysis is done as the final assignment of my 2-year master's degree in Industrial Economics at University of Stavanger, specializing in project management as well as investment and finance. Through my time of studying, as well as observing changes in the market since the covid pandemic started, I have found an interest in the commodity market and how certain events can impact the market on so many levels. While learning about market and investment theory during my time of studies, my interest also grew. I found it interesting to see how changes in one market would affect other markets and it quickly became a topic of interest to cover when I was deciding what kind of analysis to do for my master thesis. Seeing how prices of gasoline, electricity, gas, groceries, and other everyday products have increased in price the last few years made me want to investigate the commodity market further. I wanted to learn more about how events such as a pandemic or geopolitical tension impact the market, which now has resulted in this report.

I would like to thank my supervisor, Ruth Beatriz Pincinato, for the feedback and guidance she has provided during the months of writing this thesis. Her contribution has been helpful to form the result of this thesis and has been greatly appreciated.

Furthermore, I would like to thank the lecturers I had throughout my 2 years of studying. Thanks to them I have gained a lot of knowledge revolving industrial economics which I now take with me as I finish my master's degree.

This master thesis is written individually and is the result of my growing interest for the commodity markets complexity and concludes my 2-year master's degree in Industrial Economics.

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1. Introduction

1.1. Background for the analysis

The Covid-19 pandemic and invasion of Ukraine has led to major shifts in both supply and demand in the commodity market, leading to high levels of volatility in the market [1]. As the pandemic led to a shutdown all over the world in the first part of 2020, the economy took major damage and it led to a plunge in the commodity prices between the start of the pandemic in December 2019 until April 2020 [2]. The shutdown led to a huge shift in the demand of commodities as production was shut down and travel restrictions were implemented. Eventually as parts of the world started opening and the demand for commodities started to rise again the prices also increased rapidly for most commodities, as the economy was trying to recover.

While the economy was trying to recover another event led to a major shift in the market, namely Russia's invasion of Ukraine, which started in February 2022. This led to a rapid increase in some of the commodity prices, especially those that Russia and Ukraine are large exporters off. This was followed by EU, United States, and other nations sanctioning Russia to punish their economy for invading Ukraine. Thus, the war made a shift in the supply of important commodities like energy and minerals, and therefore the prices increased, which can be expected for volatility also.

Now more than 3 years after the pandemic hit and more than one year after the invasion of Ukraine the market is still highly affected by the events. As both events are expected to affect the prices of commodities and other goods, it is important to investigate the research question on how the commodity market and the volatility revolving those commodities have been impacted. It is important to analyze the uncertainty and volatility in the market for several reasons. Firstly, high volatility will provide a larger risk for investors wanting to invest in certain assets, as prices vary a lot. Generally high volatility relates to higher risk and lower volatility to lower risk. Secondly, high volatility makes the market unpredictable and the price for commodities is important for consumers as they are used for production purposes. A sudden increase in price of certain commodities can make productions more expensive, which ultimately will affect the price for the end user or the revenue of producers.

By looking at the standard deviation before and after 2020 we can look at how the volatility has changed. Further by looking at the relative risk by calculating the beta and Sharpe ratio, we can compare each commodity to gold, to see how the commodities have changed compared to gold. This is interesting as gold is seen as a safe-haven by investors, and research done by Ji, Zhang and Zhao confirms that gold is still found to have a safe-haven role during the pandemic [3].

1.2. Delineation of the analysis

The analysis is limited to covering a specific number of commodities. By picking commodities from different markets, it would be interesting to compare the changes in the different markets. The following commodities were chosen for the analysis: oil, natural gas, coal, gold, nickel, copper, and wheat.

Another limitation to the analysis is the spread of the dataset used. There have been many historical events that have made large shifts in the different commodity markets, and the commodity market is well known for being volatile. It would therefore be interesting to have the analysis cover historical data from both before and after covid. Then compare the time before covid that has not been affected by major shifts in the market to the market in the time of the pandemic and the invasion of Ukraine to see the differences. The dataset is therefore limited to starting in January 2015 and ending in December 2022. By limiting the data, the data will not be impacted by shifts like the 2008 and 2014 major downfalls of oil prices or the 2008 financial crisis. Looking at price volatility and relative risk the dataset will cover historical data from before the pandemic, after the pandemic and after the war in Ukraine. The dataset will therefore cover historical data from January 2015 until December 2022.

1.3. Previous research

There have been several studies done on the commodity market both before and after the pandemic hit. To diversify this analysis from previous research it is important to see what kind of discoveries have been made earlier, and even use other findings as a tool for new research.

Looking at previous research articles it has been shown by Rajput et al. that the short-term effect of covid-19 has led to a decrease in demand and supply for commodities [4]. Rajput et al. show in their research that oil has had the largest impact due to the sudden drop in demand and supply because of transportation and travel restrictions. Another article by Sheth et al. look at changes in commodity markets as energy, agriculture, and metals, comparing the changes between January 2019 to September 2020 [5]. They conclude with commodities volatility being more uncertain since the pandemic outbreak, stating that the oil market has had a negative impact reaching record lows. They also find that gold has had a positive impact leading to record highs from the outbreak. Since gold is seen as a safer investment during time of uncertainty, investors tend to invest in gold in times with high volatility. Overall, the commodity market was found to have faced a negative impact. Also, they find no direct impact for agricultural commodities or natural gas due to covid-19 in the short run [5]. A third study done by Cui et al. looks at gold to see if it is a safer investment during uncertain times as a pandemic, looking at volatility for oil, gold, and silver, given a dataset reaching from 30. January

2020 to 16. December 2021 [6]. The findings show that both gold and oil price volatility have a positive impact on gold price, while silver price volatility has a negative impact in the long term. While in the short-term gold volatility has a negative effect on gold prices [6]. Another research article by Salisu et al. looks at the correlation between the global fear index (GFI) and 24 commodity prices [7]. The study shows that there is a positive correlation between the GFI and the commodity prices, meaning commodity returns increase as covid-19 related fear rises. A research article by Elleby et al. looks at the effect on agricultural commodities from the pandemic during the first part of 2020 [8]. Their analysis shows that as a short-term result of the lockdown, prices of meat, dairy, biofuels, and feedstocks like maize and rapeseed decline. They link this to changes in demand for transport fuel as well as changes in the price of oil. Their report also highlights that in the short-term the consumption of food is not affected much as agricultural commodities tend to have very inelastic demands, meaning the demand does not change much in short periods of time. Looking at the invasion of Ukraine a research article by Fang and Shao suggests that as the conflict intensifies, the volatility in energy, metal and agricultural commodity markets also increase [9]. They also suggest that the bigger share of export Russia has for a commodity, the higher level of volatility risk is connected to the commodity.

Most studies look at a few commodities from energy, agriculture, or minerals sectors, but most studies do not compare different sectors. It would therefore be interesting to conduct a study that has a wider view of the market, including several different commodities from the different commodity markets. Also, several different methods have been used to analyze the commodity market. By having a different method to analyze the historical data we could see a different perspective on the development of the market. This contributes to the literature with a different view on recent shocks which provides a better understanding of the market response. Comparing the previous studies with this study, the biggest difference is that this study is using the time-varying measuring to show how standard deviation, beta and Sharpe ratio has changed over time, and in that way also volatility. This adds value to the literature by providing empirical results on how the volatility and relative risk have changed over time, highlighting both the short-term and long-term effect of covid and the war in Ukraine. This is especially important to see the effect such events have on the market over time, but it is also important for investors seeking to build their portfolio based on their risk preference in volatile times. Another big difference is the spread of data. Most of the datasets seen in other research articles end in 2020 limiting the view of the long-term effect of the pandemic. Using a dataset that also includes newer historical data could lead to different discoveries and will give a better impression of the long-term effect of the pandemic. By also including the period of the war in Ukraine we can see how two very different events happening in a relative short period of time

has impacted the economy and more specific the commodity market. This provides data on how the market that is already struggling to recover from the pandemic responds to another major shift as the war in Ukraine starts.

1.4. Structure and content of the report

Chapter 1:

This chapter introduces the analysis by looking at the background for the analysis, the delineation that sets the boundaries for the analysis and exploring what research has been conducted previously on the topic.

Chapter 2:

Here the analytical properties set for the analysis are discussed. The chapter explores the difference between quantitative and qualitative research methods, and what method is used for this analysis. Further it explores the difference between reliability and validity, and the importance of the two in qualitative research. It is then discussed the difference between causation and correlation and how correlation does not always mean causation. The chapter ends by summing up the key sources and methods used to select relevant literature for this research.

Chapter 3:

Chapter 3 looks at what a commodity is compared to a product and the basics of a commodity market. Further it looks at the commodity price risk and the different ways of trading commodities. It also explores the concepts of supply and demand and how changes in price change the supply and demand of a market. Further, the chapter explores the concepts of the law of supply and demand.

Chapter 4:

In this chapter the recent two events that have made a big impact on the economy and commodity markets, which are Covid-19 and the invasion of Ukraine, are discussed. The chapter introduces both events and look at some of the ways they have affected the commodity market.

Chapter 5:

Here we look at the different commodities, why they are important and how the market is structured. We look at the main producers of each commodity, what the commodities are mainly used for and what are the main drivers of the price of each commodity. The chapter also explores the cointegration between the different markets for each commodity around the world.

Chapter 6:

In chapter 6 the analytical methods used for this analysis are introduced. The chapter explains some basic theory revolving each method, and how the methods are utilized. The chapter also looks at previous research and how they have used standard deviation, beta, and Sharpe ratio for other studies. Further it explains how to interpret the results given from each method, as well as highlighting some strengths and weaknesses of using the methods.

Chapter 7:

In this chapter the empirical data is presented in the form of graphs for standard deviation, beta, and Sharpe ratio for the selected commodities. Each graph is commented to show how the standard deviation, beta, and Sharpe ratio for each commodity has changed over time.

Chapter 8:

Here the results are discussed, and the empirical results from chapter 7 are connected to the theory presented in the previous chapters. The chapter also compares the results to results from the other research articles that have been discussed in this report.

Chapter 9:

Chapter 9 is where the conclusion based on the empirical results is made, as well as discussing further possible research of the topic.

2. Analytical properties

The function of this chapter is to look at analytical properties that are used for research purposes, to define them, and to justify the selection of methods used for this analysis. This is done to strengthen the validity and reliability and is important to secure verifiability of the results provided in the analysis. This chapter will therefore look at research methods, reliability and validity, correlation and causality, and the selection of literature for the analysis.

2.1. Research methods

For a research question to be answered a researcher must collect data and do an analysis of the collected data. To serve the goal of the study in the best possible way, the selection of method should be carefully considered. Before looking at the types of research methods it is important to know what a research method is. A method is defined by Cambridge Dictionary as "*a particular way of doing something*", meaning different methods will have their own way of execution [10]. In addition, Cambridge Dictionary defines research as "*a detailed study of a subject, especially in order to discover (new) information or reach a (new) understanding*" [11]. Combining those definitions,

we can define a research method as a particular way of studying a subject, to discover (new) information or reach a (new) understanding. We can say that the research method is a tool for answering a research question that is meant to fill a hole in the literature, to give a better understanding of a given topic. When it comes to these tools there are different types of research methods that can be used.

Quantitative and qualitative methods are methods used for research purposes and the choice of method will impact the way data is being collected and analyzed. Grand Canyon University defines the methods as *«Quantitative studies rely on numerical or measurable data. In contrast, qualitative studies rely on personal accounts or documents that illustrate in detail how people think or respond within society"*. [12] For the quantitative method we look at numerical data and look at relations between variables, while for the qualitative method the purpose is to collect information about opinions and perspectives in words. Even though the two methods have different approaches, the two research methods are not opposites and can sometimes be used to complement each other. Table 1, gathered from simplypsychology.org, shows some key elements that distinguish the qualitative method from the quantitative method as provided below [13].

	Qualitative	***Quantitative***
Conceptual	*Concerned with understanding human behavior from the informant's perspective*	*Concerned with discovering facts about social phenomena*
	Assumes a dynamic and negotiated reality	*Assumes a fixed and measurable reality*
Methodological	*Data are collected through participant observation and interviews*	*Data are collected through measuring things*
	Data are analyzed by themes from descriptions by informants	*Data are analyzed through numerical comparisons and statistical inferences*
	Data are reported in the language of the informant	*Data are reported through statistical analysis*

Table 1 – Qualitative versus quantitative method [13]

In the end, the choice of method comes down to what kind of analysis we are doing and what kind of approach we want to use trying to find a conclusion to our research question. As the research of this analysis is based on researching the change in price of commodities, the method of choice will be quantitative method. The data being collected will be numerical values from commodity prices that will be used to do certain calculations and make graphs for comparison between changes in certain time periods and compare different commodities against each other.

2.2. Reliability and validity

Reliability and validity are crucial when it comes to the verifiability of the data and the research. Both reliability and validity are used to evaluate the quality of the research and data. They can be used to measure the accuracy of the test or method used. Even though they are closely connected, they measure different parameters, as reliability measures consistency and validity measures precision [14]. Not considering the risk of reliability and validity can lead to research bias and will impact the outcome of the research, and for that reason it is important to consider both early in the process so the right approach can be made to secure both factors. The following table, gathered from bachelorprint.eu, summarizes some of the main elements to identify reliability and validity [14]:

	Reliability	***Validity***
What does it tell you?	*The degree in which the same results are obtained when the study is repeated under identical conditions.*	*How accurately the results measure what they are intended to measure.*
How is it assessed?	*Examining the consistency of outcomes over time, between various observers, and within the test itself.*	*Comparing the accuracy of the results to accepted theories and other measurements of the same idea.*
How do they relate?	*Although the results of a reliable measurement may be reproducible, they are not always accurate.*	*A valid measurement is often reliable: if a test yield correct results, it should be repeatable.*

Table 2 - Identifying reliability and validity [14]

Measuring reliability and validity is done in different ways. If the same techniques are used under the same conditions, we should get the same result and therefore the measurement can be considered reliable. When it comes to validity, we must look at the repeatability of the test under the same conditions and see if the results match the expectations of the measurements. If we test using the same techniques under the same conditions over and over, but get different results, the test can be considered invalid. If we get the same results each time, we can consider the test as valid. A high level of reliability can also be considered as valid. The lack of reliability and validity of the research or data can lead to research bias, resulting in inaccurate results which do not represent reality. Figure 1 illustrates the effect of unreliability and invalidity [15]:

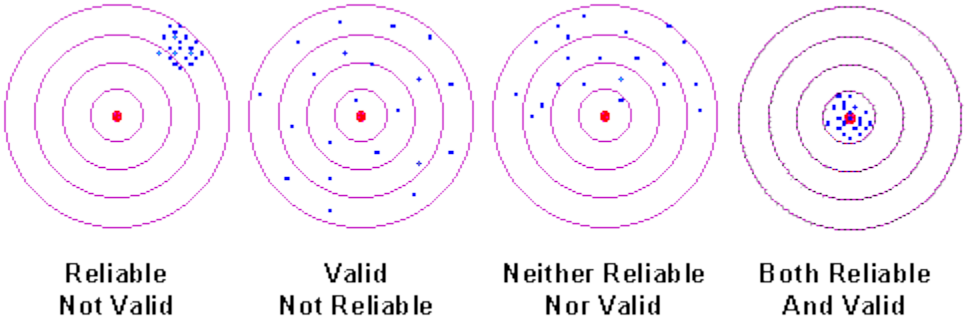

Figure 1 - Reliability and validity [15]

As figure 1 shows, having valid, but not reliable data will lead to a big variation in results. Having reliable, but not valid data will lead to similar results, but not hitting the mark. Having both reliable and valid data will ensure that we hit the mark and the research will ensure verifiability.

To ensure reliability and validity for this analysis the method of measuring is important to ensure that reliable and valid results are achieved. By using historical data of commodity prices, data with high reliability can be collected, however it is important to carefully pick the sample length and look at the history of the price changes to pick the period that gives the best representation of the data for the research. It is also important to use the same conditions and methods for the measurements of the different commodities to ensure consistency and in that way reliability. To ensure validity the most appropriate method must be used, and as there are many methods of measurement that can be used, the choice must be strongly evaluated. Further the approach and method must be based on extensive research and knowledge which will be the key element of ensuring both reliability, validity, and high quality of the overall research.

2.3. Correlation and causality

When comparing data, it is important to understand that there is a difference between correlation and causality, as correlation between two events does not mean there is causality between the two events. Correlation between two variables simply means that there is a connection between the variables, but one variable does not necessarily affect the other. When it comes to causality the relationship between two variables is that one factor causes the other [16]. The difference can be shown with an easy example showing how the sunny weather affects ice cream eating and getting sunburns. Figure 2 illustrates the difference between causation and correlation [17].

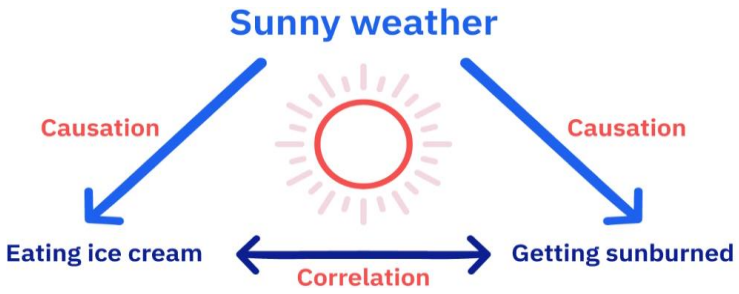

Figure 2 - Correlation versus causation [17]

As shown, sunny weather leads to an increase in both eating ice cream and getting sunburned, meaning both events are a result of the sunny weather, in other words there is a causation. As there is an increase in both variables because of the sunny weather, we can say there is a correlation

between eating ice cream and getting sunburned. However, the two variables do not affect each other, meaning there is no causation between the two. So why is this important?

