13.08.2020

Luxemburg School of Finance

Master Thesis

MSc in Banking and Finance

Interconnections between implied volatilities of the Gold, Oil, and Equity Market

– an analysis of the flight to safety effect during the Corona Crisis

By Celina Löwen

Student ID: 0180506246

Supervisor: Prof. Dr. Thorsten Lehnert

Table of Content

Abstract

The research question of this thesis deals with the interconnections of the oil, the gold, and the equity market, each represented by implied volatilities of gold, crude oil and S&P 500 options. The thesis focuses especially on the influence of the equity market on the gold market in form of a flight to safety effect during the Corona Crisis. The main findings indicate that there is a granger causality between the equity market and the oil as well as the gold market. Especially during crisis days, a stronger influence of the equity market on the gold market can be observed than during non-crisis periods, this also holds true for the Corona Crisis. However, the Corona Crisis can be identified as a special case since the increased implied volatility of gold options was caused by a surge of investors selling gold shortly after the stock market collapse. This cannot be identified as the usual flight to safety effect that can be observed during other crisis periods, where investors were buying gold to escape risky investments in the equity market and focus on less risky assets in the gold market. Additionally, a strong granger causality between equity and oil market is identifiable during the Corona Crisis, caused by the political factors of an oil price war and the economical impact of the crisis which induced a sharp drop in demand for oil.

1 Introduction and aim of the paper

Since the outbreak of COVID – 19, global markets have been shaken due to the impact of the pandemic on the economy. Millions of people all over the world have been infected and thousands have already died from the virus. Travel bans, curfews and closure of shops, restaurants, etc. and other measures to stop the spread of the virus have thrown the global economy into recession. Many small businesses and self-employed people fear for their existence, but also larger businesses (for example airlines) are in danger of going bankrupt. Governments all over the world have issued financial aid packages to limit the economic damage done by the pandemic. To determine the effect of the pandemic on markets and the change in investors' behavior this thesis focuses on implied volatilities of the oil, the gold and the equity option markets. Volatility is crucial for investors as it influences their decisions on portfolio optimization, risk management, and hedging approaches, as well as how derivatives are priced in the market. In order to measure the implied volatility in option prices, the CBOE has introduced a number of forward looking implied volatility indices, the most popular being the VIX or fear index (Bastâ & Molnár, 2018).

The crude oil price and its volatility have a significant effect on the economy since many companies are dependent on oil either for their production or the distribution of their products.

Oil is considered to be one of the most important commodities in the world. Changes in the oil price (or in the price of other crude oil derivatives) are therefore very relevant for investors behavior, it can cause uncertainty in the markets and destabilize the economy (Gokmenoglua & Fazlollahia, 2015). Consequently, it is important to consider the implied volatility of crude oil options for this paper.

Gold is not only considered a monetary asset, but also acts as a source of wealth. It is often looked at as a safe investment in times of crisis since it is considered a less risky investment than other assets, e.g. equity or other commodities. Gold is as well used as a hedge to balance out losses in the equity market. As a representative of the category of less risky investment assets, the implied gold options volatility is important to analyze investors' behavior during normal times and during times of market distress.

Finally, this paper considers the implied volatility of stock options, which should serve as an indicator of the development of the equity market. The shift of investments from the equity market to the gold market in times of increased equity market volatility is known as the flight to safety effect. The aim of this paper is to analyze the interdependencies between implied volatility changes in the oil, the gold and the equity market and to establish whether the flight to safety effect can also be observed during the Corona Crisis.

The paper is structured as follows. Section 2 provides an overview of the features of options as well as the trading in option markets. Afterwards, section 3 focuses on the implied volatility indices of options for oil, gold, and stocks. It also describes how the indices are calculated. Section 4 gives an overview of existing literature and papers that have investigated similar topics, highlighting the flight to safety effect analysis by Sarwar. In section 5 the data used for the empirical analysis of this paper is described and summarized. Furthermore, this chapter gives information on the method to identify flight to safety days used by Baele, Bekaert, and Inghelbrecht. The identified flight to safety days are used for the analysis in this paper. Section 6 deals with the research methodology that is used to perform the analysis, first to ensure the stationarity of the data and then to find the granger causality between the mentioned implied volatility indices. Additionally, chapter 6 defines the regressions for the statistical tests. The results are described and interpreted in chapter 7.1. Chapter 7.2. summarizes and concludes.

2 Options

The following chapter will focus on explaining key elements of options and how they are traded. It will define what an option is and give an overview on options terminology and how options are traded in the options market.

Options are one type of derivatives, which means that their value depends on the value of another market variable, in an option's case the price of its underlying asset. Since option trading is very common, they are also called "plain vanilla" derivatives. Derivatives trade on exchanges, as well as in over-the-counter (OTC) markets. The volume traded in OTC markets is much larger than that traded on exchanges, it has experienced steady growth in the early 2000s and is keeping roughly the same size since the Financial Crisis.

Options are another asset class that allows the investor to diversify their portfolio further. Compared to other asset classes, such as stocks, bonds, or exchange-traded funds (ETF), options can provide many advantages, because options can provide protection against downward market movements. However, hedging is only one of the reasons why option trading is so popular. Another goal for an investor to purchase options is to speculate on future market movements and gain an income in case the market moves as expected. Furthermore, they are widely used for portfolio diversification purposes. This helps market participants to be more protected in case of unexpected volatility movements in the market.

2.1 Definition and terminology

The main difference between a futures contract and an option is that in a futures contract, the holder is obliged to buy the underlying at a certain price at the expiration date, whereas an option gives the holder the right to purchase the underlying of the option contract. An additional difference is that entering into a futures contract does not create any cost for the investor, whereas options have to be purchased at an option premium, which is the acquisition cost for the option (Hull J. , 2018). There are two types of options: call options and put options. A call option gives the holder the right to purchase the underlying at a pre-defined price, the strike price, at a certain date. The holder of a call option bets on the price of the underlying to rise above the strike price. When this happens, he can realize a gain equal to the stock price less the strike price by purchasing the underlying at the strike price and selling it at market price. On the other hand, the put option gives the holder the right to sell the underlying at a pre-defined price, the strike price, at a certain date. The holder of a put option bets on the price of the underlying to fall below the strike price. In this case he can purchase the underlying at market price and sell it at strike price, so his gain would be the market price of the underlying less the strike price (Hull J. C., 2017).

Options can be American or European. European options can only be exercised at expiration date, whereas American options can be exercised at any point during the life of the contract. Most exchange-traded options are American options. Since it can be advantageous to exercise an American option early, they are usually priced higher than the European option with the same underlying, maturity and strike price. There are two positions that can be taken in an option's contract. The investor who purchases the option has the long position and the investor who sells or writes the option has the short position (Hull J. C., 2017).

Options can be in the money, at the money or out of the money. When a call option is in the money, the market price of the underlying is greater than the strike price. It is at the money, when the market price equals the strike price and out of the money, when the strike price is higher than the market price of the underlying. By contrast, a put option is considered in the money when the market price of the underlying is lower than the strike price (then the investor makes a gain by selling the underlying) and at the money when the strike price equals the market price. It is out of the money when the market price exceeds the strike price.

An option can have different types of underlying. The below figure shows some examples.

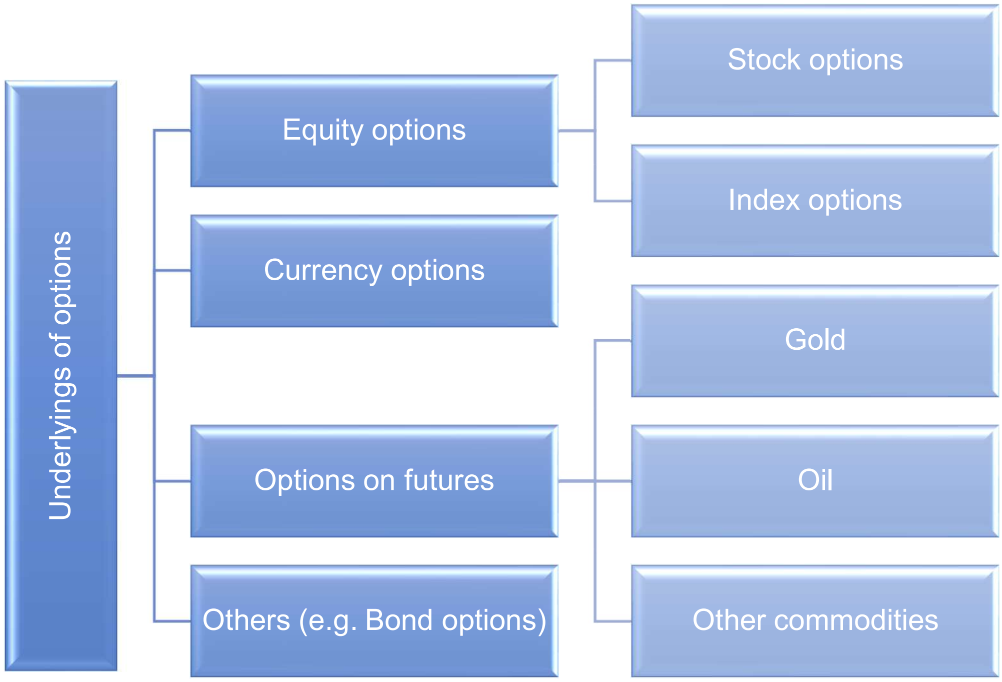

Figure 1: Types of underlying for options

One category are equity options. For these options, the underlying can be the stock of a specific company, e.g. Amazon stocks (stock options) or it can be on an index, like for example the S&P 500 Index (index options). Index options are often used to protect a portfolio against downside risk. Furthermore, there is the category of foreign currency options. One option contract gives the holder the right to buy or sell a certain amount of foreign currency units in exchange for home currency units (mostly USD). Currency options are often purchased by companies which are exposed to foreign currency risk in order to help protect them against the devaluation or appreciation of another currency. Another type of underlying are futures contracts. The expiration date of a futures option is normally just before the delivery period in the futures contract. Upon exercise of the option the holder enters into a long futures contract, in case of a futures call option, or a short futures contract, in case of a futures put option, at a certain futures price by a certain expiration date. In case of an option exercise, the holder does usually not receive the underlying asset at expiration of the futures contract, usually the futures contracts are closed out prior to the delivery date (Hull J. C., 2017). Usually, options traded based on commodity prices are futures options, as for example options on gold futures or options on crude oil futures, which are relevant for this paper.

