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Volatility of Commodity Markets: Evidence from the Crude Oil Field

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Abstract

This paper studies price volatility determinants of the Brent, Dubai and WTI crude oils by means of Prais-Winston linear regression estimation. Particularly, 6 volatility estimators are considered, including the Parkinson, Garman-Klass and Yang-Zang intraday measures. We find evidence of the crucial and equally important influence of the USA and Russian macroeconomic news surprise component, while economic policy and geopolitical uncertainty do not impact crude oil price volatility. Surprisingly, the OPEC production quotas decisions do not affect Dubai price, while the OPEC reference basket price is highly significant for all types of oil considered. Finally, we assess the Yang-Zang estimator to deliver the most accurate results among considered volatility measures.

Key words: volatility, crude oil, crude oil price volatility, macroeconomic news, investors' expectations, OPEC

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Chapter 1: Introduction

Nowadays, with petroleum being a primary energy source, its price appears to be one of the main world economy's performance and condition indicators. Even though natural reserves of crude oil are limited and in the nearest future it is foreseen to give way to alternative power sources, it retains its' positions as both energy feedstock and financial benchmark.

Throughout the years oil has been gaining substantial influence over the world economy mainly as the primary source of energy. Supposedly, some of its features such as cheapness, accessibility and ease of use encouraged men to find more and more ways to apply it. Along with the development of technologies, this fuel became involved in the manufacturing process of a vast variety of goods and commodities. Transportation sector would not have developed as quickly as it was possible by dint of oil. Since oil is also used for heating purposes, its price is one of the main determinants of energy costs for individual consumers such as households and SME. Thereby, it became an essential part of our lives and the world economy.

Furthermore, the role of this fuel is dual. For petroleum-producing countries oil represents not only an energy source, but also an important export item and a considerable GDP component. Large funds coming from petroleum and its derivatives realization replenish state budget which is at a later stage used for state procurements aimed at public and social sectors' welfare increase. Such degree of dependence causes great sensitivity of the economy to any fluctuations in oil demand and supply, as well as natural resources depletion. In particular, the limited resources problem is an issue of great concern for economies of the Russian Federation and OPEC countries. For these countries incomes from production and marketing of petroleum products appear to be a major source of income. It is clear that once natural resources are exhausted, these countries would face significant financial difficulties. And yet, it requires some time for the economy to substitute this source of income, therefore, at the moment crude oil price remains to be one of the most significant economic indicators.

Moreover, given strong interconnection of all economic markets nowadays, crisis on one of them initiates the "domino effect" and leads to a collapse on other markets. Among other, oil shocks could lead to some aftermath in financial markets, therefore, it becomes clear that oil price

movements' analysis, and namely revealing main determinants of its price volatility, would allow researchers to forecast and smooth oil price shocks and, hence, prevent some potential future crises.

In consideration of the above-described degree of petroleum integration into the world economy and production process, as well as the high sensitivity of financial markets to changes in crude oil demand and supply, it becomes doubtless that this field of energy market should be closely monitored and studied carefully. All these causes lead us to the main fundamental question: what are determinants that drive crude oil prices?

Over past decades crude oil price has shown an extreme degree of volatility which, in turn, resulted in collapses in various connected markets. As it has been noted by many specialists in the area and academic papers, the price of oil is highly sensitive to various macroeconomic indicators. On the other hand, one might also argue that oil nowadays appears to be a political leverage and indicator, at the same time. Finally, it is widely believed that OPEC plays a leading role on the oil market in general and in the crude oils price determination, in particular. Oil price shocks take place every time any breaking news comes out even when this news is not directly connected to the energy market. Thus, it comes into question whether it can be scientifically proven that macroeconomic and non-economic (political, social etc.) news, political and economic instability, as well as news concerning OPEC have a statistically significant impact on the crude oil price volatility.

Based on the above-described complex issue currently present on the oil market as a particular case of commodity markets, the following narrowed research question arises. Do the news announcements, and namely macroeconomic news coming from the USA and Russia, as well global non-macroeconomic (geopolitical) news, have statistically significant explanatory power over the crude oil price volatility?

Chapter 2: Literature review

Existing academic literature covers the energy field and, in particular, volatility of commodity markets. Among others, oil price movements' analysis is conducted in context with macroeconomic news announcements. This section is devoted to a review of the most relevant academic papers and their results correlation with the purpose of the present study.

The main paper that the present research relies on is Smales (2017). The paper is aimed at answering the question whether macroeconomic news announcements coming from the USA and China influence commodity markets and covers the period of 1997-2017. Two main commodity indices are included into consideration: the Commodity Research Bureau Index and the S&P Goldman Sachs Commodity Index. In order to answer the proposed research question, the study introduces and estimates four distinct volatility measures of these indices. Linear regression model coefficients are estimated. As to the explanatory variables, the main contribution is brought by introduction of a macroeconomic news surprise component which is estimated as the actual announced macroeconomic variable value reduced by its expected value reported in the Bloomberg Survey and scaled by its volatility. Apart from this set of variables, a series of other factors is included in the model which are supposed to cover the following aspects: state of economy (implied volatility index, 3-month T-bill rate, and differences between 2- and 10-year T-bill rates and between AAA and BBB bonds), as well as dummy variables indicating the day of the week and the 2008-2010 economic crisis presence. The paper concludes that a positive relationship between key macroeconomic variables announcements is present. These results are consistent across all the introduced volatility indicators. Finally, news coming from the USA appear to be more important than Chinese news.

A great number of papers covers the OPEC meetings and conferences influence on the oil price changes. We start by analyzing Lin & Tamvakis (2009). This paper focuses exclusively on the quotas decisions established during the OPEC meetings and announced via media at the end of these conferences as the major explanatory variable. As to the dependent variable, the scope includes several types of oils distinct across their chemical features. Additionally, some of them are also included in the OPEC basket which allows for more robust results. The methodology of the research is represented by event study and focuses on the accumulated abnormal returns. Authors of the paper report the following results. First, only OPEC announcements of quotas cuts

have statistically significant influence on the oil prices returns. Second, there is no significant difference depending on the OPEC basket belonging, as well as chemical features. Finally, price environment and media coverage that the meetings receive also matter in terms of crude oil price changes.

A study in the similar direction is represented by Schmidbauer & Rösch (2010). The methodology proposed by the authors introduces a set of dummy variables reflecting the announcement of OPEC decision with respect to quotas (cut, increased or unchanged) as regressors and series of oil price returns and its conditional variances as independent variables. Similarly to Lin & Tamvakis (2009), this paper founds some asymmetry according to the type of decision made by OPEC: reporting of quotas' increase does not have any significant influence on the oil price volatility, whereas the other two types of announcements seem to be taken into account by the market participants. Moreover, the paper observes that the volatility effects are substantially stronger in the pre-announcement periods which indicates the degree to which these announcements matter for oil price establishment and correction process.

There exist different ways in which macroeconomic, as well as political news are included into the scope of analysis. For example, Karali & Ramirez (2013) create a dummy variable of "major political news" that reflects several events such as Asian crisis (1997-1998), OPEC structural changes, the terrorist attack of 11.09.2001, Iraq war, hurricane Katrina and the world financial crisis of 2008. The main focus of the study is on the energy futures market, therefore, covers not only oil, but also natural gas. According to the reported results, that the above-mentioned events had a strong increasing impact on the crude oil price volatility, whereas the included macroeconomic variables had statistically insignificant coefficients when modeling the crude oil price volatility. The obtained findings, as well as the methodology implemented by the authors is highly interesting, relevant and useful for the purpose of the present research.

Findings of the two previous papers are supported by the evidence reported in King, Deng & Metz (2012). It is interesting to note that being employed by an economic, finance and econometric consultancy firm, authors belong to a "practical part" of researchers of the topic which ensures some kind of diversification of results reported included in the present study. Authors adhere to a similar concept and include both economic and political news into the scope of analysis. Notably, no news index or other well-known composite is used, rather the researchers create the

corresponding variable by themselves, revealing, estimating and manually sorting news into categories (natural disasters, politics, economy, inventory and speculation) and sub-categories. On average, political news dominated in terms of influence on the oil price changes, however, during the financial crisis of 2008-2010 economic news took the lead. As to the crude oil demand and supply, the authors find that "both OPEC actions and unexpected news about inventory levels had significant effects on oil prices". Most importantly, it is shown that not only there is this relationship, but also that the mechanism in charge of it is complex and even if in the short run oil price does not move in line with the other components, in the long run it returns back to the optimal level forecasted by this relationship.

Along with the macroeconomic news announcements a growing number of academic papers also takes into consideration influence of the overall economic situation on the oil price changes and volatility. For instance, Wei et al. (2017) takes into consideration the Economic Policy Uncertainty index (EPU) which is composited both locally (for every country and region) and globally. Due to a great interconnection degree of both geographical markets and different kinds of financial markets, it is assumed and proved that this group of indices has great explanatory power with respect to price changes of all kinds of financial assets, including stocks, bonds, but also commodities such as crude oil. In particular, Wei et al. (2017) investigates which one of the considered determinants, and namely crude oil demand and supply, speculation or the EPU index, provides the best explanation of the observed oil market volatility. Lead by example of many other academic articles on the topic, as econometric model specification the paper uses some of the (G)ARCH- family models and concludes that the Global EPU and the U.S. EPU indices have the strongest explanatory power in the estimated econometric model.

Another idea of a possible explanation of crude oil price volatility is reported in Bradley & Farooq (2017). By means of modified iterated cumulative sums of squares inclusion into an asymmetric GARCH model authors provide evidence of the structural breaks parameter importance among the oil price volatility determinants. The most relevant and important conclusion derived by the paper is the fact that when accounting for structural breaks persistence the estimated model provides much more precise results and both positive and negative news announcements have more explanatory power.

Finally, since the main purpose of the present research is volatility estimation and explanation, the paper of Chou et al. (2010) is included. Authors consider different volatility measures using one-day open, closing, highest and lowest prices. In more details these volatility estimations are covered in the methodology chapter.

Even though some of the reviewed academic literature in terms of econometric model is based on analysis of the (G)ARCH-family models, these papers are included into consideration mainly in order to get some inspiration on the determinants of the crude oil price volatility. In the following section, we propose a unique combination of explanatory variables selected from the variety of all the considered factors in order to establish the most accurate and closest to reality econometric model.

Chapter 3: Methodology

This section introduces the proposed econometric model and its components. We begin by determining hypotheses corresponding to the proposed research question, introduce and define several volatility estimates. Then we proceed with identifying independent variables and explaining why it is most optimal to select them and how these particular factors would improve the quality of research. Finally, we formulate an econometric model by means of a regression equation that should allow us to test the proposed hypotheses validity.

Chapter 3.1: Hypotheses

In line with the proposed research question we formulate the following hypotheses:

1. Does the macroeconomic news so-called "surprise component" have statistical significance when modeling the crude oil price volatility?

   Hypothesis 1: *Excess of announced macroeconomic news values over the projected (forecasted) values has statistically significant influence on the crude oil price volatility*

2. How do the OPEC decisions impact the crude oil price changes?

   Hypothesis 2a: *OPEC decisions regarding quotas of oil production have statistically significant influence over the crude oil price volatility*

   Hypothesis 2b: *OPEC decisions influence is equally significant for Brent, Dubai and WTI crude oil price volatility.*

3. Do non-macroeconomic (political, social etc.) news announcements and the current geopolitical situation influence crude oil price volatility?

   Hypothesis 3a: *Major global events have statistically significant influence on the crude oil price volatility*

   Hypothesis 3b: *Geopolitical Risk index has statistically significant influence on the crude oil price volatility*

4. Do crude oil price volatility determinants differ in their influence depending on the type of oil?

   Hypothesis 4: *There is no statistically significant difference between WTI, Brent Crude and Dubai Crude types of oil, when modeling determinants of their price volatility.*

Chapter 3.2: Volatility estimation

Following the logic of Smales (2017) and based on the Chou et al. (2010), we introduce several volatility measures. The following symbols are introduced for daily crude oil prices:

- O_t – opening price
- C_t – closing price
- H_t – day t highest price
- L_t – day t lowest price

The first estimator introduced is simply defined as:

$$Vol_{1,t} = |R_t| = \left|\frac{\ln(C_t)}{\ln(C_{t-1})} - 1\right| \quad \textbf{[1]}$$

where R_t represents closing price on the corresponding day *t*.

Secondly, we use several advanced volatility estimators. Firstly, it is the one introduced by Parkinson (1980). Instead of accounting for day-to-day changes, this measure focuses on the intraday price (low-high) range and is defined as:

$$Vol_{2,t} = \frac{1}{4ln2}(\ln H_t - lnL_t)^2 \quad \textbf{[2]}$$

However, as also stated in Bennett and Miguel (2012), a drawback of this measure is that it assumes continuous functioning of the financial market and does not account for natural volatility jumps between the moments of market closure and opening. Therefore, one might argue that this measure underestimates the volatility.

In the following researches on the topic, the Parkinson volatility measure was extended in Garman and Klass (1980) in order to additionally account for the difference in opening-closing daily prices and, as a consequence, the third volatility measure is formulated as:

$$Vol_{3,t} = \frac{1}{2}\left[\ln\left(\frac{H_t}{L_t}\right)\right]^2 - [2ln2 - 1]\left[\ln\left(\frac{C_t}{O_t}\right)\right]^2 \quad \textbf{[3]}$$

Nevertheless, this estimator accounts for more factors if compared to the one introduced by Parkinson, it still underestimates volatility due to the fact that it does not incorporate information on the overnight volatility jumps.

In order to overcome this issue and capture the overnight volatility jumps, we introduce an extension of the Garman-Klass by Yang-Zhang:

$$Vol_{4,t} = \frac{1}{2}\left[\ln\left(\frac{H_t}{L_t}\right)\right]^2 + \left[ln\left(\frac{O_t}{C_{t-1}}\right)\right]^2 - [2ln2 - 1]\left[\ln\left(\frac{C_t}{O_t}\right)\right]^2 \quad \textbf{[4]}$$

The added logarithm of opening price of day *t* divided by the close price of day *t-1* allows for accounting of overnight jumps. However, it still assumes the drift term to be zero and, thus, volatility is overestimated when the mean return is not equal to zero.

Furthermore, the above estimations of volatility were based on the assumption of a zero-drift. However, there are times when this assumption does not hold and the above-introduced estimators will overestimate volatility in these cases. Also supported by the arguments introduced in Rogers and Satchell (1991) and later in Smales (2017), the following concept is designed. This specification allows for a non-zero drift term which is added as an extension of the previously defined volatility estimators:

$$Vol_{5,t} = \ln\left(\frac{H_t}{O_t}\right)\left[\ln\left(\frac{H_t}{O_t}\right) - \ln\left(\frac{C_t}{O_t}\right)\right] + \ln\left(\frac{L_t}{O_t}\right)\left[\ln\left(\frac{L_t}{O_t}\right) - \ln\left(\frac{C_t}{O_t}\right)\right] \quad \textbf{[5]}$$

Finally, to combine both solutions in one estimator we introduce the Yang-Zhang (2000) drift independent specification which is determined as follows:

$$Vol_{6,t} = Vol_{overnight,t} + kVol_{open-to-close,t} + (1-k)Vol_{5,t} \quad \textbf{[6]}$$

$$\text{where } k = \frac{0.34}{1.34 + \frac{N+1}{N-1}}$$

$$Vol_{overnight,t} = \left[ln\left(\frac{O_t}{C_{t-1}}\right) - \overline{ln\left(\frac{O_t}{C_{t-1}}\right)}\right]^2$$

$$Vol_{open-to-close,t} = \left[ln\left(\frac{C_t}{O_t}\right) - \overline{ln\left(\frac{C_t}{O_t}\right)}\right]^2$$

In many cases this last estimator is considered as the most accurate one, however, if the volatility is to the greatest extent dominated by overnight jumps its accuracy decreases significantly. Therefore, we assume $Vol_{6,t}$ to deliver better results than the other estimators, but we do not exclude that in some cases it might underperform.

Chapter 3.3: Explanatory variables

Further, we introduce the set of explanatory variables and begin with the group of news factor and its surprise component. We separate them into macroeconomic news and non-macroeconomic (political, social etc.) news. Macroeconomic news, to be more precise, are represented by their surprise component which is defined as

$$S_{j,t} = A_{j,t} - E(A)_{j,t} \quad \textbf{[7]}$$

Where $A_{j,t}$ stands for the announced value of each particular macroeconomic variable (j) value in the period t, $E(A)_{j,t}$ – expected value of the corresponding variable reported prior to the announcement. We express this expectation of macroeconomic variables values by means of the World Economic Survey (WES). This is a survey filled in by investors and economic specialists across the globe. Questions are formulated in the following way: "*Do you expect the value of* [a macroeconomic variable in the corresponding country] *to increase, decrease or stay the same over the coming month/ quarter/ year?*" Thus, respondents are not asked to predict a certain value, but rather to determine the direction of change should it take place. Due to existence of the overconfidence phenomenon which influences behavior of investors, corporate managers and economists to a great extent, we believe that answers to questions of such phrasing truly reflect investors' expectations. It is assumed that not only reported absolute macroeconomic values, but also the actual deviation from their expected values creates uncertainty about the future and, thus, influences volatility. We focus on this issue with respect to investors' uncertainty coming from the USA as the world leading economy and Russia as one of the world greatest oil exporting countries.

