# Master Thesis:
# An update to the comovements of commodity, equity and USD

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**Abstract**

The current financial crisis has large impact on market structure. This research focused on the dynamic comovements among four assets: 1 month gold futures, 1 month Brent crude oil futures, USD Index and S&P500 Index. The study further examines causalities among assets using the linear Granger causality test and the nonlinear Granger causality test, and the effect of shocks on the assets price movements using the Safe Haven Analysis. As results, we found differences in the dynamic comovements among assets before and during the current financial crisis. Further using the findings of the analysis, new models are constructed. The predictions of our models, using three different methods: stable coefficients, moving window, and expanding window methods, are compared with two benchmark models. We further compute CPS, MAE and MSPE to compare the predictions. As results, our models provide outstanding accurate predictions and the predictions are most accurate using the moving window method.

**Keywords**: comovement, causality, nonlinear causality

## Special thank

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# Contents

# 1 Introduction

Traditionally, investors seek to reduce their investments risk while maximizing their returns of their investments. To lower the investments risk, investors mainly diversify their investments by incorporating different kinds of assets in their portfolio. The conventional wisdom holds that conservative investors should protect their portfolio by lowering the risk as much as possible. To be able to diversify investments risk, investors should understand the relations between different kinds of assets. Earlier researches such as Samanda and zadeh (2012), and Christner and Dicle (2011) analyzed the comovements between different kinds of assets. They concluded that some assets can be used to hedge against each others.

Although extensive researches have been done for the comovements of different assets，the relations between assets might be changed during the current financial crisis and the ordinary knowledge about the comovements may be no more useful. Therefore additional analysis is needed for the relations between different kinds of assets during and after the period of current financial crisis. Understanding the comovements may help investors to diversify their portfolio, limit investments risk while maximizing the returns of their investments.

Although comovement analysis engages different aspects, mainly two kinds of relations are analyzed. The first kind of relations is focused on the contemporaneous relations between the assets. Well-known aspects that typically are analyzed are for example correlations and cointegrations among different assets. These aspects measure the relation between assets at same time. In other words, through analyzing these aspects, we are able to know which asset can be used to hedge another asset. Therefore, analyzing these aspects is of importance to diversify investment risk.

The second kind of aspects, such as autocorrelations and causalities, are more focussed on dynamic relations. In general, analyzing these aspects may tell us the price changes of one asset in the future caused by price changes in another asset now. This helps us to predict assets price movements and, possibly, maximizing returns of investments. It's therefore of importance for taking speculative decisions.

The main focus of this research lies on the second kind of aspects. We are more interested in providing accurate predictions of assets price movements based on the relations among assets. Investors, who lost money in the crisis, may be interested in the relations between different assets to avoid the loss and increase the return of their investments in the future. As contribution of this research, the results consist of models based on comovements relations which provide accurate predictions of assets price movements. With these models, investors are able to predict the price movements of assets in the future and hence gain extra returns on their investments.

There are many different assets available in different markets for investors. Due to limited time we obviously are not able to analyze all assets in this research. Therefore we focus our analysis on four most representative assets. The assets considered in this research are the S&P 500 index, the Brent crude oil 1 month futures, the gold 1 month futures and the USD index. These assets represent the three major financial markets: the equity market, the commodity market and the currency market.

The data are daily observations of the S&P500 index, the Brent crude oil futures, the gold futures and the USD index through the period from 2004 to 2012. One of our goals of this research is to explore whether there are substantial differences in the comovements of these assets before and during the crisis. We therefore split our data into two periods, the before crisis period and the period during crisis. The split point we use is 19th September 2008 which is the date that the bankruptcy of Lehman Brothers Holdings Inc took place. Then we apply econometric tests to the period before crisis as well as to the period during the crisis. By comparing the results we can find the differences in dependencies among assets caused by the current financial crisis.

The research can be separated into two main parts. Firstly we analyze comovements among assets before and during the financial crisis. To carry out the analysis, we apply different tests on the assets price movements in the before crisis period and the period during the crisis. The related methods are linear Granger causality test, nonlinear Granger causality test and Safe Haven Analysis. We use the causality tests to verify causal relations among assets and the results of the Safe Haven Analysis to prove the influences of extreme price movements of one asset on other assets. For all tests, we also incorporate small sensitivity tests for the parameters used in the methods. Comparing the results of the tests, we found structural changes in the relations among assets between the period before and during the crisis. Considering the results of causality test, less causal relations are found in the period during the crisis than the period before the crisis. Furthermore, the results of Safe Haven Analysis show that the assets price movements are more affected by the extreme observations of other assets in the period during the crisis, which means that the extreme observations should be considered as important explanatory variables in predicting assets price movements.

Then in the second part of our research, we use the findings of our comovement analysis for the period during the crisis to construct our models.

In this part we also compare the predictions of our model with two benchmark models using different measurements. The two benchmark models are one lagged auto regression model and one lagged vector auto regression model. To provide more accurate predictions of the assets price movements, we further introduce instable coefficients by producing our predictions based on moving and expanding window methods. As results, our models give better predictions than the two benchmark models for all four assets. Comparing the results using different prediction methods, the moving window method produces more accurate forecasts than the expanding window method or the predictions using stable coefficients.

The structure of the remainder of this research is set up as follows. In the next section we discuss the relevant literature of the other researchers and their finding related to this paper. A detailed description of the data is given in section 3. Section 4 contains exhaustive explanations of methods implemented in this research, followed by the important results accompanied by the thorough interpretation in section 5. Finally the research ends with the short but compact conclusion which responses to the research question, appendix, and reference in section 6, 7, and 8.

# 2 Literature review

In 2008, the recent financial crisis took its place and had a large impact on all markets. For market participants in these markets, it's important to understand the influences of the crisis on the different financial markets for portfolio rebalancing, risk management, and speculation. In the literature section we review different academic researches to understand the relationship among different kinds of assets. These researches are using different kinds of data with different period lengths or using different econometric models, and providing different results.

## 2.1 The U.S. Dollar vs. the stock market

More recent articles, such as Darwin (2009), Lien (2009), and Pethokoukis (2009), using more recent data, suggest inverse relationship between the U.S. dollar and stock price. Hence the U.S. dollar can be used as a hedge for the stock price. However the long term study by Johnson and Soenen (2002), based on the daily observations of S&P500 index and U.S. dollar during the period from 1992 to 2002, found a significant strong positive relationship between the price movements of U.S. dollar and S&P500 index. Unfortunately Johnson and Soenen (2002) couldn't confirm any causalities between the changes in S&P500 and U.S. dollar.

Other articles, like Dimitrova (2005), the research used U.S. dollar British Pound exchange rate as measurement of currency and compare this with the U.S. stock market. The author concluded a positive relation between U.S. dollar and stock market during the period from January 1990 to August 2004. Conversely, in the earlier research by Ajayi and Mougoue (1996) an opposite conclusion is conducted. Using a two variable VAR model on their data with daily observations, Ajayi and Mougoue (1996) found an inverse relation between stock price and U.S dollar. Granger et al (2000), which did a research using similar method for the relationship between stock market and currency exchange rates for seven Asian countries during the Asian crisis of 1997, found a strong positive relation between currency exchange rates and stock market. The positive linkage between stock market and currency exchange rates is also confirmed by Bahmani-Oskooee and Sohrabian (1992), they showed in their research a positive link between S&P 500 Index and U.S. Dollar.

Now consider all the researches discussed in this subsection, we would expect an inverse relation between U.S. Dollar and stock price during the period of crisis based on the economic considerations. For stronger dollar price will not be beneficial for the domestic export and economy recovery, which is important during the period of crisis. This expectation is also consistent with the conclusion of studies using more recent data, such as Darwin (2009), Lien (2009), Pethokoukis (2009), and Condor (2010). In the period before the crisis, a positive relation between U.S Dollar and stock price is suggested. This expectation is supported by Dimitrova (2005), Johnson and Soenen (2002), Granger et al (2000), and Bahmani-Oskooee and Sohrabian (1992) which analyzed earlier data.

## 2.2 The U.S. Dollar vs. the oil price

Conventional knowledge about the relation between U.S. Dollar and oil price, based on empirical observations, is that oil can be used as hedge position for the U.S. Dollar value. A trading strategy, long in oil and short in U.S. Dollar, is often used by different traders. The academic researchers also support this relation. Yousefi and Wirjanto (2004) found a direct negative effect of U.S. dollar changes on oil prices. Sadorsky (2000) indicated that an increase in exchange rates would lower oil prices. More recent studies such as Lizardo and Mollick (2010) suggest that price of crude oil is a key factor in explaining changes in the value of U.S. dollar. Benassy-Querre et al (2007) found a positive relationship with a causality that ran from oil to U.S. dollar. However, there are also researches such as Huang and Tseng (2010) which demonstrated that oil price movements are indirectly caused by U.S. dollar price changes through the oil supply.

Based on economic relation between U.S. Dollar and oil prices, we would expect a reverse relation between these two assets in both periods before and during crisis. For the oil price is traded in U.S. Dollar, a same amount of oil should worth more U.S. Dollar when U.S. Dollar become cheaper against other currencies. This expectation is consistent with the findings of Sadorsky (2000) and Yousefi and Wirjanto (2004).

## 2.3 The U.S. Dollar vs. the gold prices

The conventional knowledge about the relation between U.S. Dollar and gold are based on their inverse correlation. So this means that the U.S. Dollar could be used as hedge for the gold price. However Marzo and Zagaglia (2010) found a positive causal relation during the period from 13th October 2004 to 5th March 2010. Further the study found that the movements of gold price during the crisis period are more stable than those of U.S. Dollar.

Based on economic considerations, we may expect a higher gold price during the period of crisis when the U.S. Dollar is less expensive. For this expectation we have similar arguments as the relation between oil price and U.S. Dollar. For gold price is traded in U.S. Dollar, same amount of gold should worth more U.S. Dollar when U.S. Dollar become cheaper against other currencies. Further a higher U.S. Dollar price is bad for national export, which will slow down the economy growth. Gold as alternative investment will be preferred by investors.

# 3 Data

In this research we use four assets to implement the comovement analysis, the related assets are S&P 500 index, Brent crude oil 1 month futures, gold 1 month futures and USD index. All the assets are traded in New York and we take their closing price to implement the analysis. One thing we have to point out here is that USD index [1] is not a conventional index. This index demonstrates the value of USD, for the value of this index is based on different exchange rates against USD.

Our data consist of daily observations of four selected assets within the period from 1st January 2005 to 9th April 2012. For each asset we use the daily last

[1] The US Dollar Index, as explained by ICE futures, was created as a way to provide external bilateral trade weighted average of the US dollar as it freely floated against global currencies. The formula for the calculation of the US dollar Index is 50.14348112 multiplied by the product of all com-ponents raised to an exponent equal to the % weighting ((EURUSD ^ –0.576) × (JPY ^ –0.136) × (GBP ^ –0.119) × (CAN ^ –0.091) × (SEK ^ –0.042) × (CHF^ –0.036)). All currencies are expressed in units of currency per U.S. dollar (ICE, 2009), and currency weights are Euro(57.6%), Canadian dollar (9.1%), Japanese yen (13.6%), Swedish krona (4.2%), British pound (11.9%), and Swiss franc (3.6%).

price at their closing time in New York. To compare comovements among assets before and during the crisis, we use the bankruptcy of the Lehman Brother Inc. as the starting point for the recent financial crisis which takes place at 19th September 2008. So our pre crisis data incorporate the daily observations of four assets during the period from 1st January 2005 to 18th September 2008 and the crisis period starts 19th September 2008 to 9th April 2012.

One of important issues related to the comovement analysis is the observation time of data. In case the considered data are not observed at same time, the results of the analysis may be not accurate and the analysis may have spurious results. Fortunately, the data considered in our analysis only have small differences in their closing time. For the commodities, the Brent crude oil 1 month futures prices are taken at 17:20 New York (NY) time and the gold futures at 16:10. Further the currency exchange rates are observed at 16:10 and S&P 500 index is taken at 16:15 NY Time. To have reliable resource for our data, we obtain all our data from the Bloomberg platform.

Furthermore, to be able to compare different kinds of assets which have unequal numbers of observations, we only use the data in which all assets are traded. In this way, our data in the period before crisis consist of the daily last prices from 1st January 2005 to 18th September 2008, which account 929 observations for each asset. The period during crisis incorporate 895 observations starting 19th September 2008 to 9th April 2012.

In the research we mainly focus on the comovements between the returns of assets. The returns are defined as percentage changes between the closing prices of the day with day before and can be calculated by equation 1.

$$\mathrm{return_t} = \frac{\mathrm{price_t} - \mathrm{price_{t-1}}}{\mathrm{price_t}} * 100\% \qquad (1)$$

The data section is further divided into three subsections. In these subsections we discuss the results of basic data analysis related to the comovements.

## 3.1 Basic Statistics

In this subsection we provide some basic statistics of data considered in this research. The return series of four assets are shown below in figures 1, 2, 3 and 4. The vertical line in each graph gives the bankruptcy of Lehman Brother Inc.

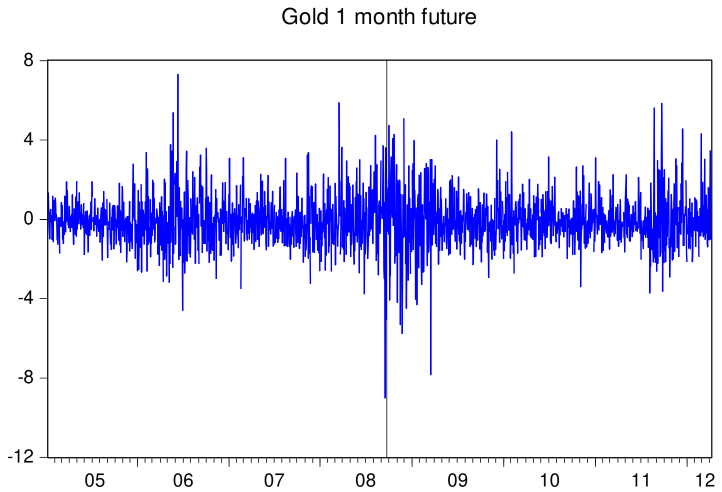


Figure 1: Gold 1 month future returns

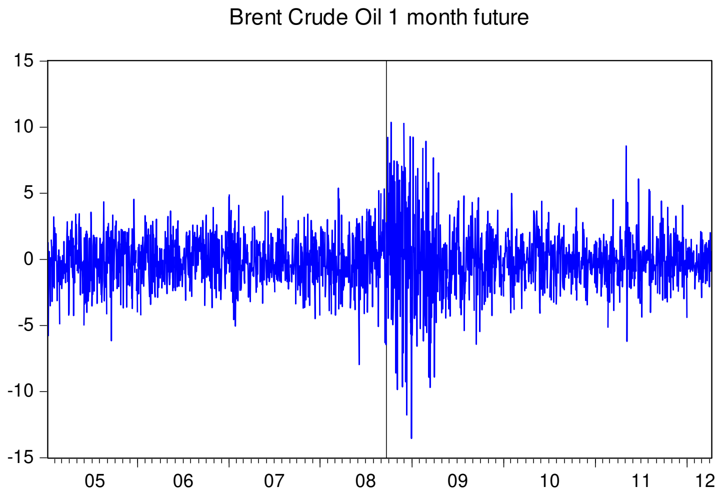


Figure 2: Brent Crude Oil 1 month future returns

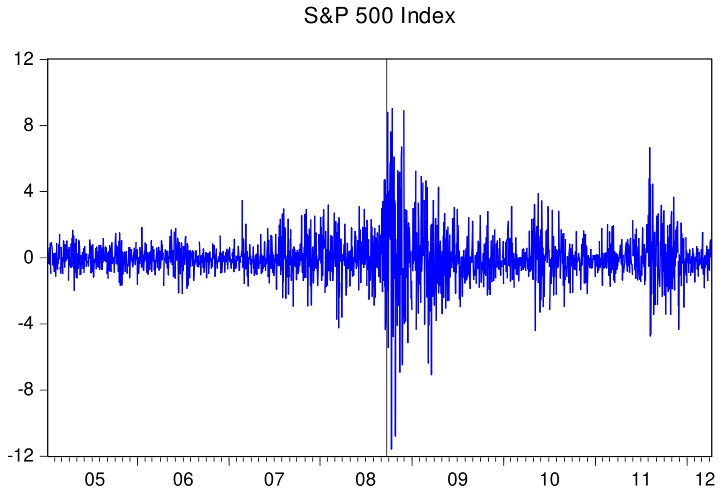


Figure 3: S&P 500 Index returns

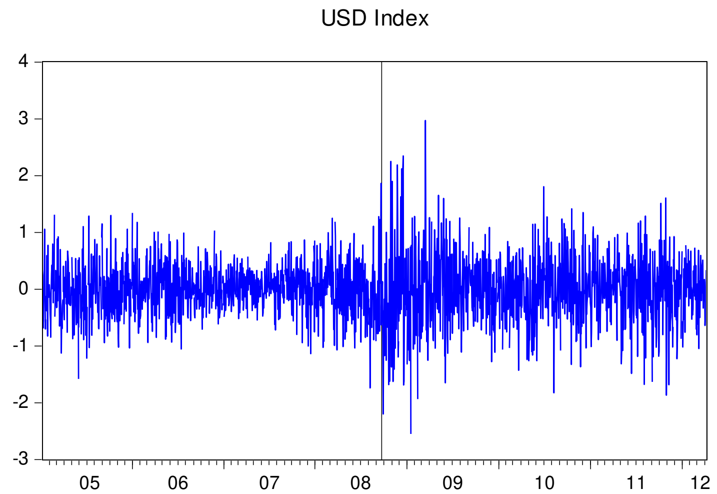


Figure 4: USD Index returns

Regarding the figures, we observe increasing fluctuations after the bankruptcy of Lehman Brother Inc. Furthermore, extreme returns are observed in all series during the crisis. Since the return series are always stationary, it's interesting to look at the basic statistics which are shown below in table 1, 2, 3 and 4.