When looking at the correlation between price changes in the commodity market we can look at how the prices have changed compared to each other. However, having a positive correlation between two commodities does not mean a price increase of one caused the price increase of the other. That is why there must be a distinction between correlation and causation. We can look at the relative risk between commodities from measuring correlation, but we must look at the factors that caused the price changes to see if there is any causation between the commodities. For the commodity market that is complex and affected by many different factors it can be complicated to find causes of price changes. Hence, it is important to look at what changes have happened in the markets and what has been the cause of these changes.

2.4. Selection of literature

Most of the topics covered in this analysis are topics that were taught in the course "IND640: Derivatives, risk and market", meaning the basic knowledge comes from taking the class and from personal notes from that class. Some topics have also been covered in other classes during studies, so general relevant knowledge has been obtained throughout the last 2 years of studying.

Search engines like Google and Google Scholar have also been used regularly throughout the process of writing to gather relevant information. Using google and searching for keywords like "Commodities", "Commodity market", "Standard deviation", "Beta", "Sharpe ratio", "Volatility", "Covid-19", "Ukraine invasion" and "Supply and demand", a lot of relevant information has been gathered. Google scholar has been used to find previous research articles revolving the commodity market to see what types of research have been done and what kind of conclusions have been made before. In Google Scholar keywords like "Commodity market", "Standard deviation", "Beta", "Sharpe ratio", "Ukraine invasion", "Volatility" and "Covid-19" have been used to find relevant research articles that cover studies on the commodity market both before and during the Covid pandemic, as well as the Ukraine invasion. Investopedia has been used extensively to gather information about economic concepts like the commodity market, supply and demand, and other topics related to the analysis. It has been a great tool to gather information and to get a better understanding of the different concepts discussed in the analysis. To gather historical data on commodity prices the webpage "Investing.com" has been used. The webpage provides historical data for several commodities where it is possible to export the relevant data for a given period. This is where the commodity price historical data has been gathered, which is the foundation for the quantitative research of this analysis.

3. Characteristics of a commodity market

3.1. What is a commodity market?

A commodity is a basic good, most often a raw material or primary product that is used for producing other goods. Commodities can be categorized as hard or soft commodities where hard commodities are materials that must be extracted or mined, such as oil, gas, gold, or copper. Soft commodities are agricultural products like corn or wheat but can also be livestock such as cattle [18]. Commodities differ from a product as a product is a finished good made from different materials and sold to consumers, unlike commodities which are used as input for making products. The quality of the specific commodity is usually the same from the different producers, meaning two different producers of gold will sell approximately the same quality of gold, unlike the consumers market where quality of products can vary a lot [19].

3.2. Commodity price risk

Trading and investing in the commodity market comes with a certain amount of financial risk, as prices can rapidly increase or decrease which will affect consumers and producers' revenue. Fluctuations in the market, meaning a high level of upwards and downwards changes in the commodity prices, characterize a volatile market. Volatility in the market leads to higher risk for both producers and investors that want to take part in the specific market as there is a high level of uncertainty. As there is uncertainty in a volatile market it is difficult to predict the future price of the commodity, which leads to risk. In that way risk, volatility and uncertainty are connected. For buyers the risk of price increase will always be present and an increase in commodity price will lead to higher cost of production which will result in a lower profit margin. On the other side producers or sellers of the commodity bear the risk of the commodity price decreasing which will lead to economic loss for the producer [20]. The commodity price risk affects all parts from the raw material to the consumer product because raw materials and end products all depend on different commodities, whether it is energy, metals, agricultural commodities, or other commodities. As a result, uncertainty or volatility in commodity prices can lead to changes in prices on, for example, grocery products, gasoline, electricity, or clothes. Because of this, producers and suppliers will try to reduce the price risk in the market. So how can companies reduce the price risk of commodities? Using different markets like spot market, forward market and futures market, producers, suppliers, and investors can reduce the price risk connected to volatility or uncertainty in the commodity market. This is important to reduce the financial risk during times of uncertainty or volatility in the market, which can be caused by events like a pandemic or geopolitical tension.

To reduce price risk in the best possible way the market used, and way of trading the commodities, must be considered to minimize the risk of potential losses. Trading commodities can therefore be done through bilateral transactions (over the counter) or by exchange trade. A bilateral transaction is a contract trade between two known parties meaning two parties agree on delivery of a commodity at an agreed upon price and delivery date. It can be in the form of a forward contract where a price is agreed upon today, but for future delivery of the commodity or product. By agreeing on a price in the contract you eliminate the element of uncertainty. The market price can still go down, meaning you would pay more in the contract than the market value at the time of delivery, meaning there is still a risk involved. However, the price will be pre-defined meaning the uncertainty is eliminated.

Another way of trading is through exchanges, which can also be used to reduce risk when there is volatility in the market. Exchange trade can be done through many different exchanges, where different exchanges focus on different types of commodities. Examples of exchanges are “London metal exchange” which trade metals like aluminum, copper, and lead, or the “New York Mercantile exchange” which trade several different commodities like oil and natural gas. The trading can be done through a spot market or a futures market, depending on whether you want the commodities delivered immediately or later in the future. The spot market is for trading commodities for a spot price and getting an immediate delivery of the material and is done through an exchange like “New York stock exchange”. The futures market is for trading futures and option contracts, meaning buying or selling contracts of a material for a price agreed on today, but for a future delivery of the material. This can be done through an exchange like “Chicago Mercantile exchange” [21].

The futures and options markets tend to be more used when there is volatility in the market as the future price of the commodity is uncertain. The futures or options market can then be used as a hedging strategy to reduce the price risk of the commodity. Hedging means to take an offsetting position in the commodity or market and is used to reduce the price risk connected to the asset or commodity [22]. This can be used by both investors, producers, and consumers of the commodity. Reducing the price risk from volatility in the market by hedging can be done in two ways, going short or going long [23]. By taking a short position you sell the commodity today as you expect the price to decrease in the future, but with a delivery in the future. By doing this you sell the commodity at a price today, but with a future delivery at a time where the price is expected to be lower, meaning you get a higher price for the commodity. This way you avoid the risk of uncertainty and volatility in the price as the price is locked in the contract. On the other hand, it is possible to go for the long position, meaning you buy the commodity today with a future delivery as you expect the price to increase in the future, being the opposite of a short position. This strategy can also be used by

investors; however, they will buy and sell contracts before the delivery date of the commodity, only taking advantage of the price changes in the market.

As mentioned, there are a few different ways to trade commodities, through spot markets or derivative markets, making the commodity market complex. Given the complexity of the market, what really determines the price of the commodities? Ultimately it is decided by the supply and demand for the given commodity.

3.3. Supply and demand

Supply and demand are the relations between the amount being sold and the amount being bought of a product or commodity, meaning the supply is the amount producers want to sell and demand is the amount consumers want to buy. Supply and demand relations follow the principles for the law of demand and supply. According to Investopedia the law of demand can be described as: "*The law of demand states that the quantity purchased varies inversely with price*" [24]. This means that if the price increases, the demand for the commodity will decrease. On the other hand, there is the law of supply which according to Investopedia can be described as: "*All other factors being equal, as the price of a good or service increases, the quantity of goods or services that suppliers offer will increase, and vice versa*" [25]. In other words, as price increases, producers or suppliers will want to sell more to increase revenue, and finally profit. Ultimately there is a relation between supply and demand, and the price of a given good. How is this related to the pandemic and invasion of Ukraine? Both events have led to large shifts in both supply and demand, which will be discussed in chapter 4, leading to price changes in the market.

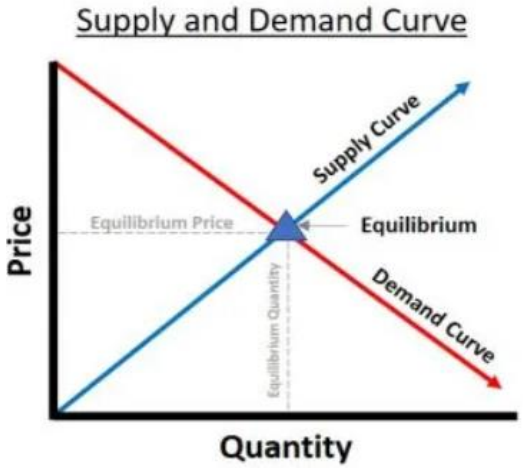

Figure 3 - Supply and demand curve [26]

The change in price of the commodity will both influence the supply and demand. By plotting the supply and demand curves it is possible to find the intersection between the two, called the equilibrium, as figure 3 shows [26]. The equilibrium is the state where supply and demand are in balance meaning the price of the commodity or product is stable [27].

Several events can lead to shifts in supply and demand. Some factors that can lead to changes in supply can be technological changes, changes in weather and climate that affect production of some commodities like agriculture, input factor changes or changes in interest rates. Factors that can affect the demand are changes in consumer preferences, income changes of consumers, population growth or changes in price for substitute products. In the next chapter we will see some changes in supply and demand that has been a result from the pandemic and the invasion of Ukraine.

4. Recent events affecting the commodity market

There have been several events that had large impacts on the supply and demand of the different commodity markets, as the financial crises in 2008 being the most serious financial crises since the great depression, which started in 1929 [28]. The most recent events affecting the world economy and the commodity markets are the covid-19 pandemic and the invasion of Ukraine.

4.1. Covid-19

The first case of the covid-19 virus was discovered in Wuhan, China, in December of 2019, and the virus quickly spread across the globe. As a result, the World Health Organization, WHO, characterized the virus as a pandemic in March 2020 [29]. Since the discovery of the virus, it has been confirmed more than 758 million cases of infections from the virus, and over 6.8 million deaths related to infections [30]. As shown in figure 4 and 5 below, constructed based on historical data, we can see the evolution of daily cases, and total registered cases since 22. January 2020 [31]. Even though there are dark figures from limitations to testing, the data gives a good representation of the spread and evolution of the pandemic.

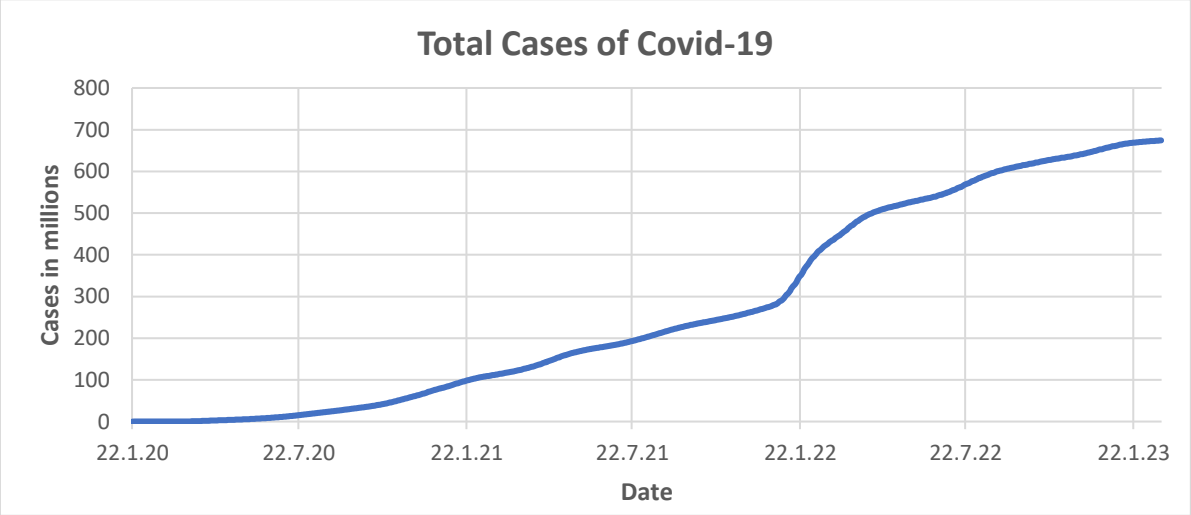

Figure 4 - Total cases of covid-19

As figure 4 shows there has been a steady increase in cases for the whole period, except for the time from December 2021 to March of 2022, where the slope is the largest. Looking at figure 5 this makes sense as this was the time with the largest number of new cases registered, far above the rest of the dataset. It is hard to tell if the difference in cases in the first half and second half is as big as shown in figure 5. The pandemic hit so fast and there were no routines as well as lack of tests in the early stages, meaning it can be assumed to be more dark figures in the early part compared to the later part. Figure 5 shows the historical data of daily new cases as seen below.

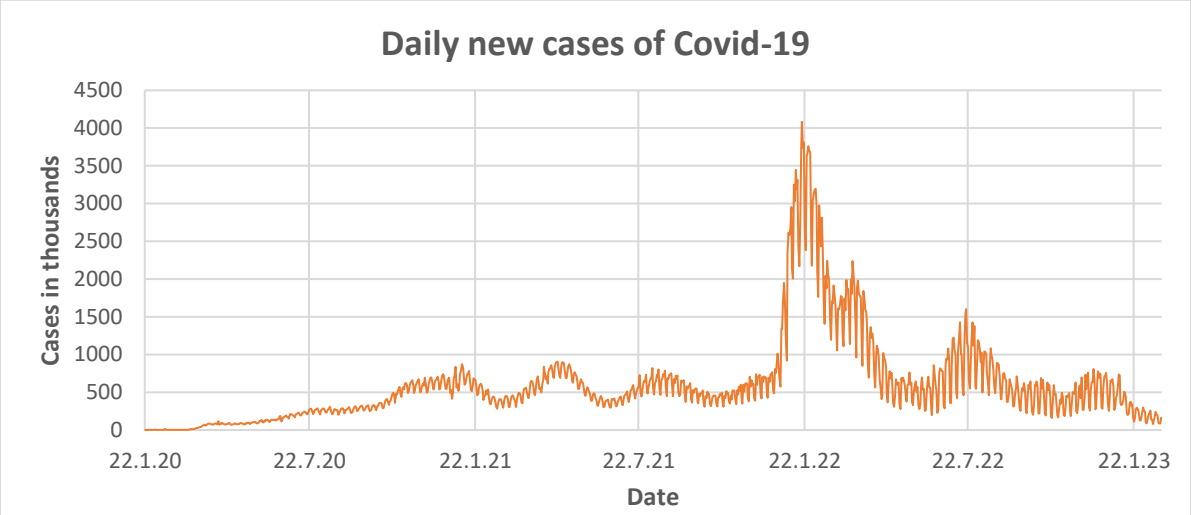

Figure 5 - Daily new cases of Covid-19

The pandemic led to major shutdowns of production to prevent the spread of the virus, and lockdowns affecting the supply chain stopping the flow of materials and goods. A report from the World Bank Group shows how the pandemic had an impact on the commodity market during the first few months [2]. The publication shows that because of the measures taken to prevent the spread of the virus affecting the supply chain, the prices of major commodities fell. The energy demand was reduced because of lockdowns leading to a reduction in travel. As fuel for transport is two-thirds of the global oil demand this led to a major shift in the demand for oil which led to the price decreasing. The downfall of oil demand can be connected to both transport disruptions and slowdown in economic activities. From the metal commodities it is shown that the prices did not fall as much as for oil, and the largest falls came from copper and zinc, while gold saw an increase in prices. One of the major connections to a decline in metal prices was the slowdown of global activities, especially in China, as China is the reason for over 50% of the metal demand. For agriculture the publication shows that due to gasoline production decline the production of corn and soybean has been affected, both which are used for producing biofuels. Overall, agriculture was less affected compared to the industrial commodities, which could be because providing food for people is so important and therefore food production is important to maintain [2].

4.2. The invasion of Ukraine

On the 24th of February 2022 the world saw the start of Russia's invasion of Ukraine, which still to date is an ongoing conflict. The market was still suffering from the pandemic trying to recover as more and more of the restrictions had been lifted. The invasion led to another major shift in the market prices, as the war affected the supply of some of the major commodities, leading to long term consequences on the commodity market. The commodity prices increased rapidly because of the war, especially for commodity groups as energy, fertilizers, grains, and metals, where Ukraine and Russia are big exporters. According to a report from the World Bank Group, this added to an already increase in the prices of commodities from trying to recover from the Covid-19 pandemic [1]. The report states that energy prices increased to being four times as high in March 2022 compared to April 2020, where April 2020 was the lowest point of the market because of the pandemic and global lockdown. Looking at fertilizer prices, the report shows that there was a 220 percent increase in prices in the same period, and an 84 percent increase in food prices.