Option prices can be calculated with the help of the Black-Scholes-Merton Model. For this model, the volatility of the underlying is important. The volatility is a measure of the uncertainty of how the returns of the underlying will develop. In case of stock options, it is defined as the square root of the variance or the standard deviation of the one year's returns of a stock (in case of continuous compounding). High volatility means that the stock prices show a strong upward movement or a strong downward movement. Consequently, the volatility does not indicate the direction in which the market is moving. The volatility to be used for the Black-Scholes-Merton formula is mostly derived from historical data. The assumption of the model is that this volatility is constant. However, this is not the volatility which can actually be observed in the market. The volatility that can be calculated from option prices in the market is called implied volatility. It has a forward-looking aspect, because current option prices are used for the calculation instead of historical prices. It can be used to track the market's impression of how the underlying will develop, as the current option prices give an indication on how much the underlying is worth to investors, currently and in the near future (Hull J. C., 2017). The indices published by the CBOE show implied volatility of option prices. This will be discussed in more detail in section 3 of this paper.

2.2 Trading in the options market

Options can be traded on an exchange or in the over-the-counter market (OTC). Stock options are mostly traded on an exchange, like for example the Chicago Board Options Exchange (CBOE) or the NYSE Euronext. Also, many Index options like options on the S&P 500 (SPX), which are relevant for this paper, trade on exchanges. However, they can also be traded in the OTC market. Today, most of the trading on exchanges is done electronically. In the over-the-counter market, the market participants are mostly financial institutions, fund managers and corporate treasurers. Options are traded over the phone. One example of options mostly traded in the OTC market are futures options. The difference between trading options on an exchange and in the OTC market is that the buyer of an option must bear some credit risk, as there is a default possibility of the option writer in the OTC market. The advantage of the OTC market is that the products sold are often precisely adjusted to the needs of the buyer and all kinds of exotic options (different from standard put and call options) are traded. Further to the primary option market, there are also secondary markets, in which the option holders can on-sell the options to a third party. Option markets are regulated by the Securities and Exchange Commission (SEC) (Hull J. C., 2017).

For each option there is a bid price at which the buyer or market maker is prepared to buy the option, and an ask price at which the seller or market maker is prepared to sell it. The difference between these two quotes is the bid-offer or bid-ask spread. This spread is often regulated, e.g. with an upper limited, by the exchanges (Hull J. C., 2017). The bid-ask spread is relevant for the calculation of volatility indices on the option prices, which will be described further in the next chapter.

In order to govern the behavior of option traders and bring stability in the trading process, each option trader has to be cleared first by a member of the Options Clearing Corporation (OCC). The goal of the OCC is to guarantee the fulfillment of the option writer's obligations. Therefore, members are required to have a certain amount of capital which is collected in a special fund. The purpose of this fund is to provide the capital in case a market participant defaults on an option obligation. Additionally, the OCC has put in place margin requirements for all market participants. In the United States, a buyer must pay an option in full, if it matures in less than 9 months. In case the maturity of the purchased option exceeds 9 months, the buyer may borrow up to 25% of the option's value (buying on margin). Consequently, the initial margin to be put in the margin account are 75% of the option's value. This is then also the maintenance margin (Hull J. , 2018) Furthermore, the trader has to maintain a margin account in order to prove to the OCC and the broker that he will not default in case an option is exercised. There are different margin requirements depending on the type of options traded and on the position of the trader. Furthermore, there are limits imposed by the CBOE on the maximum number of option contracts an investor can obtain, if these positions are on the same side of the market (short calls and long puts on the one side vs. long calls and short puts on the other side). There are also exercise limits in place, regulating the number of option contracts that can be exercised by one investor within 5 consecutive business days. The goal of these regulations is to limit the influence of single or small groups of investors on the options market (Hull J. C., 2017).

3 Indices of implied volatility at CBOE

The Chicago Board Options Exchange (CBOE) publishes various indices of implied volatility for different types of options in order to measure the market's expectation on how the volatility of the market will evolve. The indices are calculated based on the options prices and are quoted in percentage points. The options considered for the indices have different underlyings, so the indices can be clustered into different groups. There are volatility indices on stock indices (U.S. and non-U.S.), for example the CBOE NASDAQ volatility index or the CBOE Emerging Markets ETF volatility index. Another group of implied volatility index is on interest rates, for example the CBOE Interest Rate Swap volatility index. Furthermore, there are indices of implied volatility on commodity-related ETFs, for example the CBOE Gold ETF volatility index, which will be covered in the next section in more detail. Then, there are indices on currency-related futures and ETFs as for example the CBOE/CME FX Euro volatility index and indices on single stocks, such as the CBOE Equity VIX on Amazon or Apple. There is also a volatility index on the CBOE volatility index, which is covering options on the S&P 500 index. It is called the CBOE VIX of VIX index (CBOE Volatility Indexes, 2020). This paper focuses on the gold, the oil and the equity market, therefore the relevant volatility indices for these markets are discussed below in greater detail.

3.1 CBOE Gold ETF Volatility Index (GVZ)

Gold options are options that have gold futures or physical gold as their underlying. Buying a call option on gold gives the holder of the option the right to buy gold at a pre-defined price, whereas the put option gives the holder the right to sell gold at a pre-defined price, before expiration of the option. In the United States, gold options trade on the Chicago Mercantile Exchange (CME). Volatility indices calculated from real options prices can be found on the website of the CBOE (CBOE Gold Volatility Index (GVZ), 2020).

Relevant for the gold options market is the CBOE Gold ETF Volatility Index (GVZ). It "measures the market's expectation of 30-day volatility of gold prices by applying the VIX methodology to options on SPDR Gold Shares"[1]. The SPDR gold shares exchange-traded fund (GLD) reflects the spot price of gold less fund expenses and can therefore be taken as a reference for gold price movements. It is a fund of the Standard & Poor's Depositary Receipts (SPDR) family and is administered by State Street Global Advisors. As most other ETFs it has not much administrative fees, which makes it very attractive to investors. However, the ETF has become one of the largest actors on the gold market, therefore critics fear that it can influence the market by buying and selling shares (Groth, 2016).

[1] *CBOE Gold Volatility Index (GVZ)*. (2020). Retrieved May 3, 2020, from http://www.cboe.com/products/vix-index-volatility/volatility-on-etfs/cboe-gold-etf-volatility-index-gvz

Options on SPDR Gold Shares are American style options, which means they can be exercised at any day during their validity. The underlying are 100 shares of the GLD ETF. The GLD has an undivided interest in the SPDR Gold trust, whose main investment is in gold bullions (CBOE Gold Volatility Index (GVZ), 2020). The physical location of the gold is in the HSBC bank in London.

The GVZ has been calculated and published by the CBOE since 2008, the possibility to trade on this index came in April 2011 (CBOE To Launch Trading on CBOE Gold ETF Volatility Index Options (GVZ) On April 12 - Second New Tradable Product On Volatility Of Active ETF Options, 2011). The basis for the calculation of the GVZ are real-time bid-ask quotes of GLD options, which are then processed according to the VIX calculation methodology, which will be discussed in 3.3.1.

3.2 CBOE Crude Oil ETF Volatility Index (OVX)

Oil options are options that have future contracts on crude oil as their underlying. In the United States they are traded on the New York Mercantile Exchange (NYMEX). The holder of a crude oil call option has the right to obtain a long position in a crude oil future; the holder of a crude oil put option has the right to obtain a short position in a crude oil future, both at the pre-defined strike price and before the expiration date of the option.

In comparison to gold futures, that have only one underlying, crude oil futures can have many different types of crude oil as their underlying. There are 3 main benchmarks that most of the crude oil types can be assigned to. Firstly, there is Brent Crude, which refers to oil produced from various oil fields in the North Sea. It is mainly used to make gasoline or diesel fuel, etc. Transportation of this oil type is easier than for others because it is transported through underwater pipes. Then, there is West Texas Intermediate (WTI), which summarizes crude oil types extracted from wells in the United States. Since it is difficult to transport, because pipelines need to go overland, it is quite expensive to ship it to other parts of the world. Hence, it is the primary benchmark for U.S. oil consumption and trade. It is used mostly for gasoline refining. The third benchmark refers to oil from the Middle East and is called “Dubai/Oman”. It has a slightly lower quality than the other 2 benchmarks presented previously (it has a higher sulfur content and is “heavier”). Since this is the only oil from the Middle East for investors to invest in, it still represents an important benchmark. The main demand for this oil comes from Asia (Understanding Crude Oil Benchmarks and Classifications, 2020). There are more than 100 other and less traded benchmarks for crude oil, which will not be considered for the scope of this thesis.

At NYMEX, options for light sweet crude oil, belonging to the category of WTI, and options for Brent Crude are traded. Since light sweet crude oil seems to be more relevant for the U.S. market, the empirical part of the thesis will deal with options on light sweet crude oil futures. The implied volatility for these crude oil options is tracked in the CBOE Crude Oil ETF Volatility Index (OVX), which "measures the market's expectation of 30-day volatility of crude oil prices by applying the VIX methodology to United States Oil Fund, LP options"[2].