In particular, with respect to the surprise component we consider the following macroeconomic factors: Gross Domestic Product (GDP), Inflation (CPI), Import, Export, Capital

Expenditures and Consumption. These variables represent the main fields of economic activities and usually are referred to as main economic indicators by market participants.

To complement the impact of macroeconomic variables we also include into consideration an economic growth rate proxy for the same countries: the USA and Russia. Macroeconomic variables surprise component discussed above allows us to capture investors' expectations and sentiment whereas we also believe it to be important to capture the overall economic perspective of these two economies. Therefore, for the same measures as in the macroeconomic surprise component, we have measured the growth rate of corresponding variables and then summed them up separately for the United States and Russia. In this way we obtained two variables US_GR_t and Rus_GR_t which represent the joint growth rate of the 8 major macroeconomic variables for both countries. It must be noted that these variables do not represent the conventional economic growth rate usually calculated and published by governmental statistical agencies, but rather a proxy of the key macro factors' real growth assuming all the included variables to be equally important.

Moreover, apart from this uncertainty we also want to capture the effect of the overall economic policy led by the government. Economic expansion (recession) creates additional incomes (losses) which, in turn, influence purchasing power, consumption and production levels and, thus, oil prices. Economic authorities that in the first place are responsible for economic growth and prosperity sometimes make decisions that the market participants find improper or harmful for their business. If the government fails to gain investors' confidence about its actions, investors might leave the market the minute they disagree with the government decisions and feel they might incur losses. For this reason, the Economic Policy Uncertainty Indices[1] are included into consideration. They reflect market participants' uncertainty regarding the potential actions of a particular country economic authorities. These indices are composed both globally and locally (by region). We assume it to be reasonable to include the following specifications of the EPU: global ($GEPU_t$), the USA (US_EPU_t) and the Russian (Rus_EPU_t), since among the petroleum-producing countries the USA and Russia play leading role.

As to the non-macroeconomic news, firstly, we follow the approach of Karali & Ramirez (2013) and manually create a categorical variable – ME_t – that reflects the presence of any major world community events reflected by the media. To support our choice and minimize subjectivity

[1] E-source: National and Regional EPU Indices

of such a selection we rely on several e-resources and media reporting lists of the most important and influencing events of each particular year or century[2]. This variable equals to 1 in presence of any positive events that stabilize oil prices, to -1 if any events negatively influencing volatility took place and 0 otherwise.

Secondly, apart from major and global, there also were various local and less significant events that, nevertheless, were likely to be reflected in the crude oil price volatility. Therefore, in order to capture the overall geopolitical context, we include the Geopolitical Risk Index[3] (GPR_t). This index is composited monthly and based on the major national and international newspapers headings. Even though the composition methodology of GPR Index leads to a partial replication of the before introduced variable ME_t values, an undeniable advantage of this Index is the fact that it covers the overall global condition of society, while the Major Events variable distinctly highlights the most striking news and is more directed to reflect the so-called media effect. Therefore, we believe that it is useful to include both of them – ME_t and GPR_t – in order to reveal and separate the influence of these two sub-categories of non-macroeconomic news.

Based on the fact that OPEC is one of the major crude oil market players and inspired by many preceding studies we also include the OPEC conferences decision and namely announcements regarding oil production quotas established in the course of negotiation of participating countries. For this purpose, following Schmidbauer & Rösch (2010) example we create a categorical variable – $OPEC_t$ – that distinguishes between the following cases: quotas are increased, decreased and remain unchanged. The actual announcements of OPEC conference decisions are collected from the OPEC press releases published on the website[4].

Besides the determined production quotas which directly reflect the crude oil supply, we also introduce the OPEC reference basket price which is composed of weighted daily prices of crude oils produced by OPEC member countries. In addition to the quantity of supply, this variable allows us to include the absolute crude oil prices factor into consideration and, thus, capture the impact of OPEC as a trendsetter on the world crude oil market.

[2] E-source: CFR, The Most Important Historical Events of the 20th Century
[3] E-source: Geopolitical Risk Index
[4] E-source: OPEC press releases

Moreover, crude oil is not only one of the main constituents of commodity exchanges, especially among the energy sector, but also participates in financial markets since many derivative instruments are base on it as an underlying asset. Therefore, in order to capture the financial markets activity, we also include into consideration a set of several national stock indices. Assuming that crude oil price derivative contracts, among others, are used for hedging purposes, we suppose that activity on financial markets also partially determines the oil price volatility. Therefore, daily returns of the following indices are included:

- IDJ (Islamic Dow-Jones index)
- MICEX (Russian stock market index)

Apart from the above-described variables representing different parts of financial markets and geopolitical context we also introduce common for such studies dummy and categorical variables:

BC_t – Business cycle

We introduce a business cycle categorical variable that is constructed based on the National Bureau of Economic Research[5] data of business cycles expansions and contractions. The following values are assigned according to the corresponding phase of economy states: 1 – recession, 2 – crisis, 3 – recovery, 4 – peak.

$BC_t * US\_GR_t$ – Intercept of Business cycle and the USA economic growth rate

$BC_t * Rus\_GR_t$ – Intercept of Business cycle and Russian economic growth rate

These intercept variables allow us to draw attention to the fact that economic growth is usually corresponding in some way to the economic cycles.

SB_t – Structural break

This variable detects any distinct changes in the behavior of the volatility measures that might result in a corresponding dramatic change of coefficient estimates that cannot otherwise be captured by the model.

$Week_t$ – Days of the week

[5] E-source: The National Bureau of Economic Research

A categorical variable with values assigned to days of the week from Monday to Friday varying from 1 to 5, respectively.

Chapter 3.4: Model specification

Having determined and described dependent and explanatory variables and their construction methodology, we now introduce the econometric model.

$$Ln(Vol_{i,t}) = \alpha_o + \sum_{1}^{8} \beta_m USMacro_{m,t} + \sum_{1}^{8} \gamma_n RusMacro_{n,t} + \alpha_1 GEPU_t + \alpha_2 US\_EPU_t + \alpha_3 Rus\_EPU_t + \alpha_4 GPR_t + \alpha_5 OPEC_t + \alpha_6 ORB_t + \alpha_7 US\_GR_t + \alpha_8 Rus\_GR_t + \alpha_9 SB_t + \alpha_{10} ME_t + \alpha_{11} MSCI_t + \alpha_{12} IDJ_t + \alpha_{13} MICEX_t + \alpha_{14} BC_t + \alpha_{15} BC_t * US\_GR_t + \alpha_{16} BC_t * Rus\_GR_t + \alpha_{17} Week_t + u_t \quad \textbf{[8]}$$

where $Vol_{i,t}$ is estimated for each of every six introduced price volatility measures of every of the three selected crude oil types (Brent Crude, Dubai Crude and WTI) and we also impose the log-transformation of volatility variables. Thus, we estimate 18 regression equations (6 volatility measures for 3 types of oil). Finally, $USMacro_{m,t}$ and $RusMacro_{n,t}$ represent corresponding sets of macroeconomic news surprise components for each of the selected macroeconomic factors.

In order to fully specify the regression model, we introduce the following assumptions:

1. Linear relationship between volatility measures and explanatory variables; this assumption can be tested by means of plotting residuals versus independent variables. If this assumption does not hold, a non-linear transformation might be used.
2. Multivariate normality: u_t follows the normal distribution; can be assessed by means of the Jarque-Bera test. Similarly to the previous assumption, violation of this point can be resolved by applying non-linear transformation.
3. Absence of multicollinearity: independent variables are not correlated. In order to determine it, we use the variance inflation factor (VIF), which is determined as $VIF = \frac{1}{1-R_i^2}$. Ideally, VIF should not be higher than 2.5 (or 5), then we can conclude there is no multicollinearity (or it is moderate). If multicollinearity is present, we need to identify correlated regressors by alternately excluding them

from the regression; once correlated predictors are identified, they are to be either excluded or combined.

4. Absence of autocorrelation; to identify its presence we use the Durbin-Watson test. If there is pure autocorrelation, the corresponding adjustment of the initial regression equation might resolve the issue.
5. Homoscedasticity: identical variance of error terms of explanatory variables. Can be assessed by implementing the Breusch–Pagan test. If there is heteroscedasticity, a transformation of the predictor variable might help (square root, log, reciprocal transformation depending on the type of violation)

Chapter 3.5: Interpretation

We have determined volatility measures which are included in the regression equation as dependent variables and the set of explanatory variables. We expect that most predictors will have a positive influence on volatility measures, in particular, macroeconomic news surprises, EPU and GPU indices (as long as these variables represent different kinds of uncertainty) and the Major Event variable. In other words, we expect that with a rise of uncertainty represented by these factors, the volatility of crude oil price should increase. On the other hand, we expect that the growth of OPEC quotas would decrease uncertainty and the global oil price and, thus, decrease the volatility. The concrete degree to which each of the introduced variables influences the oil price volatility is determined by estimates of coefficients introduced by the Equation 8. Given a more advanced methodological approach of this research that includes log-transformation, obtained coefficients do not represent the direct connection between dependent and independent variables, but should primarily be converted accordingly. Moreover, we also assess the statistical significance of estimated coefficients and draw a conclusion based on both factors: significance level and the absolute value of the estimated coefficient. Finally, the adjusted R-squared summarizes the overall accuracy of the model specification and explanatory power.

Chapter 4: Data

Chapter 4.1: Analysis of crude oil types

A vast amount of academic literature covers the issue of volatility of commodity markets. Each separate paper usually focuses on a specific set of variables testing some rather narrow-focused hypothesis. In this light, one of the main contributions of this paper is its integration of antecedent works results. Thus, incorporation of various views on the problem leads to the following selection of dependent variables.

It is a common knowledge that nowadays over 160 types of oils are distinguished based on their chemical characteristics and, hence, areas of implementation. Moreover, the present research, among other things, is also based on the idea of significant OPEC influence on the oil market. Consequently, in order to diversify outcomes of the research and exclude any potential dependence of the outcomes on the crude oil type we partially replicate the approach of Lin & Tamvakis (2009). The idea is to include into consideration several types of crude oil distinct in their chemical characteristics and markets of trading and exploitation. We believe that this measure would not only allow us to compare the empirical results for different types of oil, but also ensure robustness of these results. Finally, we believe that it is important given such a vast variety of oil types to understand which particular oils we include into consideration, in which areas they are used and who is the main source of demand on these oil types.

In order to identify which oil types are the most reasonable to be included into consideration, in this section we provide a brief description of the existing crude oil types' segregation and its characteristics. There exist 3 widely spread characteristics of crude oils:

1. Viscosity; "measure of a fluid's resistance to flow. It describes the internal friction of a moving fluid"[6]; the higher viscosity, the least easy it is to subtract it from the ground
2. Volatility; "describes how quickly and easily the oil evaporates into the air. Higher volatility oils need additional processes to control their environments during extraction to ensure that as little oil as possible is lost."[7]

[6] E-source: Princeton University web-site
[7] E-source: The four main types of crude oil

3. Toxicity; "refers to how poisonous and harmful the oil is to the environment, wildlife, and humans during the extraction and refinement process. When oil spills do occasionally occur, each oil poses different challenges and priorities during the cleanup."[8]

As to the above mentioned chemical features, following primary groups are distinguished:

Type	Viscosity	Volatility	Toxicity	Examples
Very light oils	low	high	low	*Jet Fuel, Gasoline*
Light oils	low	moderate	moderate	*Diesel Fuel Oils*
Medium oils	moderate	low	moderate - high	most of *Crude Oils*
Heavy fuel	very high	very low	very high	*Heavy Marine Fuels*

Table 1 – Primary types of crude oils

Moreover, there are 4 most well-known market sorts of oil that attract the most attention both on the market and in the news:

- West Texas Intermediate (WTI); using the above described grouping principle, WTI is a very light oil and is mostly used for gasoline production and consumption within the USA;
- Brent Blend; belonging to the light oils group, mostly produced and consumed in Europe, but also worldwide;
- Dubai Crude; a medium sour crude oil, serves as an indicator of oil price in the Persian Gulf region;
- OPEC basket; represents a weighted average combination of 14 different oil types produced by the OPEC members[9].

[8] E-source: The four main types of crude oil

[9] Saharan Blend (Algeria), Girassol (Angola), Oriente (Ecuador), Zafiro (Equatorial Guinea), Rabi Light (Gabon), Iran Heavy (Islamic Republic of Iran), Basra Light (Iraq), Kuwait Export (Kuwait), Es Sider (Libya), Bonny Light (Nigeria), Qatar Marine (Qatar), Arab Light (Saudi Arabia), Murban (UAE) and Merey (Venezuela); E-source: OPEC web-site

While the first three types of oil are involved in the daily trading on commodity and financial markets and, thus, provide all the data needed in order to calculate the proposed volatility measures, the OPEC basket price is determined as a weighted average based on the constituents' daily quotations and does not provide open, close, high and low estimations.

Based on the above-conducted analysis, we conclude that within the framework of the present analysis it is most optimal to focus on the $WTI_t, Brent_t$ and $Dubai_t$ crude oil prices volatilities as dependent variables, which would ensure the desirable level of diversification of the study.

Chapter 4.2: Analysis of dependent variables

In this section we represent data through descriptive statistics, graphs and statistical tests. Based on the availability of data, the period under consideration covers 15 years from 2003 to 2017 inclusively. We begin by analyzing the characteristics of the crude oils price.

	No of observations	**Mean**	**Max**	**Min**	**Skewness**	**Kurtosis**	**StDev**	**Variance**
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Brent	3820	73.49	148.13	23.47	0.14	-0.97	27.92	779.30
Dubai	3820	68.71	145.41	25.31	0.30	-0.76	24.53	601.49
WTI	3820	69.51	131.22	23.38	0.22	-1.22	28.91	835.92

Table 2 - Crude oil price descriptive statistics

As can be seen from the Table 2, all the three types of oil exhibit similar results. Nevertheless, we can observe the fact that the Dubai price volatility is lower compared to both Brent and WTI crude oil price volatilities and higher skewness at the same time. We could suppose that these differences are due to different quantities of demand on these oils: while Brent and WTI are widely spread worldwide, are traded on almost all the exchanges and appear to be underlying series for many derivative instruments, Dubai oil is obviously less common, even though it is still one of the world leading crude oil benchmarks.

Figures 1 – 3 represent the dynamics of oils price over the period under consideration. These series are not the dependent variables themselves, however, since we introduce several

volatility measures, we find it more efficient to begin by analyzing dynamics based on oil prices in levels and make some conclusions about common tendencies.

Obviously, all the three lines follow the same pattern: rapid growth up to October 2008 with a peak of around 120 – 140 USD per barrel is followed by a sharp decline until May 2009 with the prices falling down to the mark of 40 USD per barrel. After crisis prices recovered during the following 3 years again reaching the level of approximately 120 USD per barrel with another sharp drop in 2014 for Brent and WTI and a bit later (in 2015) for Dubai. Finally, at the end of the period under consideration prices were recovering again, however, not reaching the preceding peak of 120 USD per barrel, but rather being equal to 40-60 USD per barrel depending on the type of oil.

Figure 1 – Brent crude oil price, USD per barrel

Figure 2 – Dubai crude oil price, USD per barrel

Figure 3 – WTI crude oil price, USD per barrel

However, this research focuses on the volatility of crude oil price, therefore, we also analyze the dynamics of the 6 selected volatility measures. First of all, we introduce the Brent crude oil price Vol1 – Vol6 estimators represented by Figures 4 – 9. As it can be easily observed, all the 6 measures deliver very similar results, excluding the Vol1 which was calculated based on the closing prices only. As expected, in this case, volatility of the oil price is overestimated and is less accurate than the more advanced measures Vol2 – Vol6. Interestingly, despite different calculation approaches, the overall dynamics of these estimators is the same: rather moderate volatility with a major peak around September 2009 and increasing volatility after January 2016.