Several economic sanctions have been established by the European Council to punish Russia after their invasion of Ukraine. The sanctions revolve around different export and import restrictions on Russia, to impact the Russian economy in a negative way. According to the European Commission, since February 2022 to March 2023, 49% of exports and 58% of imports have been sanctioned, compared to 2021 [32]. This is equivalent to 43.9 billion euro in exported goods to Russia and 91.2 billion euro in imported goods from Russia [32]. Some of the goods that cannot be imported to EU because of the sanctions are crude oil (since December 2022) and refined petroleum products (Since February 2023), coal and other solid fossil fuels, steel, steel products, iron, and gold including jewelry. It has also put a stop to exporting goods to Russia from EU such as cutting-edge technology, machinery and transportation equipment, goods and technology for oil refining and equipment, technology, and services for the energy industry. Together with import and export sanctions there has been made large restrictions to transport from Russia to and via EU. Most forms of road transport and maritime transport from Russia to EU has been prohibited, moreover the Russian carrier flights of all kinds are refused to access EU airports and to fly over EU airspace. EU also works closely with United States and other likeminded countries to coordinate the sanctions against Russia [32].

Russia being the world's largest exporter of natural gas, nickel, palladium, wheat, enriched uranium, and pig iron, as well as having a large share of crude oil, platinum, coal, and refined aluminum, it is no surprise that the war has led to a large shift in the market [1]. Furthermore, Europe imports 35% of their natural gas from Russia, as well as 20% crude oil and 40% of coal, so Russia is a big part of the energy import in Europe [1]. In total the war and sanctions have led to a decrease in the supply

of certain goods and have led to increasing prices in the commodity market as the market is highly affected by the shift in the economy, making it more volatile.

5. Commodity markets

5.1. Energy

5.1.1. Crude Oil

Crude oil, also known as petroleum or oil, is one of the primary energy sources in the world. Oil is used for products such as gasoline and diesel fuel as well as plastics, fertilizer, and making computer components, among others, meaning it is a high demand commodity [33]. The petroleum industry can be categorized into three components called upstream, midstream, and downstream. Upstream is the category of exploring for and extracting crude oil, while midstream includes transportation and storage of the oil. Downstream is the refining of the oil into a variation of end products [34]. As crude oil is vital to many industries for production it is highly demanded by nations worldwide. Looking at the world energy consumption it is shown that 32% of Europe and Asia's energy consumption is from crude oil, as well as a leading 53% for the middle east [34]. Furthermore 44% of energy consumption is from crude oil in South and Central America, 41% for Africa and 40% for North America [34]. As a result, the total world consumption of crude oil is 36 billion barrels per year. The lead producers of crude oil are United States followed by Saudi Arabia, Russia, Canada and then China [35].

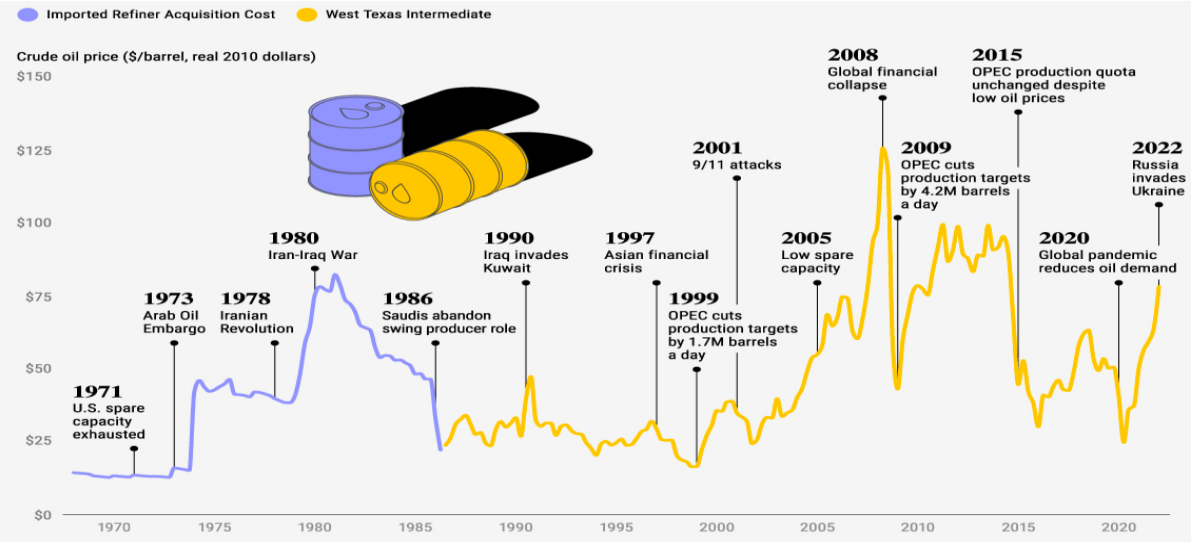

Figure 6 - Crude oil historical events [36]

Looking at figure 6, which show price history of crude oil, evidence is provided on how various political and economic events have affected the price over time, showing how volatile the oil market

can be [36]. As shown the last two events have been the invasion of Ukraine in 2022 and the pandemic starting in 2020. Another major event was the 2008 global financial collapse which led to a major downfall in oil prices. The figure also shows how OPECs production affects the price; this is because OPEC is one of the largest single influencers of oil price. OPEC is an organization consisting of 13 countries that in total are the producers of 40% of the world's oil supply, meaning changes in OPEC oil production can have a large effect on the oil supply, which can lead to shifts in oil price [35].

Looking at the cointegration of the global crude oil markets it is shown to be well integrated as regions around the world are closely correlated, as Ji and Fan prove in their research paper from 2016 [37]. The integration of the markets means that changes in one market will also affect the market in other regions as they are closely connected. Ji and Fan conclude that the increasing integration in the crude oil market is a result of fast release and transmission of information, wide cooperation in the market and high liquidity of the oil trade globally.

5.1.2. Natural gas

Natural gas is another important primary energy source which is the lead component of around one fourth of global electricity generation [38]. The largest producers of natural gas are United States, followed by Russia, Iran, Qatar, and Canada. As figure 7 shows, in 2019 natural gas had a 16.4% share of the energy consumption of the world making it one of the largest contributors after oil and electricity, making it an important resource around the world [39].

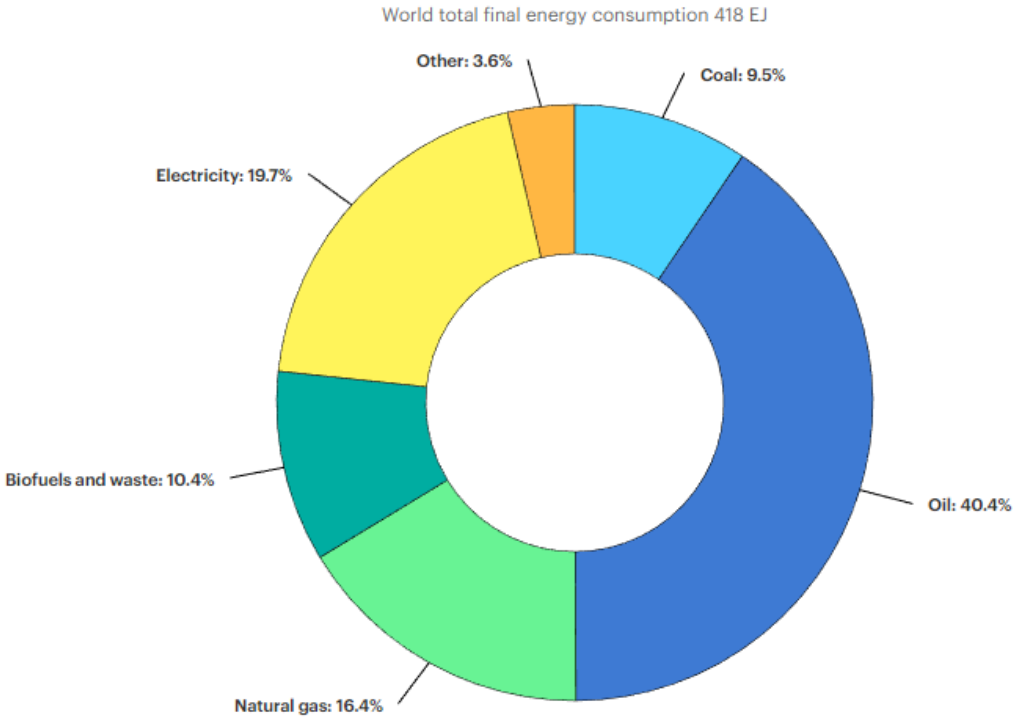

Figure 7 - World total energy consumption of 2019 [39]

Natural gas usage can mainly be split into 5 sectors being electric power, industrial, residential, commercial, and transportation sector [40]. Natural gas is used for generating electricity and in 2019 natural gas was used for 24% of the world's electricity generation, having the second largest share after coal [41]. In the industrial sector natural gas is used for heating and power systems, as well as material for producing chemicals, fertilizer, and hydrogen. Furthermore, it is used in residential and commercial sectors primarily for heating buildings and water but also for cooking, drying and in some cases outdoor lighting. For the transportation sector natural gas is used as fuel, however this is only a small portion of the usage of natural gas [40]. As seen in figure 8, the largest sector for natural gas usage in 2019 was the industry and residential sectors, having a total of 67.3% of the total consumption [42]. This is no surprise as a lot of the natural gas is used for generating electricity and for heating systems.

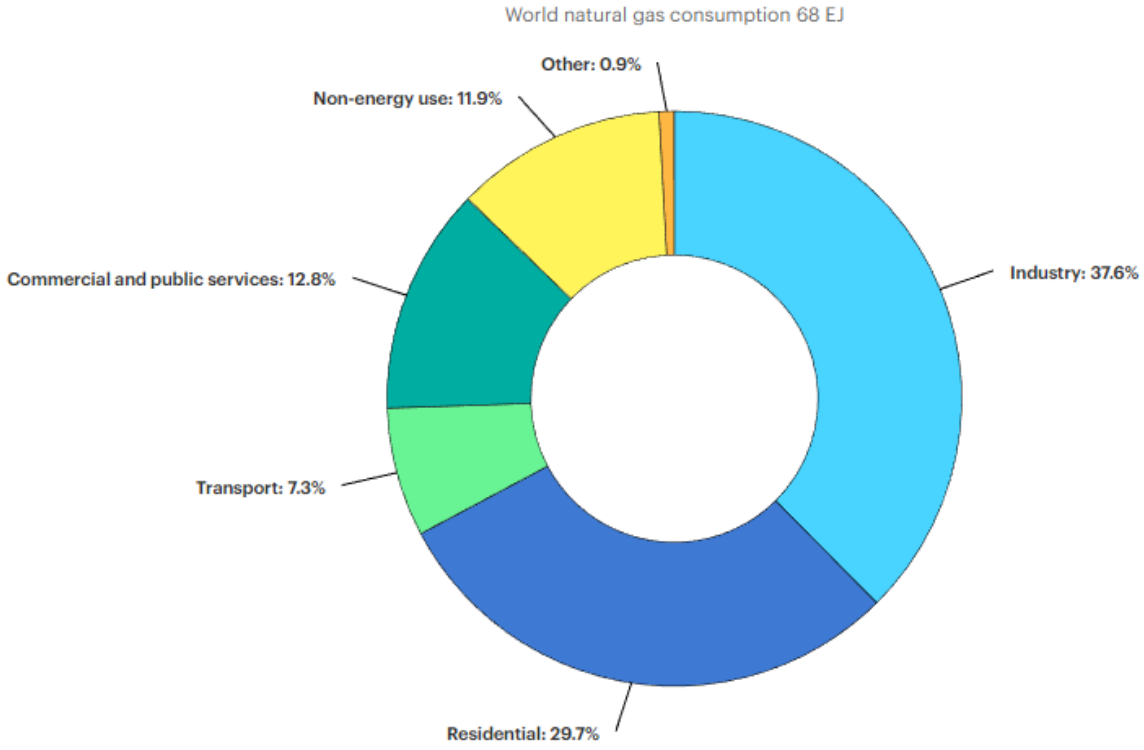

Figure 8 - World natural gas consumption of 2019 [42]

Unlike crude oil, the global natural gas markets are not as integrated, meaning there are bigger variations in prices among regions, as shown in an article posted on "IMF Blogs" [43]. In the article it is shown how the gas price from Dutch TTF, LNG Asia and Henry Hub US differ from 2019 to 2023, showing the diversity in price among regions. As the gas market is not so integrated, different regions may respond differently to shocks. This is connected to gas mostly being transported in pipes among regions and the complexity of transporting gas in other ways. This is because certain technology is

required to liquify and store gas for transportation, as natural gas must be made into compact form to be able to ship it, making it more complicated to transport [43].

5.1.3. Coal

Coal is another energy source used for several production purposes around the world. As shown in figure 7, 9.5% of the global energy consumption comes from coal [42]. The lead producers of coal are China, followed by India, USA, Indonesia, and Australia [44]. Coal is used for power generation where it is used to turn water into steam, which then can be used to power turbines to generate electricity. It is also used in the steel industry to smelt iron ore and produce steel. Further it is used in industries like aluminum refineries, paper manufacturing, chemical companies, and pharmaceutical manufacturing, as well as several products like plastic, filters, and nylon [44]. In other words, coal is a demand in several industries. As coal is used for many purposes, what drives the prices of coal? The market demand is one of the factors for coal prices, a higher demand for energy results in a higher demand for coal [44]. Substitutes will also affect the price of coal, as substitutes can lead to a lower demand for coal. Natural gas is one of the close substitutes of coal because both can be used for energy generation and natural gas is considered a cleaner source of energy. Another factor that affects the price of coal is government regulations since countries can regulate the use of fossil fuels to reduce environmental pollution. This has led to lower production of coal which leads to higher prices [44].

For the cointegration of the global coal market it is shown that the global markets are partly integrated. A research article by B. Liu and H. Geman proves this by showing evidence of cointegration among some regions, but not the full part of the global market [45]. They conclude that China does not belong to the global market and connect this to Chinas large production of coal as well as their national policies. However, for United States and the other eight regions in the research they find evidence of cointegration. The research covers data from both the Atlantic and Pacific regions, covering data from different markets around the world.

5.2. Metals

5.2.1. Gold

Gold is a precious metal that has been considered a safe-haven asset for centuries. Unlike other metals gold does not have many industrial uses, and it is mostly driven by the belief to have a store of value [46]. Therefore, the value of gold greatly exceeds its applications in the industry and thus it is a very interesting commodity to analyze. Gold is mined from the ground and can then be used to make jewelry, producing technology, used by private investors, central banks, and sovereign wealth funds [46]. The lead producers of gold are China, Australia, Russia, USA, and Canada. One of the main

demands for gold is the jewelry industry where it is used to produce products like watches, rings, and necklaces. As seen below in figure 9, around 50% of the total demand for gold comes from the jewelry market [47]. It is also commonly used to produce electronic parts, as it conducts electricity well. Because of this gold is often used for connectors, switches, and relay contacts in cellphones making it a demand in producing technology [46]. Gold is also seen as a safer investment option than most commodities and is considered a safe-haven among most investors. It has been shown that adding gold to the portfolio can reduce volatility and during times with shocks in the market it can lead to minimizing losses [47]. Because of this there is a high demand for investing in gold by purchasing physical gold or by investing in gold funds. Gold is also a key component in the global central bank reserves. Especially after the 2008 financial crisis central banks have increased their investments in gold by increasing their purchase [47]. Also, central banks in Europe stopped selling gold after the financial crisis in 2008 which led to a lower supply of gold from banks and therefore a higher demand in the market.

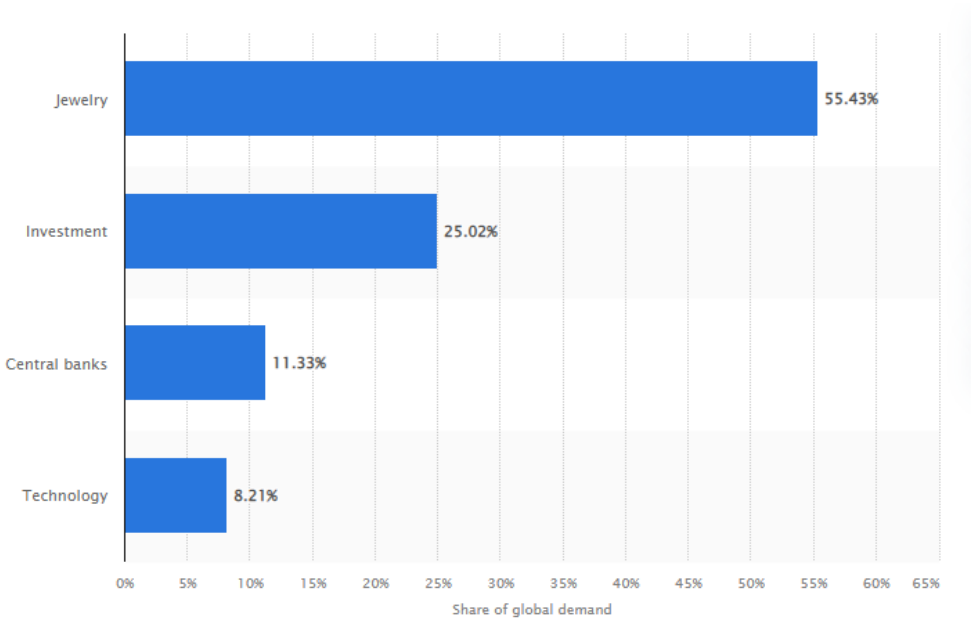

Figure 9 - Share of gold demand 2022 [48]

Figure 9 shows that as of 2022 more than half of the demand for gold comes from the jewelry industry [48]. The second largest sector is investment, which takes a quarter of the demand. Central banks take 11.33% of the demand shares and the technology industry another 8.21%.