| | Before crisis | During the crisis |
|---|---|---|
| Mean | -0.083 | -0.082 |
| Standard Deviation | 1.284 | 1.371 |
| Skewness | 0.191 | 0.128 |
| Kurtosis | 7.743 | 6.069 |
| Jarque-Bera | 876.496 | 353.278 |
| Probability | 0.000 | 0.000 |
| Observations | 928 | 895 |

Table 1: Basic statistic of gold 1 month futures returns

| | Before crisis | During the crisis |
|---|---|---|
| Mean | -0.113 | -0.057 |
| Standard Deviation | 1.883 | 2.586 |
| Skewness | -0.108 | 0.030 |
| Kurtosis | 3.278 | 6.482 |
| Jarque-Bera | 4.805 | 451.892 |
| Probability | 0.090 | 0.000 |
| Observations | 928 | 895 |

Table 2: Basic statistic of Brent crude 1 month futures returns

| | Before crisis | During the crisis |
|---|---|---|
| Mean | -0.011 | -0.027 |
| Standard Deviation | 0.968 | 1.805 |
| Skewness | 0.225 | 0.029 |
| Kurtosis | 6.267 | 9.776 |
| Jarque-Bera | 421.057 | 1710.511 |
| Probability | 0.000 | 0.000 |
| Observations | 928 | 895 |

Table 3: Basic statistic of S&P 500 Index returns

| | Before crisis | During the crisis |
|---|---|---|
| Mean | 0.005 | -0.005 |
| Standard Deviation | 0.449 | 0.655 |
| Skewness | 0.002 | 0.078 |
| Kurtosis | 3.353 | 4.190 |
| Jarque-Bera | 4.818 | 53.669 |
| Probability | 0.090 | 0.000 |
| Observations | 928 | 895 |

Table 4: Basic statistic of USD Index returns

As shown in the tables, the mean of all assets returns are close to 0%. Further the standard deviations for all assets during the crisis are larger than before the crisis. These differences suggest a structural change due to the crisis. The skewness measures the asymmetry of the probability distribution of the return. A positive skewness indicates more extreme positive returns. In the tables, the skewness is increased during the crisis for gold futures, oil futures and USD Index and decreased for S&P500 Index. It indicates that gold futures, oil futures and USD Index are less riskier assets compared to S&P500 Index during the crisis. The kurtosis gives the peakness of the probability distribution. For the returns, a higher kurtosis indicates there are more large observations than expected under the normality. Hence a higher kurtosis means more extreme rerturns. Again, in the tables, for oil futures, USD Index and S&P500

Index the kurtosis are increased during the crisis. This is in accordance with the figures. There are more and larger fluctuations during the crisis. Further comparing the kurtosis and skewness of the data in the period before crisis with the data during the crisis, we observe only small changes in skewness, but for kurtosis the changes are larger. For oil futures, S&P500 Index, and USD Index, more extreme returns are observed during the period of crisis. Finally we also provide the results of the Jarque-Bera test to examine whether the returns are Gaussian distributed. According to the p-values reported in the tables, using significance level of 5%, only the returns of oil futures and USD Index before the crisis are Gaussian distributed.

Now summarizing the finding about the basic statistic of all assets, the returns of the assets are not Gaussian distributed and more positive returns are observed for oil futures, gold futures, and USD Index in the period during crisis. For S&P500 Index, more negative returns are observed during the period of crisis. Furthermore, all four assets have more extreme observations in the period during crisis. These features indicate the assets are much riskier during the crisis and S&P500 Index has more negative price movements than oil futures, gold futures and USD Index.

## 3.2 Correlations and cross-autocorrelations

In this section we will analyze the correlations and cross-autocorrelations of the data. These properties can be used as preliminary tools to define the comovements relations among different assets. The correlations can be used to examine contemporaneous relations and cross-autocorrelations to determine the dynamic relations among assets. In our analysis we found differences in correlations before and during the crisis. Since we are more focused on the dynamic comovements, we will not carry out any further researches for the contemporaneous comevements. Table 5 and 6 give the correlations of the returns among four assets in the periods before and during the crisis respectively. Further the significances of the correlations are examined by t test using significance level of 5% and the correlations, which are significantly equal to 0, are given by italic. The standard errors are given in the parenthesis.

| | RGOLD | ROIL | RSP500 | RUSD |
|---|---|---|---|---|
| RGOLD | | 0.38 (0.028) | *-0.06 (0.033)* | -0.48 (0.025) |
| ROIL | 0.38 (0.028) | | *-0.05 (0.0328)* | -0.26 (0.031) |
| RSP500 | *-0.06 (0.033)* | *-0.05 (0.028)* | | 0.08 (0.033) |
| RUSD | -0.48 (0.025) | -0.26 (0.031) | 0.08 (0.033) | |

Table 5: Correlations of returns of four assets before crisis. RGOLD, ROIL RSP500 and RUSD represent the returns of gold futures, oil futures, S&P500 Index and USD Index. The standard errors are given in the parenthesis.

| | RGOLD | ROIL | RSP500 | RUSD |
|---|---|---|---|---|
| RGOLD | | 0.40 (0.030) | *0.06 (0.033)* | -0.28 (0.031) |
| ROIL | 0.40 (0.030) | | 0.48 (0.026) | -0.38 (0.029) |
| RSP500 | *0.06 (0.033)* | 0.48 (0.026) | | -0.47 (0.026) |
| RUSD | -0.28 (0.031) | -0.38 (0.029) | -0.47 (0.026) | |

Table 6: Correlations of returns of four assets during crisis. RGOLD, ROIL RSP500 and RUSD represent the returns of gold futures, oil futures, S&P500 Index and USD Index. The standard errors are given in the parenthesis.

Concerning table 5 and 6, for the most of cases t tests indicate zero correlations. These features indicate that there are significant contemporaneous comovements in returns of the corresponding assets. Concerning the negative correlations between gold futures and USD Index, inverse relations are suggested between gold futures and USD Index. This is in accordance with our expectation. For the oil futures and USD Index, the correlations are also negative, which is also consistent with the conclusions of earlier studies, such as Sadorsky (2000). The correlations between S&P500 Index and USD Index become negative in the period during the crisis. This feature is in accordance with our expectation. Hence the higher U.S. Dollar will slow down the economy recovery and lower the stock prices. Further, comparing table 5 and 6, the assets are more correlated during the crisis which means the assets are more dependent on each others. This may be beneficial for investors. For a highly correlated market is more convenient for investors to reduce their investment risks.

The main focus of this research lies in dynamic comovements among assets. Therefore we introduce the cross-autocorrelations of the returns to carry out the basic analysis for the dynamic comovements. The 1 lag cross-autocorrelations of the returns are given in table 7 and 8. Similar to the cross-correlations, the significances of the cross-autocorrelations are examined using t test and the standard errors are shown in the parenthesis.

| | RGOLD(-1) | ROIL(-1) | RSP500(-1) | RUSD(-1) |
|---|---|---|---|---|
| GOLD | *0.06 (0.033)* | 0.08 (0.033) | 0.08 (0.033) | -0.11 (0.033) |
| OIL | *-0.04 (0.033)* | *-0.06 (0.033)* | *-0.06 (0.033)* | *-0.03 (0.033)* |
| SP500 | *-0.04 (0.033)* | *-0.06 (0.033)* | *-0.06 (0.033)* | *-0.03 (0.033)* |
| USD | *-0.01 (0.033)* | *-0.05 (0.033)* | *-0.05 (0.033)* | *0.00 (0.033)* |

Table 7: 1 lag Cross Autocorrelation of returns of four assets before crisis. RGOLD, ROIL RSP500 and RUSD represent the returns of gold futures, oil futures, S&P500 Index and USD Index. (-1) indicates 1 lagged variables. The standard errors are given in the parenthesis.

| | RGOLD(-1) | ROIL(-1) | RSP500(-1) | RUSD(-1) |
|---|---|---|---|---|
| RGOLD | *0.02 (0.033)* | *0.00 (0.033)* | *0.00 (0.033)* | -0.11 (0.033) |
| ROIL | *0.03 (0.033)* | *-0.07 (0.033)* | *-0.07 (0.033)* | *-0.04 (0.033)* |
| RSP500 | *0.03 (0.033)* | *-0.07 (0.033)* | *-0.07 (0.033)* | *-0.04 (0.033)* |
| RUSD | *0.00 (0.033)* | *0.03 (0.033)* | *0.03 (0.033)* | *0.02 (0.033)* |

Table 8: 1 lag Cross Autocorrelation of returns of four assets during the crisis. RGOLD, ROIL RSP500 and RUSD represent the returns of gold futures, oil futures, S&P500 Index and USD Index. (-1) indicates 1 lagged variables. The standard errors are given in the parenthesis.

Regarding table 7, and 8, t tests indicate few cross-autocorrelations for both periods before and during the crisis. It seems that gold futures are driven by the oil futures, S&P500 Index, and USD Index in the period before crisis. During the crisis, gold futures are no more affected by the oil futures and S&P500 Index, but USD index still cause changes in gold futures price movements. Because cross-autocorrelation is a basic method to examine the dynamic relations among assets, some joint relations may not be indicated. Therefore we should do more investigations in the joint causalities among assets.

## 3.3 Exceedance correlations

In figures 1, 2, 3, and 4 we have observed large shocks in the returns of all assets at the beginning of the crisis. These shocks may affect the price movements of other assets. Therefore, except the ordinary cross-correlations and cross- autocorrelations, we are also interested in the effects of these extreme observations on the assets price movements. Therefore we introduce exceedance correlations as preliminary tools to analyze the influences of extreme observations. The exceedance correlations are introduced by Ang and Chen (2002) and the exceedance correlations of assets returns x and y are defined in equation 2. Note the terms $h_1, h_2, k_1$ and $k_2$ in equation 2 are the scalars which give the acceptance range of the exceedance correlations.

$$\mathrm{Corr}(x_t, y_t | \, h_1 < x_t < h_2, k_1 < y_t < k_2) \quad (2)$$

To examine the asymmetric effects, we should test for both positive and negative extreme observations. For each asset x, we compute for both extreme positive and negative returns the correlations with asset y. To make it easier, we select the 5% highest and lowest returns of each asset as extreme observations. For the period before crisis, 47 observations are selected for each asset and 45 observations are chosen for the period during crisis.

For instance using gold future returns as x variable, we first calculate the correlations of the extreme positive returns of gold futures with the returns of other three assets. Then we calculate the correlations of the extreme negative returns of gold futures with the returns of other assets. The results of the exceedance correlations are shown below in table 9 and 10 for the period before crisis and 11 and 12 for the period during the crisis.

| | RGOLD | ROIL | RSP500 | RUSD |
|---|---|---|---|---|
| $RGOLD^+$ | 1.00 | 0.25 | 0.25 | -0.13 |
| $ROIL^+$ | 0.04 | 1.00 | 1.00 | -0.10 |
| $RSP500^+$ | 0.04 | 1.00 | 1.00 | -0.10 |
| $RUSD^+$ | -0.30 | -0.30 | -0.30 | 1.00 |

Table 9: Exceedance correlations of extreme positive returns in before crisis period. RGOLD, ROIL RSP500 and RUSD represent the returns of gold futures, oil futures, S&P500 Index and USD Index.

| | RGOLD | ROIL | RSP500 | RUSD |
|---|---|---|---|---|
| $RGOLD^-$ | 1.00 | 0.26 | 0.26 | -0.21 |
| $ROIL^-$ | 0.28 | 1.00 | 1.00 | -0.10 |
| $RSP500^-$ | 0.28 | 1.00 | 1.00 | -0.10 |
| $RUSD^-$ | -0.19 | -0.12 | -0.12 | 1.00 |

Table 10: Exceedance correlation of extreme negative returns in before crisis period. RGOLD, ROIL RSP500 and RUSD represent the returns of gold futures, oil futures, S&P500 Index and USD Index.

| | RGOLD | ROIL | RSP500 | RUSD |
|---|---|---|---|---|
| RGOLD+ | 1.00 | 0.25 | 0.25 | -0.17 |
| ROIL+ | -0.04 | 1.00 | 1.00 | -0.16 |
| RSP500+ | -0.04 | 1.00 | 1.00 | -0.16 |
| RUSD+ | -0.25 | -0.33 | -0.33 | 1.00 |

Table 11: Exceedance correlation of extreme positive returns during the crisis. RGOLD, ROIL RSP500 and RUSD represent the returns of gold futures, oil futures, S&P500 Index and USD Index.

| | RGOLD | ROIL | RSP500 | RUSD |
|---|---|---|---|---|
| RGOLD- | 1.00 | 0.20 | 0.20 | -0.12 |
| ROIL- | 0.19 | 1.00 | 1.00 | -0.23 |
| RSP500- | 0.19 | 1.00 | 1.00 | -0.23 |
| RUSD- | -0.06 | -0.15 | -0.15 | 1.00 |

Table 12: Exceedance correlation of extreme negative returns during the crisis. RGOLD, ROIL RSP500 and RUSD represent the returns of gold futures, oil futures, S&P500 Index and USD Index.

First, we compare table 9 and 10 with table 11 and 12 to examine whether there are differences in the exceedance correlations before and during the crisis. For both negative and positive returns, the exceedance correlations differ slightly from each others. Then, we compare the exceedance correlations in table 9 and 11 with table 10 and 12 to examine whether there are differences in the effect of extreme positive and negative observations on the assets. We only found small differences in the exceedance correlations of extreme positive and negative returns and these feature reject asymmetric effects of extreme observations. Furthermore, concerning four tables, we observe large exceedance correlations which suggest the significant effects of extreme observations on the assets price movements. Therefore the extreme observations should be considered as possible explanatory variables in our model to predict the assets price movements.

# 4 Methods

This section incorporates the descriptions of the methods implied in this research. This study adopts the traditional Granger causality test by Granger (1969) to examine the possible joint linear causality among four assets. A detailed description of the causality test is given in section 4.1. A shortage of this causality test is that the test only assumes linear relation between the related assets which might be improper for the financial markets. As advised by Samanta and Zadeh (2011) and Hamilton (1996, 2000), we introduce the nonlinear Granger causality test by Hiemstra and Jones (1994). The description of the nonlinear Granger causality test can be found in section 4.2. The nonlinear Granger test not only indicates the linear causal relations, it can also indicate the nonlinear causal relations.

In section 3.3 of the data analysis, large exceedance correlations are found. However the exceedance correlations only examine the contemporaneous effects of the extreme observations on assets price movements. We believe that the extreme observations may also have dynamic effects on assets price movements. To examine this effect, the Safe Haven Analysis by Ciner et al (2012) is introduced in this study. This method generally examines whether the extreme observations can be a contribution in prediction of the assets price movements. A more detailed description of this test is provided by section 4.3.

## 4.1 Multivariate linear Granger causality test

Granger (1969) approach to the question whether asset i causes asset j is to see how much of the changes in the current asset j can be explained by past values of asset j and then to see whether adding lagged values of asset i can improve the explanations. Implementing this test may prove whether the linear causal relations among assets exist in the financial markets. In section 3.2, we cannot find large cross-autocorrelations in the returns among assets. Therefore more attentions are paid to the joint causalities. To examine the joint causalities, we implement the multivariate linear Granger causality test using the interpretation of Hiemstra and Jones(1994).