The underlying fund (United States Oil Fund) is an ETF that holds futures contracts on light sweet crude oil WTI traded at NYMEX, which is exactly the type of crude oil this thesis intends to focus on. The intention of the fund is to track oil prices as close as possible, using the near-term futures contracts of West Texas Intermediate as a benchmark. The fund's performance reflects the daily spot prices of these futures less USO expenses (USCF, 2020).

The OVX has been published for the first time in July 2008 by the CBOE. Options on the USO have been traded since May 2007. Since they quickly became one of the most actively traded options contracts, the OECD decided to track the implied volatility of these option prices closer (CBOE Holdings, 2008). The OVX index is calculated with the VIX methodology described in the next paragraph.

3.3 CBOE Volatility Index (VIX)

As described in chapter 2.1, equity options can be options on stocks or options on stock indices. The most relevant stock index for the U.S. market is the S&P 500, which comprises the shares of the 500 largest U.S. publicly traded companies. Options on the S&P 500 index are traded at the CBOE with the tracker symbol SPX. They are European style options, which means the trading account is settled in cash rather than ETF shares. SPX options are traded with a multiplier of 100, which means that the value of one contract is 100 times the price of one option. The advantage of index options is that the risk the investor faces is very limited, the amount is as high as the option premium. For an index call option, the profit is potentially unlimited, while for an index put option the profit is capped at the index level less the option premium paid (Turner, 2019).

[2] *CBOE Crude Oil ETF Volatility Index (OVX)*. (2020). Retrieved May 9, 2020, from http://www.cboe.com/products/vix-index-volatility/volatility-on-etfs/cboe-crude-oil-etf-volatility-index-ovx

The expected volatility of S&P 500 index option prices is tracked in the CBOE Volatility Index (VIX), which "is recognized as the world's premier gauge of U.S. equity market volatility"[3]. It shows market's 30-day expected volatility, which serves as a tool to measure market uncertainty. Options and futures are traded on the VIX since 2006 and 2004, respectively.

The VIX is designed to provide up-to-date information on how the S&P 500 index will fluctuate in the near future (30 days) according to market expectations. This is done by using the midpoint of the real-time bid-ask quotes on SPX options, which is the equivalent of an option's market price. The bid-ask quotes are measured and updated every 15 seconds between 02:15 am and 08:15 am, as well as between 08:30 am and 03:15 pm every day (timings are given for the central time zone, which is the time zone for Canada, the United States and Central America) (Cboe Global Indices, LLC, 2019).

3.3.1 Calculation method of VIX

This section will provide an overview of how the VIX is calculated. As already mentioned in the above chapters, the OVX and GVZ are calculated using the same methodology. The CBOE has issued a paper describing the calculation methodology of the VIX index in detail. The last version was launched in July 2019, but for this thesis it will be assumed that no major changes to the methodology have been made since that time. The description of the VIX calculation method provided in this chapter is based on the information from this paper.

For the calculation of the VIX, out-of-the-money put and call options on the S&P 500 index centering around an at-the-money strike price are used, which expire between 24 days and 36 days to a Friday SPX date. The day before the expiration day of SPX futures and options, the VIX is calculated with using "near-term" expiring options (e.g. options expiring 24 days later) and "next-term" expiring options (e.g. 31 days later). On the next day, the "next-term" expiring options become the "near-term" expiring options and options with an expiration date further in the future become the "next-term" expiring options. This way, the options expirations used for the VIX calculation are rolled forward. The expiration is measured in calendar days, but then broken down into minutes to adhere to the precision required for professional option trading and volatility measurement. The time to expiration in minutes (N) is the sum of remaining minutes until midnight of the current day ($M_{current\ day}$), the minutes from 0:00 to 08:30 a.m. or to 03:00 p.m., depending on whether the option has an AM-settled SPX expiration or a PM-settled SPX expiration ($M_{Settlement\ day}$) and the sum of minutes between the current day and

[3] CBOE. (2020). *CBOE VIX*. Retrieved May 11, 2020, from http://www.cboe.com/vix

the settlement day ($M_{Other\ days}$). In order to calculate the time to expiration in years (T), N needs to be divided by the total number of minutes in a year (Cboe Global Indices, LLC, 2019).

To define the strike price (K_0) relevant for the VIX calculation, the forward SPX level is used. The strike price should equal the forward SPX level (F_j) or should be immediately below. The formula for calculating the SPX level is the following:

$$F_j = Strike\ price_j + e^{R_j T_j} * (Call\ price_j - Put\ price_j)$$[4]

Where the $Strike\ price_j$ is the strike price where the difference between the call and put price with maturity j is smallest. R_j and T_j represent the risk-free rate and the time to expiration at maturity j. When the strike price K_0 is found, this allows to define which out-of-the money puts and out-of-the money calls should be considered for the calculation. All strike prices below K_0, moving successively, are considered for put options until two consecutive put options have a zero-bid price. Put options with lower strike prices are not considered anymore, even if they do have bid prices above zero. Of course, any put option with a zero-bid price is not considered. For the call options a similar methodology is used. All call options with a strike price just above K_0, moving up successively, are considered until two call options in a row have a zero-bid price. Also here, any call option with a zero-bid price (also in between) is not considered. Additionally, one put option and one call option with strike price equal to K_0 are used for the index calculation (Cboe Global Indices, LLC, 2019).

The option prices are calculated by building the arithmetic average between the bid and ask quote of each option ($Q(K_i)$. For the at-the-money options (one call and one put) a single price is calculated out of the combination of the two prices, also using the arithmetic average.

The risk-free interest rates used for the VIX calculation are taken from the U.S. Treasury yield curve. This yield curve shows the yield of a security depending plotted against its time to maturity. The yield is calculated from the closing market bid of actively traded Tresury securities in the OTC market. The yield rates are also known as “Constant Maturity Treasury rates” (U.S. Department Of The Treasury - Daily Treasury Yield Curve Rates, 2020). Due to the different expiration dates of the SPX options, there may also be different yields. Consequently, the VIX calculation formula entails different risk-free rates for the near-term options and the next-term options (Cboe Global Indices, LLC, 2019).

To find the volatility or standard deviation of the option prices, the variance σ^2 is calculated first with the following formula:

[4] Formula is quoted from Cboe Global Indices, LLC. (2019, July 26). CBOE Volatility Index. Retrieved May 14, 2020

$$\sigma^2 = \frac{2}{T}\sum \frac{\Delta K_i}{K_i^2} e^{RT} Q(K_i) - \frac{1}{T}\left[\frac{F}{K_0} - 1\right]^2$$ [5]

Where T is the time to expiration, K_i is the strike price of the ith option, if $K_i < K_0$ it is a put option, if $K_i > K_0$, it is a call option and it is both if $K_i = K_0$ (with K_0 as strike price just below the forward index level). ΔK_i is the interval between 2 strike prices closest to each other. R represents the risk-free rate and as described above $Q(K_i)$ is the arithmetic average between bid and ask price for an option with strike price K_i. F is the forward index level derived from option prices.

This variance is then calculated for the near-term options and the next-term options with two different times to maturity and two different risk-free interest rates, resulting in σ_1^2 and σ_2^2. The two variances are then combined into 30-day weighted average and the square root is taken and multiplied with 100:

$$VIX\ Index = 100 * \sqrt{\left\{T_1\sigma_1^2\left[\frac{N_{T2} - N_{30}}{N_{T2} - N_{T1}}\right] + T_2\sigma_2^2\left[\frac{N_{30} - N_{T1}}{N_{T2} - N_{T1}}\right]\right\} * \frac{N_{365}}{N_{30}}}$$ [6]

Where N_{T1} is the number of minutes to expiration for the near-term options and N_{T2} the number of minutes to expiration for the next-term options.N_{30} is the number of minutes in 30 days and N_{365} the number of minutes in one year.

The aim of the VIX is to measure the expected volatility in option prices, however, sometimes the average price calculated from the bid and ask prices can vary without being related to the expected volatility. Furthermore, the options relevant for calculation might change, for example when an option that previously had a bid price, has at the next point of measurement a zero-bid price and is therefore taken out of the calculation. To reflect the expected volatility of the market as close to reality as possible, the CBOE has developed an algorithm in case of extreme volatility fluctuations within a very short time period. The basis for this algorithm is the first VIX Index spot value calculated during the a.m. and the p.m. period, respectively. It is called the “baseline VIX index spot value”. If the next calculated index values within two minutes are lower than at least 0.5 volatility points than the baseline value, the baseline value will be kept instead of the newly calculated VIX index value. However, if this baseline value does not change for two minutes, because the currently calculated value is always lower than

[5] Formula is quoted from Cboe Global Indices, LLC. (2019, July 26). CBOE Volatility Index. Retrieved May 14, 2020

[6] Formula is quoted from Cboe Global Indices, LLC. (2019, July 26). CBOE Volatility Index. Retrieved May 14, 2020

0.5 volatility points, the first calculated VIX index spot value after two minutes will replace it (Cboe Global Indices, LLC, 2019).

4 Discussion of interconnections of the gold oil and equity market

Various papers have been published in the past, focusing on how the gold, oil and equity market influence each other. For this purpose, researchers looked at different variables and their correlation over time.

In general, it is known that in case of raising uncertainty in the stock, oil or gold market, stock prices fall. Uncertainty in the stock market is usually priced into the expected returns across the stock market (Bali & Zhou, 2016). On the other hand, oil market uncertainty seems to be sector-specific and only related to oil-relevant industries, which means it can be diversified away. Gold market uncertainty is only asset-specific, it relates only to investors that actually hold gold assets (Bams, Blanchard, Honarvar, & Lehnert, 2017). These statements imply that stock market uncertainty is most likely to influence other markets, whereas it seems less likely that other markets are influenced by oil market uncertainty and gold market uncertainty.