Looking at the cointegration for the gold markets a research article by C. Chang, J.D. Chang and Y. Huang shows bidirectional causality between the London and New York gold markets, which are the biggest gold markets [49]. Further they find a unidirectional causality between the New York market

and the other markets, being Hong Kong, Japan, and Taiwan. The Hong Kong, Japan and Taiwan markets are also found to have a bidirectional relationship and is shown to all be affected by the New York market. However, they also impact the London market. Overall, the New York market is shown to have the lead role in the gold market [49].

5.2.2. Nickel

Nickel is one of the most widely used industrial metals in the world because of its properties like having a high melting point and catalytical properties, meaning it speeds up chemical reactions. It is also strong, ductile, magnetic, and resistant to corrosion, making it ideal for a lot of industrial purposes [50]. Nickel is produced by either mining, called primary production, or from recycling, known as secondary production. As of 2023 there is a total of 2.25 million tons of nickel extracted from mines around the world and the top 5 countries that mine nickel is Philippines, Russia, Canada, Australia, and New Caledonia [50]. Nickel is also used for production such as making stainless steel, for electronic components, to cover conductive metals, for catalysts, and for rechargeable batteries. Almost two thirds are used for stainless steel production, which is then used to make products such as sinks, industrial equipment, and cookware, among other things. For catalysts nickel is used to make chemical reactions easier, because of its catalytical properties [50].

The main drivers of the nickel price are Chinese demand, global stocks, global demand outlook, government policies and input prices. China being a large producer of stainless-steel products and batteries, among other things, makes the demand of nickel in China a huge factor of the nickel price variations [50]. China accounts for more than half of the nickel demand, meaning we can expect a big price reduction from a lockdown of industries in China from the pandemic. Global stocks affect nickel prices as inventory levels will affect the accessibility of nickel, most important is the Chinese inventories as they are the lead consumers. The global demand outlook will affect prices as more demand for nickel in big building projects will increase demand and therefore also the price. Government policies are another major factor for nickel prices. An example is the Philippines who are the lead miner of nickel who have threatened to end all mining, which would greatly affect the supply of minerals like nickel. Also, for producing nickel it is required large amount of coal, electricity, and crude oil, meaning input prices will affect the price of nickel, as prices of inputs increase the price of producing nickel will also increase and therefore nickel price will increase [50]. Looking at figure 10, we see the distribution of nickel consumption worldwide based on data from 2021 [51]. We can see that stainless steel production is by far the biggest demander of nickel with 69%, and far below is battery production in second place with 13%.

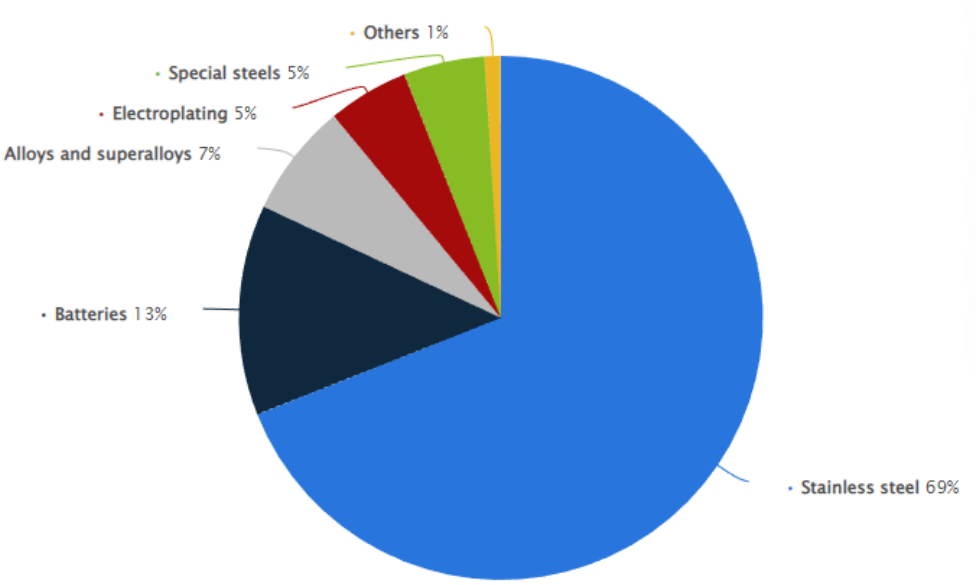

Figure 10 - Nickel consumption by category 2021 [51]

5.2.3. Copper

Copper is one of the most used metals and the characteristics make it good for use in the industry for making electrical wires, plumbing, roofing, and industrial machines [52]. As seen with nickel, copper also comes primarily from mining and recycling. The largest producers of copper are Chile, followed by Peru, China, USA, and Australia. Looking at the demand for copper by region, as shown in figure 11, China is by far the biggest consumer with a 49% share of the consumption [53].

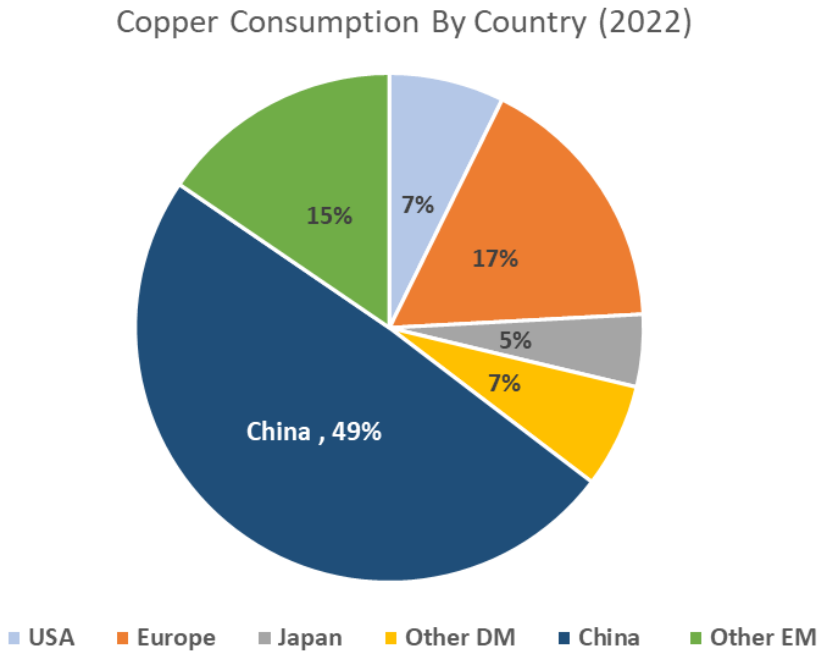

Figure 11 - Copper consumption by country 2022 [53]

This means that the demand for copper in the industry in China will have a big impact on the copper prices. As industries were closing during the Covid-19 pandemic it would be expected to see price drops for copper. In the industry the main use for copper is for building construction, but it is also used for transportation equipment where it is used as a component for making electric motors. It is also used for making electric and electronic products like circuit boards as it is a good conductor of electricity. For consumer and general products copper is used to make several products like cookware, rails, and musical instruments, and it is also used for industrial machinery and equipment [52]. As seen copper is used in several industrial productions and prices are therefore highly dependent on the industry's demand. The price of copper also depends on emerging markets, construction industry, supply disruptions and substitutes [54]. As the markets keep growing the need for copper increases, meaning the demand increases. For certain uses copper can be substituted by other metals like aluminum, nickel, lead, or iron, hence the prices of other metals will also impact the demand for copper [54].

For the copper market a research article by R.W Rutledge, K. Karim and R. Wang show strong correlation between the three primary copper markets in the world [55]. Their analysis show that the London Metals Exchange (LME) and New York Mercantile Exchange (COMEX) markets have a positive influence on each other. They also find that both LME and COMEX have a reverse direction impact on the Shanghai Futures Exchange (SHFE) market. Further they find a bidirectional Granger cause between all three markets and conclude that the three markets can be considered as one continuous trading market.

5.3. Agricultural

5.3.1. Wheat

Wheat is one of the most consumed grains in the world, being ranked as number two in grain consumption after rice which is the most consumed grain [56]. It is also the fifth most traded commodity behind oil, coffee, gas, and gold [57]. Wheat is known for being easy to grow as it is possible to grow in a range of different climates. Because of this wheat is grown all over the world and the top producers of wheat are China, India, Russia, USA, and France [56]. Wheat is also characterized to stay fresh over time while also providing a high level of nutrition and is therefore an important commodity which is demanded all over the world. The price of wheat is determined by a range of factors like oil prices, global population, income growth, price of substitutes and climate [57]. Oil is used as an input cost for producing wheat as it is used to run farm equipment and machinery. Oil is also used as fuel meaning higher costs of oil will affect the prices of both producing and shipping wheat. Another factor is the climate which affects the production of wheat, even though

wheat can grow in a range of environments, extreme weather or lack of water can lead to diminished crops which will affect the supply [57]. Furthermore, geo-political factors like the Ukraine invasion will affect the supply as both Russia and Ukraine are large producers of wheat. Russia was in 2019 the cause of 14% of the world wheat exports, while Ukraine was the cause of 8.9% [57]. In other words, we can expect the supply of wheat to have been affected by the war and as a result see price increases. On the other side demand for wheat is strongly related to population growth as there is constantly an increase in food demand as populations grow. However, wheat has some close substitutes like rice, corn, soy, and rye, meaning prices of substitutes will also affect the demand, and ultimately the price of wheat [57].

A research article by A. Ghoshray and T.Lloyd provide evidence that the wheat market is highly integrated and is segmented into three sub-markets based on the wheat strength [58]. Their report states to find a dominant price leader in each sub-market, and states that EU plays a passive role in the overall global market. The analysis also indicates that the international prices are linked through substitutes or arbitrage, as well as linking long run relationships to derived demand. Another research by B.K. Goodwin indicates that the "law of one price" is fulfilled if the wheat prices are adjusted for freight rates [59]. The report links a common long-run equilibrium in the wheat market to efficient arbitrage and trade activities.

6. Analytical methods

6.1. Price volatility

To calculate the price volatility the standard deviation will be used. Standard deviation is used to measure volatility by looking at the dispersion of the data [60]. Volatility in prices means the prices have been changing a lot, and therefore a spread in the data can be connected to volatility in the market. By calculating the standard deviation, it can be shown how the data is spread relative to the mean of the dataset. A small standard deviation means the data is closely clustered around the mean, which is related to low volatility. On the other hand, a large standard deviation means the data is more spread out from the mean, showing that the price has been volatile in that period [60].

Previous research has used standard deviation to measure volatility. A report from the world bank group shows how changes in volatility can be measured by calculating the standard deviation based on a moving average of 250 observations, calculating volatility between 1997 until 2014 [61]. 250 observations then correspond to a calendar year of daily returns. By calculating the moving standard deviation, they analyze how volatility has been in the 2008-2009 oil crisis. They conclude that the price volatility for most commodities reached historical highs during the oil crisis in 2008-2009.

Furthermore, the volatility of the S&P 500 index is shown to be affected by the increase in commodity volatility. They also conclude that the overall volatility returns to historical norms in 2010, making the volatility temporary.

In this analysis a moving standard deviation will be used to analyze the changes in volatility over time. Based on the time series for each commodity we can calculate the standard deviation of a certain period and then for each calculation we add a new price data while removing the last price data [60]. By doing this we can look at how volatility has changed over time. As mentioned earlier the time series for this analysis reaches from January 2015 until December 2022, meaning a population is taken from the complete price history. Therefore, the following formula will be used to calculate the standard deviation:

$$S = \sqrt{\frac{\sum_{i=1}^{n}(y_i - \bar{y})^2}{n-1}}$$

In the formula S is the standard deviation, y_i represents each price data in the given period, meaning the daily prices for the period, and $\bar{y}$ is the mean of the data based on a one-year period of data for each calculation. Further, i represents a specific datapoint for the specific calculation, while n is the number of observations in the time series used for the calculation.

Using standard deviation has its advantages and disadvantages and to strengthen the validity of the method it is important to highlight both. Standard deviation has the following advantages and disadvantages [62]:

Advantages:

- Commonly used to measure dispersion, meaning its well known by analysts.
- All data points are included in the calculation, unlike some other methods that use the most disperse values. Standard deviation is therefore considered more accurate and robust.
- Standard deviation can be further used in other calculations.

Disadvantages:

- Measures the squared distance instead of actual distance from a datapoint to the mean of the dataset.
- Extreme values have a big impact on the calculation of standard deviation.
- Can be difficult to calculate manually.

For this analysis the standard deviation is analyzed by looking at the daily returns and by looking at the indexed values. By using the indexed values, it can be shown how the volatility has changed compared to the base date, which in this case will be 01.01.2015, as it is the first datapoint in the dataset. Every price in the dataset is then divided by the price from 01.01.2015 to get a ratio describing the relative change in price. The standard deviation is then calculated based on one year of indexed price data for each calculation. Starting by calculating based on values from 30.12.2022 until 31.12.2021 and then for each calculation moving one day back in time, meaning the second calculation reaches from 29.12.2022 until 30.12.2021, and so on. The number of data points for each calculation varies for each commodity as there is a different number of trading days during a year for each commodity. The second way of looking at standard deviation is by using the daily returns of the commodities. The calculations are done in the same way as for the indexed values, over a one-year period and moving the data by one day for each calculation.

6.2. Relative risk

To calculate the relative risk of each commodity compared to the gold price two methods will be used, the first being beta(β) and the second being Sharpe ratio. Both the beta and Sharpe ratio will be calculated in the same way as the standard deviation, meaning a moving beta and Sharpe ratio is calculated by adding a new price data and removing the oldest for each calculation. However, the price data for beta and Sharpe ratio is based on weekly returns, so each calculation moves by one week.

6.2.1. Beta

Beta is used to measure the volatility of an asset or portfolio relative to the market, the asset in this case being a specific commodity and the market being gold. By calculating the beta, it can be shown how the asset or portfolio price has moved compared to the market price. By looking at the rate of the price change of a commodity compared to gold we can see if the commodity is relatively more or less volatile. Often it is used to evaluate the risk and return ratio and is important to look at concerning the risk of an investment [63].

Previous research used beta to show price development. Hansen and Lunde et al. calculated beta to track price development over time by comparing commodities to Spyder, which is a fund tracking the S&P 500 index [64]. By modelling the time-variate beta in graphs they illustrate how the beta has changed over the period 2007 until 2014, where most commodities have varied from positive and negative beta over time.

The following formula is used to calculate the beta [63]:

$$\beta = \frac{Covariance(R_{c,a\to b}, R_{g,a\to b})}{Variance(R_{g,a\to b})}$$

The formula uses the covariance between the returns of the commodity (R_c) compared to the returns of gold (R_g), which measures how the prices of the commodity move compared to the gold price. It is then divided by the variance of the gold returns, which is a measure of how far the gold price moved compared to its mean [63]. Dividing the covariance over a certain period by the variance of the same period we get the beta. The symbols "$a \to b$" indicates the interval of the values for the specific calculation. Here a is the first weekly historical data used for the calculation and b is the last, both moving by one week for each calculation.

As with standard deviation, beta also has its pros and cons, and to strengthen the validity of using the method it is important to look at them. The advantages and disadvantages of beta are [65]:

Advantages:

- Clear and quantifiable measure of risk.
- Straightforward and easy to work with.

Disadvantages:

- Requires a certain amount of price history to get a reliable beta.
- Does not indicate if prices move up or down, only if the prices move in the same or opposite direction.
- Uses history from the past, which might not reflect the future outcome.

For this analysis the beta can be interpreted in the following way [66]:

- **β < 0:** An inverse correlation meaning commodity price moves in the opposite direction of the gold price (because of a negative covariance in the formula).
- **β = 0:** There is no correlation between the commodity price change compared to the gold price change.
- **0 < β < 1:** The commodity price moves in the same direction but by a smaller degree compared to gold. The commodity is considered less volatile and carries less risk than gold.

- **β = 1:** The prices of the commodity and gold move in the same direction at the same rate. The commodity is as volatile as gold, carrying the same amount of risk.
- **β > 1:** The commodity and gold price move in the same direction, but the commodity moves at a higher rate than gold price. The commodity is considered more volatile than gold and is considered to carry more risk.

As the trading days differ for each commodity, the weekly returns have been used to calculate the beta between each commodity and gold. This is done as the covariance requires the same amount of data points for both the commodity and gold in the calculation. By using the daily returns, it would not be possible to get the exact same period for gold and the given commodity in the calculations. However, it can be fixed by using the weekly returns. This means the beta is calculated for a one-year period and for each calculation the time series is moved by one week.

6.2.2. Sharpe Ratio

The second method for measuring relative risk is the Sharpe ratio which is used to measure the risk-adjusted performance of an investment. This is done by comparing the returns of an asset or portfolio to a risk-free asset, in this case comparing a specific commodity to gold [67]. Of course, investing in gold does not come without risk, but as mentioned earlier gold is considered a safe-haven during volatile times. Therefore, by using gold as the "risk-free asset" we can compare each commodity's performance to gold. The index with a greater Sharpe ratio is more desirable, meaning you would want to invest in the index with the greatest Sharpe ratio.

Previous research shows the risk adjusted performance of commodities or assets using Sharpe ratio. Basu et al. calculates the Sharpe ratio of 6 commodities against the S&P 500 index over a period stretching from 2000 until 2006 [68]. They look at different scenarios in the market and calculate each commodity's Sharpe ratio against the S&P 500 index as well as the Sharpe ratio of an equally weighted portfolio of all the 6 commodities against the S&P 500. In this way they can show what commodity or portfolio performed best in the given scenario.