Consider two groups of assets x and y, the multivariate Granger causality test examines whether group x causes group y. In this research, we focus on whether the three of four assets cause the changes in the remaining asset. To carry out the test, the vector auto regression (VAR) model in equation 3 is estimated using ordinary least square (OLS) method, where vector $\mathrm{R_t} = (\mathrm{RGOlD_t}, \mathrm{ROIL_t}, \mathrm{RSP500_t}, \mathrm{RUSD_t})$. Note that $\mathrm{B_i}$ is a 4x4 matrix and lag p=1 which is determined using AIC criteria.

$$\mathrm{R_t} = \mathrm{A} + \sum_{\mathrm{i}=1}^{\mathrm{p}} \mathrm{B_i}\mathrm{R_{t-i}} + \mathrm{E_t} \qquad (3)$$

Wtih $\mathrm{A} = \begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \alpha_3 \\ \alpha_4 \end{bmatrix}$, $\mathrm{B} = \begin{bmatrix} \beta_{11} & \cdots & \beta_{14} \\ \vdots & \ddots & \vdots \\ \beta_{41} & \cdots & \beta_{44} \end{bmatrix}$, and $\mathrm{E_t} = \left(\varepsilon_{\mathrm{OIL,t}}, \varepsilon_{\mathrm{GOLD,t}}, \varepsilon_{\mathrm{SP500,t}}, \varepsilon_{\mathrm{USD,t}}\right)'$

To examine whether each asset causes another, the Wald test is applied to prove whether the related coefficients in (3) is significant equal to 0. For instance, to examine whether the gold futures cause the movements in oil futures in the joint relation in (3), we apply the Wald test on coefficient $\beta_{12}$ to examine the null hypothesis $\beta_{12} = 0$. In case the Wald test rejects the null hypothesis, the multivariate linear Granger causality test indicates there is a causal relation from gold futures to oil futures. Hence the changes in the returns of gold futures may cause changes in the price movements of oil futures.

## 4.2 Multivariate nonlinear Granger causality test

Many researchers argued that the relations between assets are often nonlinear. Since the multivariate linear Granger causality test can't examine the nonlinear relations among assets, it is therefore sensible to introduce the multivariate nonlinear Granger causality tests which do examine the nonlinear causal relations among assets. For the test the approach in Hiemstra and Jones (1994) is adopted in this study to implement the multivariate nonlinear Granger causality test. A detailed explanation of the test is further provided in this section.

First consider equality 4, $R_{i,t}^{m}$ gives the return series of asset i with starting date t and length m. The nonlinear causality does not occur when the equality holds for given values m, Li and $Lj \geq 1$. Or in other words, if the $\Pr(\| R_{i,t}^{m} - R_{i,s}^{m} \| < e)$ does not depend on $\Pr(\| R_{j,t-Lj}^{Lj} - R_{j,s-Lj}^{Lj} \| < e)$, there will be no relation between asset i and j.

$$\Pr\left(\| R_{i,t}^{m} - R_{i,s}^{m} \| < e \middle| \| R_{i,t-Li}^{Li} - R_{i,s-Li}^{Li} \| < e, \| R_{j,t-Lj}^{Lj} - R_{j,s-Lj}^{Lj} \| < e\right) = \Pr(\| R_{i,t}^{m} - R_{i,s}^{m} \| < e | \| R_{i,t-Li}^{Li} - R_{i,s-Li}^{Li} \| < e) \quad (4)$$

In (4), Pr(.) denotes the probability function and $\|.\|$ gives the maximum norm. Equality 4 is quite complex, therefore we introduce some useful expressions to simplify the equality and these are listed below in equation 5, 6, 7, and 8. C1 in (5) gives the joint probability that the largest norm of the difference between the two return series of the asset i with same length m+Li, but different starting point and the largest norm of the difference between the two return series of the asset j with length Lj, but different starting point are both smaller than e. C2 in (6) denotes the joint probability that the largest norm of the difference between the two series of the asset i with length Li, but different starting point and the largest norm of the difference between the two return series of asset j with same length Lj, but different starting point, are smaller than e. C3 in (7) gives the probability that the largest norm of the difference between two return series of asset i with same length m+Li and different starting point is smaller than e. At last C4 in (8) gives the probability that the largest norm of the difference between two return series of asset j with same length Lj and different starting point is smaller than e.

$$C1(m + Li, Lj, e) = Pr\ (\| R_{i,t-Li}^{m+Li} - R_{i,s-Li}^{m+Li} \| < e, \| R_{j,t-Lj}^{Lj} - R_{j,s-Lj}^{Lj} \| < e) \quad (5)$$

$$C2(Li, Lj, e) = Pr\ (\| R_{i,t-Li}^{Li} - R_{i,s-Li}^{Li} \| < e, \| R_{j,t-Lj}^{Lj} - R_{j,s-Lj}^{Lj} \| < e) \quad (6)$$

$$C3(m + Li, e) = Pr\ (\| R_{i,t-Li}^{m+Li} - R_{i,s-Li}^{m+Li} \| < e) \quad (7)$$

$$C4(Li, e) = Pr\ (\| R_{i,t-Li}^{Li} - R_{i,s-Li}^{Li} \| < e) \quad (8)$$

Next we substitute these expressions in equality 5 and we obtain a less complicated equality as shown in equation 9.

$$\frac{C1(m+Li,Lj,e)}{C2(Li,Lj,e)} = \frac{C3(m+Li,e)}{C4(Li,e)} \quad (9)$$

The new problem is how to calculate the expressions of C1,C2,C3 and C4. This is possible when the realizations are available, or in other words the observed data are available. Again to simplify the expressions in (9), the useful indication function represented by equation 10, is introduced.

$$I(Z_1, Z_2, e) = \begin{cases} 1 & \text{if } \| Z_1 - Z_2 \| < 0 \\ 0 & \text{otherwise} \end{cases} \quad (10)$$

Then combine the indication function in (10) with the earlier expressions of C1,C2,C3 and C4, we get the new formulas as shown in equations 11, 12, 13, and 14.

$$C1(m + Li, Lj, e) = \frac{2}{n(n-1)} \sum \sum_{t<s} I(R_{i,t-Li}^{m+Li}, R_{i,s-Li}^{m+Li}, e) * I(R_{j,t-Lj}^{Lj}, R_{j,s-Lj}^{Lj}, e) \quad (11)$$

$$C2(Li, Lj, e) = \frac{2}{n(n-1)} \sum \sum_{t<s} I\left(R_{i,t-Li}^{Li}, R_{i,s-Li}^{Li}, e\right) * I(R_{j,t-Lj}^{Lj}, R_{j,s-Lj}^{Lj}, e) \quad (12)$$

$$C3(m + Li, e) = \frac{2}{n(n-1)} \sum \sum_{t<s} I\ (R_{i,t-Li}^{m+Li}, R_{i,s-Li}^{m+Li}, e) \quad (13)$$

$$C4(Li, e) = \frac{2}{n(n-1)} \sum \sum_{t<s} I\ (R_{i,t-Li}^{Li}, R_{i,s-Li}^{Li}, e) \quad (14)$$

For $t, s = \max(Li, Lj) + 1, \ldots, T - m + 1$, $n = T + 1 - m - \max(Li, Lj)$.

Now it’s clarified how to compute the left and the right hand side of equality 9, it’s time to move on to the test. The test statistic of the multivariate nonlinear Granger causality test can be calculated with equation 15.

$$\sqrt{n}\left(\frac{C1(m+Li,Lj,e)}{C2(Li,Lj,e)}-\frac{C3(m+Li,e)}{C4(Li,e)}\right)\sim N\left(0,\sigma^2(m,Li,Lj,e)\right) \tag{15}$$

The new question is how to calculate the variance of the test statistic in 15, for $\sigma^2(m, Li, Lj, e)$ is still unknown. For calculation of the variance, Hiemstra and Jones (1994) have added a very detailed and explicit description in their appendix. In this study a similar description is incorporated. First some useful conditional probabilities are introduced, which are shown in equations 16, 17, 18, and 19. The ~ signs in the equations denote random variables.

$$h1_{C1}(m+Li,Lj,e)=Pr\left(\| R^{m+Li}_{i,t-Li}-\tilde{R}^{m+Li}_{i,s-Li}\|<e, \| R^{Lj}_{j,t-Lj}-\tilde{R}^{Lj}_{j,s-Lj}\|<e\right) \tag{16}$$

$$h1_{C2}(Li,Lj,e)=Pr\left(\| R^{Li}_{i,t-Li}-\tilde{R}^{Li}_{i,s-Li}\|<e, \| R^{Lj}_{j,t-Lj}-\tilde{R}^{Lj}_{j,s-Lj}\|<e\right) \tag{17}$$

$$h1_{C3}(m+Li,e)=Pr\left(\| R^{m+Li}_{i,t-Li}-\tilde{R}^{m+Li}_{i,s-Li}\|<e\right) \tag{18}$$

$$h1_{C4}(Li,e)=Pr\left(\| R^{Li}_{i,t-Li}-\hat{R}^{Li}_{i,s-Li}\|<e\right) \tag{19}$$

Using the delta method by Serfling (1980) under assumption that the underlying series are strictly stationary, the variances of the test statistics as equation 20 are conducted.

$$\sigma^2(m,Li,Lj,e)=d\Sigma d' \tag{20}$$

According to Denker and Keller (1983), the expressions 21 and 22 are consistent estimators for the d and $\Sigma$ in equality 20. Note that $\Sigma_{p,q}$ denotes the p-th row and q-th column element of $\Sigma$.

$$d=\left[\frac{1}{C2(Li,Lj,e)},-\frac{C1(m+Li,Lj,e)}{C2^2(Li,Lj,e)},-\frac{1}{C4(Li,e)},\frac{C3(m+Li,e)}{C4^2(Li,e)}\right] \tag{21}$$

$$\Sigma_{p,q}=4*\sum_{k=1}^{K(n)} w_k\left[\frac{1}{2(n-k+1)}\sum_t\left(A_{p,t}*A_{q,t-k+1}+A_{p,t-k+1}*A_{q,t}\right)\right] \tag{22}$$

Where $t=\max(Li,Lj)+k,\dots,T-m+1$, $n=T+1-m-\max(Li,Lj)$,

$K(n)=(int)n^{1/4}$ and $w_k=\begin{cases}1, \text{if } k=1\\ 2\left(1-\left[\frac{k-1}{K(n)}\right]\right), \text{ otherwise}\end{cases}$

Now the only unknown items in 22 are the joint probabilities $A_{p,t}$. These can be computed using following equations.

$$A_{1,t}=\frac{1}{n-1}\left(\sum_{s\neq t} I\left(R^{m+Li}_{i,t-Li},R^{m+Li}_{i,s-Li},e\right)*I\left(R^{Lj}_{j,t-Lj},R^{Lj}_{j,s-Lj},e\right)\right)-C1(m+Li,Lj,e) \tag{23}$$

$$A_{2,t} = \frac{1}{n-1}\left(\sum_{s\neq t} I\left(R^{Li}_{i,t-Li}, R^{Li}_{i,s-Li}, e\right) * I\left(R^{Lj}_{j,t-Lj}, R^{Lj}_{j,s-Lj}, e\right)\right) - C2(Li, Lj, e)) \quad (24)$$

$$A_{3,t} = \frac{1}{n-1}\left(\sum_{s\neq t} I\left(R^{m+Li}_{i,t-Li}, R^{m+Li}_{i,s-Li}, e\right)\right) - C3(m + Li, e) \quad (25)$$

$$A_{4,t} = \frac{1}{n-1}\left(\sum_{s\neq t} I\left(R^{Li}_{i,t-Li}, R^{Li}_{i,s-Li}, e\right)\right) - C4(Li, e) \quad (26)$$

Where $t, s = \max(Li, Lj) + 1, \ldots, T - m - 1$

Using expressions in 23, 24, 25 and 26, the variances of the test statistics can be calculated and the test can be implemented. For the parameters we fix m=1 and e=1.5 and put restriction Li=Lj, for these values and restrictions are suggested by Hiemstra and Jones(1994). Further for the results of the multivariate nonlinear Granger causality test, the choice of parameters m, Li, Lj and e are of importance. Therefore, this research further includes sensitivity tests using different values of Li and Lj. The sensitivity tests are computed with Li=Lj=1,2,3. The results of the nonlinear Granger test are represented in section 5.2.

## 4.3 Safe Haven Analysis

Ciner et al (2012) introduced a method to analyze whether a certain asset can be a hedge or safe haven for other asset using extreme observations. An asset is called a safe haven when it can be used to diversify risks on average. This aspect is interesting for the market participants either the academic researchers. For the Safe Haven Analysis is based on the extreme observations of the assets returns, it can further help us to create a better view about the relations between different assets. Therefore this method is adopted in this research. The Safe Haven Analysis is a quite simple test. For instance, consider asset i and j with their returns at time t, $r_{i,t}$ and $r_{j,t}$. The whole analysis is simply based on a single quartile regression model. A quartile regression model is a model which incorporates a quartile variable. The regression is shown in equation 27.

$$r_{i,t} = \alpha + \sum_{k=1}^{l} \beta_{0(i)} r_{i,t-k} + \sum_{k=1}^{m} \beta_{1(i)} r_{j,t-k} + \sum_{k=1}^{n} \beta_{2(i)} r_{j,t-k(q)} + \varepsilon_t \quad (27)$$

The term $r_{j,t(q)}$ accounts for asymmetries of negative (or positive) extreme shocks and it is included in order to focus on rising or falling markets. Therefore, this term incorporates the q% lower (or higher) quartile of the returns of asset j. If the value is larger (or smaller) than the q%, the $r_{j,t(q)}$ is equal to 0. This variable is also known as quartile variable. Since the value of q% may affect the results of Safe Haven Analysis, we compute a simple sensitivity test for q%. The examined values for q are 5%, 10% and 15%. The coefficients in (27) are further estimated using OLS method and the lags l, m and n are chosen using AIC criteria. Our main focus lies on $\beta_{2(i)}$. When the coefficients $\beta_{2(i)}$ are significant equal to zeros, it implies that the extreme negative or positive shocks of asset j have no effect on the future price movements of asset i.

# 5 Results

Section 5 incorporates the results of the tests introduced in section 4. The section is further divided into 4 subsections. As discussed in section 4.1 we applied multivariate linear Granger causality test on the returns of four assets. The tests indicate some causal associations among the assets. Comparing the results before and during the crisis, some differences are observed. More detailed descriptions of the test results can be found in section 5.1.

Section 5.2 provides the results of multivariate nonlinear Granger causality test. This test is introduced, because the linear Granger causality test only indicates the linear causality relation. Comparing the results the multivariate nonlinear Granger causality test with the results of the multivariate linear Granger causality test, extra causal relations are indicated in both periods before and during the crisis. While comparing the results of the multivariate nonlinear Granger causality test for the period before and during the crisis, the nonlinear causal relation between USD Index and S&P500 Index disappeared when the crisis took place.

In section 5.3 the results of the Safe Haven Analysis is discussed. The analysis suggests that the extreme bad returns in the crisis period have more effect on the assets price movements than the extreme positive returns. Further, comparing the results for the periods before and during the crisis, the tests indicate that the extreme observations have significant more effect on the assets price movements during the crisis.

Finally using all the finding in subsection 5.1, 5.2, and 5.3, the new models can be constructed. By comparing predictions of the new models with two benchmark models, the new models produce remarkable accurate predictions and these models are presented in the last subsection 5.4.

## 5.1 Multivariate linear Granger causality test

In section 4.1 we described the multivariate linear Granger causality test by Granger (1969). The test examines whether change of certain variable causes change in another variable. In this study the multivariate linear Granger causality test is used to examine the existence of the linear causal relations between the four assets, namely oil future, gold future, USD Index and SP500 Index. The data are further divided into the periods before and during crisis using the bankruptcy of Lehmann Brother Inc as starting point of the crisis. The test is applied on the returns of assets in both periods. To implement the tests, the 1lagged VAR model in (3) is estimated for both periods, the results of the estimations are shown in table A1 and A2 in Appendix.