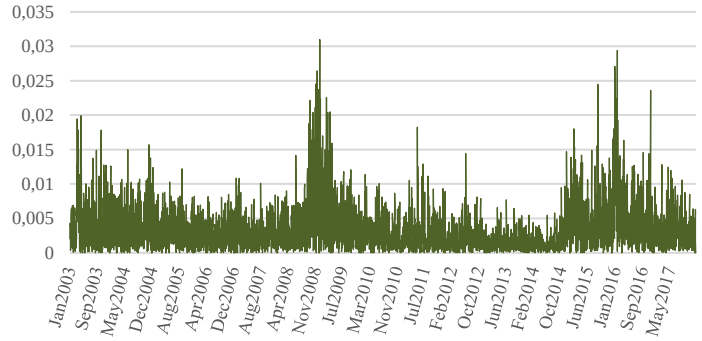

Figure 4 – Vol1 estimated for price of Brent

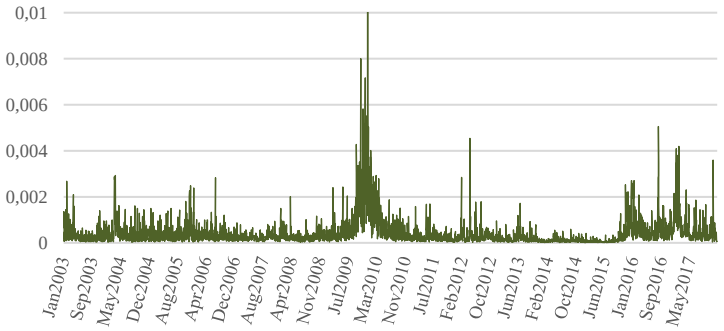

Figure 5 – Vol2 estimated for price of Brent

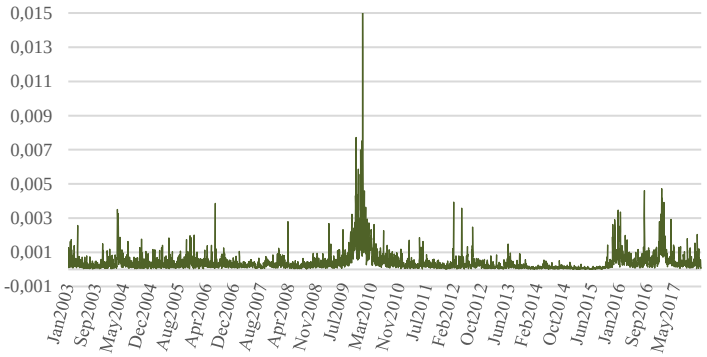

Figure 6 – Vol3 estimated for price of Brent

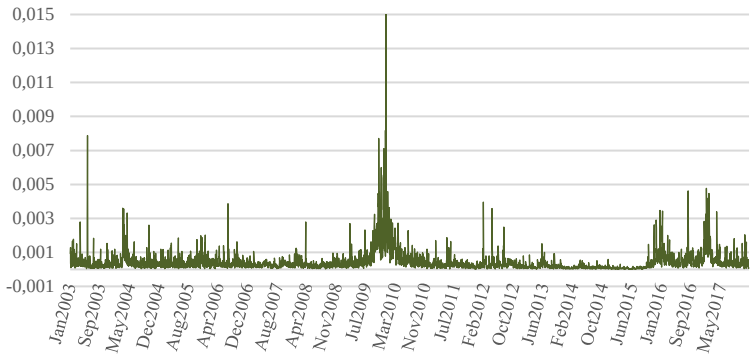

Figure 7 – Vol4 estimated for price of Brent

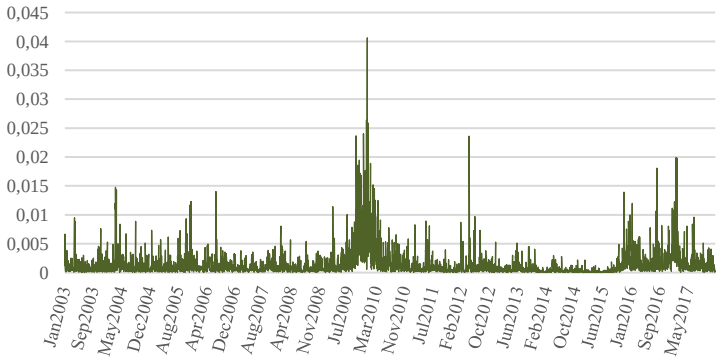

Figure 8 – Vol5 estimated for price of Brent

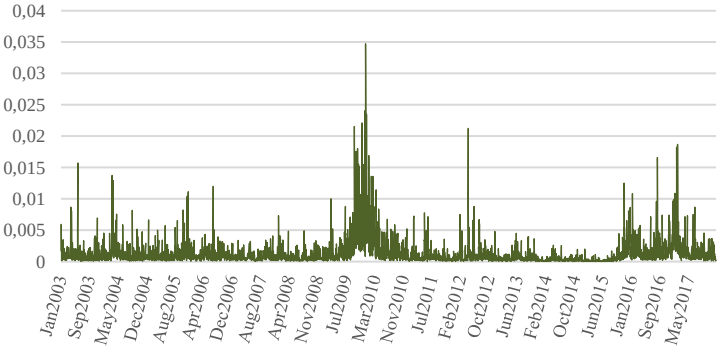

Figure 9 – Vol6 estimated for price of Brent

Moreover, we provide the same graphs of Vol1 – Vol6 estimators for the Dubai crude oil price. Compared to the Brent, volatility patterns are different: low volatility until 2006 is followed by some single jumps in 2006 – 2008 and the higher average volatility afterward. In contrast to the Brent volatility that exhibits a single peak, there were several Dubai volatility spikes. Even though the average volatility, as well as the value of its jumps varies across estimators, we again observe very similar volatility patterns across Vol2 – Vol6, while the Vol1 exhibits significantly stronger fluctuations overestimating oil price volatility.

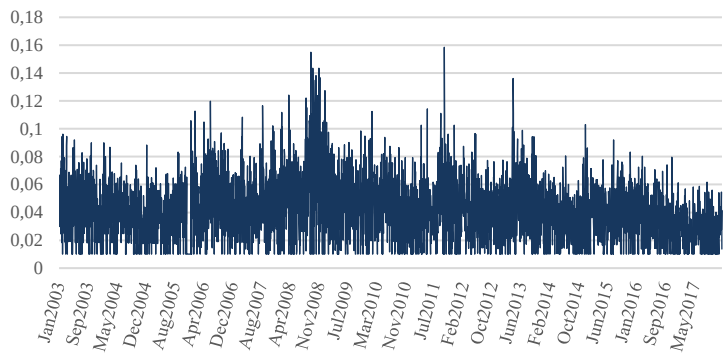

Figure 10 – Vol1 estimated for the price of Dubai

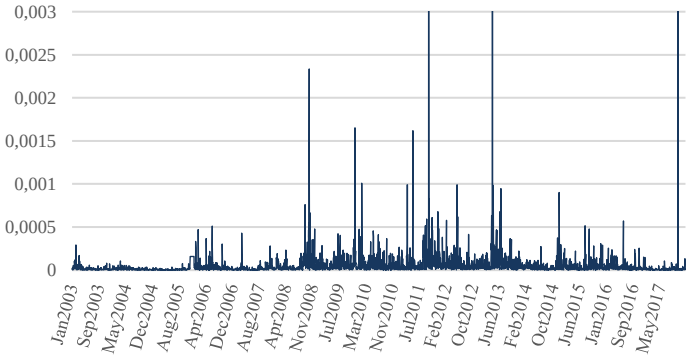

Figure 11 – Vol2 estimated for the price of Dubai

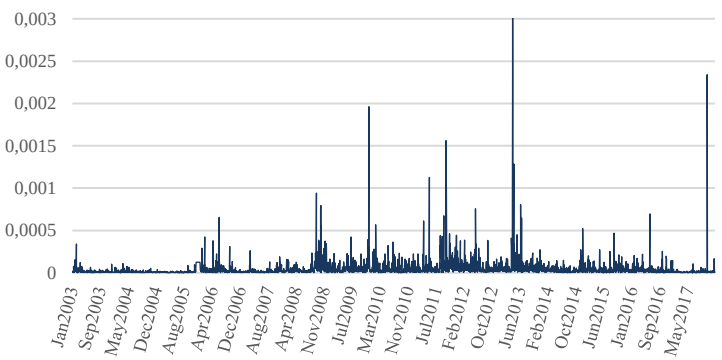

Figure 12 – Vol3 estimated for the price of Dubai

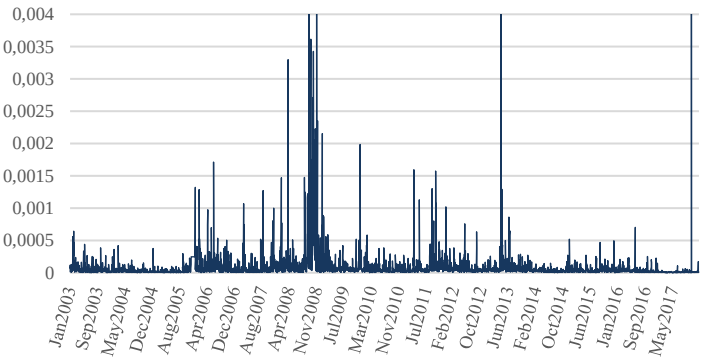

Figure 13 – Vol4 estimated for the price of Dubai

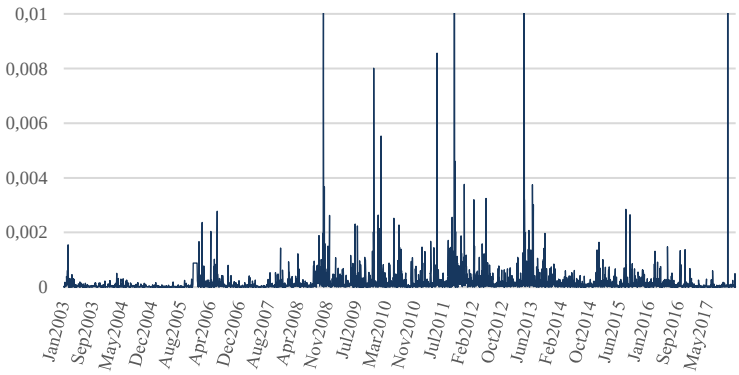

Figure 14 – Vol5 estimated for the price of Dubai

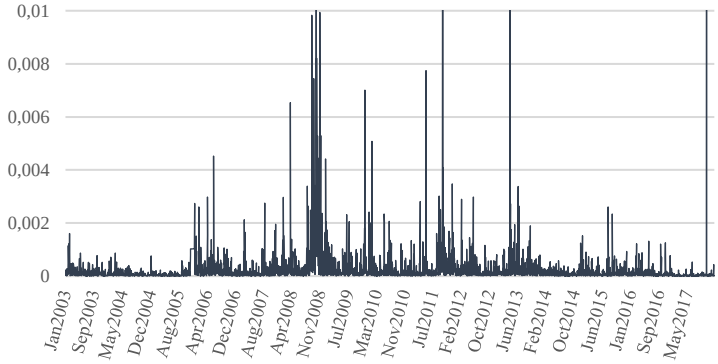

Figure 15 – Vol6 estimated for the price of Dubai

We conclude the dependent variables analysis by the WTI crude oil price volatility. In this case the observed volatility tendencies are very similar to the ones of Brent crude oil price. However, there are some distinctions: the WTI price volatility experienced an intense jump around November 2008 - somewhat earlier than Brent's volatility did. This can be explained by the fact that the recession that grew into the world economic crisis originated from the USA housing and later financial markets in 2006-2008 and then spilled over to the connected economies. Therefore, we observe the same tendency for Brent with a substantial lag. Moreover, the attenuation of volatility that followed the world economic crisis also ended earlier for WTI: around October 2014 it reached its lowest value and from that moment onwards the upward trend of volatility is noticeable. Similarly to the two previous cases, Vol1 estimator again provides overvalued volatility assessments both in terms of absolute values and the magnitude of fluctuations.

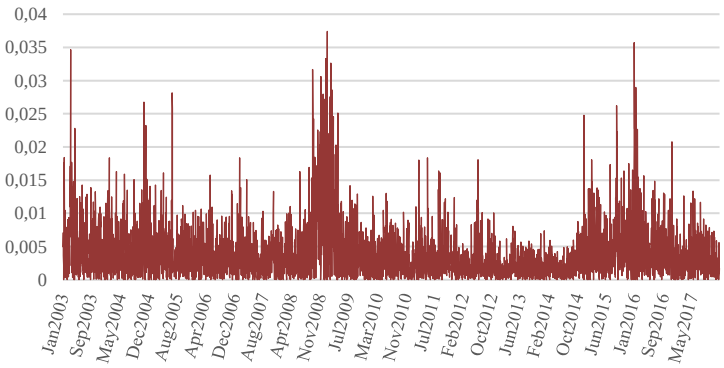

Figure 16 – Vol1 estimated for the price of WTI

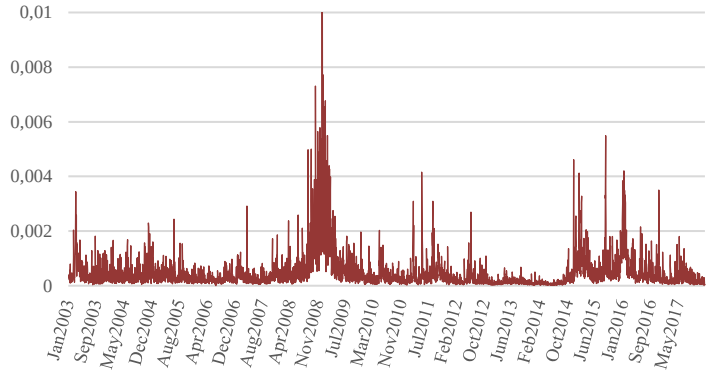

Figure 17 – Vol2 estimated for the price of WTI

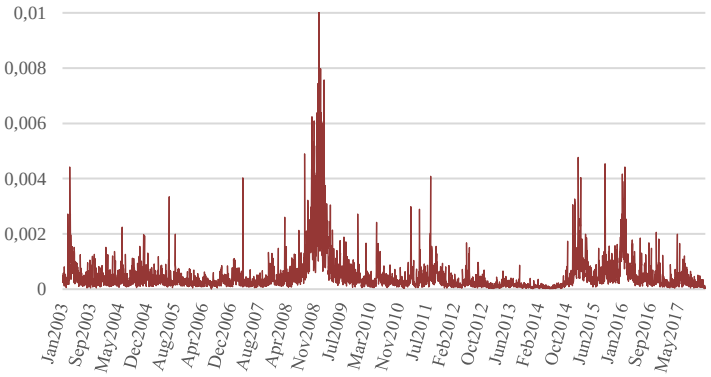

Figure 18 – Vol3 estimated for the price of WTI

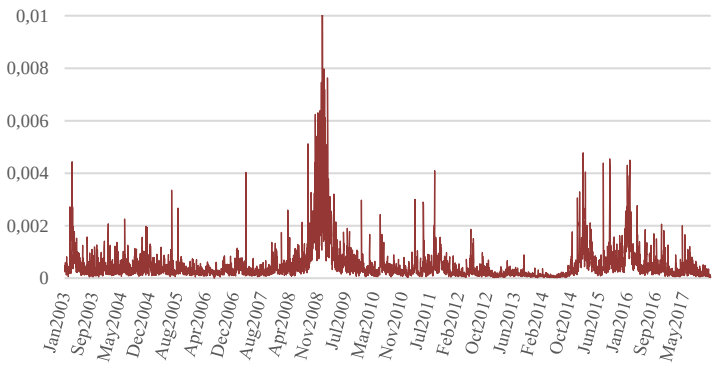

Figure 19 – Vol4 estimated for the price of WTI

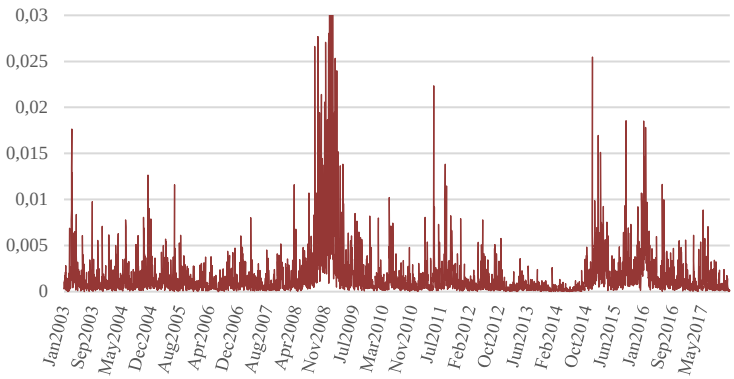

Figure 20 – Vol5 estimated for the price of WTI

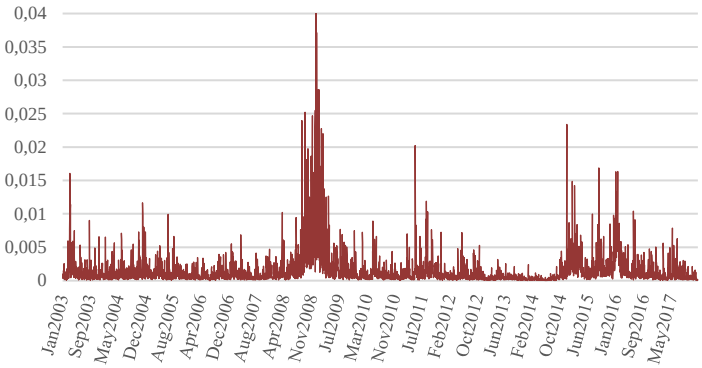

Figure 21 – Vol6 estimated for the price of WTI

Note: Figures 4 - 21 represent graphical images of the six estimated volatility measures for Brent, Dubai and WTI crude oil prices, respectively. Notably, all volatility estimators exhibit the same tendency for each of the oil types, but the only exception is Vol1 measure that distinctly differs in both pattern and values of estimated volatility.