The formula used to calculate the Sharpe ratio is [67]:

$$H = \frac{R_{c,a\to b} - R_{g,a\to b}}{\sigma_{c,a\to b}}$$

Here H is the Sharpe ratio, while R_c is the return of the specific commodity and R_g is the return of gold which will be considered the risk-free asset. Further $(R_c - R_g)$ is the expected return of the investment and σ_c is the standard deviation of the excess returns of the commodity. Here "$a \to b$"

also indicates the interval of the values for the specific calculation. Again, a represents the first weekly historical data used for the calculation and b is the last, both moving by one week for each calculation.

The Sharpe ratio also has its advantages and disadvantages, as seen with both standard deviation and beta as well. To strengthen the validity of the research, the advantages and disadvantages of Sharpe ratio are provided as follows [67]:

Advantages:

- Widely used for measuring risk-adjusted relative returns.
- Easy and straightforward to calculate.
- It is possible to apply the Sharpe ratio to all types of assets.
- Useful to evaluate a portfolio's risk-adjusted performance, and hence can be used to rank investment options, or evaluate investments.

Disadvantages:

- Does not consider tail risk, as it considers the dispersion to be normally distributed, which is not always the case.
- The Sharpe ratio can be manipulated by lengthening the return interval of measurement, which can be done to lower the risk estimate.

The Sharpe ratio can be interpreted in the following way [69]:

- **S < 0:** The yield of the investment is worse than the risk taken by investing. This means the commodity return is worse than the risk-free rate.
- **S = 0:** The yield is as expected compared to the risk taken by investing, meaning the return of the commodity is the same as the risk-free rate.
- **S > 0:** The yield is greater than expected compared to the risk taken by investing. This means the commodity return is greater than the risk-free rate.

The Sharpe ratio is calculated in the same way as the beta, using weekly returns. The calculations are based on a one-year perspective and for each calculation the time series is moved by one week. The first calculation covers data from week 52 in 2022 until week 52 in 2021, then moving by one week until the last calculation which covers data from week 1 in 2016 until week 1 in 2015.

7. Analysis of empirical data

7.1. Price volatility

7.1.1. Standard deviation

By using indexed values, it can be shown how the volatility has changed over time relative to the reference date. All data will have the same reference and hence it can be used to compare the volatility of different time periods.

Figure 12 shows the result of calculating the standard deviation based on one year of data for each calculation based on indexed prices.

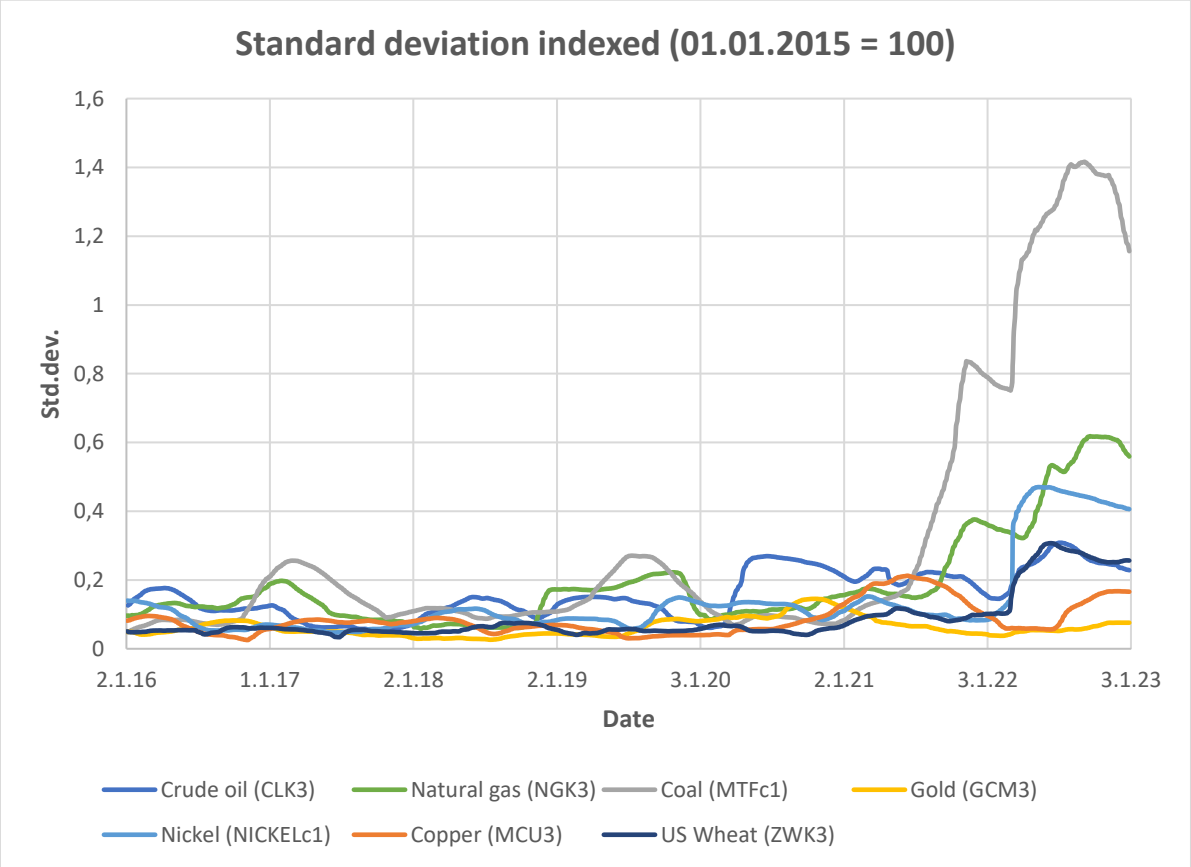

Figure 12 - Standard deviation indexed data

As figure 12 shows, the highest standard deviation in the pre-covid period is from crude oil, natural gas, and coal, however they all vary over time and which of them have the highest volatility also vary over the years. Nickel and copper also vary up and down over the years, but the standard deviation is lower than oil, gas, and coal. Gold and US wheat are the commodities that vary the least in the pre-covid period, and their graphs are therefore relatively flat compared to the other commodities. As covid hit in the end of 2019 the volatility of crude oil, natural gas and coal were declining, but in the

early part of 2020 it shifts, and they become more volatile. Crude oil has the largest jump in standard deviation in the early part of covid and stays more volatile in the rest of the period, with another jump in volatility when the war started in early 2022. Both natural gas and coal had smaller increases after covid began until mid-2021 where both made a large leap in standard deviation following a minor decrease and then another big leap when the war started. Both nickel and copper have been fluctuating in volatility both before and after covid. Copper had a steady increase until mid-2021 and then a steady decrease until flattening out for the first half of 2021. This is then followed by a minor steady increase in volatility a few months after the war started. For nickel however, it shows a sharp increase in volatility right before covid started, and then keeps fluctuating during the time between early 2020 until early 2022. It is then followed by a rapid increase in volatility as the war starts, which makes it one of the most volatile of the commodities in the last year. The volatility of US Wheat stays the same during 2020 but starts slowly increasing at the end of 2020 and for some of 2021. As the war starts, US wheat does a major leap in volatility together with crude oil. Gold has been the least, or one of the least, volatile commodities during the whole period, except for 2020 where it had its highest point. For a very short period in 2020 it was more volatile than the other commodities except crude oil. It is then followed by a steady decrease and staying relatively flat in the last 2 years. Gold is also the only commodity that did not see a large change in volatility following the war.

To further clarify how each commodity's volatility change for each of the three periods, table 3 is made to show the average standard deviation for each commodity in each period. The purpose is to compare the volatility more easily among commodities in and between the different periods.

Standard deviation averages based on indexed values (01.01.2015 = 100)							
	Crude oil (CLK3)	**Natural gas (NGK3)**	**Coal (MTFC1)**	**Gold (GCM3)**	**Nickel (NICKELc1)**	**Copper (MCU3)**	**US Wheat (ZWK3)**
Pre-Covid (2016-2020)	0,113	0,128	0,143	0,050	0,084	0,063	0,054
Post-Covid - Pre-Invasion (2020 – Feb. 2022)	0,201	0,177	0,271	0,086	0,115	0,117	0,077
Post-Invasion (Feb. 2022 – 2023)	0,258	0,511	1,278	0,060	0,429	0,108	0,260

Table 3 - Standard deviation indexed averages

As the table shows, the standard deviation is the lowest in the pre-covid period for all commodities and coal has the highest volatility based on the average, closely followed by natural gas and then crude oil. Gold is shown to have the lowest volatility in this period. The period covering data after covid hits, but before the war starts, shows an increase in volatility for all commodities. For this

period coal is still having the highest volatility, but crude oil now has the second highest volatility and natural gas the third highest. Wheat is found to be the least volatile of the commodities in this period, but gold is a close second of the least volatile commodities. For the period covering data after the invasion of Ukraine we see that coal is still the most volatile, far above the other commodities. Further we now see that natural gas is the second most volatile again, but the third most volatile has become nickel. Crude oil, natural gas, coal, nickel, and wheat is shown to have increased in volatility since the pre-invasion period, while gold and copper is less volatile than in the pre-invasion period, but still more volatile than the pre-covid period. For the post-invasion period gold is the least volatile commodity again and in general we see that gold has a low volatility over all the three periods.

Further it is interesting to do the same analysis for the daily returns of the commodity prices. By calculating the standard deviation of daily returns, we can see how the variation in daily returns volatility has changed over time for each commodity. The result is shown in figure 13 below.

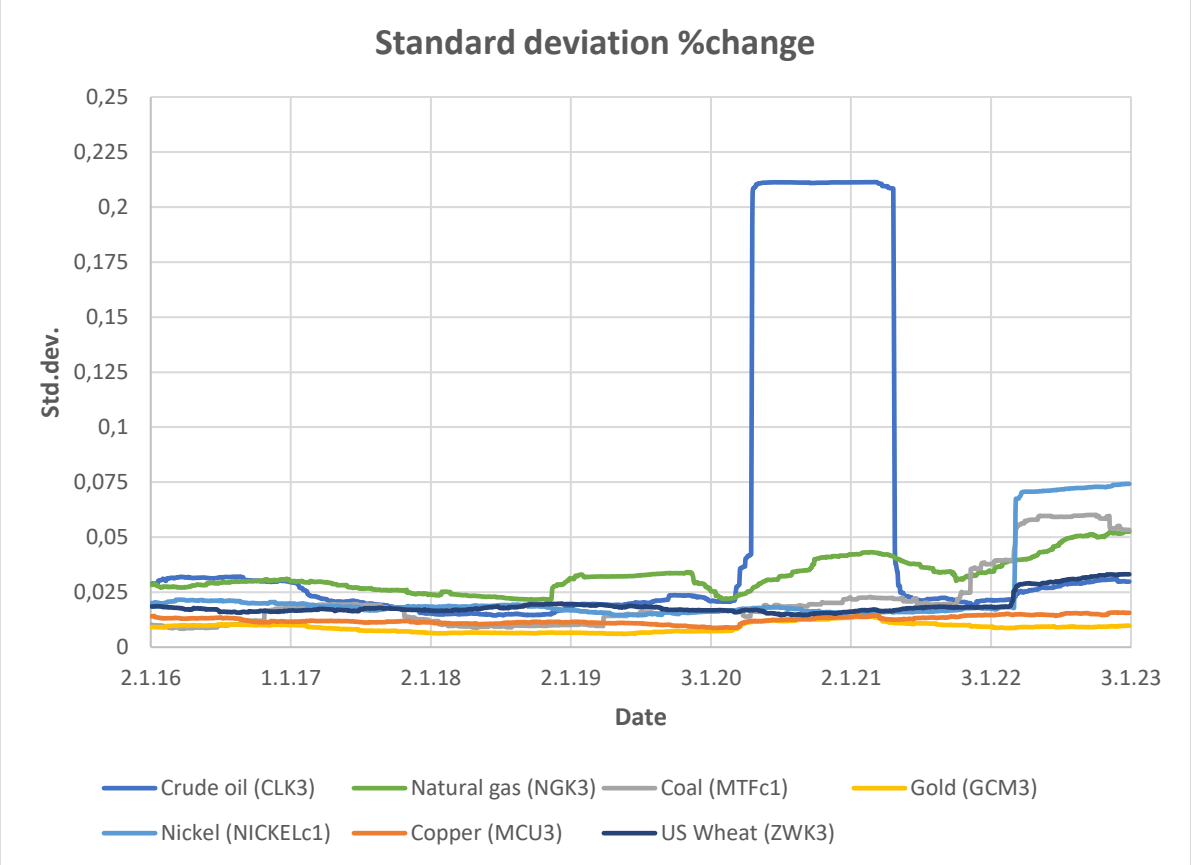

Figure 13 - Standard deviation daily returns

As figure 13 shows, based on the daily returns, both gold and copper have been the least volatile commodities and have kept an almost steady graph for the whole period. Gold is the least volatile commodity for the whole period except for the first part of 2016 where coal was the least volatile commodity. Coal has been fluctuating since 2016 until the end of 2021 where the volatility increases

sharply, followed by another leap at the start of 2022 when the war started. Both nickel and US wheat's volatility has remained steady from 2016 until the war started where both increased rapidly making nickel the most volatile commodity of the last 10 months. Natural gas has remained the most volatile commodity for most of the period moving up and down with time. As covid started the volatility of natural gas decreased rapidly but saw a steady increase again as the lockdown started. Further natural gas keeps fluctuating and as the war starts the volatility keeps increasing steadily but at a lower rate than some of the other commodities. For crude oil the volatility has been fluctuating during the pre-covid period, and it has been one of the most volatile commodities during that period. A couple of months after covid starts crude oils volatility has a massive increase. This is the result of shutdowns during the early part of covid making the oil price decrease rapidly which had a big impact on daily returns where the largest change was a -305.97% on 20.04.2020. In general March, April and May of 2020 had big changes in daily returns for crude oil making the calculations including those dates highly volatile when looking at daily returns. As mentioned, standard deviation is affected by extreme values which we can clearly see in figure 13 for crude oil. Furthermore, volatility decreased for oil in mid-2021 and was then followed by a slow and steady increase during 2022.

7.2. Relative risk

7.2.1. Beta

By looking at the beta based on the weekly returns we can see how each commodity's price changes over time compared to the change in gold price over time. It is then possible to see if the given commodity price changes in the same direction as gold or not, and at what rate the price changes compared to gold, showing volatility as well as risk. To calculate the change in beta over time the same method is used as for standard deviation, except for beta it is used weekly returns instead of daily returns.

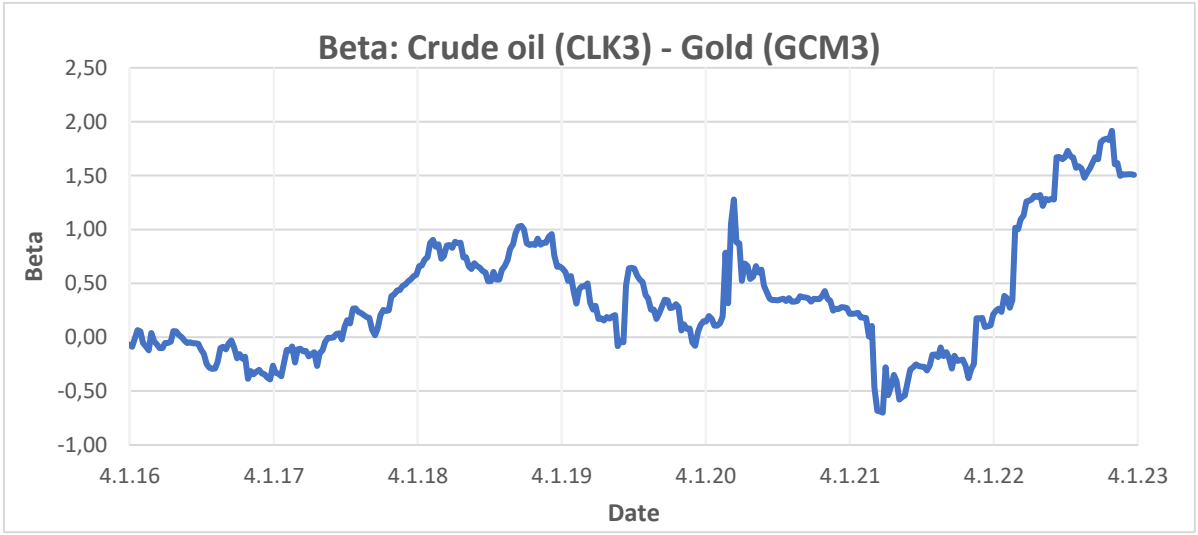

Figure 14 - Beta: Crude oil - Gold

Figure 14 shows the moving beta between crude oil and gold. As shown crude oil price has mostly been moving in the same direction as gold price, but at a smaller rate as the beta is mostly below 1, showing oil to be less volatile, carrying less risk. During 2016 and early 2017 the beta is negative, meaning the price of crude oil went in the opposite direction of gold. The same case can be seen in two small periods in 2019, as well as for most of 2021. Since the start of 2022 the beta jumps over 1 meaning the crude price moves in the same direction as gold, but at a higher rate, meaning oil becomes more volatile. This happens as the war in Ukraine starts. The same can be seen for short periods in 2018 and 2020.