Table A1 gives the estimation of 1 lagged VAR model with the pre crisis data. The log likelihood value is -4875.21 and the AIC criterion has value of 10.98. Consider the p value of the t test in the parenthesis, the coefficients estimations differ for the most cases significant from zero and these results indicate that the each asset may cause the price movements in other assets. Table A2 provides the results of the estimation of 1 lagged VAR model using the data during the crisis. The log likelihood value is -5781.73 and AIC criterion has value of 10.43. Again the coefficient estimations differ for the most cases significant from zero according to the t test. Comparing the results in table A1 and A2, we see that the coefficients are not close to each other. Further the sign are changed for some coefficients, such as the coefficient of RGOLD(-1) in the equation of ROIL. These features indicate relation changes among assets. Then the Wald test is computed to examine whether the certain coefficient equals to zero. The results of the Wald test for the data in the period before and during crisis are shown in table 13 and 14.

| | RGOLD | ROIL | RSP500 | RUSD |
|---|---|---|---|---|
| RGOLD(-1) | 0.919(0.338) | 0.239(0.625) | 0.812(0.367) | 0.06(0.807) |
| ROIL(-1) | 3.719(0.054) | 5.572(0.018) | 1.7(0.192) | 1.577(0.209) |
| RSP500(-1) | 5.85(0.016) | 13.112(0) | 17.96(0.00) | 25.652(0.00) |
| RUSD(-1) | 8.608(0.003) | 3.998(0.046) | 0.008(0.931) | 0.001(0.971) |

Table 13 : Test statistics with p value in parenthesis of multivariate linear Granger causality test using before crisis data. RGOLD, ROIL RSP500 and RUSD represent the returns of gold futures, oil futures, S&P500 Index and USD Index. (-1) indicates the 1 lagged variable.

| | RGOLD | ROIL | RSP500 | RUSD |
|---|---|---|---|---|
| RGOLD(-1) | 0.129(0.72) | 3.025(0.082) | 0.137(0.711) | 0.031(0.861) |
| ROIL(-1) | 4.077(0.043) | 30.07(0) | 4.895(0.027) | 1.366(0.242) |
| RSP500(-1) | 2.971(0.085) | 23.918(0) | 3.72(0.054) | 0.566(0.452) |
| RUSD(-1) | 5.857(0.016) | 0.143(0.705) | 0.599(0.439) | 0.492(0.483) |

Table 14 : Test statistics with p value in parenthesis of multivariate linear Granger causality test using data during the crisis. RGOLD, ROIL RSP500 and RUSD represent the returns of gold futures, oil futures, S&P500 Index and USD Index. (-1) indicates the 1 lagged variable

Table 13 gives the results of the linear Granger causality test using the before crisis data. In case the p values in parenthesis are smaller than 0.05, the Wald tests indicate the existence of the causal relations between the related assets. Regarding the p values in table 13, the test indicates 7 causal relations in the before crisis period. According to the test, the gold futures are Granger caused by S&P500 Index and USD Index. The oil futures are caused by oil futures self, S&P500 Index, and USD Index. S&P500 Index is only caused by S&P500 index self. Finally USD Index is only caused by S&P500 Index.

Table 14 shows the results of the multivariate linear Granger causality test using data during the crisis. Regarding the p values, only 5 causal relations are indicated. Comparing table 13 and 14, 4 causal associations are disappeared and there are 2 new causal relations indicated by the test in the period during crisis. This feature can be used as evidence of relation change among assets caused by the crisis. For the gold futures, its price movements still affected by the USD Index, but no more caused by S&P500 Index. It is further caused by oil futures. During the crisis the oil futures are caused by oil futures self and S&P500 Index, but not by USD Index. S&P500 Index is caused by oil future, but not by itself. The USD Index is not caused by any other assets during the crisis. It seems the USD Index is more independent during the crisis.

Now consider our expectations in section 2.1, we expected an inverse relation between USD Index and stock price during the crisis and a positive relation before the crisis. Unfortunately these expectations are not confirmed by the results of the causality test. According to the table 13, there is an inverse causal relation run from stock price to USD Index, but not verse versa. In the period during crisis, the multivariate linear Granger causality test cannot indicate any causal relations between gold futures and USD Index. In section 2.2 we suggested a reverse relation between oil and U.S. Dollar. The test results in table 13 show a reverse causal relation from USD Index to oil futures in the period before crisis. Therefore the results are consistent with our suggestion in section 2.2. But during the crisis, the Granger test in table 14 cannot find any causal relations between U.S. Index and oil futures which is not in accordance with our expectation. For the relation between U.S. Index and gold futures, a reverse relation is expected. The results of the test confirm our expectation. Consider the test results in table 13 and 14, reverse causal relations are indicated by the test from USD Index to gold futures in both periods before and during crisis.

## 5.2 Multivariate nonlinear Granger causality test

As discussed in section 4.2, the multivariate linear Granger causality test has shortage that the test only indicates the linear causality. To cover this shortage the multivariate nonlinear Granger causality test by Hiemstra and Jones (1994) is introduced. This test not only indicates the linear causalities but also the nonlinear causal relations among assets. Further, as described in section 4.2, the first step to compute the multivariate nonlinear Granger causality test, is to determine the parameters. The required parameters are Li, Lj, m, and e. We further follow the suggestions of Hiemstra and Jones (1994) for parameters and fix m at 1 and e at 1.5 and put restriction Li=Lj. Then we compute a sensitivity analysis by varying Li, and Lj between 1, 2, and 3. Table 15 and 16 show the test results with Li=Lj=1. Table A3 and A4 in Appendix give the test results with Li=Lj=2, and table A5 and A6 in Appendix provide the test results with Li=Lj=3.

| | RGOLD | ROIL | RSP500 | RUSD |
|---|---|---|---|---|
| RGOLD | NaN | 0.115(0.411) | -1.422(0.213) | -0.869(0.765) |
| ROIL | 0.294(0.298) | NaN | 0.377(0.352) | -0.668(0.015) |
| RSP500 | 0.15(0.016) | 0.115(0.008) | NaN | 0.302(0.024) |
| RUSD | 0.928(0.020) | 0.558(0.013) | 1.181(0.005) | NaN |

Table 15： Test statistics with p value in parenthesis of Nonlinear Granger causality test using before crisis data with parameter Li=Lj=1, m=1, and e=1.5. RGOLD, ROIL RSP500 and RUSD represent the returns of gold futures, oil futures, S&P500 Index and USD Index.

| | RGOLD | ROIL | RSP500 | RUSD |
|---|---|---|---|---|
| RGOLD | NaN | -0.276(0.132) | -0.126(0.453) | -0.511(0.314) |
| ROIL | -0.087(0.009) | NaN | -0.114(0.001) | -0.153(0.015) |
| RSP500 | -0.116(0.363) | -0.276(0.000) | NaN | -0.207(0.186) |
| RUSD | -0.268(0.020) | -0.551(0.426) | -0.268(0.223) | NaN |

Table 16： Test statistics with p value in parenthesis of Nonlinear Granger causality test using data during the crisis with parameter Li=Lj=1, m=1, and e=1.5. RGOLD, ROIL RSP500 and RUSD represent the returns of gold futures, oil futures, S&P500 Index and USD Index.

Concerning the results of the test, we first compare the results with different values of parameters Li and Lj. Concerning test results in table 15, A3 and A5 for the before crisis period, indeed some differences in the p values are observed, but the differences are not very large. Then we focus on the results in table 16, A4, and A6 for the period during crisis, again we can’t find large differences in p values. Since the parameters Li and Lj don’t cause large differences in the test results, the test results in table 15 and 16 with parameters Li=Lj=1, m=1, and e=1.5 are used to carry out the analysis. Note that the nonlinear Granger causality test indicates nonlinear causal relation when the p value is smaller than 0.025. Concerning table 15, the nonlinear Granger causality test indicates for most cases nonlinear causal relations in the period before crisis. Comparing the test results of multivariate nonlinear Granger causality test in table 15 with the results of linear Granger causality test in table 13 for the period before crisis, two new (nonlinear) causal associations are found by the multivariate nonlinear Granger causality test. The two new nonlinear relations in the period during crisis are the nonlinear causal relations between USD Index and oil futures and between S&P500 Index and USD Index. Now focusing on the results in table 16 for the period during crisis, several nonlinear causalities are indicated by the test. Comparing the findings of the multivariate nonlinear Granger causality test with the linear Granger causality test in table 14, the new nonlinear causal relation between USD Index and oil futures is found by the test in the period during crisis.

Further we compare the results in table 15 with table 16 to find the changes of the causal relations among assets caused by the crisis. Just like the linear Granger causality test, some causal relations are disappeared and new causalities are indicated during the period of crisis. During the crisis USD Index no more causes change in S&P500 Index. But oil futures still affect the price movements of USD Index.

## 5.3 Safe Haven Analysis

Ciner et al (2012) introduced a method called Safe Haven Analysis to analyze whether the extreme shocks of one asset can cause the price movements of another asset. The description of this method is given in section 4.3. In this section we provide and discuss the results of the Safe Haven Analysis. The Safe Haven Analysis is based on the coefficients of the quartile variables, which are the variables containing the upper or lower q% quartile observations of certain asset. The selection of level q is therefore of importance. To verify the effect of q on the test results, a sensitivity analysis on the level of q is also included in this section. The sensitivity analysis is done by computing the tests with different levels of q. The values used for q to carry out the sensitivity test are 5%, 15% and 30% lower and upper quartiles.

The test results of 5% lower and upper quartiles using data in the period before crisis are shown in table A7 and A8. For the period during the crisis the corresponding test results of 5% lower and upper quartiles are given in table A9 and A10. Respectively the test results with 15% lower and upper quartiles are shown in table A11 and A12 for using before crisis data and the results using data in the period during the crisis are given in table A13 and A14. Table A15 and A16 contain the test results with 30% lower and upper quartiles using before crisis data and the results using data in the period during the crisis are given in table A17 and A18. Each table provides the number of lag used for the quartile variable which is selected based on AIC criteria, the coefficients estimations, the t-statistics, and corresponding p values of the quartile variables. The tables also contain the results of the Wald tests which are shown in the last two columns of each table. Note that the Wald test indicates existence of the effect of the extreme shocks on the assets price movements when the p value of the Wald test is smaller than 0.05.

Furthermore, results of the Wald tests are summarized in simpler tables. These tables only contain the test statistics and p values of the Wald test. The test results using before crisis data and 5% lower and upper quartiles are given in table 17 and 18. The test results based on the data during the period of crisis are shown in table 19 and 20. For the test with 15% lower and upper quartiles, the summaries of the Wald test can be found in table A19, A20, A21, and A22 in the Appendix. Respectively tables A23, A24, A25, and A26 contain the test results with 30% lower and upper quartiles.

Comparing the results using different values for q, the effect of the level of q cannot be defined based on the results of the tests. We can't find any proof that the test using larger or smaller quartile will affect the results in a certain way. Since our main interest lays in the effect of extreme observations on the price movements of assets, the smallest quartile (5%) is used to carry out the analysis.

Regarding table 17 and 18, the test indicates no effect of extreme observations on the assets price movements in the period before crisis for both positive and negative shocks. While focusing on the results in table 19 and 20, during the period of crisis, for some cases the assets price movements are affected by the shocks. Concerning table 19, for the negative shocks during the crisis, the extreme bad returns in USD Index have effect on the other three assets. Consider table 20, the positive shocks of gold futures have effect on the USD Index. Now summarizing the finding in tables 17, 18, 19, and 20, the tests indicate no effect of the extreme shocks on the assets price movements in the period before the crisis. This relation changed in the period during the crisis. For the negative shocks of USD Index, the test indicates these shocks have influences on the price movements of gold futures, oil futures, and S&P500 Index during the crisis. Therefore the negative shocks of USD Index should be incorporated in the models for predicting the price movements of these three assets. Further the tests indicate that the positive shocks of gold futures have significant influences on the USD Index price movements. Therefore the positive shocks of gold future will be one of explanatory variables in the model for predicting the price movements of USD Index.

| | RGOLD | ROIL | RSP500 | RUSD |
|---|---|---|---|---|
| RGOLD | NaN(NaN) | 1.885(0.17) | 1.885(0.17) | 0.56(0.454) |
| ROIL | 0.083(0.773) | NaN(NaN) | 0.574(0.449) | 1.459(0.227) |
| RSP500 | 0.083(0.773) | 0.574(0.449) | NaN(NaN) | 1.459(0.227) |
| RUSD | 0.483(0.487) | 0.024(0.877) | 0.024(0.877) | NaN(NaN) |

Table 17: Test statistics with p value in parenthesis of Safe Haven Analysis for before crisis period using 5% lower quartile observations. RGOLD, ROIL RSP500 and RUSD represent the returns of gold futures, oil futures, S&P500 Index and USD Index. The column gives the asset i and rows gives the asset j in equation 27.

| | RGOLD | ROIL | RSP500 | RUSD |
|---|---|---|---|---|
| RGOLD | NaN(NaN) | 0.099(0.753) | 0.099(0.753) | 1.622(0.203) |
| ROIL | 0.533(0.465) | NaN(NaN) | 0.255(0.614) | 1.578(0.209) |
| RSP500 | 0.533(0.465) | 0.255(0.614) | NaN(NaN) | 1.578(0.209) |
| RUSD | 0.058(0.81) | 1.062(0.303) | 1.062(0.303) | NaN(NaN) |

Table 18: Test statistics with p value in parenthesis of Safe Haven Analysis for before crisis period using 5% upper quartile observations. RGOLD, ROIL RSP500 and RUSD represent the returns gold futures, oil futures, S&P500 Index and USD Index. The column gives the asset i and rows gives the asset j in equation 27.

| | RGOLD | ROIL | RSP500 | RUSD |
|---|---|---|---|---|
| RGOLD | NaN(NaN) | 0.001(0.969) | 0.001(0.969) | 0.449(0.503) |
| ROIL | 0.000(1.000) | NaN(NaN) | 0.000(1.000) | 0.000(1.000) |
| RSP500 | 0.000(1.000) | 0.000(1.000) | NaN(NaN) | 0.000(1.000) |
| RUSD | 8.521(0.004) | 24.783(0.000) | 24.783(0.000) | NaN(NaN) |

Table 19: Test statistics with p value in parenthesis of Safe Haven Analysis for after crisis period using 5% lower quartile observations. RGOLD, ROIL RSP500 and RUSD represent the returns of gold futures, oil futures, S&P500 Index and USD Index. The column gives the asset i and rows gives the asset j in equation 27.

| | RGOLD | ROIL | RSP500 | RUSD |
|---|---|---|---|---|
| RGOLD | NaN(NaN) | 0.206(0.65) | 0.206(0.65) | 7.64(0.006) |
| ROIL | 0.08(0.777) | NaN(NaN) | 0.218(0.641) | 1.823(0.177) |
| RSP500 | 1.9(0.168) | 0.218(0.641) | NaN(NaN) | 1.823(0.177) |
| RUSD | 0.274(0.6) | 0.001(0.981) | 0.001(0.981) | NaN(NaN) |

Table 20: Test statistics with p value in parenthesis of Safe Haven Analysis for after crisis period using 5% upper quartile observations. RGOLD, ROIL RSP500 and RUSD represent the returns of gold futures, oil futures, S&P500 Index and USD Index. The column gives the asset i and rows gives the asset j in equation 27.

## 5.4 Model

In previous sections, some features of the comovement relations among the four assets are analyzed. This section presents our model which is based on the findings of previous results. First we give a short summary of the earlier analysis for the comovement relations in the period during the crisis. Then the predictions are made for the new model and compared with two benchmark models using different measurements.

In this research, the three advanced methods, the multivariate linear Granger causality test, the multivariate nonlinear Granger causality test and the Safe Haven Analysis are used to analyze the comovements relations among assets during the crisis. The data consist of the daily returns of 1 month gold futures, 1 month oil futures, S&P500 Index, and USD Index through the period from 1st January 2005 to 9th April 2012. Further we use the bankruptcy of the Lehmann Brother Inc. at 19th September 2008 as the starting point of the current financial crisis. The first applied method is the multivariate linear Granger causality test to examine the linear causal relations among assets. As result the test indicates that oil futures and USD Index could explanatory variables for the gold futures during the crisis. For the oil futures, the test results show that the oil futures and the S&P500 Index can be used as explanatory variables. For the S&P500 Index, the oil futures are indicated as explanatory variables. For the USD Index, the test cannot find explanatory variables. Then the multivariate nonlinear Granger causality test is implemented to cover the shortage that multivariate linear Granger causality test only indicates linear causal associations. Compared to the results of the multivariate linear Granger causality test, the multivariate nonlinear causality test indicates one new nonlinear causal relation in the period during the crisis. According to the test, USD Index can be caused by USD Index self in a nonlinear way. Our third, also the last method is the Safe Have Analysis. This test is incorporated to examine whether the extreme observations of one asset can be explanatory variables for other assets. According to the test, 5% lower quartile observations of USD Index can be explanatory variable for gold futures, oil futures and S&P500 Index. Further 5% upper quartile observations of gold futures can be explanatory variable for USD Index.