Gokmenoglu and Fazlollahi published a paper in 2015 analyzing how the stock market price (measured with the daily S&P 500 closing price, SPC) is influenced by the gold price, the oil price, as well as the implied volatility of oil (OVX) and the implied volatility of gold (GVZ). With an autoregressive distributed lag model (ARDL) they investigate the long-term relationship of the variables. They find that an increase in the oil price has a significant influence on the stock market price, which decreases about 18% for a 1%- increase of the oil price, the reason being that many companies in the S&P 500 are somehow dependent on oil, for example for their production and for the distribution of their products. A 1% increase of the gold price would have an even larger long-run effect on the stock market price, which would decrease 74%. The reason is that investors see gold as a substitute investment for the stock market, probably an even safer investment that can be used to hedge risks. However, if the volatility of gold increases, this is seen as a sign of uncertainty by investors, which triggers an increase in the stock market price as investors return to stock investments. An increase in oil price volatility would lead to a decrease of the stock market price in the long run, as it has a direct influence on production cost of companies and an indirect effect on their profit margins. If there is no stability in the oil price, this might make investors hesitant to invest their money in the stock market (Gokmenoglua & Fazlollahia, 2015).

Another article by Ghulam Sarwar investigates the flight-to-safety effect with the help of implied volatilities. This effect describes the behavior of investors in case of increased stock market volatility. They tend to invest in other markets like for example the gold market which is generally considered as rather safe. The consequence is an increase of the gold price, acting as a potential signal for a general uncertainty in economic and financial conditions. This can lead to an increase in gold price volatility. For his analysis, Sarwar uses the implied volatility index VIX published by the CBOE, as well as the 10-year US Treasury note implied volatility (VXTYN). Additionally, he considers the implied volatilities of precious metals, the index for gold from SPDR Gold Trust ETF (GVZ) and the Market Vectors Gold Miners Fund ETF (VXGDX), as well as the iShares Silver Trust Fund ETF (VXSLV). The paper shows the effects of changes in VIX on changes in volatilities of T-note, gold and silver markets with the help of a regression model. The results show a positive effect of changes in VIX on changes of volatilities in the other markets, indicating that investors gradually analyze the new risks in the stock market and increase their investment in T-notes and precious metals. The flight-to-safety effects can be observed more intensely in times of crisis. Additionally, Sarwar performs a Granger causality test and finds that changes in VIX granger cause changes in the implied volatility of gold, but changes in the implied volatility of gold do not granger cause changes in VIX. Therefore, he assumes that there is no “flight-from-safety” effect, meaning that investors start to invest in riskier assets (stocks) once the volatility in the stock market goes down (Sarwar, 2016). The results indicate that the causality between changes in VIX and volatilities in precious metal markets exists not only in crisis period, but also in pre-crisis or post-crisis periods. Only the effect of VIX changes on changes in T-note volatility cannot be confirmed in pre-crisis periods. The flight-to-safety effect is considered as an effect in cross-market hedging, as risk-averse investors re-balance their portfolios in times of crisis, focusing more on less risky assets like gold, silver and T-notes (Sarwar, 2016).

The topic of gold being used as a safety asset is also investigated by Dirk Braur and Brian Lucey in their paper “Is Gold a Hedge or a Safe Haven?”. They define a haven asset as an asset that “reduces losses in times of market stress or financial crisis by more than hedge or diversifier assets”[7]. The test of gold being a safe haven asset is based on a regression of the stock and bond returns and two interaction terms with gold as the dependent variable and bond and stock returns as independent variables. The study focuses on the U.S. market, the U.K. market and the German market and is covering three different currencies. The results indicate that gold serves as a safe haven after severe negative stock market shocks, which means that stock market participants tend to invest their money in gold in times of stock market crisis. The study implies as well that investors sell their gold investments again after a decrease of volatility in the stock market (Baur & Lucey, 2009).

[7]Baur, D. G., & Lucey, B. M. (2009, February). Is Gold a Hedge or a Safe Haven? An Analysis of Stocks, Bonds and Gold.

All the above-mentioned papers provide evidence for the flight to safety effect, meaning that investors move their investments to the gold market in times of stock market crisis or uncertainty. The flight to safety effect will also be investigated in the empirical part of this paper. Another aspect to focus on is the relationship between the stock market and the oil market.

Milan Bastâr and Peter Molnár investigate the correlation between the implied volatility of the stock market, measured by VIX, and the implied volatility of the oil market, measured by OVX by using the wavelet method. They find that VIX and OVX are strongly correlated, but not equally over different time periods. Looking at longer time horizons there is a stronger correlation than over short time periods (with the highest correlation at a Fourier period of 210 days). Furthermore, the results of their tests indicate that the VIX slightly leads OVX, which may be due to the fact that the underlying options used for VIX calculation are more liquid than the ones used for OVX calculation and the VIX therefore reacts faster to market factors. The reactions to shocks of the oil market are mostly of a similar size as the reactions of the stock market. The authors imply that the diversification benefits of investors exposed to oil and stock market volatility are greater in the short run (a few days) than they are in the long run (a few years) (Bastâ & Molnár, 2018).

This paper will investigate the relationship between the oil market and the gold market. Wang and Chueh find that crude oil prices and gold prices are connected through interest rates. Their results show that in the short run an increase in interest rates leads to falling gold prices, but rising crude oil prices, causing an increase in volatility in both markets. They also make a connection between rising oil prices and increased gold price volatility. If oil prices rise, this eventually leads to inflation, which triggers an increase in interest rates by the monetary authorities. In the long term, interest rates lead gold prices, because they affect investors' expectations of the US Dollar. If it decreases investors will move their capital to the gold market, which also represents a kind of flight to safety aspect and causes gold market volatility to rise (Wang & Chueh, 2012). Compared to Wang and Chueh, this paper will show the direct interconnection between the implied oil market volatility and the implied gold market volatility, without looking at interest rate movements or inflation.

5 Data

The following section describes the data that is used for the empirical analysis of this paper. It includes time series of VIX, GVZ and OVX to represent the equity market, the gold market, and the oil market. This paper mainly focuses on market developments in the U.S., since the S&P 500, which is based on U.S. companies, is the basis for the VIX calculation and West

Texas Intermediate crude oil is the basis for the calculation of OVX. Accordingly, the flight to safety periods that have been identified relate to days where the U.S. market has been in distress.

5.1 Implied volatility Indices: VIX, OVX, GVZ

The data used for the analysis in sections 6 and 7 has been downloaded from finance.yahoo.com. To investigate the implied volatility of the oil, the gold and the entity market, historical data from OVX, GVZ and VIX is used. Since data for the gold volatility index is only available as of 11th of March 2010, the same starting point is used for the other two indices. Data has been obtained up to the 16th of June 2020 on a daily basis, considering only business days when options were traded on these indices. For the analysis, closing prices adjusted for splits are used for each index.

Tests are conducted on the full sample, the corona crisis period and the full sample without the corona crisis period. The corona crisis is assumed to have started beginning of December 2019, the first business day being December 2nd, 2019. It is assumed to last until the end of the sample period, so up to the 16th of June 2020. The full sample contains 2584 observations and the corona crisis period contains 136 observations, which means that the full sample without the corona crisis period contains 2448 observations.

Index	Mean (%)	SD (%)	Min (%)	Max (%)	Skewness	Kurtosis
OVX	35.67	19.47	14.50	325.15	5.47	46.92
Change OVX	0.01313	5.02	-90.61	130.22	5.66	318.15
GVZ	17.12	5.18	8.88	48.98	1.25	2.75
Change GVZ	-0.0003483	1.12	-9.50	13.16	1.10	16.56
VIX	17.50	7.37	9.14	82.69	2.95	13.85
Change VIX	0.006041	1.90	-17.64	24.86	2.39	33.28

Table 1: Summary statistics Full Sample

From the above summary statistics, it can be observed that the value range is greatest for the OVX, it has the biggest difference between its maximum and its minimum. Furthermore, the standard deviation is greatest for the OVX, as well as for the first differences of OVX, which means that this index is subject to the strongest fluctuations. The standard deviation is lowest for the GVZ, when taking the first differences, it is only subject to very weak fluctuations (SD: 1.12). The distribution of the GVZ prices, as well as the first differences of GVZ are distributed more symmetrically than the others, which can be seen from their rather small skewness values. However, none of the distributions is fully symmetrical, they are all positively skewed, which means they have longer and fatter tails on the right side of the distribution. The kurtosis is especially high, compared to the standard deviation, for the first differences of the closing prices of each index. This indicates that the number of extreme values is significantly higher than for a normal distribution, where the kurtosis should be around three standard deviations.

5.2 Flight to Safety days

In addition to the data mentioned in the above section, this study also considers flight-to-safety (FTS) days as defined in the paper “Flights to Safety” by Lieven Baele, Geert Baekert and Koen Inghelbrecht. They have identified FTS when a large, positive bond return is coincides with a large, negative equity return, when there are negative high-frequency correlations between the stock returns and the bond returns and additionally when there is high volatility in the equity market, indicating increased market stress. If these three criteria met, they define this episode as FTS. To identify the FTS episodes, a regime-switching model with three regimes (equity, bond and FTS) is used, where each regime variable can take on a value of 0 or 1, 1 indicating an FTS day. The switches from low (high) volatility to high (low) volatility are captured in a non-FTS-related jump term, which switches to 1 in case of an unexpected volatility change in the equity or the bond regime and is 0 otherwise. Another FTS jump term should highlight the effect of particularly pronounced returns on the first day of an FTS episode, it equals 1 on the first day and 0 otherwise. This regression has been performed for 23 different countries over a period from 1980 to 2015. Additionally, 2 other models have been used to verify the results. They show that the U.S. has the highest FTS incidence with about 6.74% of the sample period. Furthermore, the study shows that equity volatility is especially high during the FTS periods (95% higher on average), but also an increase in bond volatility can be observed (23% higher on average). Another finding is that the correlation between stock and bond returns is dramatically lower (highly negative) in FTS periods and risk premiums are significantly higher, especially for equity. In general, FTS periods are short-lived, the observed maximum is 10 days, but they only rarely exceed 4 days (Baele, Bekaert, & Inghelbrecht, 2019).