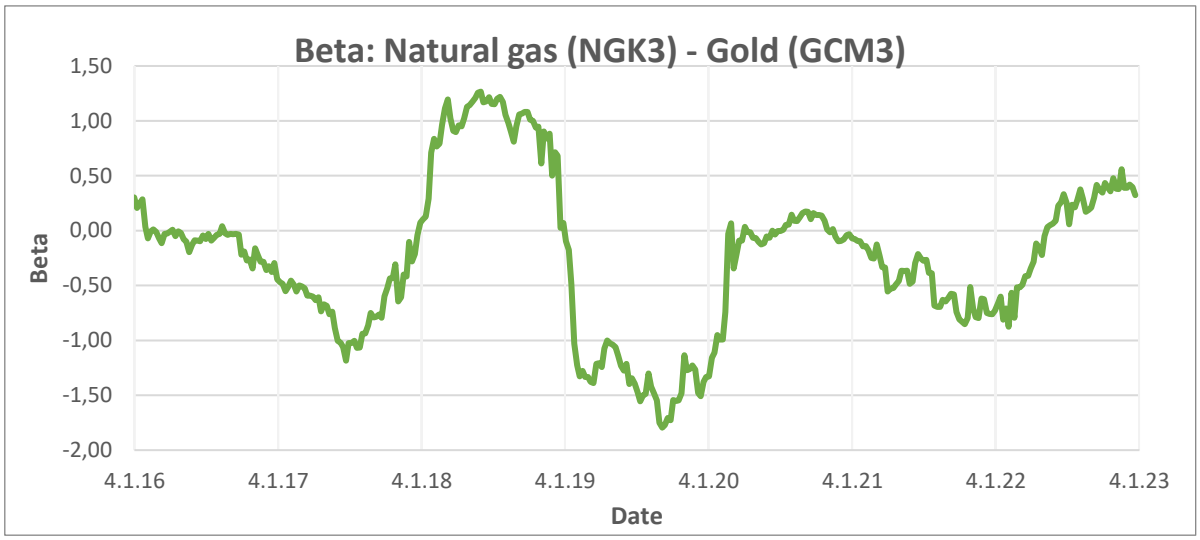

Figure 15 - Beta: Natural gas – Gold

As a contrast to crude oil, natural gas has mostly been moving in the opposite direction compared to gold, as seen in figure 15. For most of 2016 and 2017 natural gas price has moved in the opposite direction of gold and changed at a slower rate than the gold price, showing a lower level of volatility, and hence lower risk. The same is seen in 2021 and the first part of 2022. In 2018 a shift happens where natural gas price moves in the same direction as gold price with a beta of 1, meaning the price change happens at approximately the same rate. Another shift happens in 2019 where the beta moves below -1. For the whole year of 2019 the price of natural gas goes in the opposite direction of gold and at a higher rate, showing higher volatility for natural gas, before shifting again in 2020. In 2020 the beta moves around 0 meaning there is no correlation between price changes for natural gas and gold. In 2022 we see that the beta shifts from being almost -1 to being almost 0.5 at the end of 2022. In total there is a lot of shifting for natural gas, following gold prices in some periods, and going the opposite way in some periods.

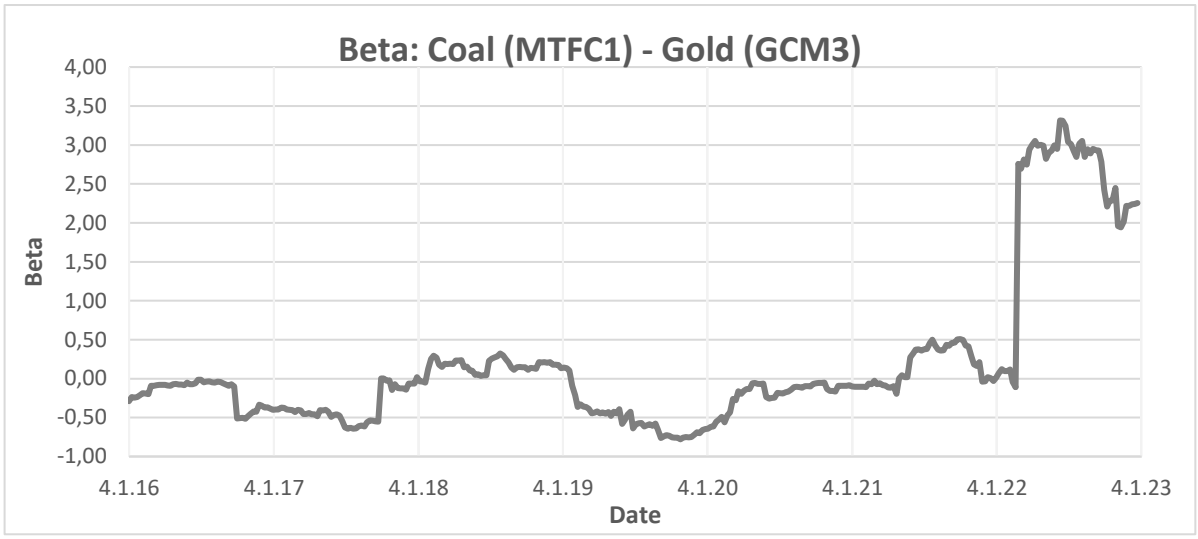

Figure 16 – Beta: Coal - Gold

For coal, as figure 16 shows, we can see that the price moves mostly in the opposite direction as gold until right before mid-2021. For the period the beta moves between 0 and -0.75 for the most part, meaning it is less volatile and carries less risk than gold. The exception is 2018 where the beta is positive, moving between 0 and 0.5. As the war starts in early 2022, we can see that the beta makes a huge leap to almost 3, making it much more volatile than gold. It stays around 3 for most of the year until it falls to around 2 for the last part of 2022. The huge leap can be connected to the large changes in coal prices because of the war.

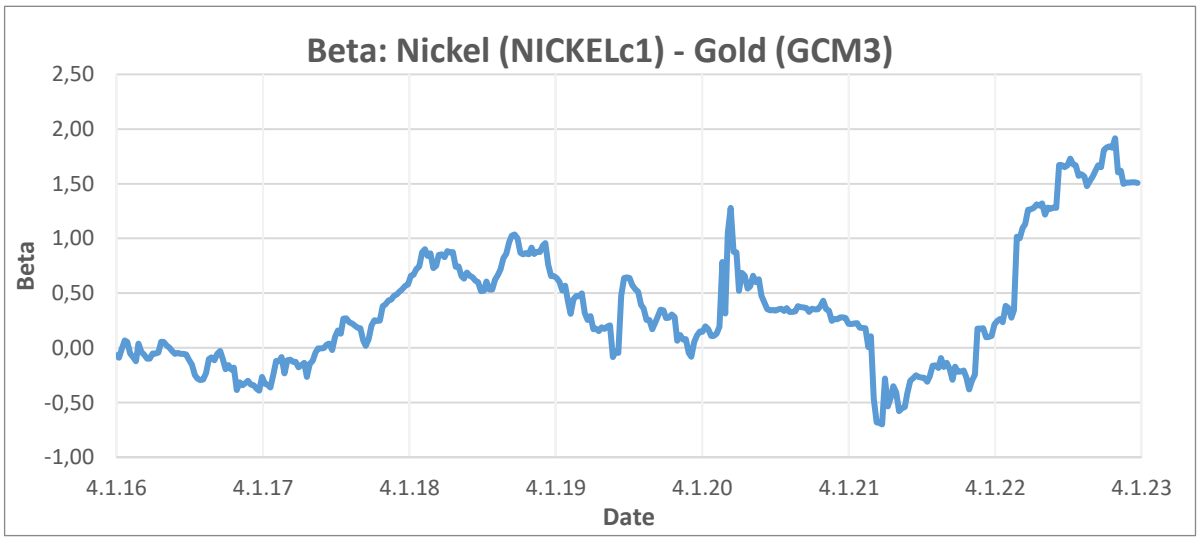

Figure 17 - Beta: Nickel – Gold

Figure 17 shows the beta relationship between nickel and gold prices. From the start of 2016 until early 2017 the beta moves around 0 and between 0 and -0.5, as gold carry more risk than nickel. Between mid-2017 until early 2021 it moves between 1 and 0 most of the time, except for a peak over 1 in early 2020 and 2 times right below 0 in 2019, meaning nickel price move mostly in the same way and mostly at a lower rate, being less volatile than gold. In early 2021, when the effect of the

pandemic hit most of the world, the beta shifts to being less than -0.5 but by the end of 2021 it moves back to being positive. When the war starts in early 2022, we see another leap as the beta goes from right under 0.5 to over 1 in a short period of time. Furthermore, it moves up to 1.75 and for the rest of the year it stays between 1.5 and 2, where nickel is being more volatile than gold, as prices change at a higher rate than gold.

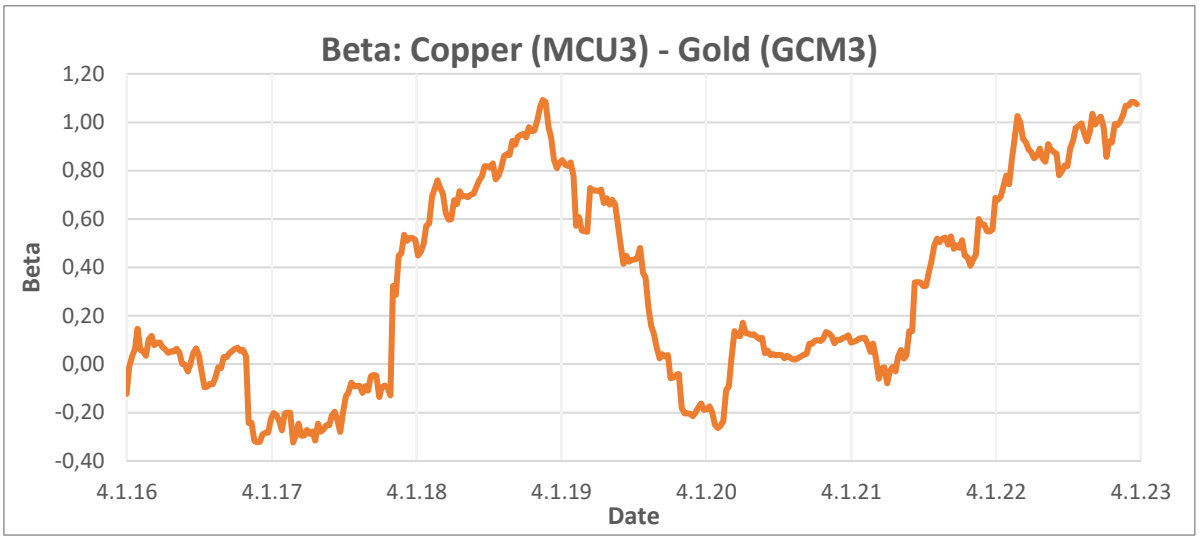

Figure 18 - Beta: Copper - Gold

The beta for copper stayed around 0 for most of 2016 before going negative for most of 2017, as seen in figure 18. Right before 2018 we can see a large shift in the beta going from -0.1 to 0.5 in a short period of time, but copper is still shown to carry less risk than gold. The beta then stays positive, peaking at 1.1 before having a downturn making it negative again in late 2019 and early 2020. After the pandemic hits the world in early 2020 the beta moves mostly upwards becoming positive again as copper and gold prices move in the same direction and over time the rate increases. In early 2022 when the war starts the beta exceeds 1, and for the rest of 2022 it moves around 1 indicating that copper and gold have approximately the same level of volatility and carry the same level of risk.

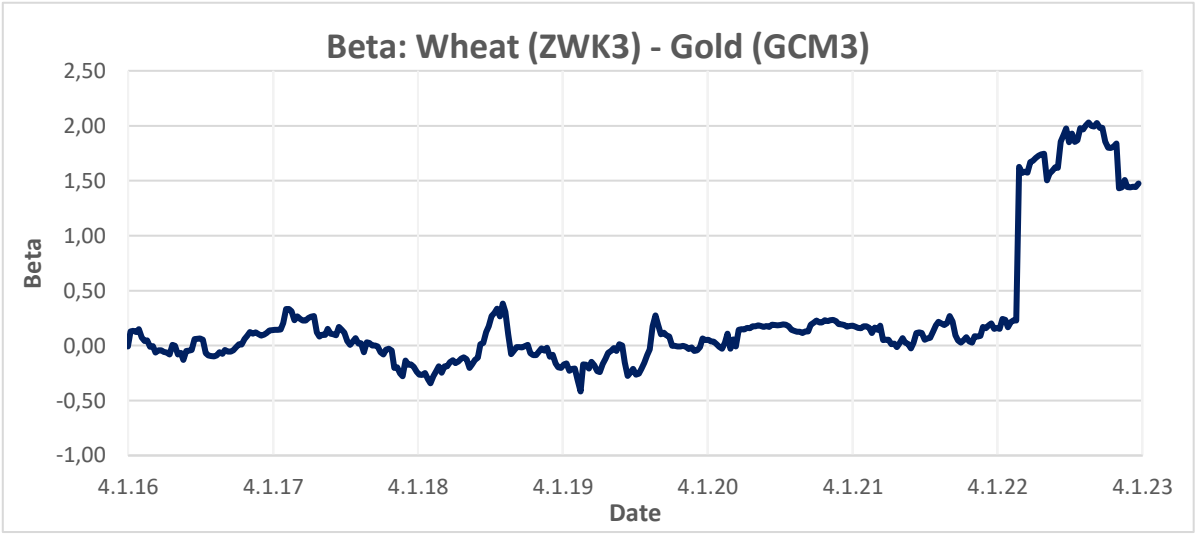

Figure 19 - Beta: Wheat - Gold

As shown in figure 19, the beta between wheat and gold fluctuates around 0 from 2016 until the pandemic starts in 2020, moving between 0.5 and -0.5. This indicates that wheat was less volatile than gold for the period and carries less risk. As the pandemic starts in 2020 the fluctuation is smaller, and the beta stays mostly between 0 and 0.25 until the war starts in early 2022. As soon as the war starts in 2022 the beta shifts rapidly upwards to over 1.5 as wheat becomes more volatile and riskier than gold. For the rest of 2022 the beta moves between 1.5 and 2, meaning wheat price move in the same direction as gold at a higher rate showing how wheat stays more volatile than gold. Another interesting observation is that the beta for wheat and the beta for coal have very similar trends, meaning they both follow the gold price in similar patterns.

7.2.2. Sharpe ratio

By looking at the Sharpe ratio we can see how the risk versus return has changed over the period from 2015 until the end of 2022. We can then see how the excess returns have changed compared to the excess volatility, which is important from an investor's perspective. By calculating the Sharpe ratio between each commodity and gold, it can be shown how each commodity performs compared to gold. We can then see how the Sharpe ratio has changed over time.

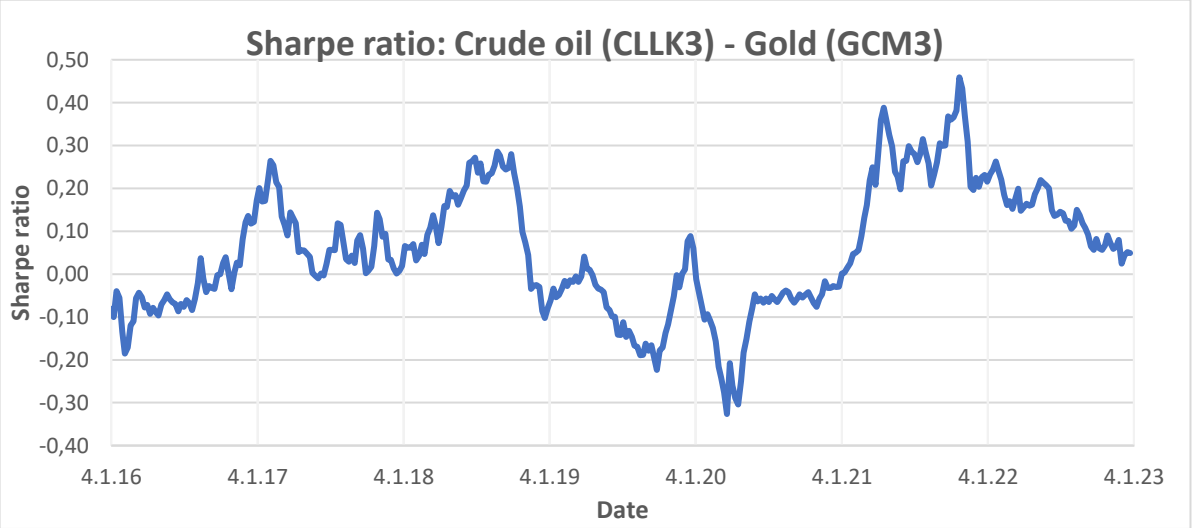

Figure 20 - Sharpe ratio: Crude oil - Gold

Looking at figure 20 we can see that the Sharpe ratio between crude oil and gold moves up and down over the years. In 2016 the Sharpe ratio was mostly negative or revolving around 0, meaning oil is a worse investment than gold. Further the Sharpe ratio becomes positive for 2017 and until the end of 2018, moving between 0 and 0.3, meaning oil performed better than gold in this period. As the pandemic hits, at the end of 2019, we see that the Sharpe ratio moves down below zero again, staying mostly under zero for 2019 and 2020, as gold becomes the better investment again. In 2021 we see another shift where the Sharpe ratio turns positive again. It stays positive for 2021 and 2022, peaking at 0.45 at the end of 2021 then followed by a slow decline towards zero for the whole year of 2022.