One problem for constructing the model is the nonlinear causal relations in USD Index. For the multivariate nonlinear Granger causality test cannot provide any information about the form of the nonlinear relation. Therefore the nonlinear relation is not incorporated in our model. Then our model, hereafter called model (1), for gold futures is shown in equation 28. For the oil futures, the S&P500 Index, and the USD Index, the corresponding models are given in equations 29, 30, and 31. Note that $\mathrm{RGOLD_t}$, $\mathrm{ROIL_t}$, $\mathrm{RSP500_t}$, and $\mathrm{RUSD_t}$ denote the returns at time t of gold futures, oil futures, S&P500 Index, and

USD Index respectively. Further $\mathrm{RUSDl}_{(5\%),t}$ denote the lower 5% quartile observations of USD Index at time t and $\mathrm{RGOLDh}_{(5\%),t}$ denote upper 5% quartile observations of gold futures at time t.

$$\mathrm{RGOLD}_t = \alpha_0 + \alpha_1 * \mathrm{ROIL}_{t-1} + \alpha_2 * \mathrm{RUSD}_{t-1} + \alpha_3 * \mathrm{RUSDl}_{(5\%),t} + \varepsilon_{\mathrm{gold},t} \quad (28)$$

$$\mathrm{ROIL}_t = \beta_0 + \beta_1 * \mathrm{ROIL}_{t-1} + \beta_2 * \mathrm{RSP500}_{t-1} + \beta_3 * \mathrm{RUSDl}_{(5\%),t} + \varepsilon_{\mathrm{oil},t} \quad (29)$$

$$\mathrm{RSP500}_t = \gamma_0 + \gamma_1 * \mathrm{ROIL}_{t-1} + \gamma_2 * \mathrm{RUSDl}_{(5\%),t} + \varepsilon_{\mathrm{SP500},t} \quad (30)$$

$$\mathrm{RUSD}_t = \delta_0 + \delta_1 * \mathrm{RGOLDh}_{(5\%),t} + \varepsilon_{\mathrm{USD},t} \quad (31)$$

The coefficients are estimated using OLS method and then the 1 step ahead predictions are made. Our in-sample data incorporate the daily returns starting 19th September 2008 to 31th December 2010 which accounts 575 observations in total. Our out sample data contain daily returns from 1st January 2011 to 9th April 2012 which incorporate 320 observations. The coefficients estimations are given in equations A1, A2, A3, and A4 in Appendix. Further an 1 lagged auto regression (AR(1)) model and an 1 lagged vector auto regression (VAR(1)) model are implemented as benchmark models. The AR(1) models are shown in equations 32, 33, 34, and 35. The VAR(1) model is given in equation 36.

$$\mathrm{RGOLD}_t = \zeta_0 + \zeta_1 * \mathrm{RGOLD}_{t-1} + \varepsilon_{\mathrm{gold},t} \quad (32)$$

$$\mathrm{ROIL}_t = \eta_0 + \eta_1 * \mathrm{ROIL}_{t-1} + \varepsilon_{\mathrm{oil},t} \quad (33)$$

$$\mathrm{RSP500}_t = \theta_0 + \theta_1 * \mathrm{RSP500}_{t-1} + \varepsilon_{\mathrm{SP500},t} \quad (34)$$

$$\mathrm{RUSD}_t = \iota_0 + \iota_1 * \mathrm{RUSD}_{t-1} + \varepsilon_{\mathrm{USD},t} \quad (35)$$

$$\begin{bmatrix} \mathrm{RGOLD}_t \\ \mathrm{ROIL}_t \\ \mathrm{RSP500}_t \\ \mathrm{RUSD}_t \end{bmatrix} = \begin{bmatrix} \kappa_1 \\ \kappa_2 \\ \kappa_3 \\ \kappa_4 \end{bmatrix} + \begin{bmatrix} o_{11} & \cdots & o_{14} \\ \vdots & \ddots & \vdots \\ o_{41} & \cdots & o_{44} \end{bmatrix} \begin{bmatrix} \mathrm{RGOLD}_{t-1} \\ \mathrm{ROIL}_{t-1} \\ \mathrm{RSP500}_{t-1} \\ \mathrm{RUSD}_{t-1} \end{bmatrix} + \begin{bmatrix} \varepsilon_{\mathrm{gold},t} \\ \varepsilon_{\mathrm{oil},t} \\ \varepsilon_{\mathrm{SP500},t} \\ \varepsilon_{\mathrm{USD},t} \end{bmatrix} \quad (36)$$

One problem in making the accurate predictions is whether the assumption of stable coefficients should be accepted. Therefore forecasts are produced not only using stable coefficients, but also based on moving window and expanding window methods. When using moving window method, for each new forecast, the oldest observation is eliminated from the in-sample data, in which way the total number of observations in the in-sample remains same. Then for each new forecast, the new coefficients are estimated. For the expanding method, for each new forecast, the oldest observation is not eliminated and the number of observations in the in-sample size is increased by one. Same as moving window method, for each new forecast, the new coefficients are estimated. The forecasts of our models are given in figure 5, 6, 7 and 8 for gold futures, oil futures, S&P500 Index, and USD Index.

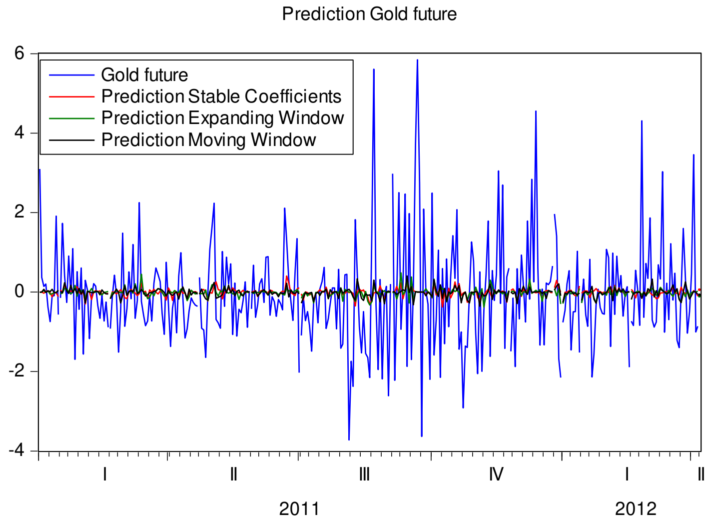


Figure 5: Forecasts of Gold 1 month future using Stable Coefficient, Expanding Window, and Moving Window methods.

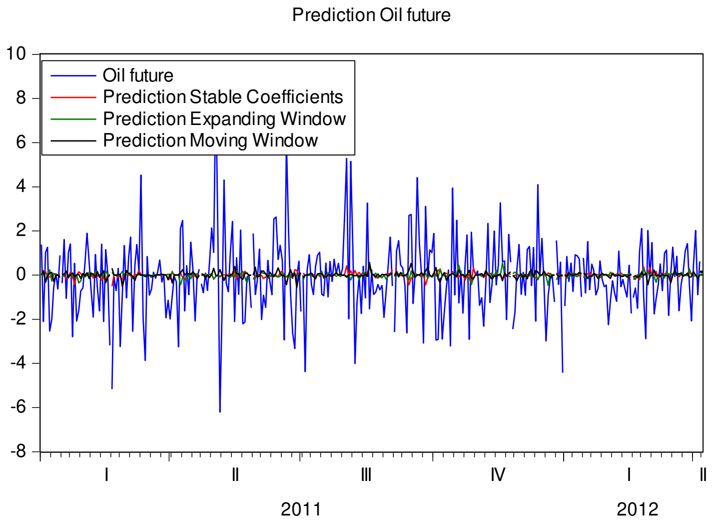


Figure 6: Forecasts of Brent Crude Oil 1 month future using Stable Coefficient, Expanding Window, and Moving Window methods.

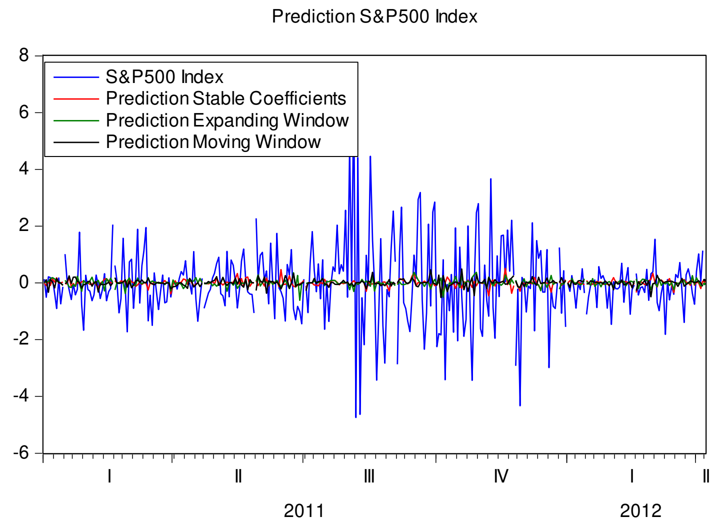


Figure 7: Forecasts of S&P500 Index using Stable Coefficient, Expanding Window, and Moving Window methods.

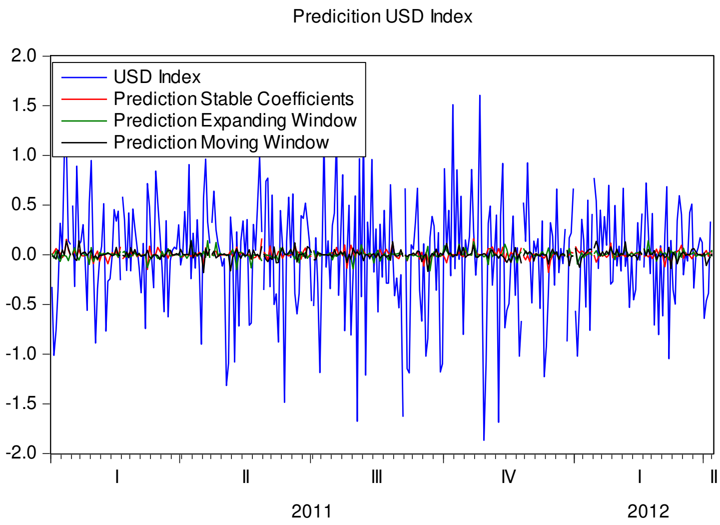


Figure 8: Forecasts of USD Index using Stable Coefficient, Expanding Window, and Moving Window methods.

To compare the predictions, the three measurements are used: correct predicted signs (CPS), mean absolute error (MAE), and mean squared prediction error (MSPE). These three measurements can be calculated using equation 37, 38, and 39. In the equations, $\hat{r}_{i,t+1}$ denotes the forecast of the returns of asset i at time t+1 and $r_{i,t+1}$ denotes the real returns of asset i at time t. Further n denotes number of forecasts which is equal to 320. The obtained CPS, MAE, and MSPE are given in table 21, 23, and 24 and Model(1) in the tables denotes our model.

$$\frac{\left(\sum_{t=1}^{n} I(\hat{r}_{i,t+1}>0)*I\left(r_{i,t+1}>0\right)+I(\hat{r}_{i,t+1}<0)*I\left(r_{i,t+1}<0\right)\right)}{n} \qquad (37)$$

$$\frac{\left(\sum_{t=1}^{n}\left|\hat{r}_{i,t+1}-r_{i,t+1}\right|\right)}{n} \quad (38)$$

$$\frac{\left(\sum_{t=1}^{n}\left(\hat{r}_{i,t+1}-r_{i,t+1}\right)^2\right)}{n} \quad (39)$$

| | RGOLD | ROIL | RSP500 | RUSD |
|---|---|---|---|---|
| Model(1) Stable Coefficient | 0.600 | 0.397 | 0.394 | 0.375 |
| AR(1) Stable Coefficient | 0.581 | 0.138 | 0.138 | 0.291 |
| VAR(1) Stable Coefficient | 0.588 | 0.388 | 0.388 | 0.325 |
| Model(1) Expanding window | 0.666 | 0.434 | 0.381 | 0.559 |
| AR(1) Expanding window | 0.584 | 0.247 | 0.247 | 0.394 |
| VAR(1) Expanding window | 0.594 | 0.378 | 0.378 | 0.359 |
| Model(1)Moving window | 0.769 | 0.638 | 0.584 | 0.628 |
| AR(1)Moving window | 0.588 | 0.528 | 0.528 | 0.434 |
| VAR(1)Moving window | 0.588 | 0.569 | 0.569 | 0.484 |

Table 21: CPS of 1 step ahead forecast of Model (1), AR(1), and VAR(1) model. RGOLD, ROIL RSP500 and RUSD represent the returns of assets gold futures, oil futures, S&P500 Index and USD Index.

In general, CPS measures whether the predictions have same sign as the real observations. For the investors higher CPS means more accurate correct predictions of the directions of the market movements, hence a higher profit. According to table 21 which shows the CPS of the predictions of model (1), AR(1), and VAR(1) model using stable coefficient, expanding window, and moving window methods, the model(1) has higher CPS than the two benchmark models. So if the investors using model(1) to predict the market directions, they will gain extra benefit compared to two benchmark models.

| | RGOLD | ROIL | RSP500 | RUSD |
|---|---|---|---|---|
| Model(1) Stable Coefficient | 3.03 (0.001) | -3.87 (1.00) | -3.77 (1.000) | -4.25 (1.000) |
| Model(1) Expanding window | 8.94 (0.000) | -2.37 (0.991) | -4.25 (1.000) | 2.18 (0.015) |
| Model(1)Moving window | 12.83 (0.000) | 4.8 (0.000) | 2.99 (0.001) | 4.46 (0.000) |

Table 22: Result of Pesaran-Timmer test of Model (1) with p value in parenthesis. RGOLD, ROIL RSP500 and RUSD represent the returns of gold futures, oil futures, S&P500 Index and USD Index.

Further we compute the Pesaran-Timmermann (PT) test by Pesaran and Timmermann (1992) to examine whether the predictions of model (1) is better than the prediction of a random walk. The description of the PT test can be found in section 7.1 in Appendix. The results are shown in table 22 and the p values are given in parenthesis. Note that the PT test indicates that model (1) provides more accurate predictions than the random walk when the p values are smaller than 0.05. Considering the results in table 22, for all four assets the predictions produced by the moving window methods have small p values which indicate the predictions of model(1) are more accurate than the random walk model. For predictions using stable coefficient method, the PT tests indicate that model (1) only provides more accurate predictions for the gold futures. For the results using expanding window method, the predictions for gold futures and USD Index are more accurate than the random walk.

| | RGOLD | ROIL | RSP500 | RUSD |
|---|---|---|---|---|
| Model(1) Stable Coefficient | 0.896 | 1.277 | 1.286 | 0.436 |
| AR(1) Stable Coefficient | 0.907 | 1.392 | 1.392 | 0.443 |
| VAR(1) Stable Coefficient | 0.911 | 1.378 | 1.378 | 0.441 |
| Model(1) Expanding window | 0.885 | 1.278 | 1.292 | 0.427 |
| AR(1) Expanding window | 0.904 | 1.383 | 1.383 | 0.436 |
| VAR(1) Expanding window | 0.903 | 1.375 | 1.375 | 0.441 |
| Model(1)Moving window | 0.872 | 1.247 | 1.259 | 0.419 |
| AR(1)Moving window | 0.911 | 1.295 | 1.295 | 0.441 |
| VAR(1)Moving window | 0.905 | 1.300 | 1.300 | 0.443 |

Table 23: MAE of 1 step ahead forecast of Model (1), AR(1), and VAR(1) model. RGOLD, ROIL RSP500 and RUSD represent the returns of gold futures, oil futures, S&P500 Index and USD Index.

Now focusing on table 23 which shows the MAE of the 1 step ahead forecasts of model (1), AR(1), and VAR(1) model. MAE measures the difference between the real observations and predictions. Therefore a smaller MAE means more accurate predictions. Concerning table 23, model(1) has lower MAE values than the two benchmark models for all assets. Further the predictions produced by moving window method have the lowest MAE values which are consistent with our findings for CPS, hence models using moving window method produce more accurate predictions than using the other two methods.

| | RGOLD | ROIL | RSP500 | RUSD |
|---|---|---|---|---|
| Model(1) Stable Coefficient | 1.566 | 3.001 | 3.043 | 0.316 |
| AR(1) Stable Coefficient | 1.599 | 3.532 | 3.532 | 0.325 |
| VAR(1) Stable Coefficient | 1.641 | 3.447 | 3.447 | 0.324 |
| Model(1) Expanding window | 1.546 | 3.011 | 3.053 | 0.306 |
| AR(1) Expanding window | 1.581 | 3.491 | 3.491 | 0.316 |
| VAR(1) Expanding window | 1.611 | 3.431 | 3.431 | 0.324 |
| Model(1)Moving window | 1.520 | 2.935 | 2.952 | 0.296 |
| AR(1)Moving window | 1.598 | 3.066 | 3.066 | 0.325 |
| VAR(1)Moving window | 1.592 | 3.069 | 3.069 | 0.325 |

Table 24: MSPE of 1 step ahead forecast of Model (1), AR(1), and VAR(1) model. RGOLD, ROIL RSP500 and RUSD represent the returns gold futures, oil futures, S&P500 Index and USD Index.