Other macroeconomic effects that have been discovered during these FTS periods include a drop in consumer confidence, an appreciation in safe-haven currencies (Swiss Franc, Japanese Yen, U.S. Dollar) and an increase in perceived credit risk, especially in the U.S. banking sector (measured by TED spread). The paper states that there is no significant increase in the price of gold during FTS periods, however, increases in the FTS beta of gold returns can be observed, which means that it might be used as a hedge against FTS events. Furthermore, the analysis concludes that the VIX increases on average by 3.18% on an ETF day in the United States, which indicates a boost in risk aversion and expected stock market volatility. The paper also investigates whether there is flight to quality or rather flight to liquidity during the FTS periods. Results indicate that there is more evidence for flight to quality (Baele, Bekaert, & Inghelbrecht, 2019).

In this paper, the goal is to investigate whether these identified FTS days have an additional significant impact on the implied gold market volatility as well as on the implied oil market volatility. Therefore, the data has been collected for the above-mentioned sample period relevant for this period. Each day that has been identified by Baele, Bekaert and Inghelbrecht as an FTS day in the U.S. market, has been added in an additional column with a value of 1. All other days have a value of 0. Then, the first differences for VIX have been multiplied with the FTS value in a column dVIXFTS. This column only shows the first differences for VIX for identified FTS periods, otherwise it contains values of 0. Consequently, this allows for a test of the influence of VIX on GVZ and OVX only for periods of market distress.

6 Research methodology

The research methodology section covers the statistical instruments and tests that have been used to process the collected data described in section 5 with the aim to conduct an analysis with statistically relevant information. The statistical instruments are defined, and their purpose is briefly explained. Since the obtained data includes time series, it is necessary to estimate regressions to be able to perform tests appropriately. The estimated regressions relevant for this paper are defined in section 6.2.1.

All statistical tests described below have been conducted with help of Eviews or Gretl software. The data results from the software are attached in the appendix.

6.1 Stationarity of data

It is important to check whether a time series used for a statistical test is stationary. Non-stationary data cannot be modeled and are not predictable. If a time series is stationary, the variance remains relatively stable over time and there is a constant long-term mean.

To ensure stationarity of the data, the first differences of the closing prices of the VIX, OVX and GVZ are considered for the further analysis. Furthermore, the stationarity of the first differences has been tested with the Augmented Dickey-Fuller Unit Root test (ADF). This test analyzes whether a time series changes its statistics properties over time. The null hypothesis in this test is that there is a unit root in this series, which means that the statistics does not follow a conventional t-distribution. The alternative hypothesis is that there is no unit root indicating that the time series is stationary. If the computed p-value is below the 5%-significance level, the null hypothesis can be rejected. The number of lags for this test has been selected according to the Schwarz Information Criterion.

The results for the first differences of OVX and GVZ both show a p-value of 0.00%, the result for the first differences of VIX show a p-value of 0.01%. This means that in all three cases the null hypothesis can be rejected, and the time series used for the further analysis is stationary. The full results of the separate ADF tests can be found in the appendix. The following figure shows the first difference values for all three indices, this graph gives the indication as well that the data is stationary. No upward or downward moving trend can be detected, the values move around 0 with peaks in the positive and the negative area, which indicates a constant long-term mean. Especially large peaks can be observed for 2020 data, during the Corona Crisis. Especially the first differences of OVX have a high volatility during this period, however without indicating any upward or downward trend.

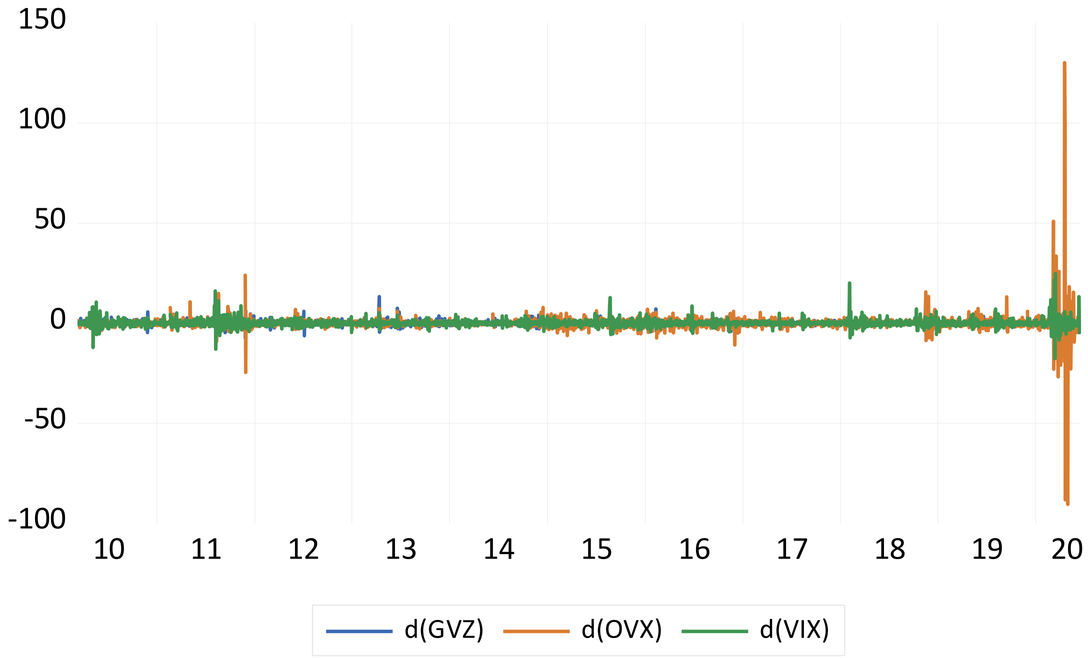

Figure 2: First differences of GVZ, OVX and VIX from March 2010 to June 2020

6.2 Granger causality – Wald test

The Granger causality is a statistical concept, which is based on the linear regression modeling. It should give indication of links between random variables by using empirical data sets and finding correlation between these data sets. One condition of this concept is that the cause happens prior to the effect, which means that the time series for the cause variable need to be lagged. In order to perform a Granger causality test multiple time series of independent variables are needed, which are then tested for correlation (bottom-up approach). Using multiple time series (historical data sets) helps to understand the relationship between several components. A null hypothesis is established, which assumes that the development of the first variable does not cause a variation of the second variable. In a t-test for individual coefficients this means that the coefficients are all 0. It is then tested if the null hypothesis should be rejected or accepted (it is rejected in case one of the coefficients is not 0). The goal of the Granger causality method is to provide a basis for a better forecast for the basis data, showing how other time series granger cause values in the time series of the basis data (Zaiontz, 2020).

In this paper, the Wald test is used to identify Granger causality. The Wald test helps to find explanatory variables in a model that are significant. To find out whether the coefficients are not 0, the Ordinary Least Squares (OLS) are computed of the dependent variable and the regressor to be tested. The greater the sum of the coefficients, the higher the effect of the regressor on the dependent variable. However, the results need to be significant, which means that the calculated p-value needs to be below 5%. Only if this criterium is fulfilled, the null hypothesis can be rejected. For these tests, heteroscedasticity-consistent or robust standard errors and p-values are used to adjust for possible heteroscedastic residuals and fit the model accordingly. This ensures that with the OLS method, the variances estimated by the model are really the smallest, even when the variances of the distribution are not homogenous.

For the performance of a proper Wald test, the correct number of lags relevant for the regression needs to be identified. The lag number indicates when the causality of the variables takes effect. For example, if the implied volatility of the equity market would immediately (on the same business day) affect the implied volatility of the gold market, then the number of lags should be 0. Since the data used for this test is downloaded per business day, one lag would refer to a causality delay of one business day. The ideal number of lags can be identified using several information criteria. The most common ones are the Bayes Information Criterion (BIC), which is also called the Schwarz Information Criterion (SIC) and the Akaike Information Criterion (AIC). To find the optimal lag order, the value of the criterion should be minimized. For this time series, the SIC gives the most conclusive result, the optimal number of lags should be 4. The results of the test are presented in the appendix.

6.2.1 Regressions

The granger causality test should provide insights of the predictive ability of the VIX on other non-equity implied volatilities, like GVZ and OVX, considering the lead-lag relationship between the first differences in VIX and the first differences of OVX and GVZ (Equation 2). Furthermore, it should also give results on whether non-equity implied volatilities have a predictive ability on the VIX, again considering the first differences of the indices (Equation 1).