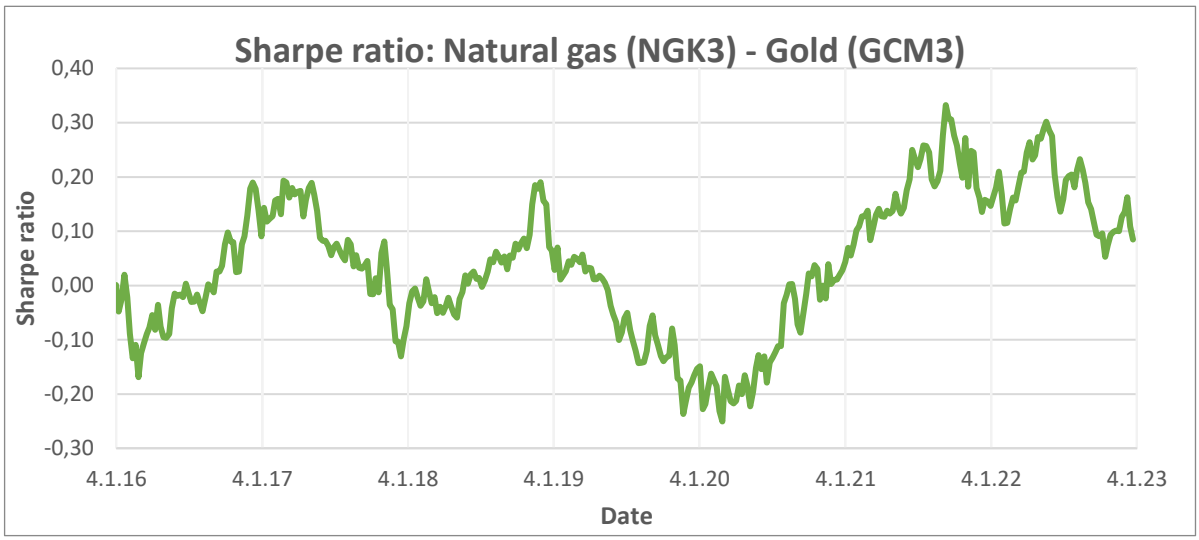

Figure 21 - Sharpe ratio: Natural gas - Gold

As seen in figure 21, showing the Sharpe ratio between natural gas and gold, the Sharpe ratio fluctuates a lot over time being both positive and negative. Overall, it follows the same trend as for crude oil, roughly moving up and down in the same periods of time. As shown the Sharpe ratio was negative or around zero for most of 2016, indicating gold is a better investment. It then mostly moves between zero and 0.2 from the end of 2016 until early 2019, as natural gas is a better investment than gold. The exception is a downfall in the year change between 2017 and 2018 where it was negative again as gold becomes the better investment. As the pandemic started at the end of 2019, we see that the Sharpe ratio decreases and becomes negative for most of 2019 and 2020, going as low as -0.25. As 2021 starts the Sharpe ratio turns positive again and increases steadily during 2021, meaning natural gas outperforms gold. For 2021 and 2022 the Sharpe ratio stays positive and fluctuates mostly around 0.2.

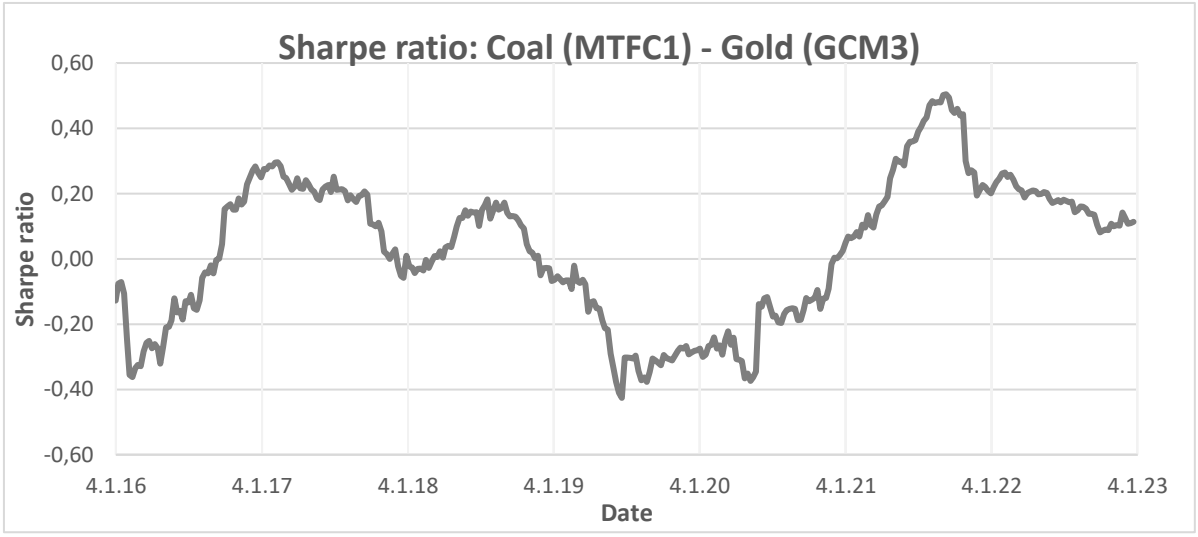

Figure 22 - Sharpe ratio: Coal - Gold

The Sharpe ratio between coal and gold follows a similar trend as crude oil and natural gas, as figure 22 shows. It stays negative for most of 2016, reaching almost a low of -0.4, meaning coal is being outperformed by gold as an investment in that period. From the end of 2016 until the end of 2018 coal mostly outperforms gold as the Sharpe ratio stays positive, except for a drop in late 2017 to early 2018. In late 2018 the Sharpe ratio turns negative again as gold becomes a better investment. When the pandemic started at the end of 2019 the Sharpe ratio is still negative. It reaches a low of -0.4 and stays negative until the end of 2020. As 2021 starts the Sharpe ratio turns positive again and reaches a high of 0.55 in the later part of 2021, followed by rapidly decreasing by the end of 2021 and from there decreasing slowly throughout 2022. For this period coal is a better investment than gold as the Sharpe ratio is still positive.

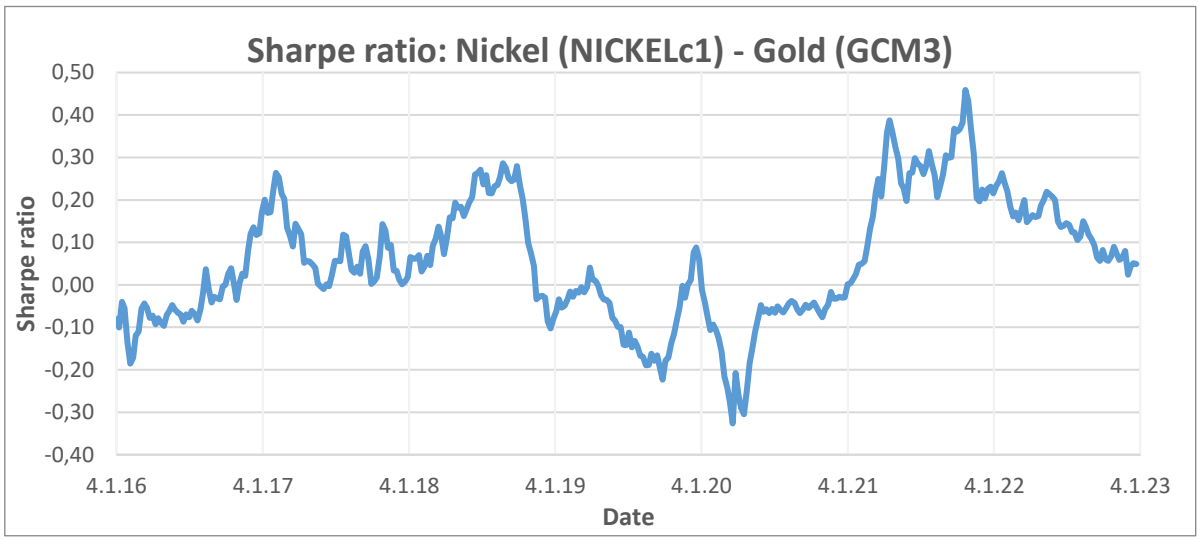

Figure 23 - Sharpe ratio: Nickel - Gold

Figure 23 shows the Sharpe ratio of nickel and gold where we see that the Sharpe ratio started by being negative for the first half of 2016 and then stayed around zero for the second half. This indicates that gold is a better investment for the period. By the end of 2016 it turns positive and moves around zero and 0.3 until the end of 2018, meaning nickel outperformed gold. At the end of 2018 we see a large decline making the Sharpe ratio negative again, as gold started performing better compared to nickel. For 2019 and 2020 the Sharpe ratio is mostly negative and reaches a low of less than -0.3 in early 2020. For this period gold outperforms nickel as an investment. An interesting observation is that right before the pandemic hits, the Sharpe ratio shifts becoming positive again. Further as the pandemic started at the end of 2019, we observe another shift making the Sharpe ratio negative again and then shortly after moving closer to zero. During 2021 it sharply increased and fluctuates around 0.3 for the rest of the year, as nickel outperforms gold. It is then followed by a slow decline towards zero throughout 2022, still outperforming gold.

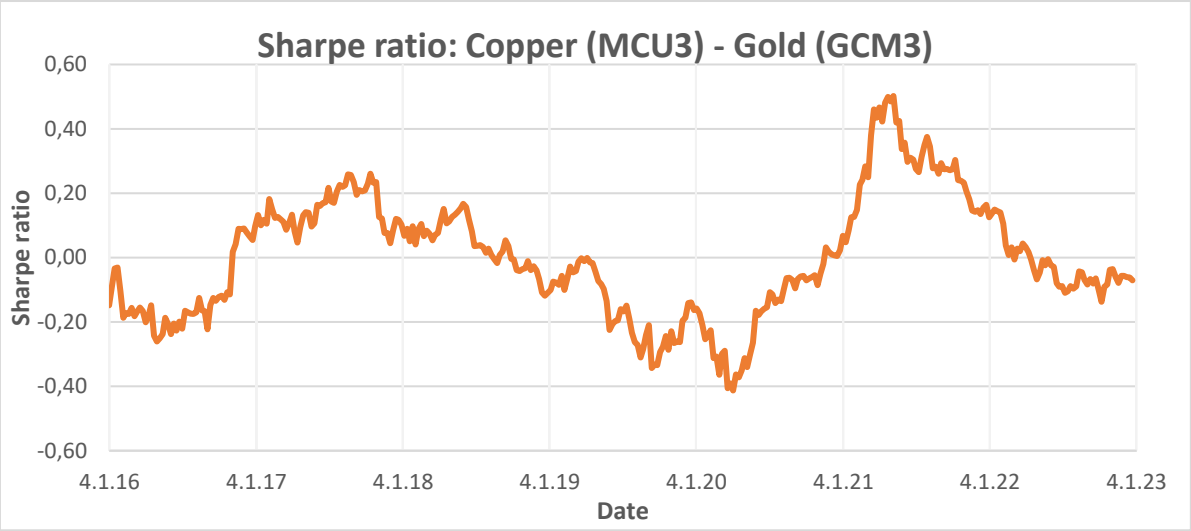

Figure 24 - Sharpe ratio: Copper - Gold

The Sharpe ratio between copper and gold, as seen in figure 24, is negative for most of 2016. The same observation as we saw with the previous commodities, and gold is then the better investment. Further it shifts to positive values in late 2016, and stays positive until late 2018, making copper a better investment than gold for the period. In late 2018 it turns negative again and it stays negative until late 2020, meaning gold outperforms copper in the period. When the pandemic started in late 2019, we see the Sharpe ratio decreasing even more. Shortly after it starts steadily increasing until early 2021 where it reaches its peak of 0.5 making copper the better investment. Following its peak, it slowly decreases and in early 2022 we observe a negative Sharpe ratio which is the case for the rest of 2022. As the war started in early 2022, we see a small downfall in the Sharpe ratio.

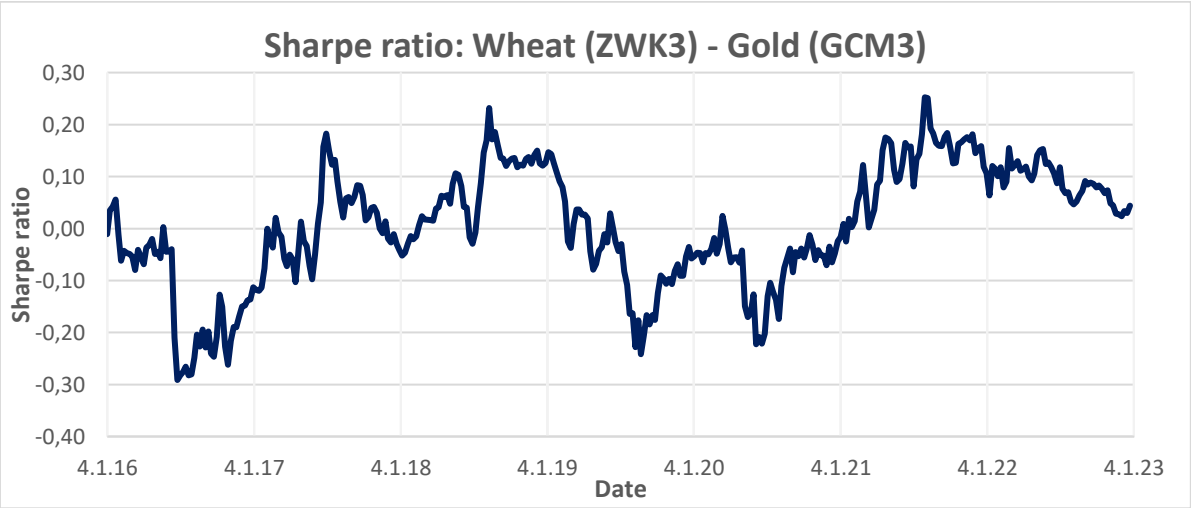

Figure 25 - Sharpe ratio: Wheat – Gold

The Sharpe ratio between wheat and gold, represented by graph 25, is positive in the first part of 2016 and then shortly after becomes negative. It goes down to as low as -0.3 in 2016 and stays negative until mid-2017, meaning gold was a better investment for the period. It then stays mostly positive from mid-2017 until mid-2019, except for a few minor periods where it goes right below

zero, making wheat a better investment overall in the period. From mid-2019 we see another shift where the sharp ratio turns negative again and it stays mostly negative until the start of 2021 as gold outperforms wheat. It has a minor positive top in early 2020 right after the pandemic started, before rapidly decreasing again. From the beginning of 2021 wheat becomes a better investment than gold again with a positive Sharpe ratio and reaching a high of 0.25 in mid-2021. It is then followed by a decline with some fluctuations for the rest of the period until the end of 2022. As the war starts in early 2022 there is no major change in the Sharpe ratio of wheat.

8. Discussion

The analysis of empirical data shows a lot of variation both before and after covid, as well as before and after the invasion of Ukraine. Looking at the standard deviation, based on indexed values, we see that the energy commodities have the highest standard deviation of all the commodities in the period before covid. This is also shown in figure 3 showing coal to have the highest volatility, followed by natural gas and crude oil. They also vary the most as figure 12 clearly shows them moving up and down over the pre-covid years. This indicates that the energy commodities are changing more in volatility in the pre-covid period, making them more uncertain. This could come from oil, natural gas and coal being primary commodities which are demanded for most production purposes as well as for heating, as mentioned in chapter 5.1. Looking at the standard deviation of daily returns in the pre-covid period we see most of the commodities have low standard deviation and do not vary much. We see that oil and natural gas are the commodities with the highest standard deviation based on daily returns indicating that they are more volatile, meaning they carry more risk. Coal is also one of the commodities that varies the most, but it has a lower standard deviation of daily returns than oil, gas, nickel, and wheat for most of the period, meaning the volatility of coal varies more over time.

As the pandemic hits, we can see both for indexed values and daily returns that oil makes a large leap in standard deviation, which is an interesting observation. This is likely connected to the reduction in travels and the lockdown happening in early 2020. As mentioned in chapter 4.1, two-thirds of oil demand is used for fuel for transport, meaning this had a big impact on the oil demand. Further, as mentioned in chapter 5.1.1, oil is the primary energy source in the world, and as global activities were slowed down because of the pandemic, the demand for oil declined. For the other commodities there is no large change in the standard deviation both for indexed values and daily returns in the early phase of the pandemic. However, the further into the pandemic we get, the more variation we see for the different commodities, meaning the volatility changes more over time. This is likely connected to more and more restrictions being lifted and more production being increased over time. It is also interesting to see how the volatility of gold increases further into 2020. This is likely a result of

investors investing more in gold to reduce their risk of financial loss during the time of uncertainty, making the price of gold increase. Further copper volatility increases a lot as standard deviation increase in the late 2020 to early 2021 period. As seen in chapter 5.2.3, China consumes 49% of copper demand and as industries in China start producing again after a lockdown period, the demand for copper will increase leading to price increase and higher volatility. As mentioned in chapter 4.1, the slowdown of global economy lowers the price of metals, mostly because of China which demands 50% of metals, but as restrictions open the price will increase because of demand. Higher volatility is also seen for natural gas and coal which have a sudden increase in 2020. As mentioned in chapter 5.1, both natural gas and coal are highly demanded in industry, as well as for producing electricity and heating in residence. It therefore makes sense that the volatility of gas and coal increases as restrictions are lifted over time and more energy is demanded for production and transport. Other commodities as nickel and wheat have less variation in volatility. Nickel had a relatively high standard deviation compared to the other commodities for the whole pandemic period, but there is not much variation. As nickel also is widely used for productions, we could expect to see higher variation in volatility for the metal, but it stays at a relatively high and constant standard deviation, which indicates high volatility. Wheat had a low volatility in the pandemic period, and it does not vary much either except for a slow and steady increase from late 2020 until mid-2021. This can be expected as agriculture was less affected by the pandemic shut down, as mentioned in chapter 4.1.

