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Oil Price Volatility Post 2008 Recession and Impact of World Growth and Exchange Rate on it

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Abstract

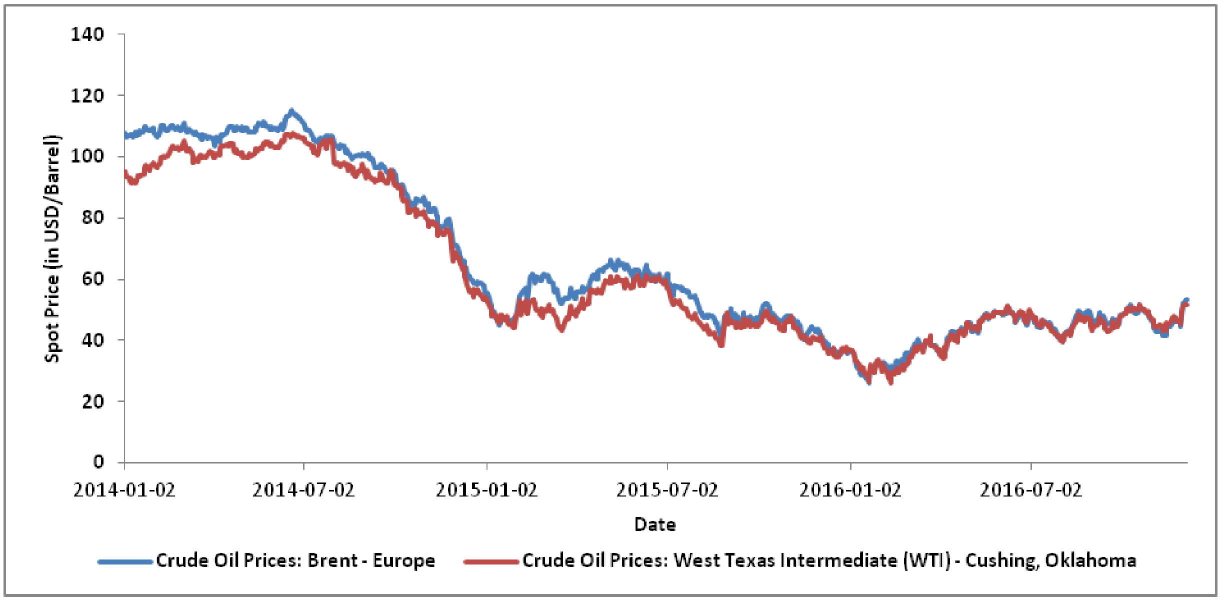
Oil price volatility has always been a topic of debate, with the steep fall in oil prices since mid-2014 especially taking the focus back on oil prices and their volatility. Given this backdrop, this study explores oil price volatility during the Pre-2008 and Post-2008 periods while taking into account two stylized properties namely, 'clustering' and 'leverage effect'. While modelling volatility, we take two exogenous variables: World GDP growth rate (with Industrial Production taken as its proxy) and USD/Euro Exchange Rate. It is intuitively expected that these two variables can affect volatility in the oil market. Also, we observed that the combined effect of these two variables has been neglected so far in the literature. Using GARCH and EGARCH models, and monthly log return data of West Texas Intermediate over a tenure of nearly sixteen years, our analysis shows that persistence exists in the Pre-2008 period whereas there is a lot more spikiness during the post-2008 period. Our analysis also shows that both the exogenous factors become significant in their impact on volatility during the Post-2008 period while remaining insignificant during the Pre-2008 period. This can be a potential policy issue for governments around the world.

Keywords: Oil Prices, US Dollar, Recession, GARCH, Exchange rate
JEL Classification Codes: C22, D51, Q02

I. Introduction

Predicting Oil prices and their volatility has gained a lot of interest over the years and with the recent nosedive in oil prices, the importance of accurate modelling has gained even more importance. Given that oil has been a major source of energy in the world, this dip in oil prices has had a widespread effect. Also, the fact that modelling and forecasting oil price volatility are important inputs into various option pricing formulas, and portfolio selection models, it becomes important to understand how the price volatility varies.