Finally, the granger causality test is used to define the lagged impact of the changes in VIX on the changes in GVZ and OVX during pre-defined flight to safety days (Equation 3). For these tests, the following regressions can be estimated[8]:

$$\Delta_{VIX,t} = \alpha_0 + \sum_{i=1}^{n} \alpha_{ns,i} \Delta V_{ns,t-i} + \sum_{i=1}^{n} \alpha_{VIX,i} \Delta_{VIX,t-i} + \varepsilon_t \quad (1)$$

$$\Delta V_{ns,t} = \beta_0 + \sum_{i=1}^{n} \beta_{VIX,i} \Delta_{VIX,t-i} + \sum_{i=1}^{n} \beta_{ns,i} \Delta V_{ns,t-i} + e_t \quad (2)$$

$$\Delta V_{ns,t} = \gamma_0 + \sum_{i=1}^{n} \gamma_{VIX,i} \Delta_{VIX,t-i} + \sum_{i=1}^{n} \gamma_{ns,i} \Delta V_{ns,t-i} + \sum_{i=1}^{n} \gamma_{VIX,i} \Delta_{VIX\_FTS,t-i} + u_{tFTS} \quad (3)$$

$\Delta_{VIX,t}$ and $\Delta V_{ns,t}$ represent the changes (first differences) in VIX and the changes in implied OVX and GVZ (here grouped into the non-stock implied volatility). The changes of implied volatilities are measured at time *t*, *i* equals the number of lags used for this regression. The optimal number of lags has been determined as 4 as per Schwarz Information Criterion.

For the equation (1) the intercept is α_0. $\sum_{i=1}^{n} \alpha_{ns,i} \Delta V_{ns,t-i}$ represents the lagged changes in OVX and GVZ and $\sum_{i=1}^{n} \alpha_{VIX,i} \Delta_{VIX,t-i}$ represents the effect of the lagged changes of VIX on the changes of VIX at time *t*. This means that the VIX is not only tested for the influence of non-stock implied volatilities, but also for the influence of its own lagged values. ε_t is the error term in this regression. Equation (2) describes the influence of changes in VIX on non-stock implied volatilities OVX and GVZ using $\sum_{i=1}^{n} \beta_{VIX,i} \Delta_{VIX,t-i}$ as the lagged changes in VIX and $\sum_{i=1}^{n} \beta_{ns,i} \Delta V_{ns,t-i}$ as lagged changes of non-stock implied volatilities. β_0 is the intercept and e_t is the error term in this regression. Equation 3 measures the additional influence of changes in VIX on changes in non-stock implied volatilities during FTS days, where $\sum_{i=1}^{n} \gamma_{VIX,i} \Delta_{VIX,t-i}$ is the effect of lagged VIX changes, $\sum_{i=1}^{n} \gamma_{ns,i} \Delta V_{ns,t-i}$ is the effect of lagged changes in non-stock volatilities and $\sum_{i=1}^{n} \gamma_{VIX,i} \Delta_{VIX\_FTS,t-i}$ is the additional effect of lagged VIX changes on FTS day. In this regression γ_0 represents the intercept and u_{tFTS} the error term.

7 Results

To analyze the results, it is helpful to look at the simple correlations of the variables in the regressions. The following correlation matrix summarizes the relationships:

[8] The estimated regressions are similar to the regressions used in Sarwars paper “Examining the flight-to-safety with the implied volatilities”

Correlation	GVZ	OVX	VIX	Change GVZ	Change OVX	Change VIX
GVZ	1.000000					
OVX	0.445228	1.000000				
VIX	0.678376	0.678006	1.000000			
Change GVZ	0.108214	0.004314*	0.081856	1.000000		
Change OVX	0.031912*	0.130866	0.084120	0.159208	1.000000	
Change VIX	0.014993*	-0.012983*	0.132455	0.378239	0.255467	1.000000

*Table 2: Correlation between implied volatilities, full sample period. The correlations that are not statistically relevant have been market with **

The correlations between GVZ and VIX and OVX and VIX are the highest, but there is also a significant correlation between GVZ and OVX. The correlations between the first differences are in general not as high as the correlations between the closing prices of the indices. All significant correlations are positive. The correlation matrix gives a good indication on the relationship between the indices. However, it does not provide any information on whether an implied volatility change is an effect of another implied volatility change. This will be further investigated in the next section.

7.1 Data analysis of Wald test

As already stated in section 4 the Wald test is used to find any Granger Causality between VIX, OVX and GVZ. The results obtained from this test have been clustered into 4 sections. First, the results of the full sample test are presented, then the full sample results are compared to the results obtained for the Corona Crisis period. The third section covers the results of the test of the full sample without the Corona Crisis period. Finally, the findings from the full sample test with focus on flight to safety days are presented.

7.1.1 Full sample analysis

The first analysis to be done considers the whole test period from the 12th of March 2010 until the 16th of June 2020. The results are summarized in the following table:

Test hypothesis	Sum of coefficients	p-value with HC0 estimator
dVIX does not Granger cause dOVX	0.78854	1.680%
dOVX does not Granger cause dVIX	-0.02005	52.539%
dVIX does not Granger cause dGVZ	0.21251	0.077%
dGVZ does not Granger cause dVIX	0.06608	57.848%
dGVZ does not Granger cause dOVX	0.95574	6.435%
dOVX does not Granger cause dGVZ	0.04209	4.012%

Table 3: Wald test Full sample 12.03.2010 to 16.06.2020: dVIX, dGVZ and dOVX represent the first differences calculated from the closing prices of the indices.

From this table, it can be observed that the null hypothesis cannot be rejected for three tests. The sum of coefficients is negative for the effect of the implied volatility of the oil market on the implied volatility of the equity market. This means that the reactions in volatility would be opposite, e.g. if the implied volatility in the oil market goes up, it goes down in the equity market. However, the test is not significant since the p-value is well above 5% (52.539%). Additionally, the granger causality is also not significant for the implied volatility of the gold market on the equity market and on the oil market (57.848% and 6.435% respectively).

The first result below the 5% significance level shows that the implied volatility of the equity market granger causes the implied volatility of the oil market. Here, the sum of the coefficients is rather high (0.78854), which means that there is a rather strong correlation. This finding is consistent with the results presented by Bastar and Molnár in their paper “Oil market volatility and stock market volatility” which has already been discussed in section 4. They also find that there is a strong effect of the equity market volatility on the oil market volatility, especially in the long run and that VIX leads OVX. Since the above test covers a sample of approximately 10 years, this can be identified as a “long-run” sample. Furthermore, a financialization of the oil market can be observed. The oil market is more and more exposed to a variety of financial instruments like options, futures, and exchange traded funds. The OVX is an index displaying the implied volatility calculated from options on oil futures, this means that the oil price volatility is influenced not only by the oil price, but also by the trading volume of the futures and options. Oil futures and options are not only used for portfolio diversification, but also for speculation. This might explain the spill-over effect of equity market implied volatility to oil market implied volatility.

The most significant result with a p-value of only 0.077% is that the changes in the implied volatility of the equity market granger cause changes in the implied volatility of the gold market. This is in line with the papers of Sarwar and Gokmenoglu and Fazlollahi mentioned in section 4. Gold is in general perceived to be a safe asset to invest in. With increases in implied equity market volatility often comes a sense of crisis or instability so that investors try to move their money to safer assets. This is the flight to safety effect. Since this portfolio rebalancing causes changes in the gold price, also the implied volatility of the gold market increases. As mentioned above, the changes in the implied volatility of the gold market do not granger cause the changes in implied volatility of the stock market, the sum of the coefficients is very low and the p-value well above the 5% significance level. This is also consistent with the findings of Sarwar that there is no “flight from safety” effect once the VIX goes down.

Finally, the granger causality between the OVX and the GVZ is significant, although the sum of coefficients is not very high (only 0.04209). Often, an increase in implied oil market volatility is seen as a sign for raising inflation and for distressed markets in general. Not only are many companies of the economy dependent on oil either for production or transportation of their products, but as stated before, there is a financialization of the oil market and an increase in the implied volatility could therefore be seen in a similar way as the increase of implied volatility in the equity market. Since investing in gold is known to be a hedging strategy against rising inflation, this might trigger a kind of flight to safety effect as well, although not as big and obvious as the one described above.

7.1.2 Corona Crisis analysis

The same test as above has been performed only considering the business days during the Corona Crisis. The first cases of the new coronavirus were identified in the city of Wuhan, China in December 2019 (World Health Organization, 2020). Therefore, the sample period starts at the 2nd of December 2019. Since the crisis is still ongoing, the final date for the Corona Crisis sample equals the final date of the full sample, the 16th of June 2020. The following table summarizes the results:

Test hypothesis	Sum of coefficients	p-value with HC0 estimator
dVIX does not Granger cause dOVX	2.33155	0.350%
dOVX does not Granger cause dVIX	-0.03013	47.618%
dVIX does not Granger cause dGVZ	0.39550	2.285%
dGVZ does not Granger cause dVIX	0.12113	83.478%
dGVZ does not Granger cause dOVX	3.56607	8.318%
dOVX does not Granger cause dGVZ	0.02483	24.471%

Table 4: Wald test Corona Crisis 02.12.2019 to 16.06.2020: dVIX, dGVZ and dOVX represent the first differences calculated from the closing prices of the indices

Some of the results may show less significance during the Corona Crisis period, because the number of observations used for the test is a lot smaller than that of the full sample. However, the least significant results from this test are in line with the not significant results from the full sample test. We cannot reject the null hypothesis that OVX does not granger cause VIX, that GVZ does not granger cause VIX and that GVZ does not granger cause OVX. What is different in this data sample, is that also the null hypothesis that OVX does not granger cause GVZ cannot be rejected here. This is probably because oil prices were falling during the beginning of the crisis (spring 2020), so from the oil market investors did not get the warning signals of rising inflation which led them to invest in safer assets like gold. Rather, the rise in GVZ was caused by changes in the implied volatility of the equity market which will be discussed further below.