Chapter 4.3: Analysis of independent variables

This subchapter introduces the analogous analysis of independent variables. In particular, Table 3 represents descriptive statistics for the independent variables. There are many facts that can be derived from analyzing this table, however, we focus on the most important conclusions. Considering the macroeconomic surprise component, we observe higher volatility of Russian macroeconomic surprise component in general, if compared to the USA and outstandingly high variance of the Russian GDP surprise variable, in particular. It is also worth noting that the proxy of economic growth for the United States has an average value of 0.07, while for Russia this indicator is negative. Finally, if compared to prices of crude oil considered in Table 2, the OPEC reference basket price has significantly high volatility especially if compared to the Dubai crude oil. This is a valuable observation since both OPEC oils and Dubai oil comes from the same geographic region.

	No of observations	**Mean**	**Max**	**Min**	**Skewness**	**Kurtosis**	**StDev**	**Variance**
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
US GDP	180	-0.38	0.71	-1.99	-0.71	-0.18	0.74	0.54
US CPI	180	0.69	1.64	0.24	1.16	1.52	0.27	0.08
US Import	180	-0.30	1.19	-1.68	1.10	2.26	0.31	0.09

US Export	180	-0.30	1.59	-0.84	0.96	0.75	0.35	0.12
US STIR	180	-0.42	1.49	-1.86	0.48	0.70	0.40	0.16
US LTIR	180	-0.46	1.19	-1.78	0.34	1.69	0.29	0.09
US CapEx	180	0.21	1.97	-0.87	0.36	-0.24	0.39	0.15
US Consumption	180	-0.13	1.42	-1.52	0.60	0.92	0.30	0.09
Russian GDP	180	0.14	2.7	-4.72	-1.09	1.46	1.77	3.13
Russian Inflation	180	0.91	0.96	0.85	-0.34	-0.81	0.02	0
Russian Import	180	-0.02	1.91	-2.00	-0.35	-0.64	1.04	1.09
Russian Export	180	-0.34	1.74	-1.75	0.52	-1.27	1.10	1.2
Russian STIR	180	0.03	1.44	-1.56	0.10	-1.52	0.89	0.8
Russian LTIR	180	-0.07	1.54	-1.42	0.31	-1.57	0.89	0.8
Russian CapEx	180	1.17	1.94	-0.36	-0.74	-0.09	0.57	0.33
Russian Consumption	180	0.55	1.94	-1.15	-0.68	-0.24	0.77	0.6
US Growth Rate	180	0.07	0.63	-0.87	-1.41	5.88	0.19	0.03
Russian Growth Rate	180	-1.00	1.36	-6.91	-1.53	1.22	2.07	4.30
Global EPU	180	115.97	283.32	50.12	1.06	1.30	47.32	2238.78
US EPU	180	115.52	245.13	57.2	0.69	-0.15	37.59	1412.99
Russian EPU	180	137.49	400.02	24.11	1.11	0.91	75.56	5708.81
Geopolitical Risk	180	94.7	536.22	41.01	4.29	25.06	62.92	3958.97
Major Events	3820	-0.04	1.00	-1.00	-1.65	10.57	0.26	0.07
OPEC quotas decision	180	0.36	1.00	-1.00	-0.77	-1.39	0.93	0.86
OPEC Reference Basket price	3820	69.29	140.73	22.48	0.31	-1.16	28.64	820.02

Table 3 - Independent variables descriptive statistics

Moreover, we present a graphical depiction of the explanatory variables in Figures 22 – 32. We begin by analysis of the macroeconomic news surprise component coming from the USA and Russia. It must be noted, that these variables in a nutshell detect divergence between investors' expectations and actual facts in terms of the direction of changes in macroeconomic variables. Overall, we can conclude that the uncertainty about changes of the Russian macroeconomic variables was much higher than of the American. This is particularly discernible with respect to

the GDP, Import and Interest Rates, whereas the Inflation variable was rather flat. Furthermore, it should be pointed out, that on average investors were more acute and successful when making predictions about the USA macroeconomic conditions rather than forecasting about the Russian economy. This can be explained by a higher overall degree of political and economic uncertainty of the Russian market, on the one hand, and a lower degree of investors' awareness about the Russian economic tendencies, on the other hand. Indeed, the USA economy, attracts more investors from all over the world and is closely monitored by experts worldwide, while the Russian economy stays comparatively more closed these days still.

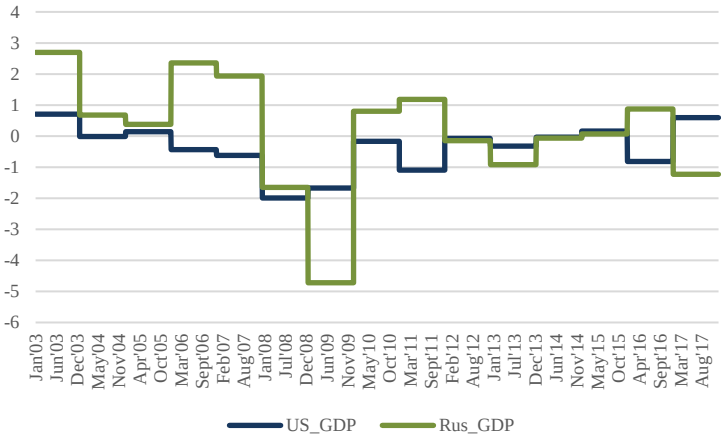

Figure 22 – Deviations in investors' expectations of GDP

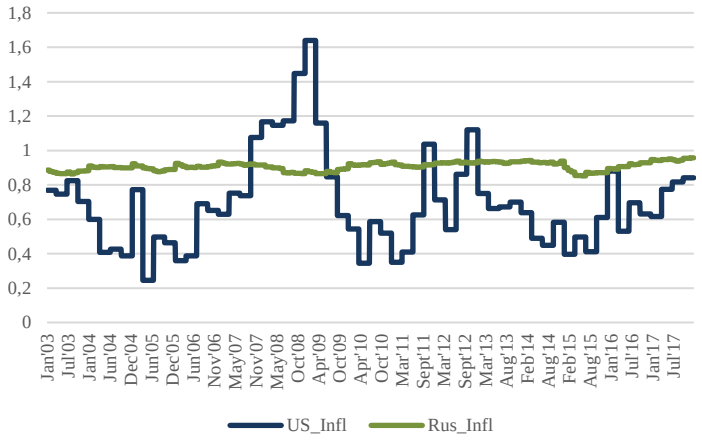

Figure 23 – Deviations in investors' expectations of Inflation

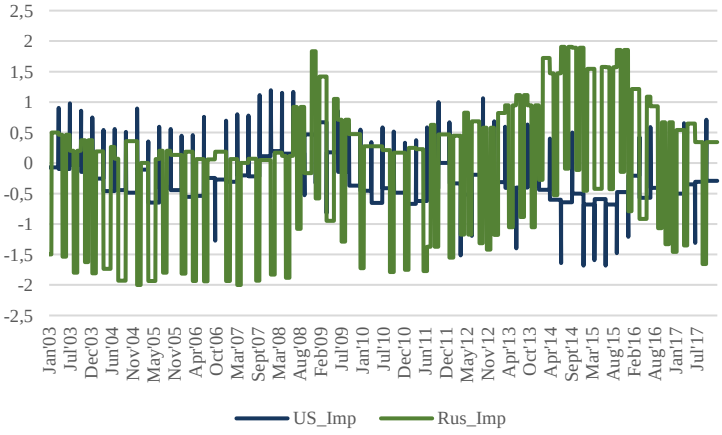

Figure 24 – Deviations in investors' expectations of Import

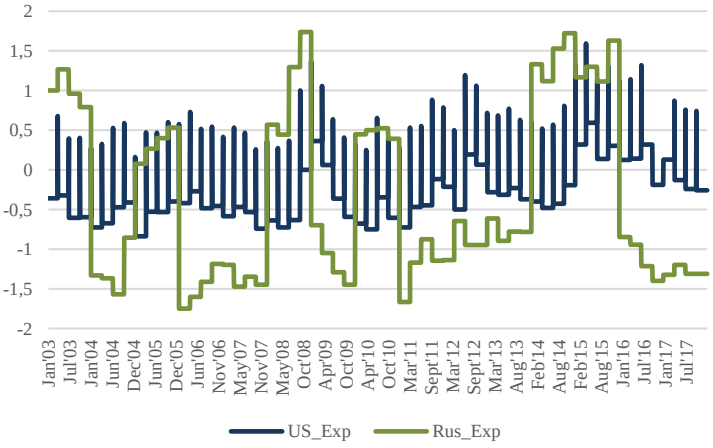

Figure 25 – Deviations in investors' expectations of Export

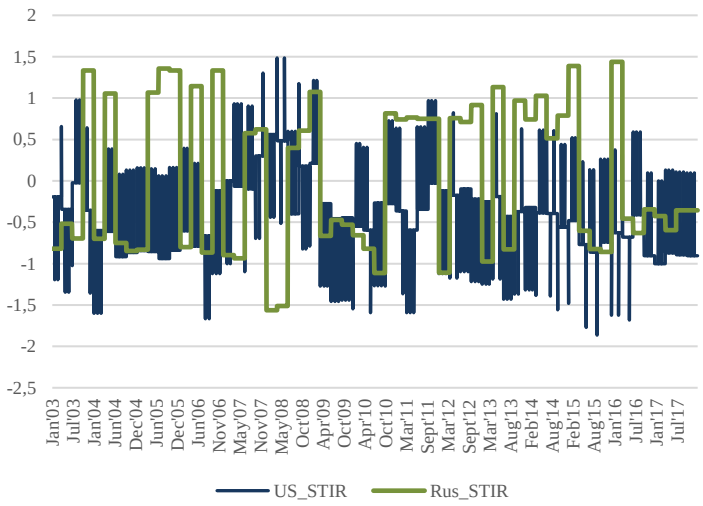

Figure 26 – Deviations in investors' expectations of Short-term IR

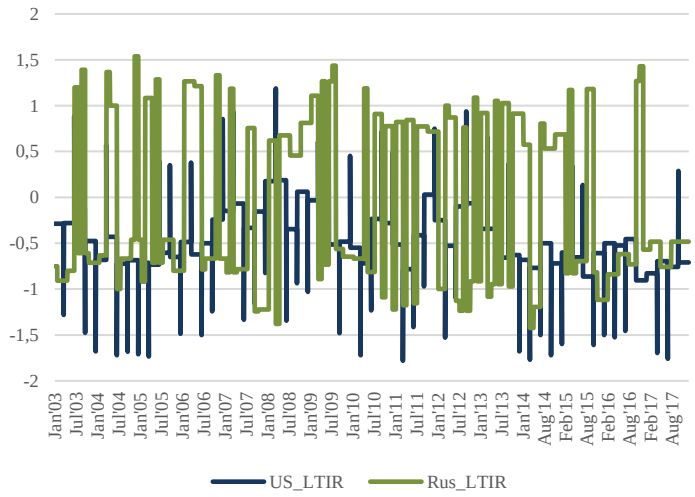

Figure 27 – Deviations in investors' expectations of Long-term IR

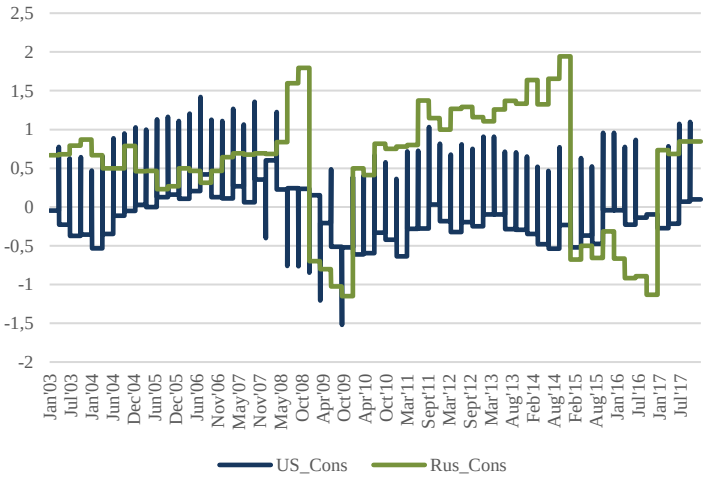

Figure 28 – Deviations in investors' expectations of Consumption

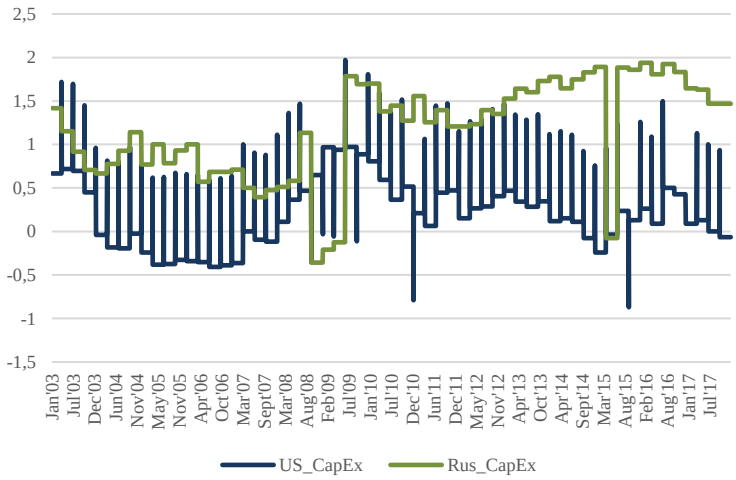

Figure 29 – Deviations in investors' expectations of Capital Expenditures

Apart from uncertainty with respect to the macroeconomic variables, it is also worth to analyze the dynamics of Economic Policy Uncertainty and Geopolitical Risk indices, as well as the proxy of economic growth variable. While the Global Economic Policy Uncertainty and Geopolitical Risk indices exhibit similar trends, the differences between the USA and Russian EPU indices supports our previous speculations. In particular, we supposed that the deviations in investors' expectations about the Russian economy are stipulated by higher uncertainty about this country in general and this is indeed proved to be true by the Economic Policy Uncertainty index: it exhibits a much higher volatility if compared to the USA's index and on average is higher in value reaching a peak of 400 points lately while the USA's index fluctuates around 100.

Moreover, we make some notes on the proxy of economic variables growth and its comparison between the USA and Russia. The USA variable fluctuates around 0 throughout the whole period with some deviations ranging from -1 to 1. This fact along with a rather flat EPU index speaks for the fact that the USA economy is relatively stable and predictable. At the same time. The Russian economic growth proxy was much more volatile and took mostly negative values, in particular around the world economic crisis and after the Ukrainian crisis escalation. In light of the economic sanctions imposed by the European Union and the USA, this recession is explainable, but also shows us that the Russian economy is not hedged enough and is much more vulnerable and sensitive to any downturns of the world economy.