Table 24 gives the MSPE of 1 step ahead forecasts of model(1), AR(1), and

VAR(1) model using stable coefficients, expanding window and moving window methods. Regarding table 24, comparing the results using different methods, again predictions produced by the moving method have the lowest MSPE values which indicate the moving window method produces most accurate forecasts. Further comparing the results of three models, model(1) has much lower MSPE values.

| Alternative model | RGOLD | ROIL | RSP500 | RUSD |
|---|---|---|---|---|
| AR(1) Stable Coefficient | 1.71 (0.043) | 8.03 (0.000) | 7.78 (0.000) | 2.22 (0.013) |
| AR(1) Expanding window | 1.78 (0.038) | 7.81 (0.000) | 7.28 (0.000) | 2.5 (0.006) |
| AR(1)Moving window | 3.76 (0.000) | 2.8 (0.003) | 2.29 (0.011) | 7.04 (0.000) |
| VAR(1) Stable Coefficient | 2.59 (0.005) | 6.48 (0.000) | 5.71 (0.000) | 1.71 (0.044) |
| VAR(1) Expanding window | 2.34 (0.010) | 6.35 (0.000) | 6.01 (0.000) | 4.05 (0.000) |
| VAR(1)Moving window | 2.54 (0.006) | 2.74 (0.003) | 2.27 (0.012) | 6.77 (0.000) |

Table 25: Result of Diebold-Mariano test of Model (1) with p value in parenthesis. RGOLD, ROIL RSP500 and RUSD represent the returns of gold futures, oil futures, S&P500 Index and USD Index.

Since the MAE and MSPE in tables 23 and 24 are close to each other, it might be useful to compute Diebold-Mariano (DM) test by Diebold and Mariano (1993). The DM test examines whether the predictions produced by two models are different to each other and the description of DM test can be found in section A7.2 in Appendix. The results of the DM test with p values in the parenthesis are shown in table 25. DM tests indicate the model (1) provides more accurate predictions than the alternative models for p values smaller than 0.05. According to table 25, the p values are always smaller than 0.05 which means that model(1) provides more accurate predictions than the AR(1) and VAR(1) models for all assets.

Now we summarize our findings of the results. According to the CPS and PT test, model(1) using moving window method provides better predictions for market direction than AR(1), and VAR(1) model or a random walk model. Further according to MAE, MSPE and DM test model(1) using moving window method also produces more accurate predictions than the two benchmark models. Hence investors can gain extra benefit by using model(1) to take their investment decisions than the two benchmark models.

# 6 Conclusion

Traditionally, the investors always seek to reduce their investment risk while maximizing their returns of investments. To lower the investments risk, investors mainly diversify their investments by incorporating different kind assets in their portfolios. The conventional knowledge about the relation between different assets exist and investor could take benefit from these knowledge. Unfortunately in 2008, the global financial crisis breaks out which has large impacts on financial markets. It has also caused large changes in dependencies of assets. The conventional knowledge may no more valid for financial markets during the crisis. In order to diversify the investments risk while maximizing the investments returns, investors should understand the new relations among assets in the period during the crisis. Therefore this study attempts to find out which factors are important in the period during the crisis to obtain accurate predictions of assets price movements.

In this study four assets are incorporated for comovements analysis, namely the Brent crude oil 1 month futures, the gold 1 month futures, the SP500 Index, and the USD Index. The study starts with basic statistics analysis on the data in section 3 and the results of the analysis suggest possible causal relations between assets and the extreme shocks may influence the assets price movements. To examine causal relations, two kinds of causality tests are implemented, namely the multivariate linear Granger causality test and the multivariate nonlinear Granger causality test. The multivariate nonlinear Granger causality tests are introduced to cover the lack of the multivariate linear Granger causality tests, for the multivariate linear Granger causality tests only assume linear relations between the assets. The study further introduces the Safe Haven Analysis which examines the existence of the effect of extreme shocks on the assets price movements. For all three methods, we found differences in the results using data in the periods before and during the crisis. These differences imply relation changes between assets caused by the crisis. Therefore the new model is needed to help investors to understand the assets price movements in the period during the crisis. The results of these analyses can further help us to understand the relations among assets and build our model.

Using findings about the relations among assets obtained for the period during the crisis, the model(1) can be constructed. In order to produce accurate predictions, the stable coefficients, moving window and expanding window methods are used for making forecasts. Then the predictions of model(1) is compared with the AR(1) and VAR(1) models using CPS, MAE, and MSPE. As result, the model(1) provides outstanding accurate predictions for all four assets. Further the predictions are most accurate using moving window method. According to the PT test, the predictions of model 1 are better than the random walk model. The DM tests show that the predictions of model (1) are more accurate than these of the AR(1) and VAR(1) models.

Now look back to our research goal, are we succeed in providing good predictions? Yes, this research has adopted a few advance econometrical methods to analyze the dynamic comovements relations among assets. The model(1) which is build based on the results of the analyses, is able to produce accurate predictions for the Brent crude oil 1 month futures, the gold 1 month futures, the SP500 Index, and the USD Index. Furthermore, the results of the analyses also provide a sketch of the relation changes caused by the financial crisis.

## 6.1 Discussion and topics of further research

In this research we provide our model based on the results of comovement analysis. Although our analysis is quite extensive, but we would like to point out some possible extensions for further research. In this research we mainly focused on the dynamic relations among assets which are important to maximizing returns of investments, but a shortage is that the research doesn't cover contemporaneous relations among assets which is important to reduce investments risks. In our data analysis we showed significant correlations and exceedance correlations among assets, therefore we would like to suggest a further research more focused on the contemporaneous comovements relations among assets to help investors reduce their investments risk.

The second topic we would like to carry out a further research is the dynamic nonlinear relations among assets. In section 5.2 we presented the results of the multivariate nonlinear Granger causality test and the results show some dynamic nonlinear relations among assets. Unfortunately the multivariate nonlinear Granger causality test is a non parametric test which doesn't provide any information about the structure of the relation. Therefore the nonlinear causal relations are not considered in our model. A further research could contain models which accept the nonlinear structures.

# 7 Appendix

| | RGOLD | ROIL | RSP500 | RUSD |
|---|---|---|---|---|
| C | -0.077(0.093) | -0.137(0.037) | -0.004(0.805) | 0.002(0.975) |
| RGOLD(-1) | -0.059(0.34) | -0.056(0.626) | -0.011(0.37) | 0.011(0.808) |
| ROIL(-1) | 0.058(0.055) | -0.074(0.019) | -0.032(0.195) | -0.014(0.212) |
| RSP500(-1) | 0.127(0.016) | 0.261(0.00) | -0.156(0.00) | -0.085(0.00) |
| RUSD(-1) | -0.359(0.004) | -0.368(0.047) | 0.018(0.931) | 0.013(0.971) |
| R-squared | 0.02 | 0.02 | 0.02 | 0.03 |
| Log likelihood | -4875.209 | | | |
| Akaike AIC | 10.97581 | | | |

Table A1： VAR estimation of equation 3 using before crisis data. The p values of the coefficient estimations are given in parenthesis. RGOLD, ROIL RSP500 and RUSD represent the returns of gold futures, oil futures, S&P500 Index and USD Index. (-1) indicates 1 lagged variables.

| | RGOLD | ROIL | RSP500 | RUSD |
|---|---|---|---|---|
| C | -0.089(0.061) | -0.008(0.931) | -0.016(0.795) | -0.005(0.812) |
| RGOLD(-1) | 0.014(0.721) | 0.121(0.084) | 0.018(0.713) | -0.003(0.861) |
| ROIL(-1) | -0.046(0.045) | -0.231(0.00) | -0.066(0.028) | 0.013(0.245) |
| RSP500(-1) | 0.057(0.087) | 0.296(0.00) | -0.082(0.055) | -0.012(0.455) |
| RUSD(-1) | -0.211(0.016) | -0.061(0.707) | -0.088(0.442) | 0.029(0.486) |
| R-squared | 0.02 | 0.06 | 0.04 | 0.01 |
| Log likelihood | -5781.73 | | | |
| Akaike AIC | 13.43 | | | |

Table A2： VAR estimation of equation 3 using data during the crisis. The p values of the coefficient estimations are given in parenthesis. RGOLD, ROIL RSP500 and RUSD represent the returns of gold futures, oil futures, S&P500 Index and USD Index. (-1) indicates 1 lagged variables.

| | RGOLD | ROIL | RSP500 | RUSD |
|---|---|---|---|---|
| RGOLD | NaN | 0.557(0.374) | -0.373(0.223) | -0.302(0.341) |
| ROIL | 0.428(0.313) | NaN | 0.428(0.313) | -0.889(0.022) |
| RSP500 | 3.143(0.010) | 0.557(0.004) | NaN | 0.302(0.011) |
| RUSD | 25.037(0.050) | 3.283(0.023) | 25.037(0.045) | NaN |

Table A3： Test statistics with p values in parenthesis of Nonlinear Granger causality test using before crisis data with parameter Li=Lj=2, m=1, and e=1.5. RGOLD, ROIL RSP500 and RUSD represent the returns of gold futures, oil futures, S&P500 Index and USD Index.

| | RGOLD | ROIL | RSP500 | RUSD |
|---|---|---|---|---|
| RGOLD | NaN | -0.457(0.112) | -3.041(0.411) | -13.582(0.334) |
| ROIL | -1.118(0.005) | NaN | -0.98(0.004) | -2.487(0.024) |
| RSP500 | -1.425(0.389) | -0.488(0.008) | NaN | -3.332(0.126) |
| RUSD | -1.553(0.024) | -0.551(0.382) | -2.055(0.264) | NaN |

Table A4： Test statistics with p values in parenthesis of Nonlinear Granger causality test using data during the crisis with parameter Li=Lj=2, m=1, and e=1.5. RGOLD, ROIL RSP500 and RUSD represent the returns of gold futures, oil futures, S&P500 Index and USD Index.

| | GOLD | OIL | SP500 | USD |
|---|---|---|---|---|
| GOLD | NaN | 19.139(0.476) | -14.312(0.226) | -11.282(0.314) |
| OIL | 14.059(0.312) | NaN | 0.335(0.349) | -18.209(0.015) |
| SP500 | 12.384(0.008) | 16.139(0.000) | NaN | 21.992(0.021) |
| USD | 11.166(0.002) | 14.112(0.009) | 11.712(0.022) | NaN |

Table A5： Test statistics with p values in parenthesis of Nonlinear Granger causality test using before crisis data with parameter Li=Lj=3, m=1, and e=1.5. RGOLD, ROIL RSP500 and RUSD represent the returns of gold futures, oil futures, S&P500 Index and USD Index.

| | RGOLD | ROIL | RSP500 | RUSD |
|---|---|---|---|---|
| RGOLD | NaN | -4.137(0.104) | -7.221(0.421) | -17.752(0.304) |
| ROIL | -13.505(0.003) | NaN | -6.405(0.010) | -6.625(0.022) |
| RSP500 | -8.794(0.343) | -3.673(0.009) | NaN | -0.217(0.463) |
| RUSD | -5.741(0.014) | -15.031(0.413) | -10.73(0.212) | NaN |

Table A6： Test statistics with p values in parenthesis of Nonlinear Granger causality test using data during the crisis with parameter Li=Lj=3, m=1, and e=1.5. RGOLD, ROIL RSP500 and RUSD represent the returns of gold futures, oil futures, S&P500 Index and USD Index.

| Asset i | Asset j | Lag | $\beta_{2(1)}$ | t-stat | Pvalue | $\beta_{2(2)}$ | t-stat | Pvalue | Wald test | Pvalue |
|---|---|---|---|---|---|---|---|---|---|---|
| Gold | Brent | 2 | -0.087 | 0.228 | 0.410 | 0.031 | -0.802 | 0.211 | 0.083 | 0.773 |
| Gold | Sp500 | 2 | -0.087 | 0.228 | 0.410 | 0.031 | -0.802 | 0.211 | 0.083 | 0.773 |
| Gold | USD Index | 1 | 0.007 | -0.692 | 0.245 | 0.000 | 0.000 | 0.000 | 0.483 | 0.487 |
| Brent | Gold | 1 | -0.051 | -1.366 | 0.086 | 0.000 | 0.000 | 0.000 | 1.885 | 0.170 |
| Brent | Sp500 | 1 | -0.044 | -0.754 | 0.226 | 0.000 | 0.000 | 0.000 | 0.574 | 0.449 |
| Brent | USD Index | 2 | -0.112 | 1.097 | 0.136 | -0.071 | -1.406 | 0.080 | 0.024 | 0.877 |
| Sp500 | Gold | 1 | -0.051 | -1.366 | 0.086 | 0.000 | 0.000 | 0.000 | 1.885 | 0.170 |
| Sp500 | Brent | 1 | -0.044 | -0.754 | 0.226 | 0.000 | 0.000 | 0.000 | 0.574 | 0.449 |
| Sp500 | USD Index | 2 | -0.112 | 1.097 | 0.136 | -0.071 | -1.406 | 0.080 | 0.024 | 0.877 |
| USD Index | Gold | 1 | -0.003 | 0.745 | 0.228 | 0.000 | 0.000 | 0.000 | 0.560 | 0.454 |
| USD Index | Brent | 2 | -0.019 | 0.812 | 0.208 | -0.017 | 1.592 | 0.056 | 1.459 | 0.227 |
| USD Index | Sp500 | 2 | -0.019 | 0.812 | 0.208 | -0.017 | 1.592 | 0.056 | 1.459 | 0.227 |

Table A7: Test statistics with p values of Safe Haven Analysis for before crisis period using 5% lower quartile observations. RGOLD, ROIL RSP500 and RUSD represent the returns of gold futures, oil futures, S&P500 Index and USD Index. Asset i and asset j denotes the asset i and j in equation 27.

| Asset i | Asset j | Lag | $\beta_{2(1)}$ | t-stat | Pvalue | $\beta_{2(2)}$ | t-stat | Pvalue | Wald test | Pvalue |
|---|---|---|---|---|---|---|---|---|---|---|
| Gold | Brent | 2 | -0.098 | 0.881 | 0.189 | 0.028 | 0.572 | 0.284 | 0.533 | 0.465 |
| Gold | Sp500 | 2 | -0.098 | 0.881 | 0.189 | 0.028 | 0.572 | 0.284 | 0.533 | 0.465 |
| Gold | USD Index | 2 | -0.081 | -1.376 | 0.085 | 0.005 | 0.898 | 0.185 | 0.058 | 0.810 |
| Brent | Gold | 1 | -0.052 | 0.313 | 0.377 | 0.000 | 0.000 | 0.000 | 0.099 | 0.753 |
| Brent | Sp500 | 1 | -0.050 | -0.502 | 0.308 | 0.000 | 0.000 | 0.000 | 0.255 | 0.614 |
| Brent | USD Index | 2 | -0.140 | 0.779 | 0.218 | -0.071 | 1.272 | 0.102 | 1.062 | 0.303 |
| Sp500 | Gold | 1 | -0.052 | 0.313 | 0.377 | 0.000 | 0.000 | 0.000 | 0.099 | 0.753 |
| Sp500 | Brent | 1 | -0.050 | -0.502 | 0.308 | 0.000 | 0.000 | 0.000 | 0.255 | 0.614 |
| Sp500 | USD Index | 2 | -0.140 | 0.779 | 0.218 | -0.071 | 1.272 | 0.102 | 1.062 | 0.303 |
| USD Index | Gold | 1 | -0.006 | 1.267 | 0.103 | 0.000 | 0.000 | 0.000 | 1.622 | 0.203 |
| USD Index | Brent | 1 | -0.016 | -1.250 | 0.106 | 0.000 | 0.000 | 0.000 | 1.578 | 0.209 |
| USD Index | Sp500 | 1 | -0.016 | -1.250 | 0.106 | 0.000 | 0.000 | 0.000 | 1.578 | 0.209 |

Table A8: Test statistics with p values of Safe Haven Analysis for before crisis period using 5% upper quartile observations. RGOLD, ROIL RSP500 and RUSD represent the returns of gold futures, oil futures, S&P500 Index and USD Index. Asset i and asset j denotes the asset i and j in equation 27.