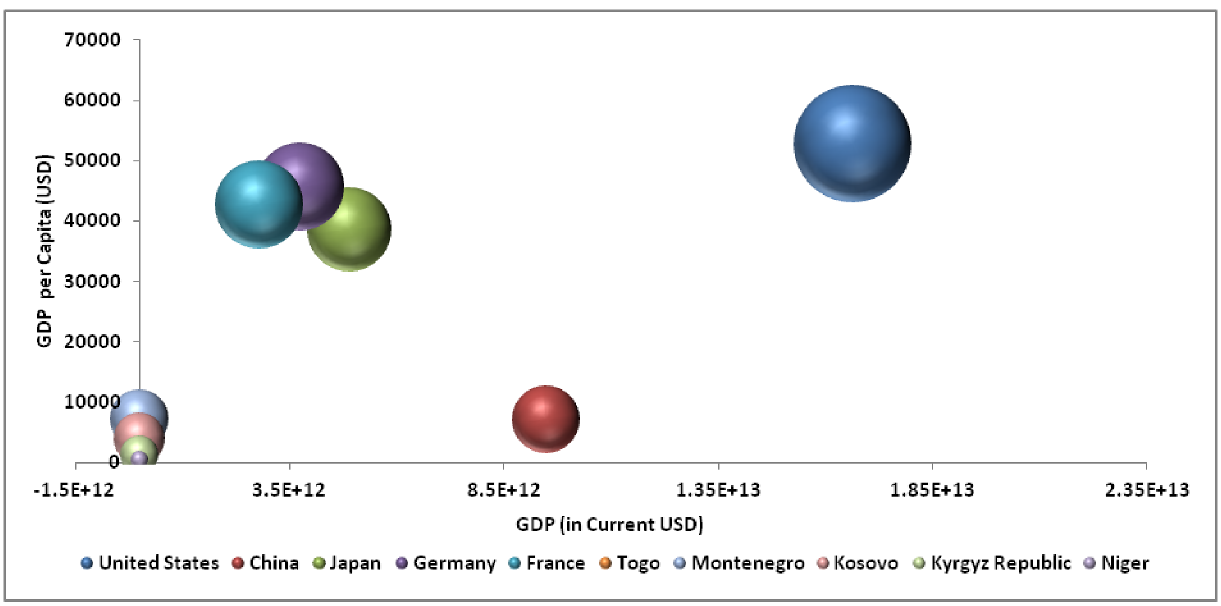
Figure 1: Daily Spot Crude oil prices of Brent and WTI since January 2014



Source: Graph plotted by the author based on data taken from US. Energy Information Administration

As mentioned before, Oil has been a major source of energy in the world and historically, consumption of energy has been linked with world Growth. Intuitively, this should link oil prices to World GDP (higher the GDP, higher the demand for energy (and hence, oil)) and hence, higher the GDP growth rate, higher may be the volatility. Therefore, this dissertation will try to enquire the relationship between oil price volatility and world GDP growth rate (measured by taking World Industrial Production as a proxy).

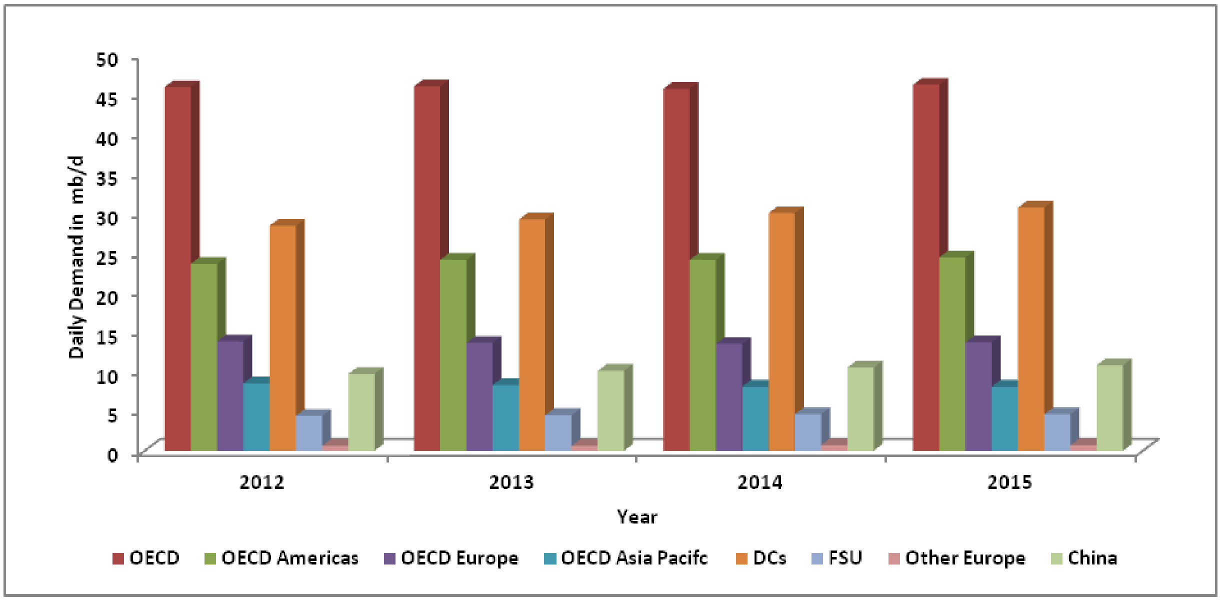
Figure 2: Comparison of countries on the basis of their GDP, GDP per capita and Energy Consumed per capita (kg of oil equivalent per capita) (depicted by the size of the sphere).