One striking result of this test is that the granger causality of OVX on VIX is even stronger during the Corona Crisis (the sum of coefficients is 2.33 compared to 0.788 for the full sample). Since beginning of January 2020, the prices of the United States Oil fund (on which the OVX is based), have been declining steeply. However, on 28th of April a sudden significant increase could be observed, and the prices have been rising again since. The reason was a material cut in oil supply in the U.S. during the month of April and an agreement of OPEC+ countries for the biggest oil supply cut in history as of May 1st, 2020. This led to a spike in OVX during end of April (IEA, 2020). On the other hand, the equity market has had the biggest turbulences in March 2020, due to the economic impact of the coronavirus in Europe and the U.S. This indicates that the Corona Crisis has had a significant impact on the oil price, the big cut in oil supply was a result of the economic situation. Due to the almost complete stop of air traffic and a significant reduction in other transportation because of global travel restrictions and border closings, the crisis caused oil demand to fall even further. This was intensified by the oil price war between Russia and Saudi Arabia, resulting in oil price drops also in the U.S. and OPEC countries. Therefore, the changes in oil market volatility have been caused by the downfall of the real economy, which is also reflected in the increased equity market volatility, as well as by other political factors.

Finally, the test shows that VIX granger causes GVZ also during the Corona Crisis. Here, the sum of coefficients is also significantly larger than in the full sample period (0.3955 vs. 0.2125). This seems to confirm the findings from Sarwar, that the flight to safety effect intensifies during a crisis period. Indeed, the price of the SPDR gold shares ETF has been rising during January and February 2020. However, then we observe a steep decline in gold prices, which explains the peak of GVZ during March 2020, but not in the expected direction. The drop in the gold price originates in the selling of huge amounts of gold, because investors were in the need of cash due to the economic consequences of the coronavirus. Many companies needed to be saved from insolvency and owners had to pay short term liabilities with other assets, since the generated income has decreased significantly for many businesses. Gold has been used for liquidation, because it has been one of the best-performing assets during the beginning of the Corona Crisis. The spike in the implied volatility of the gold market can be observed only a few days after the crash of the stock market on 16th of March. Consequently, we can observe a granger causality between the VIX and the GVZ, but it is not resulting from the typical flight to safety effect. The results of this test lead to the conclusion that the Corona Crisis cannot be seen as a "typical" financial crisis. The difference to other crisis in the past years is that the origin is not only in the financial markets (like for example during the Financial Crisis 2007/2008) nor triggered by an economic event, but rather caused by a health crisis, which was aggravated by globalization.

7.1.3 Full sample analysis without Corona Crisis period

The next test covers the full sample, but without the Corona Crisis period to identify any granger causality that may not result mainly from a crisis period. The results are presented in the following table:

Test hypothesis	Sum of coefficients	p-value with HC0 estimator
dVIX does not Granger cause dOVX	0.15939	8.929%
dOVX does not Granger cause dVIX	-0.00543	91.998%
dVIX does not Granger cause dGVZ	0.14776	0.679%
dGVZ does not Granger cause dVIX	-0.03410	72.567%
dGVZ does not Granger cause dOVX	0.16762	34.525%
dOVX does not Granger cause dGVZ	0.10239	0.319%

Table 5: Wald test Full sample without Corona Crisis 12.03.2010 to 29.11.2019: dVIX, dGVZ and dOVX represent the first differences calculated from the closing prices of the indices

These results indicate again that OVX does not granger cause VIX, GVZ does not granger cause VIX and GVZ does not granger cause OVX, which is consistent with the previous results. For this sample period, the influence of VIX on OVX is not significant, which shows that the correlation is triggered mostly by the crisis period. Furthermore, the sum of coefficients is significantly lower in this test than in the previous two (only 0.15939).

The result of VIX granger causing GVZ is still significant, this proves that there is a general influence of the stock market implied volatility on the gold market implied volatility. However, it is a lot smaller than during the Corona Crisis period (0.39550 vs 0.14776). This indicates that the market participants always do react on increases in the stock market volatility with buying or selling gold, but the reaction is a lot stronger if there is an economic crisis. The general conclusion cannot be that it is always a flight to safety effect, since the results during the Corona Crisis show that gold was sold causing the gold price to decrease, which is the opposite of what happens during a flight to safety period.

For the test, the null hypothesis can be rejected that OVX does not granger cause GVZ. There is a significant correlation between the oil market implied volatility and the gold market implied volatility, which is stronger in the test sample without Corona Crisis data as in the full test sample. As described already previously, this can come from the fact that investors look at the oil market volatility as an indicator for inflation and try to hedge their portfolios with investments in the gold market. Furthermore, both markets are connected through interest rate changes. As mentioned in section 4, Wang and Chueh find that interest rates influence the U.S. dollar and the U.S. dollar leads gold prices. Interest rate changes transform investors' expectations on the expected value of the U.S. dollar. In case of a U.S. dollar depreciation, investors will move their assets to the gold market, either to hedge their portfolios or for speculation purposes. Crude oil prices also react to interest rate changes, e.g. in case of a reduction of interest rates, oil prices will fall as demand decreases as investors see this as a sign of economic recession. This relationship could also explain the influence of implied volatility of the oil market on the implied volatility of the gold market.

7.1.4 Full sample analysis with FTS days

The last test focuses on the U.S. FTS days identified by Baele, Bekaert and Inghelbrecht as described in section 5.2. Therefore, the influence of the VIX on these flight to safety days is tested on the OVX and the GVZ. The sample period includes all business days from the 12th of March 2010 to 16th of June 2020. The results are summarized in the following table:

Test hypothesis	Sum of coefficients	p-value with HC0 estimator
dVIXFTS does not Granger cause dGVZ	0.20775	3.181%
dVIXFTS does not Granger cause dOVX	0.81263	3.509%

Table 6: Wald test Full sample 12.03.2010 to 16.06.2020: dVIXFTS represents the first differences of VIX on FTS days, dGVZ and dOVX represent the first differences of the indices calculated from closing prices

Both results have p-values below 5%, consequently both are significant. Since the FTS days show several crisis periods over the 10-year sample, the results are more general then the test that was done just during the Corona Crisis period.

It is obvious that the VIX granger causes GVZ during FTS days. The sum of the coefficients of 0.20775 can be added to the sum that has been found in the first test (0.21251). This means that the influence of the implied volatility of the equity market on the implied volatility of the gold market is almost double during FTS days compared to normal business days. It confirms that the flight to safety effect is indeed stronger during a period of distressed markets, even though the volatility change during the Corona Crisis came from investors selling gold instead of buying it. These findings are compliant with the results published by Sawar as mentioned in section 4.

Furthermore, the test indicates that VIX does granger cause OVX on FTS days, substantiating the results from the Corona Crisis period. The sum of coefficients of 0.81263 is substantial and can be added to the sum of coefficients found for the granger causality during the full sample (0.78854). It shows again the financialization of the oil market, which can be seen clearest during periods of distressed markets. This finding is also consistent with the paper by Basta and Molnár, where they state that the influence of the implied equity market volatility has the biggest influence on the implied oil market volatility in the long run.

7.2 Summary and conclusion

As mentioned in chapter 1, this thesis aimed to answer the question of interconnectedness of the gold, oil and equity market with a focus on the flight to safety effect during the Corona Crisis. The paper first focused on explaining the basics of options and option trading and the different implied volatility indices published by the CBOE. Then, different standpoints on the relationships of the gold, oil and equity market were discussed, presenting different viewpoints already published in previous research. The data used for the empirical analysis of this thesis was gathered ranging from March 2010 until June 2020 to cover an extensive time period and to allow obtaining statistically significant results. Daily closing prices of VIX, OVX and GVZ, as well as an index on flight to safety days in the U.S. serve as the basis for further analysis. The Wald test has been identified as appropriate methodology to test for granger causality between the variables. Finally, three regressions have been estimated to describe the influence of the different implied volatilities on one another. The Wald test has been conducted for three different time periods, once for the full sample period, once only for the Corona Crisis period and once for the full sample period without the Corona Crisis period. Additional tests have been conducted to analyze whether there is additional influence of the VIX on the GVZ and OVX on flight to safety days.

The conclusion of these tests is that a clear influence of the VIX on GVZ can be observed during all test periods, and an additional influence is present during FTS days. On the one hand, this confirms the flight to safety effect that has already been detected in other papers. On the other hand, this flight to safety effect was only partly present during the Corona Crisis. The main influence of VIX on GVZ could be detected when investors started to sell their assets in the gold market to receive cash. This also increased the implied volatility of the gold options market, but not in the same way as during previous crisis, when investors invested in the gold market to get away from highly volatile and risky stock markets.

A further finding is that VIX granger causes OVX, which is not only significant during the full sample period, but especially in the Corona Crisis period and on FTS days in general. This shows the high financialization of the oil market. Since the paper looks at the implied volatility of oil options, which are financial derivatives, they do not just reflect the development of the oil market but are also highly influenced by other financial markets and instruments. Especially during FTS days, there seems to be a spill-over effect from the equity market to the oil market implied volatility. The strong granger causality during the Corona Crisis has been increased by an oil price war and severe global supply cuts, which affected the implied volatility of crude oil options.

In the long run (for the full sample with and without Corona Crisis), also the granger causality of OVX on GVZ is significant, which underlines the findings mentioned above. If the VIX tends to lead OVX and has a significant influence on GVZ, consequently OVX has also an influence on GVZ. Since an increase in oil market volatility can also be a sign of rising inflation and investors might seek further portfolio diversification in the less risky gold market.