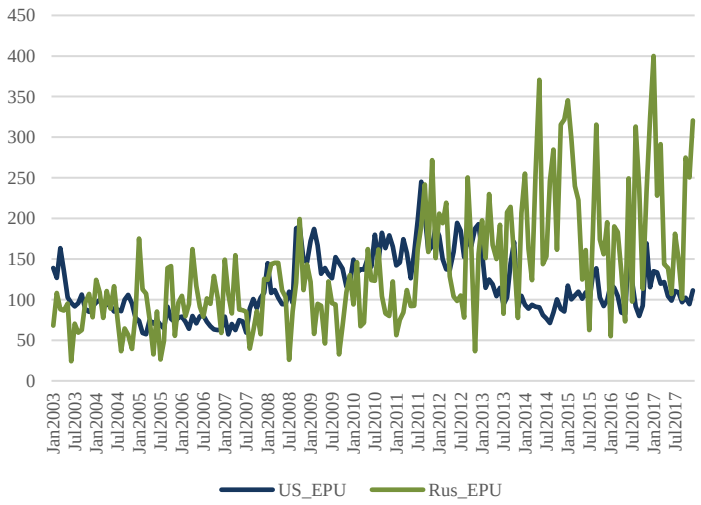

Figure 30 – The USA and Russian EPU indices

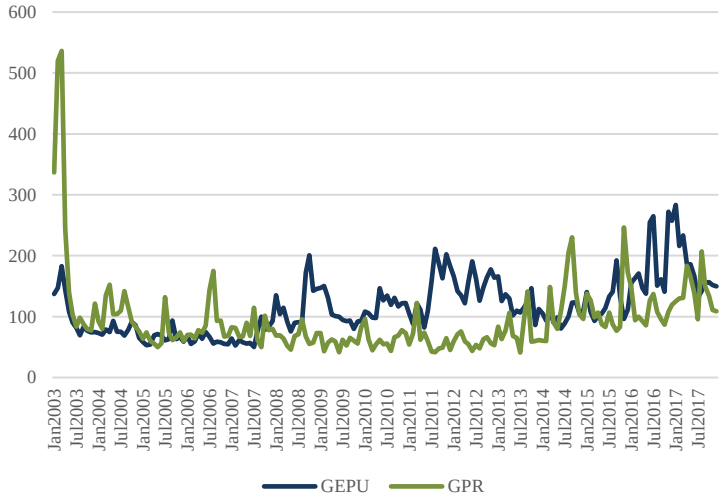

Figure 31 – Global EPU and Geopolitical Risk indices

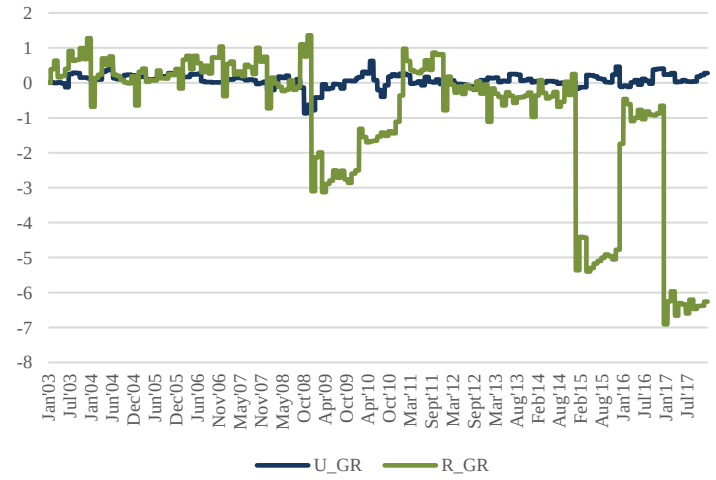

Figure 32 – Proxy variables of macroeconomic growth rate

Note: Figures 21 - 32 represent graphical images of the dependent variables. Overall, it must be noted that the Russian macroeconomic surprise component was more volatile than the one in the United States.

Having conducted the primary analysis of dependent and independent variables, we also ran statistical tests in order to detect deviations from the main model assumptions (homoscedasticity, absence of autocorrelation and multicollinearity, stability, normal distribution of the error term etc.). In order to overcome the stability issue and account for the fact that in levels independent variables were ranging too much in value, we have included our nominal variables in growth rates, rather than in levels. During this stage of analysis, we detected several problems, such as autocorrelation and the non-normality of the error term distribution, in the first place. In order to overcome these issues, instead of the regular OLS regression we introduced the Prais-Winston estimation that allowed us to conquer several problems at the same time: substantially increased the Durbin-Watson test statistics and ensured the error term distribution very close to normal. Corresponding test statistics, as well as error term distribution graphs can be found in the Appendix. Of course, it was not possible to eliminate all the issues fully and we have to take it into account when summarizing and analyzing the results. However, we can ensure that with this approach we obtain statistically reliable results.

Chapter 5: Results and discussion

This chapter is devoted to the empirical results analysis. We begin by considering coefficients estimates derived for the model determined in the Chapter 3. Then we proceed with comparing performance of different volatility estimators included into consideration. Due to the high volume of data under consideration and regression outcomes, four groups of variables are formed and we conduct a comparative analysis of their influence on the six volatility measures calculated for of three oil types: Brent, Dubai and WTI. Therefore, the rest of this chapter is divided into corresponding subchapters focusing on macroeconomic news surprise components coming from the USA and from Russia, uncertainty indices and OPEC decisions and, finally, financial indicators.

Chapter 5.1: The USA macroeconomic news

We begin by analyzing results for the macroeconomic surprise component coming from the United States that are summarized in Table 4. According to the methodology of this study, these variables represent deviations of investors' and economists' expectations about forthcoming values of key macroeconomic variables from actually announced values. In particular, the following macroeconomic factors were included into consideration: gross domestic product (GDP), inflation (CPI), import, export, short- and long-term interest rates (STIR and LTIR), capital expenditures (CapEx), and consumption (Consump). At this stage we not only analyze and interpret estimated coefficients for each volatility measure of each oil type, but also compare outcomes for the same volatilities across types of oil.

GDP. The first macroeconomic indicator we consider within this subchapter is GDP of the USA. Most of the times, WTI is considered to be the main indicator of the American commodity market, crude oils subfield. Therefore, we would expect that across the three oil types covered in this analysis, in the first place we would expect the WTI oil price volatility to be the most sensitive to the uncertainty of macroeconomic variables coming from the USA. Surprisingly, not WTI, but rather the Brent crude oil price volatility was highly influenced by divergence in investors' expectations of the USA GDP level. Should the USA GDP surprise component be subject to a 1% rise in value, the volatility of Brent price would go up by around 0.8%.

Inflation. In comparison to GDP of the US, experts' uncertainty about the American inflation rate has more influence on the crude oil price volatility. In particular, estimated coefficients indicated the statistically significant impact on the Dubai and WTI price volatilities with estimates varying in accordance with the chosen volatility estimator. Thus, WTI would increase by 0.6% – 0.8% and Dubai volatility would decrease by 0.4%, should the USA CPI surprise variable increase by 1%.

Import and Export. Foreign trade surprise components of the USA performed differently when estimating the coefficients of the regression equation. Uncertainty about the American import level was not statically significant for any of the volatility estimations of the three types of crude oil considered. In contrast, the export surprise variable's coefficient was estimated to be statistically significant for the Brent crude oil price volatility and, depending on the volatility estimator, also for the Dubai crude oil. If the Export variable increases by 1%, the volatility of Brent oil price falls by 0.3%, while Dubai volatility by only 0.15%. Thus, we again obtain the result similar to the one of US GDP surprise component: the WTI price volatility was neutral with respect to investors' uncertainty about these indicators but was highly sensitive to changes in expectations about American level of export in case of the other two types of oil.

Interest rates. In contrast to the trade balance macroeconomic surprise component, the short- and long-term interest rates behaved similarly. We note that investors' uncertainty of these indicators in general was important mainly for the Dubai oil price volatility only. In particular, short-term interest rate's influence was less notable, with a 1% rise in the regressor's value corresponding to a 0.2% – 0.4% rise of volatility, while the long-term rate would react with a corresponding rise of 0.4% – 0.6%. Remarkably, uncertainty about these important macroeconomic indicators of a major world economy did not affect neither Brent, nor WTI crude oil price volatilities.

Capital Expenditures. The USA CapEx surprise component coefficients' estimates had statistically significant impact on price volatility of all the three types of crude oil in the analysis, even though in case of the Dubai oil this influence was less significant. It is worth noting that these results were consistent across all volatility estimators except the Vol1 measure. As we show later, this observation holds true in cases of some other explanatory variables. Overall, we even might conclude that this least sophisticated volatility measure exhibits almost opposite coefficient

estimates compared to all the other volatility variables. However, back to the influence of capital expenditures surprise component, we notice that an increase of 1% in the regressor value resulted in growth of volatility by 0.5% – 0.8% and 0.3% – 0.5% for Brent and Dubai oils, respectively, and a fall by 0.2% for the WTI oil price volatility.

Consumption. The divergence in investors' expectations regarding the consumption level reported by the United States played a crucial role in determination of Brent and WTI crude oil price volatility at the 1% level of statistical significance with a 1% rise in this variable resulting in a reduction of volatility by 0.5% and 1%, correspondingly. In contrast, the Dubai crude oil price volatility was not affected by this macroeconomic surprise factor, except for the Vol4 and Vol6 estimators.

Finally, the following remarks must be made. First of all, due to the fact that the WTI oil type is most widely spread on the American markets and stock exchanges and is often viewed as the USA "domestic" crude oil, we would expect volatility of this oil type to be most sensitive to the macroeconomic news factors coming from the United States. This result would be consistent with the common understanding of market mechanisms. Surprisingly, WTI price volatility was not affected by all the USA macroeconomic surprise variables, and if anything, was even the least responsive to changes in those factors in some cases. At the same time, volatility of the Brent crude oil price was subject to these factors' influence to a great extent, which seems consistent with the fact that Brent is probably the most widespread oil type on the world commodity market. The last, but not least, Dubai crude oil price was affected by only some of the factors, for example, the CPI and capital expenditures. However, we note that in this case results were rather differing across the volatility estimators with no distinct pattern to be observed.

		GDP	**CPI**	**Import**	**Export**	**STIR**	**LTIR**	**CapEx**	**Consump**
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Vol1	*Brent*	0.145 (0.09)	0.662*** (0.239)	-0.277 (0.200)	0.053 (0.116)	-0.048 (0.079)	-0.142 (0.124)	-0.148 (0.116)	0.069 (0.137)
	Dubai	-0.061 (0.045)	0.046 (0.135)	-0.051 (0.121)	-0.178*** (0.067)	0.056 (0.041)	0.018 (0.065)	0.063 (0.058)	0.024 (0.071)
	WTI	0.299*** (0.088)	0.083 (0.382)	-0.201 (0.322)	-0.279** (0.138)	0.236** (0.109)	0.184 (0.179)	-0.254* (0.133)	0.253 (0.167)

	Brent	0.461***	0.226	-0.234	-0.677***	-0.027	-0.097	0.446***	0.508***
		(0.078)	(0.216)	(0.176)	(0.151)	(0.059)	(0.102)	(0.105)	(0.145)
Vol2	*Dubai*	-0.137	-0.59**	-0.122	-0.129	0.16**	0.26**	0.355***	0.142
		(0.107)	(0.270)	(0.218)	(0.134)	(0.079)	(0.122)	(0.128)	(0.146)
	WTI	0.08	0.439***	-0.036	-0.065	0.033	0.008	-0.27***	0.352***
		(0.061)	(0.170)	(0.123)	(0.083)	(0.054)	(0.094)	(0.085)	(0.089)
	Brent	0.408***	0.122	-0.135	-0.643***	0.004	-0.034	0.372***	0.438***
		(0.079)	(0.199)	(0.155)	(0.145)	(0.055)	(0.092)	(0.100)	(0.135)
Vol3	*Dubai*	-0.085	-0.776***	-0.086	-0.146	0.225***	0.286**	0.346***	0.185
		(0.111)	(0.268)	(0.218)	(0.130)	(0.080)	(0.123)	(0.126)	(0.143)
	WTI	0.036	0.467***	0.001	-0.036	0.021	-0.016	-0.253***	0.312***
		(0.059)	(0.157)	(0.117)	(0.075)	(0.047)	(0.086)	(0.083)	(0.082)
	Brent	0.486***	0.160	-0.134	-0.628***	0.026	-0.049	0.365***	0.411***
		(0.082)	(0.202)	(0.151)	(0.152)	(0.055)	(0.091)	(0.102)	(0.136)
Vol4	*Dubai*	-0.259**	-0.319	-0.173	-0.324**	0.141**	0.333***	0.222*	0.378***
		(0.106)	(0.253)	(0.214)	(0.130)	(0.071)	(0.119)	(0.127)	(0.140)
	WTI	0.037	0.491***	-0.012	-0.034	0.021	-0.016	-0.250***	0.303***
		(0.060)	(0.157)	(0.115)	(0.075)	(0.047)	(0.086)	(0.084)	(0.082)
	Brent	0.435***	-0.007	-0.082	-0.885***	0.038	-0.107	0.487***	0.626***
		(0.083)	(0.242)	(0.207)	(0.143)	(0.074)	(0.122)	(0.112)	(0.154)
Vol5	*Dubai*	-0.018	-1.118***	-0.008	-0.157	0.319**	0.219	0.274*	0.203
		(0.147)	(0.357)	(0.261)	(0.174)	(0.137)	(0.173)	(0.165)	(0.18)
	WTI	-0.001	0.401**	0.096	0.07	0.024	-0.038	-0.356***	0.311***
		(0.064)	(0.193)	(0.152)	(0.092)	(0.065)	(0.108)	(0.09)	(0.104)
	Brent	0.508***	0.062	-0.110	-0.842***	0.037	-0.130	0.475***	0.593***
		(0.082)	(0.232)	(0.189)	(0.149)	(0.069)	(0.113)	(0.111)	(0.152)
Vol6	*Dubai*	-0.238**	-0.485*	-0.08	-0.370***	0.130	0.388***	0.196	0.369**
		(0.11)	(0.278)	(0.221)	(0.139)	(0.08)	(0.126)	(0.134)	(0.146)
	WTI	0.028	0.427**	0.037	0.039	0.035	-0.034	-0.332***	0.330***
		(0.063)	(0.183)	(0.141)	(0.09)	(0.06)	(0.104)	(0.088)	(0.100)

Table 4 – The USA macroeconomic news surprise component

Notes: this table reports estimated coefficients and standard errors for macroeconomic surprise component coming from the USA solely. These results are obtained from Equation 5 with the dependent variable being in turns equal to each of Vol1 – Vol6 measures. For each of the volatility measures we estimate the regression three times: for Brent, Dubai and WTI crude oils. This approach allows us to compare estimated coefficient not only across volatility measures, but also among different oil types within the same volatility estimator. Statistical significance levels are indicated as "***" denoting 1%, "**" denoting 5% and "*" being equal or less than 10%.

Chapter 5.2: Russian macroeconomic news

This subchapter delivers a review of the key estimation results within the Russian macroeconomic news variables represented by the Table 5. While the USA economy is perceived as a global benchmark of the whole world economic condition and we believe that this group of variables should be included in any model estimating volatility of commodities prices, we consider the influence coming from the Russian economy to be important specifically with respect to the crude oil field. Nowadays, Russia is one of the major oil producing and exporting countries. Its economic growth and situation are highly dependent on the crude oil price, demand and supply on the world commodity market. Therefore, we suppose that unexpected changes in macroeconomic variables of this country might also have some influence on the price volatilities of different oil types. Following the approach of the previous subchapter, variables enter the analysis in the same order and grouping.

GDP. The first surprise component of the Russian macroeconomic news group has delivered the following results. For most of the volatility estimators, coefficients of this variable had statistically significant influence on the Brent and WTI oil price volatilities at 1% or 5% level, whereas for the Dubai price volatility we obtained same results only for the Vol1 estimator. Estimating the extent of influence, we note that the GDP surprise variable increase of 1% led to a 0.1% decline of Brent volatility, while the WTI price would gain around 0.05% in volatility.

Inflation. When estimating regression equations, among all the oil types the CPI surprise component was statistically significant at the 1% level for the volatility of both Dubai and WTI crude oil prices, however in terms of actual influence the numbers are very low: both of the volatilities would go up by less than 0.01% with a 1% increase in the CPI variable. Notably, statistically significant influence of the same extent was the case for all volatility estimates except for the first one which was calculated simply as a log of daily returns. As for the Brent oil, differences in investors' expectations and announced values of the Russian CPI were not statistically significant for any of the volatility measures, except for the Vol1 which again delivered results opposite to the rest of volatility estimators.

Import and Export. Overall, we can conclude that both Russian Import and Export surprise variables have some strong influence on certain crude oils price volatilities. Both variables were statistically significant for the Brent price volatility at the significance level of 1%-5% for Import and

1% for Export. A 1% growth in this variable resulted in a decline of volatility by 0.05% and 0.2% for Import and Export variables, correspondingly. Dubai oil price volatility was mainly influenced by the Export surprise component with a 1% rise in this variable leading to a decrease in volatility by approximately 0.1%. As for WTI, a rather moderate influence of the Import variable was noted on the Vol2 – Vol4 measures with a fall of volatility by 0.4% as a result of a 1% increase in this surprise variable.

Interest rates. Analyzing short- and long-term interest rates surprise components, it must be noted that the Dubai oil price volatility was not influenced by them. On the other hand, all the Brent crude oil price volatilities experienced the influence of experts' expectations deviations at the 5% significance level. Remarkably, this result was consistent only for long-term interest rate surprise variable and in this case 1% increase in the independent variable resulted in 1.3% reduction of Brent crude oil price volatility, while the short-term interest rate surprise component was not statistically significant in any of the estimated regressions. A lower, but still statistically significant influence was also discovered in case of the WTI price volatility.