Source: Graph plotted by the author based on data taken from World Bank Data base. All values of three parameters are as per 2013.

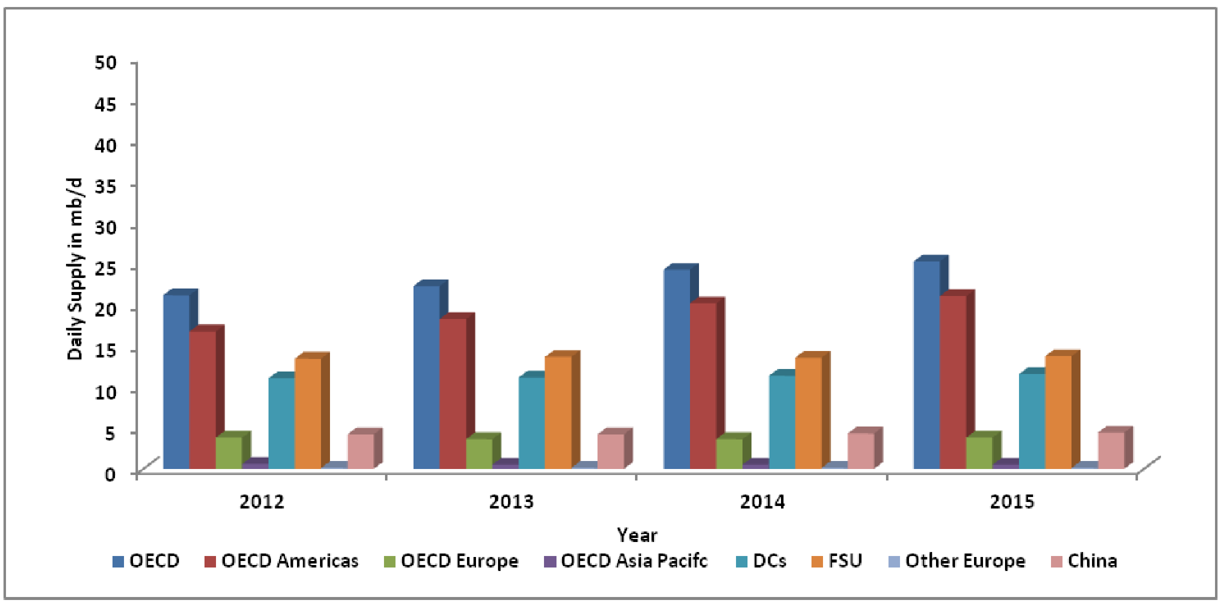
Further as the production of oil is happens primarily in only a few countries but oil is demanded by countries around the world. Further, the US Dollar remains the most used currency for paying for oil imported from other countries. Hence, oil price volatility should be affected by exchange rate of a country's currency against the US Dollar. Thus, we also aim to model oil price volatility against Exchange rate (specifically the exchange rate of US Dollar versus Euro).

Figure 3: Daily Demand of crude oil of various countries/country groups



Source: Graph plotted by the author based on data taken from OPEC annual report 2015

Figure 4: Daily Supply of crude oil by various countries/country groups



Source: Graph plotted by the author based on data taken from OPEC annual report 2015

Further, modelling the Oil Price Volatility will help us in distinguishing between two separate periods: before the 2008 slowdown and post 2008 slowdown. Based on our model, we aim to answer questions like: Has the volatility increased since the slowdown or not? If yes (or no), what might be the reasons behind it? Has the increase or decrease been sustained or not?

II. Previous Research

Modelling Oil price volatility has been the basis of many studies over a long period of time. Hamilton (1983) observed in his seminal paper that all but one of the recessions in the United States between the end of World War II and 1973 were preceded by a sharp rise in the price of oil, and hence, understanding the movement of oil prices and their volatility is important. Hamilton's work has both been challenged and supported by other writers. Most famously, Hooker (1996) demonstrated and argued that the relationship between oil and macro-economy that was suggested by Hamilton, did not apply in the last 80's and early 90's. Hamilton himself published a paper in the same journal (and the same issue) (Hamilton 1996) suggesting that by extending the data used by Hooker, one can see that his evidence only been strengthened and not weakened since 1983.

The importance of oil price volatility can be further seen in the work of Ferderer (1996), in which he points out how oil price shocks can have adverse impact in the long run. His work has roots in the fact that the importance of oil as a production input and oil's overall usefulness lends oil to a position where it can affect the Macroeconomy in a variety of ways. So, many linking channels between oil and Macroeconomy have been proposed over the years to account for their relationship. First among these, the 'real balances' channel says that when oil prices increase, inflation increases leading lower quantities of real balance in the system. This in turn leads to recession through monetary channels. The second channel (Darby 1982; Bohi 1991) emphasises that counter-inflationary monetary policy responses to oil prices increases result in the loss of real output. Another channel that has been suggested has been of 'income-transfer'. This channel posits that with an increase in oil prices leads to consumers of oil-importing countries rationing their consumption leading to a decrease in aggregate demand. Another channel that has been suggested over the years is (see Berndt and Wood (1979); Tatom (1988) for more details), that since oil and capital are complements in the production process, increases in oil prices make entrepreneurs respond by reducing their utilization of both oil and capital pushing down economy's productive capacity.