When the Ukraine war started in early 2022, we see that most of the commodities, except copper and gold, have a large leap in volatility, both for indexed values and daily returns. We saw how the volatility increased the further into the pandemic we got, and the leap can likely be connected to an already suffering economy from the pandemic follow by the war. As mentioned in chapter 4.2, several sanctions were established by the European council, as well as USA and other countries, against Russia because of the war. Further it was mentioned that Europe import 35% of their natural gas, 20% of crude oil and 40% of coal from Russia. It can therefore be expected to see price increases in the commodities as the supply of commodities decrease, which further will make them more volatile and carry more risk. In both chapter 4.2 and chapter 5 it is shown that Russia has a very large share in both production and export of crude oil, natural gas, coal, gold, nickel, and wheat. Based on this it is no surprise that the war will greatly affect the markets of those commodities, as many countries now have sanctioned Russia. As figure 12 and 13 shows, crude oil, natural gas, coal, nickel, and wheat are highly affected as the war starts, and it can be closely connected to the war and Russia, as Russia is such a big part of those markets. It is surprising to see no effect on gold, as Russia is the third biggest producer of gold, but this can be because gold is mostly used for jewelry and investments and not much for production, as mentioned in chapter 5.2.1. The large leap in coal

volatility is also likely connected to both covid and the war, as more industry opened again making coal highly demanded during Covid. Further, Russia is the sixth largest producer of coal in the world, and has the second largest reserve of coal, making a negative shift in the supply as the war started, because of sanctions against Russia [70]. This is likely connected to the big increase in coal volatility.

It is hard to pinpoint the exact cause of the changes in volatility in the markets as they are highly complex, and many factors contribute to changes in the market. However, there is no doubt that both the pandemic and the war have made an impact on the volatility of the commodity markets.

To discuss the beta results, it can be interesting to look at how the price of gold has changed over time. As seen in figure 26, based on historical data from investing.com, the price of gold has fluctuated around 1200 USD from 2015 until mid-2019, when it starts increasing steadily until mid-2020 [71]. In this period, we can interpret a positive beta as an increase in the commodity price, while from mid-2020 until the end of 2022 the gold price is decreasing for the most part. In that period a positive beta can be interpreted as a downfall in commodity prices. As mentioned in chapter 6, a positive beta indicates that the gold price and commodity price move in the same direction. In the later part of the time series, from mid-2020 until the end of 2022 a positive beta will indicate that the commodity price is falling, as the price of gold has mostly gone down in the last couple of years.

Figure 26 - Gold price historical data [71]

For most of the commodities we see that the beta varies a lot from being both positive and negative. This indicates that the prices of the commodities and gold change over time moving both in the same and in opposite directions. In general, we can see that all the commodities shift from being positive to negative, and the other way around, multiple times over the years. In other words, there is no clear evidence showing the gold price affecting the other commodity prices directly, or the other way

around. What is interesting to observe is that both in early 2020 and early 2022 most of the commodities make a positive leap in beta value. Some going from negative to a smaller negative value, some going from negative to positive value and some going from positive to a larger positive value. Looking at the gold price for early 2020 and 2022, both times gold has increased in price, meaning the other commodities also jump up in price. The exception is wheat in early 2020, which does not show any major change in beta. As the beta shows, there is clearly a shift in the market as the pandemic hits in early 2020 and the war starts in early 2022. Another observation that is interesting is that the beta of all the commodities follow the same trend to different degrees. They all start around zero in 2016 and for the next one to two years they move downwards. Further for 2018 they move up and stay higher for that year for then going down in 2019, followed by an increase again in 2020. The most variation is seen in 2021 where some commodity beta values move up and some move down, but in 2022 all of them increase again and we see positive beta values for all the commodities by the end of 2022.

The volatility of the commodities compared to gold show different results looking at standard deviation and beta, this is likely due to standard deviation being based on daily returns while beta is based on weekly returns. On a weekly basis the change can be seen as small, but withing that week a lot of variations may have occurred. Hence, as data based on each of the methods calculations are different, we get different results. As standard deviation shows gold to be mostly the least volatile commodity, while beta shows gold to carry more risk than the other commodities for most of the time series. It is therefore important to clarify that the basis for each of the methods are different, as weekly returns will not catch the daily fluctuations happening in the markets.

For the Sharpe ratios we can also see a positive leap for almost all the commodities when covid hits in early 2020. The exception is for natural gas that does not show a significant change, as well as wheat that has a decline in the Sharpe ratio quickly followed by a positive jump. As with the beta, there is also a common trend for the Sharpe ratio. We can see that for the first year from 2016 to 2017 the Sharpe ratios of all commodities are mostly negative, meaning gold would be a better investment in the period. From 2017 until the end of 2019 the Sharpe ratios of the commodities are mostly positive, meaning investing in the commodities is a better option than investing in gold. Furthermore, from 2019 until the end of 2021 the Sharpe ratios are mostly negative again. Then for the rest of the time series stretching from 2021 until the end of 2022 the commodities have positive Sharpe ratios again, except for copper which turns negative again close to mid-2022. Another common trend we can observe is that from early 2020 until early- to mid-2021 all Sharpe ratios of the commodities are increasing rapidly. Furthermore, from 2021 until the end of 2022, all the Sharpe ratios are falling and ending very close to zero by the end of 2022. The trends clearly show that from

an investment perspective the best option to invest in changes over time. This means that in some periods it is better to invest in gold, and in others it is better to invest in other commodities. To reduce the risk from changes in prices it is possible to create a portfolio of different commodities or indexes. This reduces the financial risk of your investment decreasing in value as one commodity or index reduces in value. During uncertain times where the market is volatile this can be a good strategy to avoid big losses from investments as it reduces unsystematic risk. However, losses for investors and producers are not the only downsides regarding risk in commodity markets.

As mentioned in chapter 3.2, volatility leads to higher risk in the market as there is a high level of uncertainty and in that way a volatile market makes it hard to predict the future price of the commodity. There are many factors that affect supply and demand in the market, which will impact the price and can ultimately lead to losses for producers and investors, or increased prices for buyers and end consumers. In that way high volatility reflects large changes in supply and demand in the market. However, the price risk also affects people's everyday life by reducing purchase power as prices increase, and it is therefore important to highlight the consequences of volatility and uncertainty in markets and how it can affect other parts of the supply chain. This is because volatility in markets does not only come from extreme events such as a pandemic or war, but it can also come from speculations, government regulations, weather conditions, among other factors. As volatility increase in the market, making prices increase from uncertainty, the purchasing power decreases for consumers, also known as inflation. This means that people will be able to afford less products as prices increase more relative to people's income. Ultimately, this will affect people with the lowest income the most as they might already struggle to afford the basic products and services needed to live and will now be able to afford less than before. This is one of the major challenges faced when volatility increases rapidly in the markets. Another factor that has been in the spotlight for years is climate change. As mentioned in chapter 5.3.1, production of wheat can be affected by extreme weather or climate change, which also accounts for other agricultural products such as soybeans, corn, cattle, among others. However, climate can affect several commodities supply and demand. According to the European Commission, climate changes can lead to changes in demand and supply of energy as we face more cases of extreme weather [72]. Both extremely warm and cold temperatures will lead to changes in demand for energy for both heating and cooling, increasing demand for energy. Further production of energy will be affected by uncertainty in weather conditions, as renewable energy production will be affected because of less sun and wind in regions where there used to be more [72]. The European Commission also list more extreme weather as a risk as it may affect the "*physical energy infrastructure*", meaning transmission and distribution of energy. Further it can affect substations and transformers, which could lead to lower production [72].

These are all factors that can affect supply and demand, and in that way make the markets more volatile. Furthermore, the agricultural sector is highly affected by climate and climate changes can have large consequences on the production and supply of agricultural commodities. Climate change can lead to changes in production of different types of agricultural commodities in different areas as they require certain conditions to grow. A combination of increased heat and less access to water can lead to losses in production as some crops will not survive in certain climates. This will also be a problem regarding animals as they will have less access to water and will have problems surviving extreme temperatures. Furthermore, extreme weather will affect production and may result in lower yields. This will then impact the supply of crops, meat, and other products from animals, as well as production of biofuel. In general, these are only a few of the factors affecting the market which is why we can see changes in commodity prices over time making the markets risky and in times highly volatile.

When it comes to the global impact on the commodity prices from the shocks we can expect a different response for the different commodities, as they have varying levels of integration between global markets. As mentioned in chapter 5, previous research show that crude oil, copper, and wheat markets are integrated globally meaning there is a long-term correlation between markets in different regions for each commodity. As a result, we can expect that the price of crude oil across different global markets will respond to the same degree to a shock like the pandemic and invasion of Ukraine. The same can be expected for copper and wheat prices across the global markets. As the volatility increased for these commodities both after covid and after the invasion, compared to before, they will have a bigger impact globally. In that way we can expect to see the same volatility levels across the different markets for the same commodity. For natural gas, however, the previous research did not find cointegration in the global markets and it can therefore be expected to see a different response to the shocks in different regions of the world. This means that the pandemic and invasion will affect the different natural gas markets around the world in different ways, some more than others. This information is especially important for investors that want to either reduce risk or take advantage of the volatility in certain markets. For coal and gold, the previous research found that some markets around the world were integrated, and some were not, as well as finding bidirectional causality between some markets and unidirectional between some. We can therefore expect that the response to the shocks affect some parts of the global coal and gold markets different than others. Especially for coal where China was not found to be a part of the global market, we can expect that the Chinese coal market will be affected first when the pandemic first started in China. However, for the invasion we can expect the opposite as the other global markets may be more affected and see a different response in the Chinese market.

Comparing previous research articles to the results in this report, results shown by the standard deviation in this report match the findings of previous research introduced in chapter 1.3. As Rajput et al. found crude oil to have the largest impact due to supply and demand drops related to the restriction as the pandemic starts, this corresponds to the sudden increase in standard deviation found for crude oil in this report [4]. Further the findings in this report partly correspond with the research by Sheth et al. as they found the volatility of commodities to be more uncertain in the early part of the pandemic [5]. However, the evidence found in this report show that most volatility levels show significant changes later in 2020 and early 2021, and not an immediate response for all commodities in the start. Further their conclusion on gold reaching record highs matches the findings in this report as golds volatility steadily increased after the pandemic started, as figure 12 proves. Their results of agriculture not being affected also matches the low and relatively steady standard deviation found for wheat in this report, however they find no change for natural gas. Here it is found that natural gas slowly increases as the pandemic hit, even though the large effect is not shown until later in 2021 in the period which was not covered by Sheth et al. Further the research article by Cui et al. found that both gold and oil prices had a positive effect on gold price as their dataset stretched from January 2022 to December 2021 [6]. As found in this report it matches with the gold volatility increasing in the period and looking at figure 26 the price of gold increased the most in the same period that the highest volatility of gold was found, as well as volatility for gold decreasing as the gold price trend turns in late-2020. Further for agricultural products it was found by Elleby et al. that prices declined, and that short-term consumption of food is not affected much looking at data from early 2020 [8]. Their findings in the agricultural markets match the findings of wheat in this report. Looking at the average standard deviation in table 3 it was shown that wheat was the least volatile commodity in the covid period with a small increase since the pre-covid period. Figure 12 also show the volatility for wheat decreasing for most of 2020 supporting the claim that agriculture was not affected in the short run. Looking at the research done by Fang and Shao, they suggest that as the conflict between Russia and Ukraine intensifies the volatility for commodities also increase. As figure 12 shows this matches their statement as we see higher volatility throughout 2022 compared to the start of 2022. Even though copper and gold are less volatile compared to the pre-invasion period, they have also increased compared to early 2022, as seen in figure 12. The research done by Fang and Shao suggested that volatility for energy, metal and agricultural commodities increased as the conflict between Russia and Ukraine intensified. This partly corresponds to the findings in this report as we see an increase in most of the commodity's volatility, however we see no immediate increase for copper and gold. The volatility for copper increases later in the same year, but gold is shown to be unaffected as the war starts.

9. Conclusion

The results found in this analysis show that the energy commodities coal, natural gas, and crude oil are the most volatile in the pre-pandemic period, based on the standard deviations. Based on the average standard deviation from table 3, coal is found to be the most volatile in the pre-pandemic period, closely followed by natural gas and crude oil. Gold is shown to have the lowest level of volatility pre-covid. As the pandemic starts, we can see that crude oil has by far the biggest immediate increase in volatility. Based on the standard deviation of daily returns we see an increase in volatility for natural gas as well. For the other commodities we see no clear change as soon as the pandemic starts, but the further into 2020 and 2021 we move, the larger the standard deviation gets for most of the commodities. Oil has the largest increase in volatility in 2020, later followed by copper, but in mid-2021 most of the commodities have started to decrease in volatility again. The exception is for natural gas and coal that make large leaps in volatility in mid-2021 and as table 3 showed, coal was the most volatile on average before the war as well, followed by crude oil and natural gas. In the post-covid to pre-war period wheat is found to be the least volatile of the commodities. As the war starts in early 2022, we see that most of the other commodities follow coal and natural gas by making a leap in volatility as well. This shows the commodities being much more volatile than before, except for copper and gold that do not show any immediate response in volatility. Copper, however, follows the increase in volatility in mid-2022, but at a lower rate than the other commodities, while gold stays unaffected. This matches the result of averages in table 3, which shows an increase in volatility for all commodities except for copper and wheat, as their average volatility for the post-war period is lower than the post-covid to pre-invasion period. Gold is again found to be the least volatile in the post-invasion period. The standard deviation clearly shows an effect on volatility from both covid-19 and the war in Ukraine. The difference is that from covid the immediate response is only shown for crude oil, and then as time goes by, other commodities follow. For the war in Ukraine, we see an immediate response for most of the commodities and most of them reaching their highest level of standard deviation for the time series after the invasion. The evidence shows that volatility has increased both during covid and after the war started, as all the commodities reach their highest standard deviation either during 2020, 2021 or 2022. The largest effect seen in the covid period is from the energy commodities like coal, natural gas, and crude oil, but there is also a big response from copper. For the last year with the war in Ukraine we see large responses from wheat and nickel as well. Gold reaches a top during the covid period, but the volatility is lower compared to the other commodities for the later years of the time series. During the war gold's volatility stayed relatively low and unchanged.

For the beta, based on weekly returns, we can see that there is no clear correlation between any of the commodity's prices and the gold price, as all of them fluctuate from being positive and negative over the time series. For the pre-covid period we see that all the commodities vary from positive to negative beta and most of them stay between 1 and -1, meaning they change at a lower rate than gold. This shows the commodities being less volatile relative to gold. The exception is natural gas which moves above 1 for 2018 and below -1 for 2019, meaning it is more volatile. The beta shows a lot of variations in the price changes, but as the beta is mostly between 1 and -1, gold has a higher rate of price change than the other commodities, meaning gold is more volatile. This is the case until the war starts in 2022 when we see a large leap in all commodities beta, where all of them end at a beta above 1, except for natural gas. This shows how the commodities volatility increases as the war starts. Overall gold is shown to be mostly more volatile than the other commodities before the war, and after the war starts the other commodities show a larger level of volatility compared to gold.

The Sharpe ratio, based on weekly returns, also varies a lot over the years showing gold to be a better investment option in some periods and the commodities being a better investment in other periods. The overall observation seen is that the commodities follow mostly the same pattern where gold is the better investment in the first 3 quarters of 2016, as well as from 2019 until 2021. It also shows that the commodities are better investments from late 2016 until late 2019, as well as from 2021 until mid- to late-2022. At the end of 2022 most commodities are still a better investment than gold, with positive Sharpe ratios, except for copper which gets a negative Sharpe ratio in early 2022.

9.1. Further research

To further investigate the volatility analyzed in this report it could be interesting to see the effect on other types of commodities such as lithium, soybeans, lumber, rubber, aluminum, among others. By using the same methods, results can be used for comparing other commodities to the ones analyzed in this report. It could also be interesting to use a different length of the period for the calculations, instead of using a one year moving calculation it could for example be used a two-year moving calculation to compare. Furthermore, it would be interesting to analyze the same commodities with the same amount of historical data using different methods, such as "Average true range", "Simple moving average", or "Bollinger bands", to see if similar results are found. Most of the previous research found during the writing of this report used other methods, but with relatively short time intervals. It would therefore be interesting to see other methods being used for a longer time series to compare the results. Also, instead of using gold as a common reference for comparing relative risk, other commodities or assets can be used, like for example the S&P 500 index.

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