Capital Expenditures. Similarly to the USA Capital Expenditures surprise component, the Russian CapEx variable exhibits strong statically significant impact on almost all the volatility measures across all Brent and WTI oil price volatilities. Brent crude oil price volatility increased by 0.4% – 0.6%, WTI price volatility goes up by 0.4% given a rise in the explanatory variable of 1%. At the same time, the Dubai price was less influenced: statistically significant coefficient estimates were discovered only when estimating regression equations for Vol2 and Vol3 with a rise of 1% in the uncertainty of capital expenditures resulting in either a rise by 0.3% or a slight decline of around 0.4%.

Consumption. Along with the capital expenditures surprise variable of the Russian economy, divergence in investors' expectations of the consumption level in Russia played a pivotal role. Likewise, it had statistically significant influence on all the six volatilities for all oil types. This is one of the few cases when results are common for all types of oil under consideration and all the six volatility measures including the Vol1 estimator which usually exhibits quite differing estimates. In this case Brent volatility declines by 0.3%, WTI volatility decreased by 0.13% and Dubai volatility growth ranged from 0.1% to 0.3% all corresponding to a rise in the Consumption variable of 1%.

Overall, concluding this part of the analysis, we must bring to the reader's attention the fact that macroeconomic news coming from Russia in case of all the factors except for CPI and short-term interest rate had the strongest influence on the Brent crude oil price volatility. Similar results were obtained for the WTI price volatility, though the important variables were slightly different: GDP, CPI, consumption and capital expenditures levels played a crucial role. The Dubai price volatility was in this case influenced to the least extent by macroeconomic surprise component coming from Russia. Obtained results are rather consistent among the volatility measures, except for the Vol1 which was also observed in the previous subchapter devoted to the USA macroeconomic surprise component.

		GDP	**CPI**	**Import**	**Export**	**STIR**	**LTIR**	**CapEx**	**Consump**
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Vol1	*Brent*	0.089***	-6.937***	0.003	-0.095***	-0.043	0.042	0.272***	-0.241***
		(0.029)	(2.060)	(0.024)	(0.037)	(0.031)	(0.028)	(0.098)	(0.055)
	Dubai	0.028**	-4.948***	0.011	-0.047***	-0.020	0.001	-0.002	0.063**
		(0.012)	(1.044)	(0.012)	(0.017)	(0.015)	(0.013)	(0.041)	(0.027)
	WTI	0.023	-14.208***	0.043*	-0.102***	0.000	0.060**	0.135	-0.170***
		(0.031)	(2.377)	(0.026)	(0.038)	(0.033)	(0.028)	(0.093)	(0.061)
Vol2	*Brent*	-0.078***	0.052	-0.068***	-0.268***	-0.012	-0.153***	0.323***	-0.437***
		(0.028)	(2.034)	(0.023)	(0.035)	(0.031)	(0.026)	(0.098)	(0.053)
	Dubai	-0.051	-16.792***	-0.042	-0.090**	-0.046	-0.012	0.237**	0.252***
		(0.032)	(2.504)	(0.031)	(0.045)	(0.039)	(0.034)	(0.109)	(0.069)
	WTI	0.043**	-19.016***	-0.036*	-0.044	0.000	0.036	0.268***	-0.152***
		(0.022)	(1.622)	(0.020)	(0.030)	(0.025)	(0.024)	(0.076)	(0.045)
Vol3	*Brent*	-0.071***	-0.082	-0.052**	-0.262***	-0.018	-0.149***	0.349***	-0.4***
		(0.027)	(1.913)	(0.023)	(0.034)	(0.030)	(0.026)	(0.095)	(0.051)
	Dubai	-0.049	-17.373***	-0.036	-0.128***	-0.041	0.002	0.258**	0.274***
		(0.032)	(2.441)	(0.031)	(0.044)	(0.039)	(0.033)	(0.110)	(0.069)
	WTI	0.046**	-18.152***	-0.039**	-0.031	-0.007	0.036	0.256***	-0.136***
		(0.022)	(1.570)	(0.020)	(0.030)	(0.025)	(0.023)	(0.075)	(0.044)
Vol4	*Brent*	-0.072**	-1.095	-0.058**	-0.276***	-0.026	-0.142***	0.363***	-0.407***
		(0.028)	(2.001)	(0.023)	(0.035)	(0.031)	(0.027)	(0.102)	(0.053)
	Dubai	0.004	-15.368***	-0.021	-0.075*	-0.019	0.027	-0.033	0.195***
		(0.030)	(2.338)	(0.029)	(0.041)	(0.038)	(0.032)	(0.101)	(0.067)
	WTI	0.048**	-17.991***	-0.038*	-0.029	-0.006	0.038*	0.253***	-0.141***
		(0.022)	(1.576)	(0.020)	(0.030)	(0.025)	(0.023)	(0.075)	(0.045)

Vol5	*Brent*	-0.069** (0.029)	-1.389 (2.15)	-0.042* (0.025)	-0.289*** (0.036)	0.011 (0.033)	-0.151*** (0.028)	0.412*** (0.093)	-0.468*** (0.053)
	Dubai	-0.022 (0.044)	-16.578*** (3.250)	-0.049 (0.039)	-0.13** (0.057)	-0.027 (0.050)	0.019 (0.043)	0.151 (0.143)	0.257*** (0.091)
	WTI	0.049** (0.023)	-18.853*** (1.661)	-0.032 (0.021)	-0.032 (0.031)	-0.012 (0.026)	0.047** (0.023)	0.329*** (0.074)	-0.122*** (0.044)
Vol6	*Brent*	-0.072** (0.029)	-2.173 (2.176)	-0.055** (0.025)	-0.298*** (0.036)	0.000 (0.033)	-0.148*** (0.028)	0.419*** (0.096)	-0.468*** (0.054)
	Dubai	0.004 (0.033)	-16.036*** (2.536)	-0.029 (0.031)	-0.062 (0.044)	-0.028 (0.040)	0.026 (0.034)	-0.042 (0.109)	0.168** (0.072)
	WTI	0.049** (0.023)	-19.075*** (1.659)	-0.032 (0.021)	-0.034 (0.031)	-0.010 (0.026)	0.046* (0.024)	0.312*** (0.073)	-0.134*** (0.045)

Table 5 – Russian macroeconomic news surprise component

Notes: this table reports estimated coefficients and standard errors for macroeconomic surprise component coming from Russia solely. These results are obtained from Equation 5 with the dependent variable being in turns equal to each of Vol1 – Vol6 measures. For each of the volatility measures we estimate the regression three times: for Brent, Dubai and WTI crude oils. This approach allows us to compare estimated coefficient not only across volatility measures, but also among different oil types within the same volatility estimator. Statistical significance levels are indicated as "***" denoting 1%, "**" denoting 5% and "*" being equal or less than 10%.

Finalizing this stage of analysis, we compare results obtained for the two groups of macroeconomic surprise components. In this regard we draw the following conclusions.

As was assumed, investors' uncertainty about macroeconomic variables often plays a key role in determination of crude oil price volatility regardless of the volatility estimation approach or crude oil type.

Some macroeconomic surprise variables were particularly strongly affecting price volatilities of all oil types under consideration, for example, the Russian consumption and capital expenditures variables of this group. Interestingly, the USA capital expenditures variable had similarly strong influence over same dependent variables, which proves robustness of these results and the overall integration and interconnection of all world economies and markets, as well as the fact that investors tend to monitor macroeconomic situation not only of their residence country. At this stage, we already find support of the statement that the Russian economy plays one of the leading roles on the energy markets in general and within determination of the crude oil price in particular.

Across the three selected oil types Brent price volatility is the most sensible to the uncertainty about macroeconomic news coming from both Russia and the USA. It can be explained by the fact that this oil is considered to be a world indicator, is involved into trading on all major exchanges worldwide and, thus, represents a diversified set of investors' views.

On the contrary, Dubai oil price is the least sensible to any divergences in investors' expectation regarding macroeconomic variables values. Probably, this can be explained by the fact that Dubai oil represents a rather narrowed Middle East region, covered by trades of a less diversified group of investors. However, there were some unexpected results such as strong dependence on the USA CPI and long-term interest rates, which probably can be explained by the fact that the US dollar is the most commonly used world currency and the USA economy attracts, nowadays, the majority of international investments. Less straightforward to explain in this respect is the influence of Russian GDP and consumption surprise variables.

WTI price volatility was affected more by the USA macroeconomic surprise component, rather than the Russian one. However, this influence was yet not as strong as we would expect given the fact that WTI is viewed as the 'American' oil. More precisely, the USA's level of import and long-term interest rate were the most powerful predictors of the WTI price volatility.

Based on estimated coefficients and their statistical significance, we cannot conclude that investors' uncertainty about macroeconomic variables of either the USA or Russia had distinctly more powerful impact on crude oils price volatility. This an important observation since usually the USA economy is considered to be leading and trendsetting on most of the world markets.

Finally, comparing coefficients estimations for different volatility measures, we conclude that the results follow the same pattern across all measures for every oil type, which increases confidence in the accuracy of our findings.

Chapter 5.3: Uncertainty variables and OPEC decisions

This subchapter delivers results of regression equation estimates within another very interesting and promising group of factors, and namely, the economic and political uncertainty estimations and the OPEC decisions with respect to oil production quotas and the OPEC reference basket price. The main results are provided by the Table 6.

Nowadays, with media being the so-called fifth power, it comes without any doubt that striking political and social news immediately reach all the market participants and usually have a strong influence on the financial and commodity markets in general and energy markets in particular, creating uncertainty about future state of the world economy and allowing considerable price jumps. Therefore, we anticipated that introduced uncertainty indices and the Major Events variable, which indicates presence of particularly notable news highlighted by the media, would have a lot of predictive power over crude oil price volatility.

However, this part of the research delivered the most surprising results. Based on the estimated coefficients, most of these variables did not have any statistically significant influence on the crude oil price volatility. The only distinct exception was the Geopolitical Risk Index that considerably affected the Dubai and WTI oil price volatilities, even though these results were subject to change according to the selected volatility estimator. Geopolitical Risk index had statistically significant influence on the WTI crude oil price volatility in a few cases only, while the rest of the estimated coefficients were insignificant. These results are consistent across all the three types of oil regardless of the selected volatility estimator.

In contrast, the OPEC decision variable considerably influenced the Brent and WTI oil prices volatilities in most cases. Interestingly, the Dubai oil price volatility was mostly not affected by this variable at all. Taking into consideration the fact that OPEC plays the leading role on the world crude oil market, results provided by regression equations estimated for Brent and WTI oils is quite foreseeable. In particular, a 1% increase in this independent variable results in a decrease in volatility of 0.2% for both Brent and WTI. However, insensitivity of the Dubai crude oil price volatility to changes in the OPEC crude oil production level is a rather astonishing finding, given that both OPEC members and the United Arabic Emirates are located in the same geographic region and, inter alia, these types of oil are often traded on the same exchanges.

The last factor estimated within this group was the OPEC reference basket price. Compared to the OPEC quotas decisions, these results are more in line with our expectations. When estimating regression equations for the Dubai oil, we observe statistically significant influence at the 10% level that still varies across volatility estimators. In some cases, it is also true for the Brent and WTI oils price volatilities, i.e. for Vol5 and Vol6 estimators. Interestingly, measured in percentage, this impact would be rather low in absolute terms and could vary in direction with

according to the chosen volatility estimator: Vol2 – Vol4 estimators would go down by around 0.3% whereas Vol5 and Vol6 of WTI would slightly increase should the OPEC reference basket price increase by 1%. Based on these findings, we conclude that OPEC oil supply has an impact on the world crude oil market represented by Brent and WTI oils, whereas OPEC oil price mostly has substantial relevance for the local market which is represented by the Dubai crude oil. Therefore, we infer that the oil price on the world market is not only determined by laws of demand and supply as prescribed by the perfect competition laws, but rather is subject to influence by political and economic factors.

Overall, some results of this part of the study rather go against our assumptions and predictions. It is proven that macroeconomic uncertainty has a greater impact on the crude oil market than uncertainty about the political and social situation.

		Global Economic Policy Uncertainty Index	**USA Economic Policy Uncertainty Index**	**Russian Economic Policy Uncertainty Index**	**Geo-political Risk Index**	**Major Events**	**OPEC quotas decision**	**OPEC reference basket price**
		(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Brent	0.365*	0.027	0.032	-0.029	-0.026	-0.072	-1.416
		(0.188)	(0.12)	(0.034)	(0.061)	(0.069)	(0.045)	(1.45)
Vol1	*Dubai*	0.053	-0.043	0.012	0.037	-0.045	-0.005	0.067
		(0.093)	(0.063)	(0.015)	(0.029)	(0.036)	(0.021)	(0.658)
	WTI	0.316*	-0.010	0.009	0.000	0.026	-0.080*	-3.033*
		(0.192)	(0.126)	(0.036)	(0.065)	(0.080)	(0.044)	(1.597)
	Brent	0.010	0.049	-0.004	-0.007	0.061	-0.234***	-1.401*
		(0.187)	(0.115)	(0.031)	(0.058)	(0.043)	(0.038)	(0.840)
Vol2	*Dubai*	0.199	0.128	0.007	0.127*	-0.045	-0.098*	-2.555*
		(0.237)	(0.146)	(0.04)	(0.073)	(0.067)	(0.055)	(1.453)
	WTI	0.309**	0.045	0.003	-0.087*	-0.057	-0.19***	-1.303
		(0.153)	(0.097)	(0.028)	(0.048)	(0.045)	(0.032)	(0.893)
	Brent	0.022	0.050	0.010	-0.024	0.056	-0.225***	-1.304
		(0.183)	(0.112)	(0.029)	(0.056)	(0.040)	(0.037)	(0.796)
Vol3	*Dubai*	0.265	0.105	0.003	0.119	-0.060	-0.079	-2.586*
		(0.230)	(0.144)	(0.040)	(0.072)	(0.072)	(0.056)	(1.541)
	WTI	0.310**	-0.009	-0.002	-0.099**	-0.071*	-0.192***	-1.537**
		(0.149)	(0.093)	(0.027)	(0.047)	(0.042)	(0.031)	(0.762)

	Brent	0.020 (0.191)	0.049 (0.116)	0.014 (0.030)	-0.040 (0.058)	0.047 (0.039)	-0.235*** (0.038)	-1.049 (0.767)
Vol4	*Dubai*	0.062 (0.230)	0.074 (0.148)	0.083** (0.039)	0.104 (0.071)	-0.067 (0.068)	-0.030 (0.051)	-1.229 (1.283)
	WTI	0.311** (0.148)	-0.007 (0.092)	0.002 (0.027)	-0.099** (0.047)	-0.057 (0.042)	-0.193*** (0.031)	-1.390* (0.757)
	Brent	-0.053 (0.198)	0.082 (0.123)	0.019 (0.033)	-0.034 (0.061)	0.065 (0.058)	-0.210*** (0.042)	-2.223** (1.068)
Vol5	*Dubai*	0.203 (0.317)	0.149 (0.199)	0.049 (0.050)	0.181** (0.092)	-0.088 (0.109)	-0.033 (0.069)	-11.35*** (2.120)
	WTI	0.203 (0.161)	0.036 (0.101)	-0.002 (0.029)	-0.139*** (0.053)	-0.018 (0.058)	-0.208*** (0.033)	-15.001*** (1.120)
	Brent	-0.050 (0.197)	0.074 (0.122)	0.017 (0.032)	-0.044 (0.061)	0.068 (0.052)	-0.221*** (0.041)	-1.704* (0.975)
Vol6	*Dubai*	0.081 (0.253)	0.081 (0.159)	0.087** (0.041)	0.110 (0.077)	-0.052 (0.074)	-0.033 (0.054)	-6.474*** (1.413)
	WTI	0.230 (0.161)	0.039 (0.101)	0.004 (0.029)	-0.126** (0.052)	-0.011 (0.055)	-0.204*** (0.033)	-12.094*** (1.041)

Table 6 – Uncertainty indices and OPEC influence

Notes: this table reports estimated coefficients and standard errors for economic and political uncertainty, OPEC quotas decisions and the OPEC reference basket price variables solely. These results are obtained from Equation 5 with the dependent variable being in turns equal to each of Vol1 – Vol6 measures. For each of the volatility measures we estimate the regression three times: for Brent, Dubai and WTI crude oils. This approach allows us to compare estimated coefficient not only across volatility measures, but also among different oil types within the same volatility estimator. Statistical significance levels are indicated as "***" denoting 1%, "**" denoting 5% and "*" being equal or less than 10%.

Chapter 5.4: Financial indicators

The final subchapter on the model estimation analysis covers the performance of variables representing financial markets and the overall economic growth (recession) of the American and Russian economies.