There has also been some research de-emphasizing the role of oil price levels in pushing economies towards recessions. First, Hamilton (1988) suggested that it is the magnitude of relative price changes that matter. Based on his multi-sectoral model, Hamilton proved and implied that aggregate unemployment rises when relative price shocks become more variable. Another channel that has been suggested argues that oil price volatility is an important determinant of economic activity because in case of uncertainty firms look to delay their irreversible investment expenditures (Bernanke 1983). Whatever be the model employed, it is clear that there exists a strong link between the oil price market and Macroeconomy suggesting how the movements in the oil markets directly affect macro-economic factors. Add to this, that Regnier (2007) showed that the prices of crude oil, refined petroleum and natural gas were more volatile than prices for about 95% of the products sold by producers; the need to successfully model oil price volatility becomes further important.

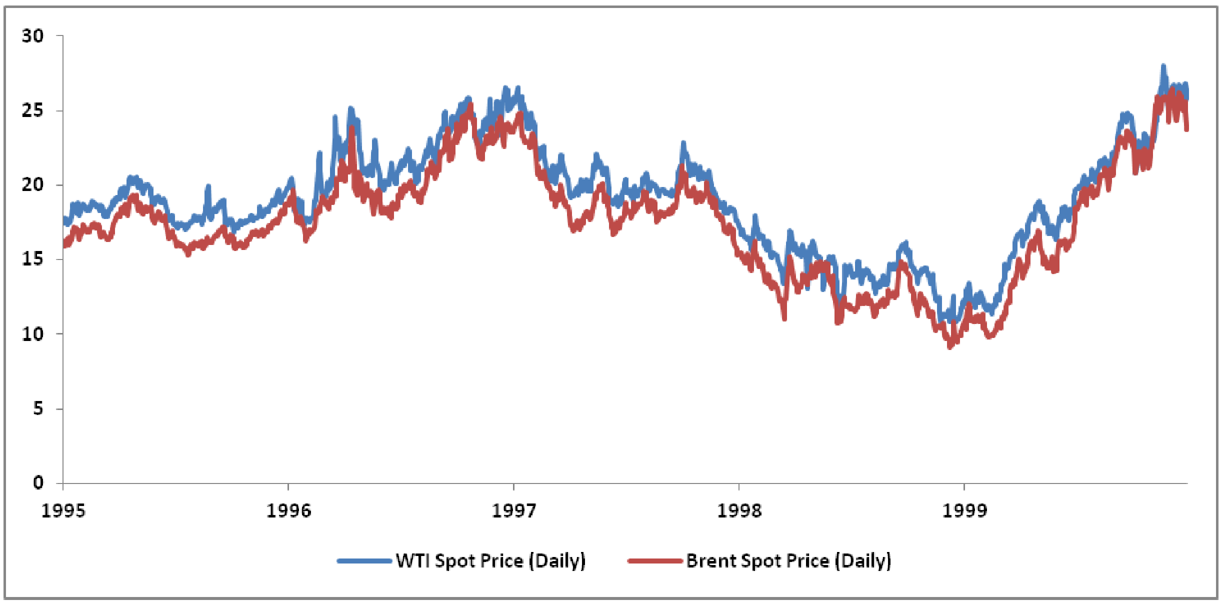
However, prima facie less attention has been paid to the effect of macroeconomic factors and exchange rate movements on oil prices. In this context Robays (2016) showed that higher macroeconomic uncertainty can significantly increase the sensitivity of oil prices to shocks in oil demand and supply, in turn inferring that higher macroeconomic uncertainty causes higher oil price volatility. His is a novel study as before this not much attention had been paid to the role of macroeconomic uncertainty in driving the oil prices. There can be basically two ways in which macroeconomic uncertainty can drive oil price volatility. First is an implication of one of the channels that has been explained before. As an extension of Bernanke's model (explained before) the adjustment to quantity of oil demanded would be low, pushing down the price elasticity of supply. This shall make sure that any shock from the supply side causes more volatility.

The second way related to speculation via futures markets. A higher amount of use of oil futures should make demand or supply less price responsive, in turn pushing up oil price volatility post an oil shock. This model is supported by the findings of Baumeister and Peersman (2013) and Hubbard (1986).

Yang *et al* (2002) also studied the effect of macroeconomic factors on volatility of the US oil market. In particular, they studied the impact of prosperity and recession of the world economy and the resulting demand shift on crude oil price. They argued that though increases in oil prices lead to recessions; recessions themselves can depress the oil prices to lower levels. This observation can be indeed supported by the fact that post the Asian Bank crisis circa 1997, the oil prices fell to around USD 10/barrel.