The outlook that can be derived from this thesis is that the implied volatilities of gold, oil and stock market options are interconnected and partly influence each other. However, not necessarily through a flight to safety effect. Also, during the Corona Crisis, an increasing equity market implied volatility granger caused a rise in the implied volatility of gold options, but due to the fact that investors were selling their investments in the gold to cover their liabilities as economic income has been low. Of course, the analysis performed in this thesis only uses data until mid of June 2020 and the Corona Crisis is expected to last months if not years longer. Therefore, the same analysis could be done again once the crisis is over to verify the results and check the development of the markets. In general, investors should look at implied options' volatilities, as they do give indication on the expectations of market participants, but they also need to look at the direction the prices change, as rising volatility is not in every crisis connected to the classic flight to safety effect. Especially, for the Corona Crisis this means that we are experiencing not the typical financial or economic crisis that we have been trough before, but that this is a new type of crisis which triggers different investor behavior in the financial markets.

8 References

Baele, L., Bekaert, G., & Inghelbrecht, K. (2019, January 11). Flights to Safety. *NBER working paper series*. Retrieved July 7, 2020

Bali, T., & Zhou, H. (2016, July 29). Risk, Uncertainty, and Expected Returns. (C. U. Press, Ed.) *Journal of Financial and Quantitative Analysis*, pp. 707-735. Retrieved August 3, 2020

Bams, D., Blanchard, G., Honarvar, I., & Lehnert, T. (2017). Does oil and gold price uncertainty matter for the stock market? (Elsevier, Ed.) *Journal of Empirical Finance*, pp. 270-285.

Bastâ, M., & Molnár, P. (2018). Oil market volatility and stock market volatility. (Elsevier, Ed.) *Finance Research Letters*, pp. 204-214. Retrieved July 18, 2020

Baur, D. G., & Lucey, B. M. (2009, February). Is Gold a Hedge or a Safe Haven? An Analysis of Stocks, Bonds and Gold. Retrieved July 18, 2020

CBOE. (2020). *CBOE VIX*. Retrieved May 11, 2020, from http://www.cboe.com/vix

CBOE Crude Oil ETF Volatility Index (OVX). (2020). Retrieved May 9, 2020, from http://www.cboe.com/products/vix-index-volatility/volatility-on-etfs/cboe-crude-oil-etf-volatility-index-ovx

Cboe Global Indices, LLC. (2019, July 26). CBOE Volatility Index. Retrieved May 14, 2020

CBOE Gold Volatility Index (GVZ). (2020). Retrieved May 3, 2020, from http://www.cboe.com/products/vix-index-volatility/volatility-on-etfs/cboe-gold-etf-volatility-index-gvz

CBOE Holdings (Ed.). (2008, July 14). *CBOE INTRODUCES NEW CRUDE OIL VOLATILITY INDEX (OVX)*. Retrieved May 9, 2020, from http://ir.cboe.com/~/media/Files/C/CBOE-IR-V2/press-release/2008/CBOE_News_2008_7_14_General_Releases-1.pdf

CBOE To Launch Trading on CBOE Gold ETF Volatility Index Options (GVZ) On April 12 - Second New Tradable Product On Volatility Of Active ETF Options. (2011, April 4). Retrieved May 3, 2020, from https://mondovisione.com/news/cboe-to-launch-trading-on-cboe-gold-etf-volatility-index-options-gvz-on-april/

CBOE Volatility Indexes. (2020). Retrieved May 3, 2020, from http://www.cboe.com/products/vix-index-volatility/volatility-indexes

Gokmenoglua, K. K., & Fazlollahia, N. (2015, May 29). The Interactions among Gold, Oil, and Stock Market: Evidence from S&P 500. (E. B.V., Ed.) *Procedia Economics and Finance*, 478-488. Retrieved June 26, 2020

Groth, J. (2016, August 16). *Fonds im Fokus - SPDR Gold Shares*. Retrieved May 3, 2020, from https://www.capital.de/geld-versicherungen/fonds-im-fokus-spdr-gold-shares

Hull, J. (2018). *Risk Management and Financial Institutions.* Hoboken, New Jersey: John Wiley & Sons.

Hull, J. C. (2017). *Fundamentals of Futures and Options Markets.* Harlow, Essex: Pearson Education Limited.

IEA. (April 2020). *Oil Market Report - April 2020*. Abgerufen am 3. August 2020 von https://www.iea.org/reports/oil-market-report-april-2020

Sarwar, G. (2016, September 20). Examining the flight-to-safety with the implied volatilities. (E. B.V., Ed.) *Finance Research Letters*, 118-124. Retrieved June 26, 2020

Turner, C. (2019, September 19). *Index Options - Explained And Simplified*. Retrieved May 11, 2020, from https://www.stockinvestor.com/37181/index-options-explained-simplified/

U.S. Department Of The Treasury - Daily Treasury Yield Curve Rates. (2020, May 15). Retrieved May 17, 2020, from https://www.treasury.gov/resource-center/data-chart-center/interest-rates/pages/textview.aspx?data=yield

Understanding Crude Oil Benchmarks and Classifications. (2020). Retrieved May 9, 2020, from http://www.oilscams.org/crude-oil-benchmarks

USCF (Ed.). (2020). *USO - United States Oil Fund*. Retrieved May 9, 2020, from http://www.uscfinvestments.com/uso

Wang, Y. S., & Chueh, Y. L. (2012, September 30). Dynamic transmission effects between the interest rate, the US dollar, and gold and crude oil prices. (Elsevier, Ed.) *Economic Modelling*, pp. 792-298. Retrieved July 18, 2020

World Health Organization. (2020). Retrieved August 3, 2020, from https://www.who.int/emergencies/diseases/novel-coronavirus-2019/events-as-they-happen

Zaiontz, C. (2020). Retrieved August 3, 2020, from Real Statistics Using Excel - Granger Causality: https://www.real-statistics.com/time-series-analysis/time-series-miscellaneous/granger-causality/

9 Appendix

The following section gives an overview of the appended files with the research results. File names are stated italic.

- Summary Statistics
  - *Summary Statistics Full Sample.pdf*
- Results from the Augmented Dickey-Fuller Unit Root Test
  - *ADF test d_GVZ.pdf*
  - *ADF test d_OVX.pdf*
  - *ADF test d_VIX.pdf*
- Correlation Matrix
  - *Correlation Matrix.pdf*
- Results from Wald test to determine Granger Causality
  - Lag Order Selection Criteria
    - *Lag length criteria.pdf*

- Results from Wald test for the full sample with dGVZ as dependent variable
    - *GVZ_VIX_4_lags.pdf*
    - *GVZ_VIX_4_lags_sum_coefficients.pdf*
    - *GVZ_OVX_4_lags.pdf*
    - *GZV_OVX_4_lags_sum_coefficients.pdf*
- Results from Wald test for the full sample with dOVX as dependent variable
    - *OVX_VIX_4_lags.pdf*
    - *OVX_VIX_4_lags_sum_coefficients.pdf*
    - *OVX_GVZ_4_lags.pdf*
    - *OVX_GVZ_4_lags_sum_coefficients.pdf*
- Results from Wald test for the full sample with dVIX as dependent variable
    - *VIX_OVX_4_lags.pdf*
    - *VIX_OVX_4_lags_sum_coefficients.pdf*
    - *VIX_GVZ_4_lags.pdf*
    - *VIX_GVZ_4_lags_sum_coefficients.pdf*
- Results from Wald test for Corona Crisis with dGVZ as dependent variable
    - *GVZ_VIX_4_lags_CORONA.pdf*
    - *GVZ_VIX_4_lags_sum_coefficients_CORONA.pdf*
    - *GVZ_OVX_4_lags_CORONA.pdf*
    - *GZV_OVX_4_lags_sum_coefficients_CORONA.pdf*
- Results from Wald test for Corona Crisis with dOVX as dependent variable
    - *OVX_VIX_4_lags_CORONA.pdf*
    - *OVX_VIX_4_lags_sum_coefficients_CORONA.pdf*
    - *OVX_GVZ_4_lags_CORONA.pdf*
    - *OVX_GVZ_4_lags_sum_coefficients_CORONA.pdf*
- Results from Wald test for Corona Crisis with dVIX as dependent variable
    - *VIX_OVX_4_lags_CORONA.pdf*
    - *VIX_OVX_4_lags_sum_coefficients_CORONA.pdf*
    - *VIX_GVZ_4_lags_CORONA.pdf*
    - *VIX_GVZ_4_lags_sum_coefficients_CORONA.pdf*
- Results from Wald test for the full sample without Corona Crisis period with dGVZ as dependent variable
    - *GVZ_VIX_4_lags_wo_CORONA.pdf*
    - *GVZ_VIX_4_lags_sum_coefficients_wo_CORONA.pdf*
    - *GVZ_OVX_4_lags_wo_CORONA.pdf*
    - *GZV_OVX_4_lags_sum_coefficients_wo_CORONA.pdf*

- Results from Wald test for the full sample without Corona Crisis period with dOVX as dependent variable
  - *OVX_VIX_4_lags_wo_CORONA.pdf*
  - *OVX_VIX_4_lags_sum_coefficients_wo_CORONA.pdf*
  - *OVX_GVZ_4_lags_wo_CORONA.pdf*
  - *OVX_GVZ_4_lags_sum_coefficients_wo_CORONA.pdf*
- Results from Wald test for the full sample without Corona Crisis period with dVIX as dependent variable
  - *VIX_OVX_4_lags_wo_CORONA.pdf*
  - *VIX_OVX_4_lags_sum_coefficients_wo_CORONA.pdf*
  - *VIX_GVZ_4_lags_wo_CORONA.pdf*
  - *VIX_GVZ_4_lags_sum_coefficients_wo_CORONA.pdf*
- Results from Wald test for the full sample with FTS days with dGVZ and dOVX as dependent variables
  - *Full Sample_4 lags_FTS_GVZ.pdf*
  - *Full Sample_4 lags_FTS_sum coefficients_GVZ.pdf*
  - *Full Sample_4 lags_FTS_OVX.pdf*
  - *Full Sample_4 lags_FTS_sum coefficients_OVX.pdf*