We begin by studying the two economies' growth variables and already at this stage some valuable results come to light. First of all, it is the crucial influence that the actual USA economic growth has on volatilities of Brent and WTI prices regardless of volatility estimator usually at the 1%-5% significance level. An increase of 1% in this regressor's value resulted in a decline of volatility by 0.06% for both Brent and WTI, while Dubai crude oil price volatility would decline

more dramatically by 0.3%. Such consistent findings leave no doubt in the importance of the USA economic growth rate in terms of crude oil price movements. One could argue that economic growth in general, regardless of the country, plays a crucial role in the crude oil price volatility. However, the results delivered by the Russian economy's growth prove the fallacy of this judgment. This variable had a strong influence in terms of the Brent volatility with a 1% rise in explanatory variable resulting in a 4% rise of volatility. However, it exhibited a rather moderate impact on the WTI crude oil price with a 0.4% decline in volatility corresponding to an increase of 1% in the explanatory variable. Finally, changes in Russian economic growth were never affecting the Dubai oil price volatility.

The business cycle variable consistently had the strongest impact on the Brent and WTI price volatility with a 1% change in this variable resulting in 0.4% and 0.2% – 0.3%, respectively, whereas Dubai crude oil price was not affected by it at all at a statistically significant level. These findings should also make researchers ponder the reasons behind, since normative theory would probably not predict such differences across the selected types of oil. One of the possible explanations could be the fact that while Brent and WTI are the most widespread types of oil, are traded on commodity exchanges all around the globe and represent underlying assets for many derivative instruments, in other words, are more involved into the financial markets and commove in accordance with them, Dubai oil is a more specialized and local type of oil, therefore, its price movements should probably be unidirectional with the local financial markets.

In order to investigate the business cycle influence deeper, we also introduce its interception with the two economic growth rate variables covered above. Overall, coefficient estimates for these variables are in line with the results obtained for the underlying variables, with the economic growth rate of the corresponding country defining the statistical significance of the influence.

Structural Changes was introduced as the variable denoting any principal changes in variables behavior under consideration. In practical terms it represents any breaking point in the markets under consideration that would notably change the situation on those markets. Notably, we again obtain contrasting results: while structural changes variable did not affect the Brent crude oil price volatility in case of any considered volatility estimators, its coefficients gained highly statistically significant estimates for both WTI and Dubai oils across almost all the volatility

measures. A 1% growth in this variable corresponded with a 1.2% and 0.5% – 0.6% increases in Dubai and WTI oil price volatilities, accordingly.

		USA Economic Growth Rate	Russian Economic Growth Rate	Business Cycle	Structural Changes	Business Cycle * US Growth Rate	Business Cycle * Russian Growth Rate	Constant
		(1)	(2)	(3)	(4)	(5)	(6)	(7)
Vol1	*Brent*	-2.502**	0.610***	-0.793***	-0.065	0.629*	-0.217***	1.716
		(0.989)	(0.215)	(0.204)	(0.081)	(0.365)	(0.070)	(1.880)
	Dubai	-0.552	-0.011	-0.007	0.046	0.131	0.006	0.911
		(0.525)	(0.095)	(0.089)	(0.028)	(0.189)	(0.030)	(0.983)
	WTI	-2.595**	0.388**	-0.536***	0.240***	0.705*	-0.116*	8.112***
		(1.102)	(0.197)	(0.185)	(0.081)	(0.404)	(0.065)	(2.136)
Vol2	*Brent*	-3.948***	1.217***	-0.985***	0.108	1.372***	-0.387***	-6.032***
		(0.863)	(0.207)	(0.185)	(0.099)	(0.326)	(0.067)	(1.816)
	Dubai	-2.157*	-0.068	0.095	0.607***	0.758*	0.085	3.238
		(1.216)	(0.253)	(0.226)	(0.061)	(0.443)	(0.080)	(2.328)
	WTI	-4.216***	0.303**	-0.377***	0.206***	1.225***	-0.096**	9.620***
		(0.760)	(0.141)	(0.133)	(0.052)	(0.282)	(0.047)	(1.465)
Vol3	*Brent*	-4.292***	1.110***	-0.886***	0.105	1.508***	-0.355***	-6.087***
		(0.878)	(0.203)	(0.189)	(0.094)	(0.330)	(0.066)	(1.740)
	Dubai	-2.064*	-0.068	-0.044	0.599***	0.690	0.083	4.171*
		(1.199)	(0.265)	(0.248)	(0.061)	(0.435)	(0.084)	(2.307)
	WTI	-4.168***	0.259*	-0.291**	0.200***	1.238***	-0.083*	8.601***
		(0.768)	(0.139)	(0.128)	(0.050)	(0.283)	(0.046)	(1.414)
Vol4	*Brent*	-4.255***	1.165***	-0.935***	0.076	1.502***	-0.370***	-4.952***
		(0.917)	(0.218)	(0.202)	(0.099)	(0.346)	(0.071)	(1.822)
	Dubai	-2.093	0.026	0.135	0.335***	0.657	0.035	2.827
		(1.279)	(0.238)	(0.226)	(0.059)	(0.456)	(0.075)	(2.224)
	WTI	-4.172***	0.271*	-0.297**	0.206***	1.242***	-0.087*	8.486***
		(0.772)	(0.139)	(0.129)	(0.051)	(0.285)	(0.046)	(1.421)
Vol5	*Brent*	-4.440***	1.201***	-0.891***	0.133	1.504***	-0.391***	-3.976**
		(0.990)	(0.188)	(0.172)	(0.096)	(0.366)	(0.062)	(1.918)
	Dubai	-2.197	-0.070	-0.523	0.646***	0.694	0.079	5.884*
		(1.375)	(0.311)	(0.326)	(0.080)	(0.516)	(0.098)	(3.034)
	WTI	-4.525***	0.230	-0.263**	0.200***	1.366***	-0.073	10.201***
		(0.812)	(0.148)	(0.132)	(0.054)	(0.298)	(0.049)	(1.505)

Vol6	*Brent*	-4.368*** (0.970)	1.253*** (0.199)	-0.966*** (0.186)	0.099 (0.101)	1.486*** (0.361)	-0.404*** (0.065)	-3.069 (1.934)
	Dubai	-2.119 (1.293)	-0.018 (0.241)	0.095 (0.226)	0.407*** (0.064)	0.665 (0.464)	0.050 (0.077)	4.475* (2.375)
	WTI	-4.484*** (0.806)	0.248* (0.147)	-0.290** (0.131)	0.209*** (0.054)	1.339*** (0.296)	-0.078 (0.049)	10.426*** (1.500)

Table 7 – Financial indicators

Notes: this table reports estimated coefficients and standard errors for American and Russian economic growth, business cycle dummies and the structural breaks variables solely. These results are obtained from Equation 5 with the dependent variable being in turns equal to each of Vol1 – Vol6 measures. For each of the volatility measures we estimate the regression three times: for Brent, Dubai and WTI crude oils. This approach allows us to compare estimated coefficient not only across volatility measures, but also among different oil types within the same volatility estimator. Statistical significance levels are indicated as "***" denoting 1%, "**" denoting 5% and "*" being equal or less than 10%.

Concluding the latest two subchapters, we derive the following important findings with respect to the crude oil price volatility determinants. Political and social uncertainty, as well as the presence of big news highlighted by the media mostly did not have any statistically significant influence on the crude oil price volatility regardless of oil type or volatility estimator. The only exception was the Geopolitical Risk Index. OPEC decisions regarding quotas on crude oil production were important only in case of Brent and WTI oils price volatility, but not Dubai oil. At the same time, the OPEC reference basket price was mostly relevant for determination of the Dubai crude oil price. The growth of the USA economy was crucial for all the three types of oil, whereas the Russian economic growth overall had a rather moderate influence being most important for the Brent oil price volatility.

Overall, these results were consistent across all volatility estimators, even though differing across types of crude oils, but, similarly to the previous section, the Vol1 measure in most of the cases delivered results opposite to the other volatility measures.

Chapter 5.5: Comparative analysis of volatility measures

In order to obtain the most accurate estimate of the oil price volatility we introduced six different volatility estimators. In their calculative sophistication they ranged from a quite straightforward Vol1 variable to a very complex one and namely, the Vol6. At this stage of the research we introduce an analysis of these volatility estimators' comparative performance.

First of all, it should be noted that for almost all the estimated regression equations the Vol1 coefficients severely differed from the rest of the variables in both statistical significance and coefficients values. For example, whereas the USA CPI surprise component had statistically significant influence of about 1.3% estimated for Vol1 measure for the Brent crude oil price volatility, in case of the other five estimators this impact was evaluated as less than 1% being also statistically insignificant. The same applies to the Russian export surprise variable interacting with Dubai price volatility, but in this instance the influence was around 0.1% and significant for Vol1 and much less than 0.1% and statistically insignificant for all the other volatility estimations. This inconsistency in statistical power and absolute estimates of coefficients between Vol1, on the one hand, and Vol2 – Vol6 estimators, on the other hand, can be traced throughout the whole study.

Primarily, this discrepancy raises the question whether we can rely on the results delivered by the Vol1 estimator. Arguably, the answer depends on the purpose of research: in case of the intraday volatility attention should be shifted towards more sophisticated volatility measures.

Moreover, it is worth noting that other coefficients delivered by all the other volatility estimators were in line with each other. Nevertheless, there were some examples, when results were pairwise more similar. For instance, findings for Vol5 and Vol6 were more often consistent with each other than with the rest of the variables. This can be explained by the calculation approach of Vol6: it partially relied on the Vol5 value adding to our consideration open-to-close and overnight volatility jumps. Interestingly, estimated coefficients in these two cases were on average statistically significant to the same extent, however, the absolute values, as well as standard errors usually were slightly lower for Vol6 if compared to Vol5. Overall, we can conclude that both volatility estimators deliver the most accurate estimates of volatility among the 6 considered measures, they are equally reliable and broadly speaking similarly accurate, but if very precise estimates are needed, the preference might be given to the Vol6 estimator. At the same time, properties of the Vol1 estimator are so distinct from the rest that since it is based on closing prices only it represents a special kind of volatility. Therefore, the results it delivers should not be compared with more advanced volatility measures and be rejected due to lack of accuracy. Based on these observations we rather conclude that both types of volatility measures have their right to live and one should think carefully about the purpose, methodology and concept of their research when choosing the appropriate volatility estimator.

Chapter 6: Conclusion, limitations and further research

Nowadays, crude oil plays one of the leading roles on energy and financial markets. This research focuses on analyzing the main determinants driving the crude oil price volatility. In particular, it integrates such explanatory variables as investor expectations of macroeconomic factors and its deviations from expected values, impact of media coverage and major events, economic and political instability, and, finally, impact of the crude oil market main player – the Organization of Petroleum Exporting Countries which is one of the trendsetters at the moment. Incorporation of all these factors allows us to obtain noteworthy results and link them to hypotheses of this research in the following way.

The main finding discovers the influence of macroeconomic news surprise component which represents discrepancy between investors' expectations and actual announced macroeconomic values. In particular, we detect substantial influence of the USA macroeconomic news surprise component on the crude oil price volatility which was an expected outcome, but also the equally intense impact of the Russian macroeconomic new surprise component. This fact proves the significance of investors' expectations, as well as market's imperfections. Therefore, we accept hypothesis 1: *Excess of announced macroeconomic news values over the projected (forecasted) values has statistically significant influence on the crude oil price volatility*. In contrast to these findings and our forecasts, media and both economic and politic uncertainty did not play the key role in the crude oil price volatility. Thus, we reject hypotheses 3a and 3b: *Major global events and Geopolitical Risk index have statistically significant influence on the crude oil price volatility.* This result held true across all the three types of crude oil considered which proves the reliability of derived findings

Furthermore, a valuable result is the considerable power of the OPEC both in terms of crude oil production quotas and the OPEC reference basket price. In other words, OPEC influences both quantity of demand and price of the crude oil on the world energy market. Therefore, we accept hypothesis 2a: *OPEC decisions regarding quotas of oil production have statistically significant influence over the crude oil price volatility*. Moreover, the recent news about potential formation of a new organization which would include several non-OPEC countries, such as Russia [19], creates room for further research on this institutional influence on the crude oil market in

general and price volatility in particular. However, we fail to accept hypothesis 2b: *OPEC decisions influence is equally significant for Brent, Dubai and WTI crude oil price volatility.* In contrast to our expectations, changes in OPEC production quotas were highly relevant for Brent and WTI crude oil price volatilities but did not influence dynamics of the Dubai crude oil price changes.

Overall, considering oil price determinants, we conclude that the three considered types of oil were affected by varying factors and to a different extent. These distinctions in considered determinants' influence were quite dramatic in some cases, though we might note that on average obtained results were rather resembled for the Brent and WTI price volatilities, while estimated coefficients for Dubai price were detached. Therefore, we reject hypothesis 4: *There is no statistically significant difference between WTI, Brent Crude and Dubai Crude types of oil, when modeling determinants of their price volatility.*

Finally, apart from oil price volatility determinants and the extent of their influence, we also consider several volatility measures which cover multiple aspects such as overnight jumps and non-zero drift term. Interestingly, most of the volatility estimators considered in this study deliver similar and comparable results, while only the common day-to-day volatility was sustainably delivering distinctly differing results both in terms of statistical significance of estimated coefficients and their absolute values.

Summarizing the results in light of introduced hypotheses, we note that the rationally expected outcomes do not take place as often as we would forecast. This speaks in favor of the fact that the current state of energy and financial markets is far from perfect competition, market participants, obviously, frequently behave irrationally and apart from laws of demand and supply prescribed by the standard economic theory, there exist other powers driving prices in these markets.

Introducing the results obtained in the conducted research we cannot bypass its limitations. Firstly, as any empirical study that involves econometric analysis, there are restrictions implied by the chosen regression estimation method. In particular, we were not able to fully eliminate the autocorrelation and heteroscedasticity issues, even though the used estimation approach has

substantially improved tests statistics. Probably, some more advanced econometric methodology could be able to overcome these issues to a greater extent. However, represented results are still reliable and robust.

Moreover, we imply that the macroeconomic news surprise component variable created in this research reflect the true unbiased deviation of macroeconomic variables from their expected values. At the same time, based on the studies conducted in the behavior finance area, we know that investors and economists' beliefs are subject to several biases, such as overconfidence and self-attribution bias. Especially this is true when conducting surveys about predicting economic situation. For example, several academic papers have shown that CEO's fail to predict macroeconomic variables, while we would expect them to be more skilled and rational than the rest of the market participants. Therefore, data presented by the World Economic Survey provides us only a proxy of rationally expected macroeconomic values. Nevertheless, a more accurate proxy of the true expected value of macroeconomic indicators probably does not exist at the moment.

The main contribution of this paper consists of the following aspects. Firstly, it brings together and incorporates several different groups of explanatory variables into one model which was not done before. Preceding studies mostly focused on each particular factor individually and dug into analyzing its influence separately. Secondly, it introduces the macroeconomic news surprise component of the Russian economy which was not studied in this aspect earlier. Russia plays a leading role in the world crude oil production and its economy is highly dependent on the crude oil demand and price. Finally, this research covers three different types of crude oil that represent different economic and geographic markets, which allows us not only to compare results, but also ensures additional reliability of findings reported by this paper. In addition, we also provide extra assessments of different intraday volatility measures which enables us to study volatility patterns on a more advanced level and conclude with respect to their applicability according to research questions.

Concluding this chapter, we assess possibilities for further research. In line with the vast amount of literature on this topic, we conclude that macroeconomic news and OPEC decisions matter for the crude oil price volatility. First of all, it might be useful to go deeper into these interdependencies and study causality effects: do these factors determine oil price volatility or, in contrast, do they take such values as a result of preceding oil price movements? Furthermore, in

addition to Russian and the USA, it might be interesting to introduce macroeconomic surprise component coming from the OPEC-member economies. Inasmuch as we did not detect any influence of OPEC quotas decisions on the Dubai price volatility, even though both of them represent the same market, it is required to study this geographical market more closely and, presumably, detect another important determinant of the crude oil price volatility. Finally, if an OPEC-alternative organization is created and operates successfully, in a few years it might not substitute OPEC to the full extent, but would definitely change the world crude oil market dramatically. Researchers agree that OPEC as an organization has an enormous influence on the crude oil market, even though it does not directly interact with other market participants. Therefore, should this Super-OPEC organization be formed, additional studies must be carried out with respect to these changes, especially covering the OPEC influence, as well as the impact of this newly formed institution.