Krichene (2002) studied the world markets for crude oil and natural gas over 1918-1999, thereby covering the periods prior to and following the oil shock that occurred. They studied the time-series properties of crude oil and natural gas output and prices and concluded among other things that the oil shock did effect the crude oil price, making it reach a higher level (on a permanent basis) than was there before the shock.

Figure 5: Daily WTI and Brent Spot prices from 1995 to 2000.



Source: Graph plotted by the author based on data taken from US. Energy Information Administration

Extensive research on movement of crude oil prices was also done by Hamilton (2009) as he explored three broad ways in which the changes in oil prices can be explained: (1) Statistical investigation of the basic correlations in the historical data (2) Use of the economic theory to predict as to how oil prices should behave over time (3) Examine in detail the fundamental determinants and prospects for demand and supply. In their approach towards modelling demand and supply, they took OPEC as a traditional cartel. It should be pointed out here, that the way of functioning of OPEC has remained a topic of debate. Many models have been proposed to study the working of OPEC. These include the cartel model, competitive model, target revenue model and the partial market-sharing cartel model with different authors suggesting different methods. We would not be considering any geo-political scenarios in our work and would be limiting our work to world growth.

Oil prices have also been continually linked to the functioning of financial markets. One of the main reasons for this lies in the equity pricing model, which states that the price of equity at any point is equal to the expected present value of discounted future cash flows. As we have stated earlier, oil is one of the most important components that go into production of most goods and services. Hence, it is natural that changes in the prices of oil can affect cash flows. Add to this, increasing oil prices are often indicative of inflationary pressures, which are controlled by the central banks through their monetary policies (refer to the channels described above). This would in turn be reflected in the discount rates used for calculating the values of the equity. It is for these reasons, that we see a rich vein of literature linking oil prices with stock markets. Diaz *et al* (2016); Cong *et al* (2008); Basher and Sadorsky (2006); Sadorsky (1999); Park and Ratti (2008) and Sadorsky (2003) discuss this relationship in various contexts.

Another important area of research has been one linking exchange rate with oil prices. As already stated, it is intuitive that since oil purchases and sales can be invoiced in currency other than the importing and exporting countries (generally the invoicing currency is US Dollar), the changes in exchange rates can affect oil prices (say by affecting demand from the importing country). This supply-demand model of the price implications of exchange rates was studied by Dornbusch (1985) and further explored by Krugman (1986) as he studied pricing to markets in face of changing exchange rates. All this has promulgated research into role of exchange rates in oil prices. Yousefi and Wirjanto (2004)'s novel work looked at combining the oil supply structure (i.e. behaviour of OPEC countries) and change in exchange rates. Their study documented the price reactions of OPEC member countries to changes in exchange rates of US Dollar hence, implying that changes in US Dollar does play a role in determining oil prices. There have been other studies as well that discuss the relationship between exchange rates and oil prices. The work of Zhang *et al* (2008) discussed spillover effects from the US Dollar exchange rate to the oil price market. Amano and Norden (1998) studied the empirical evidence for relationship between oil price and US dollar real exchange rate shocks by using co-integration theory, error correction model and finally concluded that oil prices appeared to be the dominant source of persistent US dollar real exchange rate shocks. Indjehagopian *et al* (2000) studied the German and French heating oil market and attempted to establish both long-term and short-term relationships between German and French monthly heating oil prices in dollars, the Rotterdam spot price for the same product and the DM/US$ and FF/US$ exchange rates. Their results showed that a variation in exchange rates had an instantaneous impact on the variations in oil price.

There has been research linking oil market with exchange rates of other currencies. Zalduendo (2006) concluded that Brent real oil price, with other factors, plays a significant role in determining a time-varying equilibrium real exchange rate of Venezuela. Chen and Chen (2007) investigated the long-run relationship between real oil prices and real exchange rates of G7 countries suggesting that there exists a significant long-term relationship between the two. Further Camarero and Tamarit (2002) concluded that in addition to real interest rate, real oil price also should be taken as one of the main long-term determinants of real exchange rate of Spanish Peseta.

There has also been research to investigate the efficacy of different types of volatility models used for modelling oil price volatility (Hou and Suardi 2012; Sang *et al* 2009; Sadorsky 2006). These overwhelmingly establish GARCH type methods are best for studying volatility. Sang *et al* (2009) further established the correlation between three major benchmarks: Brent, WTI and Dubai, demonstrating that the movement in oil prices was not attributable to regional dislocations but rather global market factors. Further many researchers like Narayan and Narayan (2007) pointed out the asymmetric effects of shocks on oil price volatility. Evidence of volatility clustering was also found by them. Salisu and Fasanya (2013) also found evidence of asymmetric effects.