| Asset i | Asset j | Lag | $\beta_{2(1)}$ | t-stat | Pvalue | $\beta_{2(2)}$ | t-stat | Pvalue | Wald test | Pvalue |
|---|---|---|---|---|---|---|---|---|---|---|
| RGOLD | RGOLD | NaN | NaN | NaN | NaN | NaN | NaN | NaN | NaN | NaN |
| RGOLD | ROIL | 2 | 0.574 | 0.000 | 0.500 | 0.322 | 0.000 | 0.500 | 0.000 | 1.000 |
| RGOLD | RSP500 | 2 | 0.574 | 0.000 | 0.500 | 0.322 | 0.000 | 0.500 | 0.000 | 1.000 |
| RGOLD | RUSD | 1 | 0.042 | -2.905 | 0.005 | 0.000 | 0.000 | 0.000 | 8.521 | 0.004 |
| ROIL | RSP500 | 1 | 0.039 | 0.000 | 0.500 | 0.000 | 0.000 | 0.000 | 0.000 | 1.000 |
| ROIL | RUSD | 1 | 0.093 | -4.954 | 0.000 | 0.000 | 0.000 | 0.000 | 24.783 | 0.000 |
| RSP500 | RGOLD | 1 | 0.247 | 0.038 | 0.485 | 0.000 | 0.000 | 0.000 | 0.001 | 0.969 |
| RSP500 | ROIL | 1 | 0.039 | 0.000 | 0.500 | 0.000 | 0.000 | 0.000 | 0.000 | 1.000 |
| RSP500 | RUSD | 1 | 0.093 | -4.954 | 0.000 | 0.000 | 0.000 | 0.000 | 24.783 | 0.000 |
| RUSD | RGOLD | 2 | 0.059 | -0.688 | 0.251 | 0.006 | 2.022 | 0.031 | 0.449 | 0.503 |
| RUSD | ROIL | 1 | -0.560 | 0.000 | 0.500 | 0.000 | 0.000 | 0.000 | 0.000 | 1.000 |
| RUSD | RSP500 | 1 | -0.560 | 0.000 | 0.500 | 0.000 | 0.000 | 0.000 | 0.000 | 1.000 |

Table A9: Test statistics with p values of Safe Haven Analysis for the period during crisis using 5% lower quartile observations. RGOLD, ROIL RSP500 and RUSD represent the returns of gold futures, oil futures, S&P500 Index and USD Index. Asset i and asset j denotes the asset i and j in equation 27.

| Asset i | Asset j | Lag | $\beta_{2(1)}$ | t-stat | Pvalue | $\beta_{2(2)}$ | t-stat | Pvalue | Wald test | Pvalue |
|---|---|---|---|---|---|---|---|---|---|---|
| Gold | Brent | 2 | 0.590 | -1.372 | 0.095 | -0.545 | 1.935 | 0.036 | 0.080 | 0.777 |
| Gold | Sp500 | 1 | 0.590 | -1.372 | 0.095 | -0.545 | 1.935 | 0.036 | 1.900 | 0.168 |
| Gold | USD Index | 1 | -0.055 | -0.521 | 0.305 | 0.000 | 0.000 | 0.000 | 0.274 | 0.600 |
| Brent | Gold | 2 | 0.216 | -1.649 | 0.060 | -0.028 | 2.551 | 0.011 | 0.206 | 0.650 |
| Brent | Sp500 | 2 | -0.069 | -1.105 | 0.143 | 0.320 | 2.034 | 0.030 | 0.218 | 0.641 |
| Brent | USD Index | 1 | 0.014 | 0.023 | 0.491 | 0.000 | 0.000 | 0.000 | 0.001 | 0.981 |
| Sp500 | Gold | 2 | 0.216 | -1.649 | 0.060 | -0.028 | 2.551 | 0.011 | 0.206 | 0.650 |
| Sp500 | Brent | 2 | -0.069 | -1.105 | 0.143 | 0.320 | 2.034 | 0.030 | 0.218 | 0.641 |
| Sp500 | USD Index | 1 | 0.014 | 0.023 | 0.491 | 0.000 | 0.000 | 0.000 | 0.001 | 0.981 |
| USD Index | Gold | 2 | 0.067 | 2.292 | 0.018 | -0.300 | -4.086 | 0.000 | 7.640 | 0.006 |
| USD Index | Brent | 1 | -0.609 | -1.344 | 0.100 | 0.000 | 0.000 | 0.000 | 1.823 | 0.177 |
| USD Index | Sp500 | 1 | -0.609 | -1.344 | 0.100 | 0.000 | 0.000 | 0.000 | 1.823 | 0.177 |

Table A10: Test statistics with p values of Safe Haven Analysis for period during crisis using 5% upper quartile observations. RGOLD, ROIL RSP500 and RUSD represent the returns of gold futures, oil futures, S&P500 Index and USD Index. Asset i and asset j denotes the asset i and j in equation 27.

| Asset i | Asset j | Lag | $\beta_{2(1)}$ | t-stat | Pvalue | $\beta_{2(2)}$ | t-stat | Pvalue | Wald test | Pvalue |
|---|---|---|---|---|---|---|---|---|---|---|
| Gold | Brent | 2 | -0.100 | -0.457 | 0.324 | 0.031 | -0.543 | 0.294 | 0.253 | 0.615 |
| Gold | Sp500 | 2 | -0.100 | -0.457 | 0.324 | 0.031 | -0.543 | 0.294 | 0.253 | 0.615 |
| Gold | USD Index | 1 | 0.007 | -0.053 | 0.479 | 0.000 | 0.000 | 0.000 | 0.003 | 0.957 |
| Brent | Gold | 1 | -0.052 | -0.306 | 0.380 | 0.000 | 0.000 | 0.000 | 0.094 | 0.759 |
| Brent | Sp500 | 1 | -0.034 | -0.825 | 0.205 | 0.000 | 0.000 | 0.000 | 0.687 | 0.407 |
| Brent | USD Index | 1 | -0.071 | 0.277 | 0.391 | 0.000 | 0.000 | 0.000 | 0.077 | 0.781 |
| Sp500 | Gold | 1 | -0.052 | -0.306 | 0.380 | 0.000 | 0.000 | 0.000 | 0.094 | 0.759 |
| Sp500 | Brent | 1 | -0.034 | -0.825 | 0.205 | 0.000 | 0.000 | 0.000 | 0.687 | 0.407 |
| Sp500 | USD Index | 1 | -0.071 | 0.277 | 0.391 | 0.000 | 0.000 | 0.000 | 0.077 | 0.781 |
| USD Index | Gold | 2 | -0.001 | -0.092 | 0.463 | -0.002 | -0.948 | 0.172 | 0.273 | 0.602 |
| USD Index | Brent | 1 | -0.019 | 1.829 | 0.034 | 0.000 | 0.000 | 0.000 | 3.379 | 0.066 |
| USD Index | Sp500 | 1 | -0.019 | 1.829 | 0.034 | 0.000 | 0.000 | 0.000 | 3.379 | 0.066 |

Table A11: Test statistics with p values of Safe Haven Analysis for before crisis period using 15% lower quartile observations. RGOLD, ROIL RSP500 and RUSD represent the returns of gold futures, oil futures, S&P500 Index and USD Index. Asset i and asset j denotes the asset i and j in equation 27.

| Asset i | Asset j | Lag | $\beta_{2(1)}$ | t-stat | Pvalue | $\beta_{2(2)}$ | t-stat | Pvalue | Wald test | Pvalue |
|---|---|---|---|---|---|---|---|---|---|---|
| Gold | Brent | 1 | 0.035 | 2.141 | 0.016 | 0.000 | 0.000 | 0.000 | 4.630 | 0.031 |
| Gold | Sp500 | 1 | 0.035 | 2.141 | 0.016 | 0.000 | 0.000 | 0.000 | 4.630 | 0.031 |
| Gold | USD Index | 2 | -0.101 | -0.345 | 0.365 | 0.008 | 1.315 | 0.094 | 0.237 | 0.626 |
| Brent | Gold | 2 | -0.171 | 1.011 | 0.156 | -0.053 | 0.894 | 0.186 | 0.916 | 0.338 |
| Brent | Sp500 | 2 | -0.146 | 0.316 | 0.376 | -0.069 | 0.976 | 0.165 | 0.421 | 0.516 |
| Brent | USD Index | 2 | -0.123 | -0.389 | 0.349 | -0.072 | 1.055 | 0.146 | 0.112 | 0.738 |
| Sp500 | Gold | 2 | -0.171 | 1.011 | 0.156 | -0.053 | 0.894 | 0.186 | 0.916 | 0.338 |
| Sp500 | Brent | 2 | -0.146 | 0.316 | 0.376 | -0.069 | 0.976 | 0.165 | 0.421 | 0.516 |
| Sp500 | USD Index | 2 | -0.123 | -0.389 | 0.349 | -0.072 | 1.055 | 0.146 | 0.112 | 0.738 |
| USD Index | Gold | 1 | 0.000 | -0.517 | 0.303 | 0.000 | 0.000 | 0.000 | 0.270 | 0.603 |
| USD Index | Brent | 1 | -0.016 | -1.834 | 0.034 | 0.000 | 0.000 | 0.000 | 3.395 | 0.065 |
| USD Index | Sp500 | 1 | -0.016 | -1.834 | 0.034 | 0.000 | 0.000 | 0.000 | 3.395 | 0.065 |

Table A12: Test statistics with p values of Safe Haven Analysis for before crisis period using 15% upper quartile observations. RGOLD, ROIL RSP500 and RUSD represent the returns of gold futures, oil futures, S&P500 Index and USD Index. Asset i and asset j denotes the asset i and j in equation 27.

| Asset i | Asset j | Lag | $\beta_{2(1)}$ | t-stat | Pvalue | $\beta_{2(2)}$ | t-stat | Pvalue | Wald test | Pvalue |
|---|---|---|---|---|---|---|---|---|---|---|
| Gold | Brent | 2 | 0.753 | 1.130 | 0.138 | 0.318 | 1.465 | 0.082 | 1.700 | 0.192 |
| Gold | Sp500 | 1 | 0.753 | 1.130 | 0.138 | 0.318 | 1.465 | 0.082 | 1.289 | 0.256 |
| Gold | USD Index | 2 | 0.796 | -0.630 | 0.269 | -0.002 | 0.782 | 0.223 | 0.006 | 0.939 |
| Brent | Gold | 2 | 0.227 | -0.474 | 0.321 | 0.211 | -1.995 | 0.032 | 1.539 | 0.215 |
| Brent | Sp500 | 1 | 0.068 | -0.428 | 0.337 | 0.000 | 0.000 | 0.000 | 0.185 | 0.667 |
| Brent | USD Index | 1 | -0.074 | -3.683 | 0.001 | 0.000 | 0.000 | 0.000 | 13.697 | 0.000 |
| Sp500 | Gold | 2 | 0.227 | -0.474 | 0.321 | 0.211 | -1.995 | 0.032 | 1.539 | 0.215 |
| Sp500 | Brent | 1 | 0.068 | -0.428 | 0.337 | 0.000 | 0.000 | 0.000 | 0.185 | 0.667 |
| Sp500 | USD Index | 1 | -0.074 | -3.683 | 0.001 | 0.000 | 0.000 | 0.000 | 13.697 | 0.000 |
| USD Index | Gold | 2 | -0.076 | -0.565 | 0.290 | 0.008 | 2.285 | 0.019 | 0.747 | 0.387 |
| USD Index | Brent | 1 | -0.606 | 1.951 | 0.035 | 0.000 | 0.000 | 0.000 | 3.844 | 0.050 |
| USD Index | Sp500 | 1 | -0.606 | 1.951 | 0.035 | 0.000 | 0.000 | 0.000 | 3.844 | 0.050 |

Table A13: Test statistics with p values of Safe Haven Analysis for period during crisis using 15% lower quartile observations. RGOLD, ROIL RSP500 and RUSD represent the returns of gold futures, oil futures, S&P500 Index and USD Index. Asset i and asset j denotes the asset i and j in equation 27.

| Asset i | Asset j | Lag | $\beta_{2(1)}$ | t-stat | Pvalue | $\beta_{2(2)}$ | t-stat | Pvalue | Wald test | Pvalue |
|---|---|---|---|---|---|---|---|---|---|---|
| Gold | Brent | 1 | -0.406 | -0.916 | 0.187 | 0.000 | 0.000 | 0.000 | 0.846 | 0.358 |
| Gold | Sp500 | 1 | -0.406 | -0.916 | 0.187 | 0.000 | 0.000 | 0.000 | 0.846 | 0.358 |
| Gold | USD Index | 1 | 0.023 | -1.000 | 0.167 | 0.000 | 0.000 | 0.000 | 1.010 | 0.315 |
| Brent | Gold | 2 | 0.558 | 0.831 | 0.209 | -0.869 | 1.460 | 0.082 | 1.325 | 0.250 |
| Brent | Sp500 | 2 | -0.219 | 0.597 | 0.280 | -0.248 | 1.614 | 0.064 | 1.233 | 0.267 |
| Brent | USD Index | 1 | 0.019 | 0.565 | 0.290 | 0.000 | 0.000 | 0.000 | 0.322 | 0.570 |
| Sp500 | Gold | 2 | 0.558 | 0.831 | 0.209 | -0.869 | 1.460 | 0.082 | 1.325 | 0.250 |
| Sp500 | Brent | 2 | -0.219 | 0.597 | 0.280 | -0.248 | 1.614 | 0.064 | 1.233 | 0.267 |
| Sp500 | USD Index | 1 | 0.019 | 0.565 | 0.290 | 0.000 | 0.000 | 0.000 | 0.322 | 0.570 |
| USD Index | Gold | 1 | -0.406 | 2.378 | 0.016 | 0.000 | 0.000 | 0.000 | 5.712 | 0.017 |
| USD Index | Brent | 1 | -0.673 | -2.056 | 0.029 | 0.000 | 0.000 | 0.000 | 4.270 | 0.039 |
| USD Index | Sp500 | 1 | -0.673 | -2.056 | 0.029 | 0.000 | 0.000 | 0.000 | 4.270 | 0.039 |

Table A14: Test statistics with p values of Safe Haven Analysis for period during crisis using 15% upper quartile observations. RGOLD, ROIL RSP500 and RUSD represent the returns of gold futures, oil futures, S&P500 Index and USD Index. Asset i and asset j denotes the asset i and j in equation 27.

| Asset i | Asset j | Lag | $\beta_{2(1)}$ | t-stat | Pvalue | $\beta_{2(2)}$ | t-stat | Pvalue | Wald test | Pvalue |
|---|---|---|---|---|---|---|---|---|---|---|
| Gold | Brent | 1 | 0.032 | -0.863 | 0.194 | 0.000 | 0.000 | 0.000 | 0.753 | 0.386 |
| Gold | Sp500 | 1 | 0.032 | -0.863 | 0.194 | 0.000 | 0.000 | 0.000 | 0.753 | 0.386 |
| Gold | USD Index | 1 | 0.007 | -0.456 | 0.324 | 0.000 | 0.000 | 0.000 | 0.210 | 0.647 |
| Brent | Gold | 1 | -0.052 | -0.279 | 0.390 | 0.000 | 0.000 | 0.000 | 0.079 | 0.779 |
| Brent | Sp500 | 2 | -0.078 | -0.053 | 0.479 | -0.056 | 1.000 | 0.159 | 0.226 | 0.635 |
| Brent | USD Index | 1 | -0.070 | -0.335 | 0.369 | 0.000 | 0.000 | 0.000 | 0.113 | 0.737 |
| Sp500 | Gold | 1 | -0.052 | -0.279 | 0.390 | 0.000 | 0.000 | 0.000 | 0.079 | 0.779 |
| Sp500 | Brent | 2 | -0.078 | -0.053 | 0.479 | -0.056 | 1.000 | 0.159 | 0.226 | 0.635 |
| Sp500 | USD Index | 1 | -0.070 | -0.335 | 0.369 | 0.000 | 0.000 | 0.000 | 0.113 | 0.737 |
| USD Index | Gold | 2 | -0.003 | -0.048 | 0.481 | -0.002 | -0.968 | 0.167 | 0.261 | 0.610 |
| USD Index | Brent | 1 | -0.017 | 1.732 | 0.042 | 0.000 | 0.000 | 0.000 | 3.028 | 0.082 |
| USD Index | Sp500 | 1 | -0.017 | 1.732 | 0.042 | 0.000 | 0.000 | 0.000 | 3.028 | 0.082 |

Table A15: Test statistics with p values of Safe Haven Analysis for before crisis period using 30% lower quartile observations. RGOLD, ROIL RSP500 and RUSD represent the returns of gold futures, oil futures, S&P500 Index and USD Index. Asset i and asset j denotes the asset i and j in equation 27.