References

1. Aloui R, Gupta R, Miller M (2015). Uncertainty and Crude Oil Returns, Energy Economics, Vol. 55
1. Baker S, Bloom N, Davis S (2015). Measuring Economic Policy Uncertainty. NBER Working Paper No. 21633
2. Balcilar M, Bekiros S, Gupta R (2015). The Role of News-Based Uncertainty Indices in Predicting Oil Markets: A Hybrid Nonparametric Quantile Causality Method, Empirical Economics, Vol. 53, Issue 3, pp. 879–889
3. Balduzzi P, Elton E, Green T (2001). Economic News and Bond Prices: Evidence from the U.S. Treasury Market, The Journal of Financial and Quantitative Analysis, Vol. 36, Issue 4, pp. 523-543
4. Bennett C, Miguel A (2012). Measuring historical volatility: Close-to-Close, Exponentially Weighted, Parkinson, Garman-Klass, Rogers-Satchell and Yang-Zhang Volatility, Santander Consumer Finance
5. Bradley T, Farooq M (2017). Modeling asymmetric volatility in oil prices under structural breaks, Energy Economics, Vol. 63, pp. 227–233
6. Chou Y, Chou H, Liu N (2010). Range Volatility Models and Their Applications in Finance. Handbook of Quantitative Finance and Risk Management, pp. 1273–1281
7. Garman M, Klass M, (1980). On the estimation of security price volatilities from historical data, Journal of Business, Vol. 53, pp. 67-78
8. Fawzan A (2015). Volatility and efficiency of the world crude oil market, Journal of Economic and Administrative Sciences, Vol. 31 Issue: 1, pp. 20-29
9. Karali B, Ramirez O (2013). Macro determinants of volatility and volatility spillover in energy markets, Energy Economics, Vol. 46, pp. 413–421
10. King K, Deng A, Metz D (2012). An Econometric Analysis of Oil Price Movements: The Role of Political Events and Economic News, Financial Trading, and Market Fundamentals, Bates White Economic Consulting
11. Lin S, Tamvakis M (2009). OPEC announcements and their effects on crude oil prices, Energy Policy, Vol. 38, Issue 2, pp. 1010-1016
12. Parkinson M (1980). The extreme value method for estimating the variance of the rate of return, Journal of Business, Vol. 53, pp. 61–65

13. Rogers L, Satchell S (1991). Estimating variance from high, low and closing prices, The Annals of Applied Probability, Vol. 1 (1991), Issue 4, pp. 504-512
14. Schmidbauer H, Rösch A (2010). OPEC news announcements: Effects on oil price expectation and volatility, Energy Economics, Vol. 34 (2012), pp. 1656–1663
15. Smales, L (2017). Commodity market volatility in the presence of U.S. and Chinese macroeconomic news, Journal of Commodity Markets, Vol, 7, pp. 15–27
16. Yin L (2014). Does oil price respond to macroeconomic uncertainty? New evidence. Empirical Economics (2016), Issue 51, pp. 921–938
17. Wei Y, Liub J, Lai X, Hub Y (2017). Which determinant is the most informative in forecasting crude oil market volatility: Fundamental, speculation, or uncertainty? Energy Economics, Vol. 68 (2017), pp. 141–150
18. Yang D and Zhang Q (2000). Drift Independent Volatility Estimation Based on High, Low, Open and Close Prices. Journal of Business, Vol. 73 (3), pp. 477-491
19. E-source: Russia-Saudi Plans for Super-OPEC Could Reshape Global Order; Bloomberg.com [https://www.bloomberg.com/news/articles/2018-06-22/russia-saudi-plans-for-super-opec-could-reshape-global-oil-order]

Appendix

Appendix 1 – Statistical tests results

	Brent		Dubai		WTI	
	Original	Transformed	Original	Transformed	Original	Transformed
	(1)	(2)	(3)	(4)	(5)	(6)
Vol1	0.072	0.115	0.056	0.181	0.063	0.082
Vol2	0.293	0.741	0.203	0.509	0.356	0.726
Vol3	0.307	0.771	0.184	0.440	0.377	0.779
Vol4	0.315	0.785	0.182	0.593	0.381	0.784
Vol5	0.225	0.476	0.106	0.171	0.346	0.469
Vol6	0.254	0.580	0.158	0.473	0.359	0.551

Table 8 - Adjusted R-squared values

Note*:* Table 8 reports adjusted R^2 values. In particular, columns (1), (3) and (5) deliver results of the basis OLS estimation; columns (2), (4) and (6) represent the Prais-Winston estimation results. We introduce these results in order to highlight the benefits of the Prais–Winston approach implementation. As can be observed, application of this method considerably improves the adjusted R^2 and this outcome holds true for all the six volatility estimators of all the three types of oil.

	Brent		Dubai		WTI	
	Original	Transformed	Original	Transformed	Original	Transformed
	(1)	(2)	(3)	(4)	(5)	(6)
Vol1	1.429	1.623	1.364	1.651	1.444	1.497
Vol2	0.969	1.948	1.186	1.845	1.062	1.917
Vol3	0.937	1.976	1.256	1.831	0.988	1.985
Vol4	0.887	2.009	1.111	1.871	0.973	1.996
Vol5	1.165	1.819	1.407	1.732	1.296	1.794
Vol6	1.070	1.885	1.161	1.836	1.212	1.842

Table 9 - Durbin-Watson test statistics

Note: Table 8 reports Durbin-Watson test statistics. In particular, columns (1), (3) and (5) deliver results of the basis OLS estimation; columns (2), (4) and (6) represent the Prais-Winston estimation results. We introduce these results in order to highlight the benefits of the Prais–Winston approach implementation. As can be observed, application of this method considerably improves the Durbin-Watson statistics and this outcome holds true for all the six volatility estimators of all the three types of oil.

	Brent	Dubai	WTI
	(1)	(2)	(3)
Vol1	0.108	0.008	0.027
Vol2	0.849	0.117	0.297
Vol3	0.515	0.000	0.828
Vol4	0.959	0.001	0.972
Vol5	0.555	0.601	0.015

	Brent	Dubai	WTI
	(1)	(2)	(3)
Vol1	0.000	0.000	0.000
Vol2	0.054	0.000	0.000
Vol3	0.000	0.000	0.000
Vol4	0.000	0.000	0.000
Vol5	0.076	0.000	0.000

Vol6	0.429	0.004	0.219

Table 10 **-** Breusch-Pagan test statistics

Vol6	0.000	0.000	0.000

Table 11 **-** Jarque–Bera test statistics

Note: Tables 10 and 11 report Breusch-Pagan and Jarque-Bera tests statistics based on the regular OLS estimation of all the 18 regression equations introduced in this study. Based on these results we detect that some of the assumptions do not hold (such as homoscedasticity and normal distribution of the error term). Based on these observations, as well as results reported in Tables 8 and 9, we have decided to implement the Prais-Winston estimation. Among other things, it improved the distribution of the error term, as shown by Figures 33-50.

Appendix 2 – Error term distribution plots

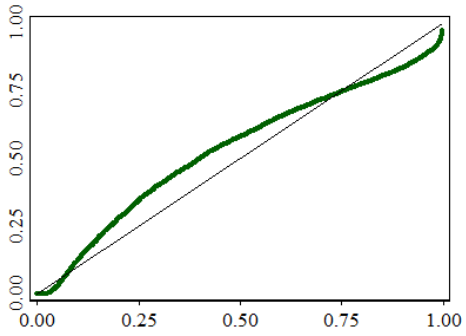

Figure 33 – Vol1 of Brent

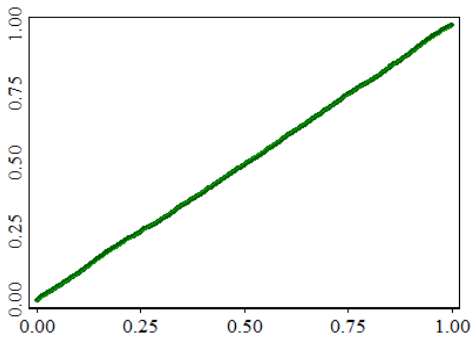

Figure 34 – Vol2 of Brent

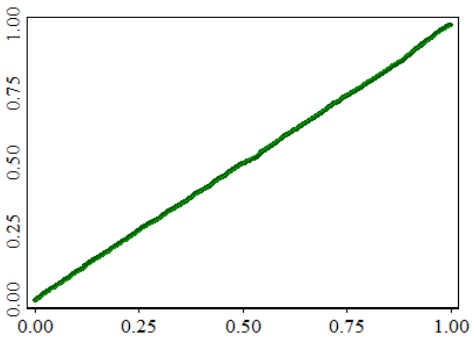

Figure 35 – Vol3 of Brent

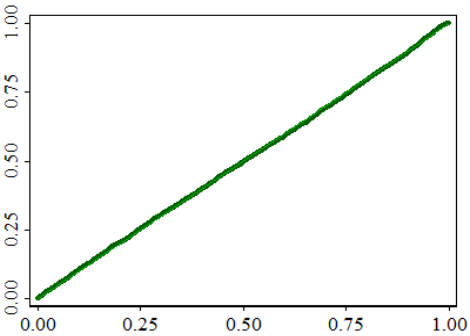

Figure 36 – Vol4 of Brent

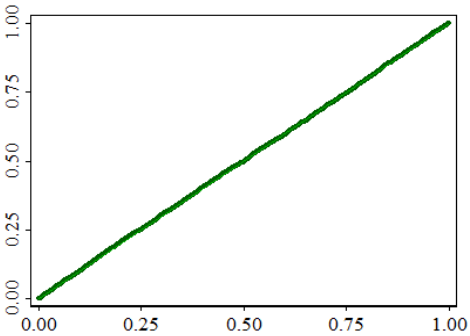

Figure 37 – Vol5 of Brent

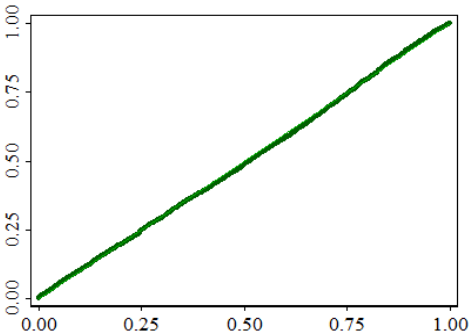

Figure 38 – Vol6 of Brent

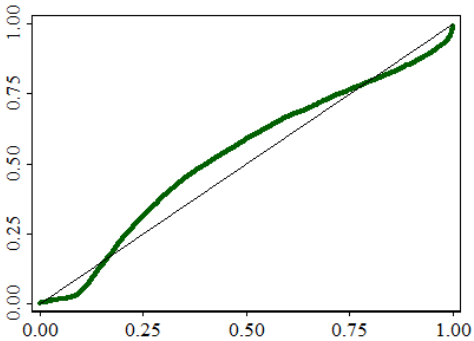

Figure 39 – Vol1 of Dubai

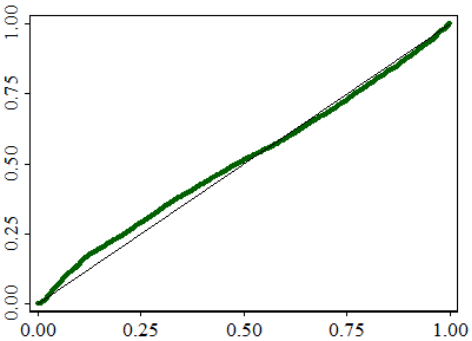

Figure 40 – Vol2 of Dubai

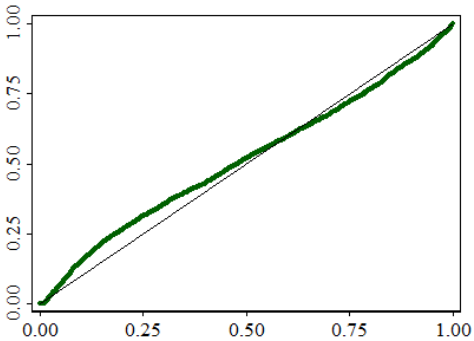

Figure 41 – Vol3 of Dubai

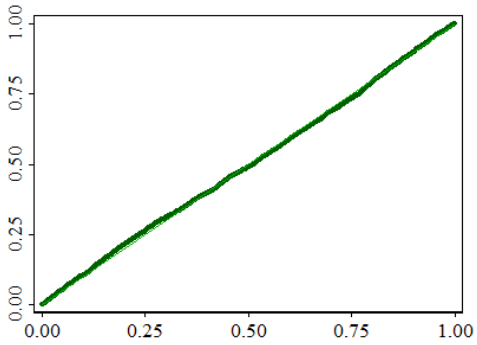

Figure 42 – Vol4 of Dubai

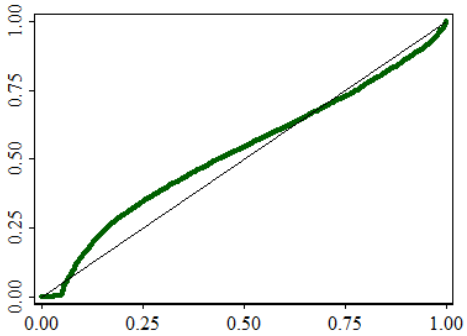

Figure 43 – Vol5 of Dubai

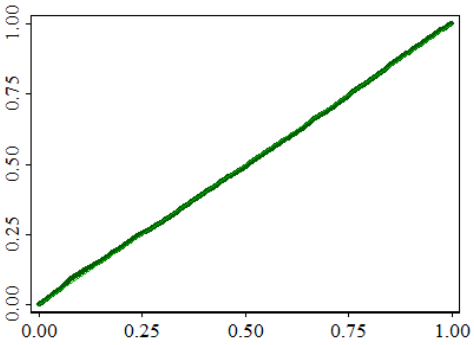

Figure 44 – Vol6 of Dubai

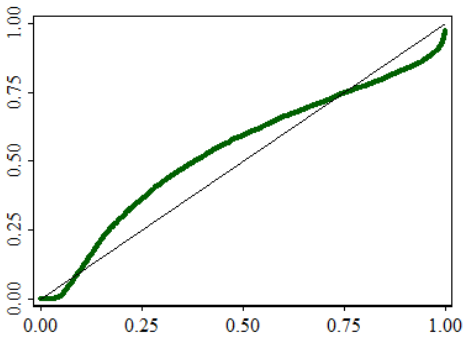

Figure 45 – Vol1 of WTI

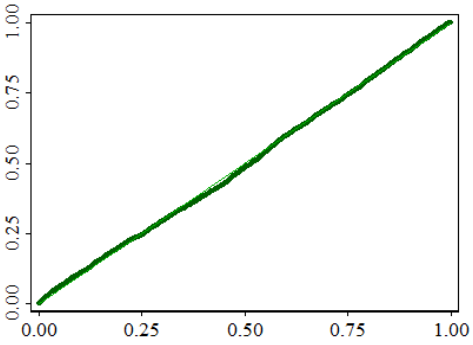

Figure 46 – Vol2 of WTI

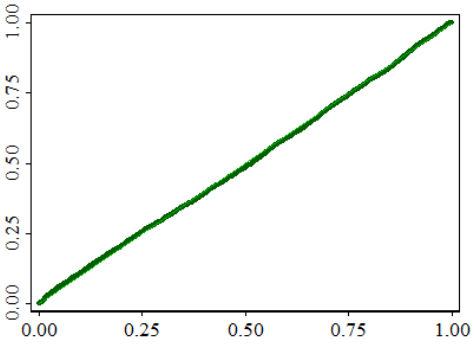

Figure 47 – Vol3 of WTI

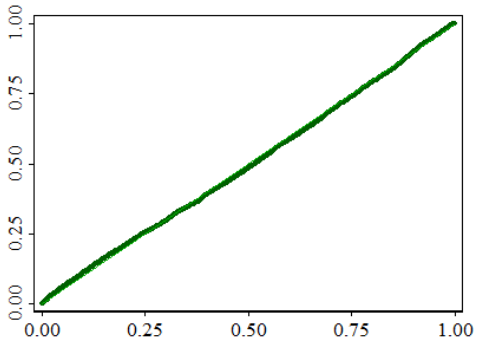

Figure 48 – Vol4 of WTI

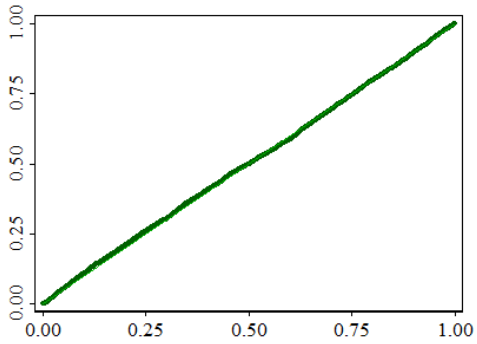

Figure 49 – Vol5 of WTI

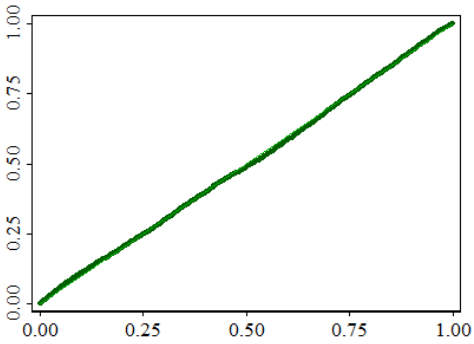

Figure 50 – Vol6 of WTI

Note: Figures 33 – 50 plot the distribution of error terms obtained after the Prais-Winston estimation against the normal distribution. As can be seen, in the majority of the cases the distribution is close or equal to normal. This observation supports the choice of Prais-Winston estimation approach.