As one can see, there has been a gap in terms of studies based on finding the effect of exchange rate and world GDP growth rate (we shall take World Industrial Production as a proxy) on oil price volatility. On this basis, we would like to state the objective of our study as: ***To complement existing literature to develop an understanding of the impact of exchange rate and World GDP Growth rate on oil price volatility.***

III. Methodology

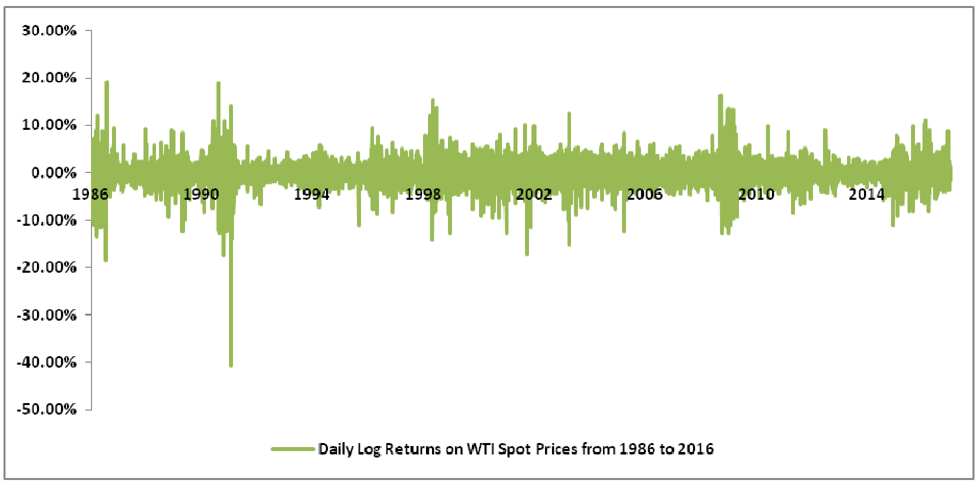
Stylized Facts: Various analyses have helped a number of stylized facts (defined as empirical findings consistent enough for them to be accepted as truth) emerge over the years. So, it is expected and intended for a good volatility model to show these stylized facts. Let us first try and list these stylized facts and introduce the models we will be using.

- **Leverage effect:** Many volatility models including GARCH (1,1), have an inbuilt assumption that both negative and positive events symmetrically affect conditional volatility. For example, in GARCH (1,1) model the variance has equal effect of negative and positive lagged terms because contribution of these lagged terms comes through their squared values.

  But it is highly unlikely that both negative and positive lagged terms produce the same effect on volatility in case of oil price volatility. This asymmetry has been called 'Leverage effect', which means the tendency for volatility to rise more following a large price fall than following a price rise of the same magnitude.
- **Volatility Clustering:** Volatility Clustering is the tendency for volatility to appear in bunches. So small returns (of either sign) are expected to follow small returns. Similarly, large returns (of either sign) are expected to follow large returns. The most important result of volatility clustering is that volatility today will influence the volatility tomorrow.

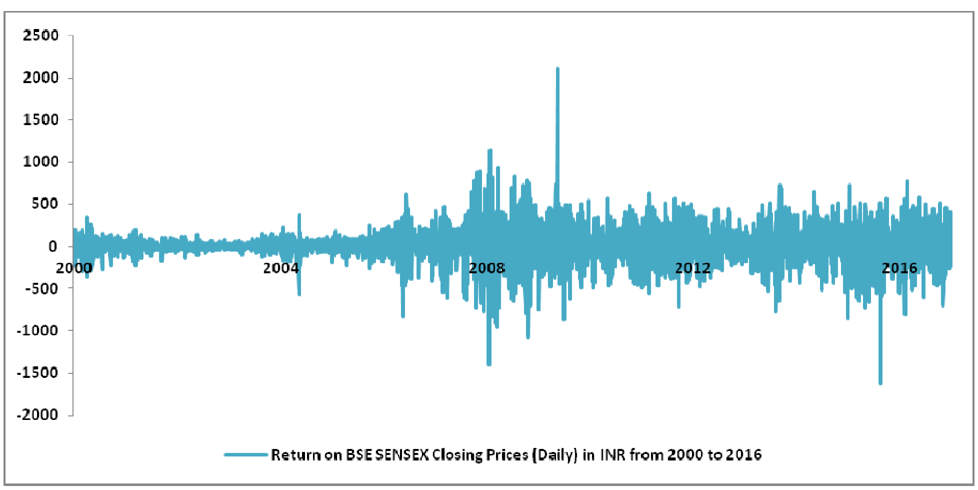
  This can be seen from the figures given below. The first figure depicts the daily log returns on WTI Oil Spot Prices and the second figure depicts the daily returns on BSE SENSEX from 2000 to 2016 (in INR). The main thing to observe here is the volatility occurs in bursts. If one were to abuse the terminology slightly, one can say that 'volatility is auto-correlated'.