| Asset i | Asset j | Lag | $\beta_{2(1)}$ | t-stat | Pvalue | $\beta_{2(2)}$ | t-stat | Pvalue | Wald test | Pvalue |
|---|---|---|---|---|---|---|---|---|---|---|
| Gold | Brent | 1 | 0.033 | 1.124 | 0.131 | 0.000 | 0.000 | 0.000 | 1.275 | 0.259 |
| Gold | Sp500 | 1 | 0.033 | 1.124 | 0.131 | 0.000 | 0.000 | 0.000 | 1.275 | 0.259 |
| Gold | USD Index | 1 | 0.007 | 0.351 | 0.363 | 0.000 | 0.000 | 0.000 | 0.124 | 0.724 |
| Brent | Gold | 2 | -0.167 | 0.462 | 0.322 | -0.053 | 0.938 | 0.174 | 0.495 | 0.482 |
| Brent | Sp500 | 1 | -0.058 | -0.026 | 0.490 | 0.000 | 0.000 | 0.000 | 0.001 | 0.979 |
| Brent | USD Index | 1 | -0.070 | -0.007 | 0.497 | 0.000 | 0.000 | 0.000 | 0.000 | 0.995 |
| Sp500 | Gold | 2 | -0.167 | 0.462 | 0.322 | -0.053 | 0.938 | 0.174 | 0.495 | 0.482 |
| Sp500 | Brent | 1 | -0.058 | -0.026 | 0.490 | 0.000 | 0.000 | 0.000 | 0.001 | 0.979 |
| Sp500 | USD Index | 1 | -0.070 | -0.007 | 0.497 | 0.000 | 0.000 | 0.000 | 0.000 | 0.995 |
| USD Index | Gold | 1 | -0.002 | -0.038 | 0.485 | 0.000 | 0.000 | 0.000 | 0.001 | 0.969 |
| USD Index | Brent | 1 | -0.015 | -1.260 | 0.104 | 0.000 | 0.000 | 0.000 | 1.603 | 0.205 |
| USD Index | Sp500 | 1 | -0.015 | -1.260 | 0.104 | 0.000 | 0.000 | 0.000 | 1.603 | 0.205 |

Table A16: Test statistics with p values of Safe Haven Analysis for before crisis period using 30% upper quartile observations. RGOLD, ROIL RSP500 and RUSD represent the returns of gold futures, oil futures, S&P500 Index and USD Index. Asset i and asset j denotes the asset i and j in equation 27.

| Asset i | Asset j | Lag | $\beta_{2(1)}$ | t-stat | Pvalue | $\beta_{2(2)}$ | t-stat | Pvalue | Wald test | Pvalue |
|---|---|---|---|---|---|---|---|---|---|---|
| Gold | Brent | 2 | 0.863 | 0.776 | 0.225 | 0.234 | 1.414 | 0.089 | 1.211 | 0.271 |
| Gold | Sp500 | 2 | 0.863 | 0.776 | 0.225 | 0.234 | 1.414 | 0.089 | 1.211 | 0.271 |
| Gold | USD Index | 1 | -0.049 | -1.546 | 0.072 | 0.000 | 0.000 | 0.000 | 2.412 | 0.120 |
| Brent | Gold | 2 | 0.226 | -0.683 | 0.253 | 0.200 | -2.028 | 0.030 | 1.855 | 0.173 |
| Brent | Sp500 | 1 | 0.098 | -0.703 | 0.246 | 0.000 | 0.000 | 0.000 | 0.499 | 0.480 |
| Brent | USD Index | 2 | -0.875 | -3.379 | 0.002 | -0.178 | -1.801 | 0.046 | 6.772 | 0.009 |
| Sp500 | Gold | 2 | 0.226 | -0.683 | 0.253 | 0.200 | -2.028 | 0.030 | 1.855 | 0.173 |
| Sp500 | Brent | 1 | 0.098 | -0.703 | 0.246 | 0.000 | 0.000 | 0.000 | 0.499 | 0.480 |
| Sp500 | USD Index | 2 | -0.875 | -3.379 | 0.002 | -0.178 | -1.801 | 0.046 | 6.772 | 0.009 |
| USD Index | Gold | 2 | -0.072 | -0.155 | 0.439 | -0.002 | 2.357 | 0.016 | 1.224 | 0.269 |
| USD Index | Brent | 1 | -0.646 | 2.192 | 0.022 | 0.000 | 0.000 | 0.000 | 4.853 | 0.028 |
| USD Index | Sp500 | 1 | -0.646 | 2.192 | 0.022 | 0.000 | 0.000 | 0.000 | 4.853 | 0.028 |

Table A17: Test statistics with p values of Safe Haven Analysis for period during crisis using 30% lower quartile observations. RGOLD, ROIL RSP500 and RUSD represent the returns of gold futures, oil futures, S&P500 Index and USD Index. Asset i and asset j denotes the asset i and j in equation 27.

| Asset i | Asset j | Lag | $\beta_{2(1)}$ | t-stat | Pvalue | $\beta_{2(2)}$ | t-stat | Pvalue | Wald test | Pvalue |
|---|---|---|---|---|---|---|---|---|---|---|
| Gold | Brent | 1 | -0.378 | -0.959 | 0.176 | 0.000 | 0.000 | 0.000 | 0.929 | 0.335 |
| Gold | Sp500 | 1 | -0.378 | -0.959 | 0.176 | 0.000 | 0.000 | 0.000 | 0.929 | 0.335 |
| Gold | USD Index | 2 | 0.586 | 0.135 | 0.447 | -0.056 | 0.878 | 0.197 | 0.259 | 0.611 |
| Brent | Gold | 2 | 0.366 | 0.258 | 0.400 | -0.513 | 2.355 | 0.016 | 1.724 | 0.189 |
| Brent | Sp500 | 2 | -0.232 | 0.434 | 0.335 | -0.193 | 1.640 | 0.061 | 1.086 | 0.297 |
| Brent | USD Index | 1 | 0.018 | 0.998 | 0.167 | 0.000 | 0.000 | 0.000 | 1.006 | 0.316 |
| Sp500 | Gold | 2 | 0.366 | 0.258 | 0.400 | -0.513 | 2.355 | 0.016 | 1.724 | 0.189 |
| Sp500 | Brent | 2 | -0.232 | 0.434 | 0.335 | -0.193 | 1.640 | 0.061 | 1.086 | 0.297 |
| Sp500 | USD Index | 1 | 0.018 | 0.998 | 0.167 | 0.000 | 0.000 | 0.000 | 1.006 | 0.316 |
| USD Index | Gold | 1 | -0.075 | 2.408 | 0.015 | 0.000 | 0.000 | 0.000 | 5.853 | 0.016 |
| USD Index | Brent | 1 | -0.665 | -1.709 | 0.054 | 0.000 | 0.000 | 0.000 | 2.949 | 0.086 |
| USD Index | Sp500 | 1 | -0.665 | -1.709 | 0.054 | 0.000 | 0.000 | 0.000 | 2.949 | 0.086 |

Table A18: Test statistics with p values of Safe Haven Analysis for period during crisis using 30% upper quartile observations. RGOLD, ROIL RSP500 and RUSD represent the returns of gold futures, oil futures, S&P500 Index and USD Index. Asset i and asset j denotes the asset i and j in equation 27.

| | RGOLD | ROIL | RSP500 | RUSD |
|---|---|---|---|---|
| RGOLD | NaN(NaN) | 0.094(0.759) | 0.094(0.759) | 0.273(0.602) |
| ROIL | 0.253(0.615) | NaN(NaN) | 0.687(0.407) | 3.379(0.066) |
| RSP500 | 0.253(0.615) | 0.687(0.407) | NaN(NaN) | 3.379(0.066) |
| RUSD | 0.003(0.957) | 0.077(0.781) | 0.077(0.781) | NaN(NaN) |

Table A19: Test statistics with p values in parenthesis of Safe Haven Analysis for before crisis period using 15% lower quartile observations. RGOLD, ROIL RSP500 and RUSD represent the returns of gold futures, oil futures, S&P500 Index and USD Index. The column gives the asset i and rows gives the asset j in equation 27.

| | RGOLD | ROIL | RSP500 | RUSD |
|---|---|---|---|---|
| RGOLD | NaN(NaN) | 0.916(0.338) | 0.916(0.338) | 0.27(0.603) |
| ROIL | 4.63(0.031) | NaN(NaN) | 0.421(0.516) | 3.395(0.065) |
| RSP500 | 4.63(0.031) | 0.421(0.516) | NaN(NaN) | 3.395(0.065) |
| RUSD | 0.237(0.626) | 0.112(0.738) | 0.112(0.738) | NaN(NaN) |

Table A20: Test statistics with p values in parenthesis of Safe Haven Analysis for before crisis period using 15% upper quartile observations. RGOLD, ROIL RSP500 and RUSD represent the returns of gold futures, oil futures, S&P500 Index and USD Index. The column gives the asset i and rows gives the asset j in equation 24.

| | RGOLD | ROIL | RSP500 | RUSD |
|---|---|---|---|---|
| RGOLD | NaN(NaN) | 1.539(0.215) | 1.539(0.215) | 0.747(0.387) |
| ROIL | 1.7(0.192) | NaN(NaN) | 0.185(0.667) | 3.844(0.05) |
| RSP500 | 1.289(0.256) | 0.185(0.667) | NaN(NaN) | 3.844(0.05) |
| RUSD | 0.006(0.939) | 13.697(0) | 13.697(0) | NaN(NaN) |

Table A21: Test statistics with p values in parenthesis of Safe Haven Analysis for period during crisis using 15% lower quartile observations. RGOLD, ROIL RSP500 and RUSD represent the returns of gold futures, oil futures, S&P500 Index and USD Index. The column gives the asset i and rows gives the asset j in equation 24.

| | RGOLD | ROIL | RSP500 | RUSD |
|---|---|---|---|---|
| RGOLD | NaN(NaN) | 1.325(0.25) | 1.325(0.25) | 5.712(0.017) |
| ROIL | 0.846(0.358) | NaN(NaN) | 1.233(0.267) | 4.27(0.039) |
| RSP500 | 0.846(0.358) | 1.233(0.267) | NaN(NaN) | 4.27(0.039) |
| RUSD | 1.01(0.315) | 0.322(0.57) | 0.322(0.57) | NaN(NaN) |

Table A22: Test statistics with p values in parenthesis of Safe Haven Analysis for period during crisis using 15% upper quartile observations. RGOLD, ROIL RSP500 and RUSD represent the returns of gold futures, oil futures, S&P500 Index and USD Index. The column gives the asset i and rows gives the asset j in equation 24.

| | RGOLD | ROIL | RSP500 | RUSD |
|---|---|---|---|---|
| RGOLD | NaN(NaN) | 0.079(0.779) | 0.079(0.779) | 0.261(0.61) |
| ROIL | 0.753(0.386) | NaN(NaN) | 0.226(0.635) | 3.028(0.082) |
| RSP500 | 0.753(0.386) | 0.226(0.635) | NaN(NaN) | 3.028(0.082) |
| RUSD | 0.21(0.647) | 0.113(0.737) | 0.113(0.737) | NaN(NaN) |

Table A23: Test statistics with p values in parenthesis of Safe Haven Analysis for before crisis period using 30% lower quartile observations. RGOLD, ROIL RSP500 and RUSD represent the returns of gold futures, oil futures, S&P500 Index and USD Index. The column gives the asset i and rows gives the asset j in equation 24.

| | RGOLD | ROIL | RSP500 | RUSD |
|---|---|---|---|---|
| RGOLD | NaN(NaN) | 0.495(0.482) | 0.495(0.482) | 0.001(0.969) |
| ROIL | 1.275(0.259) | NaN(NaN) | 0.001(0.979) | 1.603(0.205) |
| RSP500 | 1.275(0.259) | 0.001(0.979) | NaN(NaN) | 1.603(0.205) |
| RUSD | 0.124(0.724) | 0(0.995) | 0(0.995) | NaN(NaN) |

Table A24: Test statistics with p values in parenthesis of Safe Haven Analysis for before crisis period using 30% upper quartile observations. RGOLD, ROIL RSP500 and RUSD represent the returns of gold futures, oil futures, S&P500 Index and USD Index. The column gives the asset i and rows gives the asset j in equation 24.

| | RGOLD | ROIL | RSP500 | RUSD |
|---|---|---|---|---|
| RGOLD | NaN(NaN) | 1.855(0.173) | 1.855(0.173) | 1.224(0.269) |
| ROIL | 1.211(0.271) | NaN(NaN) | 0.499(0.48) | 4.853(0.028) |
| RSP500 | 1.211(0.271) | 0.499(0.48) | NaN(NaN) | 4.853(0.028) |
| RUSD | 2.412(0.12) | 6.772(0.009) | 6.772(0.009) | NaN(NaN) |

Table A25: Test statistics with p values in parenthesis of Safe Haven Analysis for period during crisis using 30% lower quartile observations. RGOLD, ROIL RSP500 and RUSD represent the returns of gold futures, oil futures, S&P500 Index and USD Index. The column gives the asset i and rows gives the asset j in equation 24.

| | RGOLD | ROIL | RSP500 | RUSD |
|---|---|---|---|---|
| RGOLD | NaN(NaN) | 1.724(0.189) | 1.724(0.189) | 5.853(0.016) |
| ROIL | 0.929(0.335) | NaN(NaN) | 1.086(0.297) | 2.949(0.086) |
| RSP500 | 0.929(0.335) | 1.086(0.297) | NaN(NaN) | 2.949(0.086) |
| RUSD | 0.259(0.611) | 1.006(0.316) | 1.006(0.316) | NaN(NaN) |

Table A26: Test statistics with p values in parenthesis of Safe Haven Analysis for period during crisis using 30% upper quartile observations. RGOLD, ROIL RSP500 and RUSD represent the returns of gold futures, oil futures, S&P500 Index and USD Index. The column gives the asset i and rows gives the asset j in equation 24.

$$\mathrm{RGOLD_t} = -0.097 + -0.0334 * \mathrm{ROIL_{t-1}} + 0.224 * \mathrm{RUSD_{t-1}} \pm -0.037 * \mathrm{RUSD_{(5\%),t}} \quad \text{(A1)}$$

$$\mathrm{ROIL_t} = -0.018 + -0.209 * \mathrm{ROIL_{t-1}} + 0.358 * \mathrm{RSP500_{t-1}} + -0.025 * \mathrm{RUSD_{(5\%),t}} \quad \text{(A2)}$$

$$\mathrm{RSP500_t} = -0.019 + -0.091 * \mathrm{ROIL_{t-1}} + -0.261 * \mathrm{RUSDl_{(5\%),t}} + \varepsilon_{\mathrm{SP500,t}} \quad \text{(A3)}$$

$$\mathrm{RUSD_t} = -0.008 + 0.021 * \mathrm{RGOLDh_{(5\%),t}} \quad \text{(A4)}$$

## A7.1 Pesaran-Timmermann test

We apply the Pesaran-Timmermann (PT) test to examine whether the CPS are significantly better than those from a random walk forecast. In this study the approach by Pesaran and Timmermann (1992) is used. Let $\hat{y}_t$ be the point forecast of time t and $y_t$ the real value at time t. Further assume that the total number of forecasts is equal to n. Then we introduce variables $Z_t = 1 \text{ if } \hat{y}_t y_t > 0$ , $\hat{P} = \frac{\sum_{t=1}^{n} Z_t}{n}$ and $P^* = \Pr(\hat{y}_t > 0)\Pr(y_t > 0) + (1 - \Pr(\hat{y}_t > 0))(1 - \Pr(y_t > 0$

The test statistic of PT test can be defined by equation A5

$$S_{PT} = \frac{\hat{P} - P^*}{\sqrt{\frac{P^*(1-P^*)}{n}}} \sim N(0,1) \qquad \text{(A5)}$$

## A7.2 Diebold-Mariano test

Diebold-Mariano (DM) test is introduced to test whether the differences in MAE and MSPE between models are significantly different by following the approach in Diebold and Mariano (1993). First consider model 1 and model 2 with their point predictions $\hat{y}_t^1$ and $\hat{y}_t^2$ at t and let $y_t$ be the real value at time t. The prediction errors of model i can be calculated using equation A6.

$$e_t^i = y_t - \hat{y}_t^1 \qquad \text{(A6)}$$

Further we introduce quadratic loss function $L(e_t^i) = \{e_t^i\}^2$ and the difference between the loss functions $d_t = L(e_t^1) - L(e_t^2)$. The test statistic can be calculated using equation A7.

$$S = \frac{\frac{1}{n} * \sum_{t=0}^{n} d_t}{\sqrt{\text{sample variance of } d_t}} \sim N(0,1) \qquad \text{(A7)}$$

The variance $LRV$ can be assessed by equation A8

$$LRV = \gamma_0 + 2\sum_{j=1}^{\infty} \gamma_j \text{ with } \gamma_j = \text{cov}(d_t, d_{t-j}) \qquad \text{(A8)}$$

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