Figure 6: Daily Log Returns on WTI Spot Prices from 1986 to 2016



Source: Graph plotted by the author based on data taken from US. Energy Information Administration

Figure 7: Daily return on BSE SENSE from 2000 to 2016 (in INR)



Source: Graph plotted by the author based on data taken from BSE's website (www.bseindia.com)

Our work looks to utilize two of the most well-known econometric models: GARCH and EGARCH. These methods will be used to analyse the volatility in the WTI Oil Prices during our chosen time period (2000 to 2016), keeping in mind the above stylized properties. A brief description of the methods is given below:

- **Generalized Autoregressive Heteroskedasticity (GARCH) Model:** Before GARCH, another method, which was designed to model volatility, was ARCH (Autoregressive Conditional Heteroskedasticity). It was designed by Engle (1982). As the term 'autoregressive' alludes, the basic principle of this model is that the variance of a dependent variable is described as a function of its own lagged values and other exogenous variables. We can write the ARCH process as:

$$y_t = x_t'\xi + \varepsilon_t \qquad t = 1, \ldots, T$$

Where we define, y_t = dependent variable
x_t= $kx1$ vector of exogenous variables, and it can include the lagged values of the dependent variable itself. Note that x_t' is the transpose of this vector
ξ = $kx1$ vector of regression coefficients
ε_t = error term and it is taken as conditional on the realized values of the set of variables i.e. $I_{t-1} = \{y_{t-1}, x_{t-1}, y_{t-2}, x_{t-2}, \ldots\ldots\}$.

The error term was modelled by Engle as being normally distributed. The mathematical depiction for the same being:

$$\varepsilon_t | I_{t-1} \sim N(0, \sigma_t^2)$$

Where, $\sigma_t^2 = \alpha_0 + \alpha_1\varepsilon_{t-1}^2 + \ldots\ldots\ldots + \alpha_q\varepsilon_{t-q}^2$, is the *conditional variance,* with $\alpha_0 > 0$ and $\alpha_i \geq 0$, $i = 1, \ldots\ldots q$, which ensures that the conditional variance is positive. Note that if one or more of the coefficients were to take on a negative value, then in case we have a sufficiently large lagged squared innovation term attached to that coefficient, the fitted value for the conditional variance obtained from the model could be negative. Hence, this condition is known as the *non-negativity condition*, and it is a sufficient but not a necessary condition for non-negativity of the conditional variance.

The reason behind the name 'conditional variance' is that, σ_t^2 (forecast variance for the current period) is based on the past information that we have i.e. I_{t-1}. So, conditional variance can be described as a distributed lag of the past squared error terms: ε_{t-i}^2, $i = 1, \ldots. q$. Further, the term 'heteroscedasticity' means that variance of the error term is not constant. All this explains the name Autoregressive Conditional Heteroscedasticity Model of order q, or simply, ARCH (q). One can also interpret the conditional variance of the error term as volatility of the dependent variable itself.

Though prima facie, the ARCH model provides a good framework for the analysis and development of time series models of volatility, it has rarely been used over time. This is because a number of difficulties are there in its use:

- **Value of 'q'**: There is no clear best approach to find the value of q. One of the more famous approaches to finding the value of 'q' is the 'Likelihood Test'.
- **Model might not be parsimonious**: If the value of 'q' is large, the model might not be parsimonious and hence, difficult to implement.
- **Non-negativity constrains might be violated:** Logically speaking, the higher number of parameters are there, the more likely it becomes that one or more of these parameters will have negative estimated values.

GARCH is a natural extension of ARCH and overcomes some of these problems. As a reflection of this, GARCH models are extremely widely employed in practice. It was developed separately by Taylor (1987) and Bollerslev (1986). According to them, the conditional variance can be described as:

$$\sigma_t^2 = \alpha_0 + \alpha_1\varepsilon_{t-1}^2 + \ldots\ldots + \alpha_q\varepsilon_{t-q}^2 + \beta_1\sigma_{t-1}^2 + \ldots\ldots + \beta_p\sigma_{t-p}^2$$

The above equation is subject to constraints:

$\alpha_0 > 0$

$\alpha_i \geq 0$, for $i = 1, \dots \dots q$

$\beta_i \geq 0$, for $i = 1, \dots \dots p$

These constraints are put to ensure a positive conditional variance. This model is a called a GARCH (p, q) model. A simplified version of the same is the 'generic' or 'vanilla' GARCH model, in other words the GARCH (1, 1) model. It can be written as:

$$\sigma_t^2 = \alpha_0 + \alpha_1 \varepsilon_{t-1}^2 + \beta_1 \sigma_{t-1}^2$$

Thus the forecast variance for the present period, σ_t^2 , is expressed as a function of:

α_0 = a constant

ε_{t-1}^2 = News about volatility from the previous period (also called ARCH term)

σ_{t-1}^2 = Previous period's forecast variance (also called GARCH term)

If one recursively substitutes for the lagged variance (σ_{t-1}^2), then in the above equation, the conditional variance can be described as:

$$\alpha_\varepsilon^2 = E(\varepsilon_t^2) = \frac{\alpha_0}{1 - \alpha_1 - \beta_1}$$

Thus the GARCH (1,1) model puts the constraint, $\alpha_1 + \beta_1 < 1$ under which the conditional variance can exist. If $\alpha_1 + \beta_1 = 1$, we say that 'a unit root in variance' exists and as suggested by Brooks (2002), it is called 'Integrated GARCH'.

Before we move forward, we need to understand the role played by the relative magnitude and significance of the ARCH and the GARCH terms. In case the ARCH term is large and the GARCH term is small, the volatility in the series is highly reactive to the recent most news about volatility (i.e. the ARCH term). In this case, one can expect the volatility pattern to be less 'persistent' and 'spiky'. On the other hand, if we have a small ARCH term and a large GARCH term, it implies the opposite and it can be expected that the volatility pattern is more 'persistent' and 'smooth'.

- **Exponential GARCH (EGARCH) Model:** As discussed before, one of the limitations of GARCH model is that it assumes symmetric effects for both the negative and positive shocks. This goes against the empirical evidence which suggests that negative shocks have a bigger impact on volatility than a positive shock of the same magnitude. Nelson (1991) first modelled this by using the EGARCH model. There are various ways to express this model, but one possible specification can be written as:

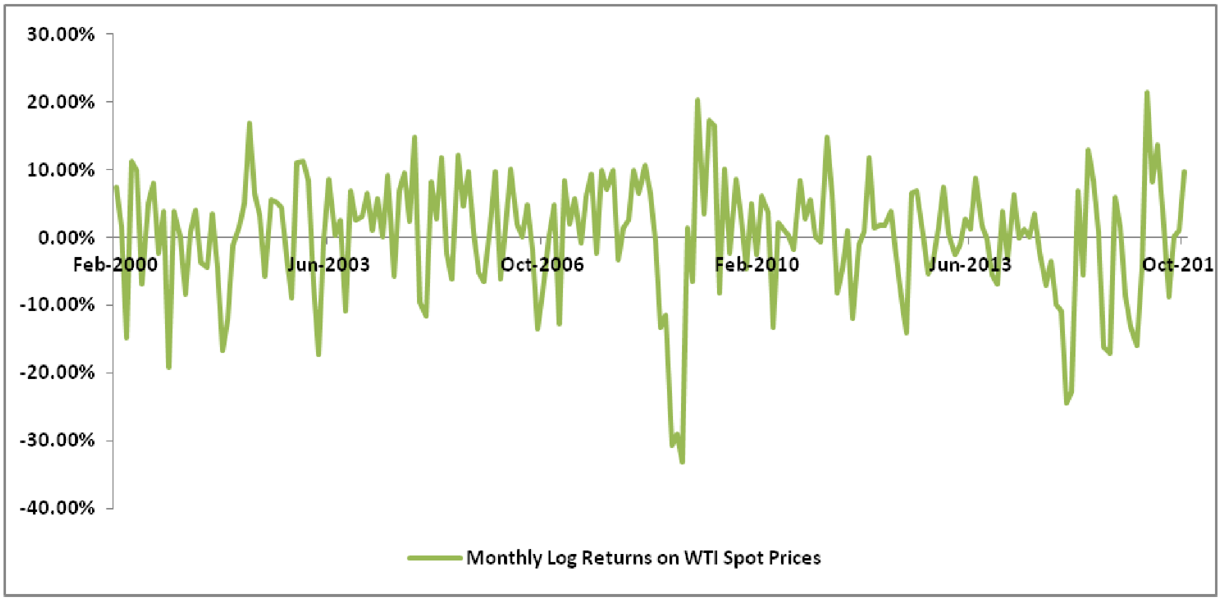
$$\log(\sigma_t^2) = \alpha_0 + \sum_{j=1}^{q} \beta_j \log(\sigma_{t-j}^2) + \sum_{i=1}^{p} \alpha_i \frac{|\varepsilon_{t-i}|}{\sigma_{t-i}} + \sum_{k=1}^{r} \gamma_k \frac{\varepsilon_{t-k}}{\sigma_{t-k}}$$

The above model can be called the EGARCH (p, q, r) model. One can acknowledge from the above formula that the exponentiality comes because of the log term. This further implies that as opposed to the leverage effect being quadratic (and hence, non-existent) in GARCH, it is exponential in EGARCH. Further, the presence of leverage effect can be tested by testing the hypothesis $\gamma_k = 0$ against the alternative hypothesis $\gamma_k < 0$. If γ_k is negative and statistically significant, then when the error term is negative, the final term in the above equation will become positive. This will help in capturing the asymmetric impact of the positive shock because the effect of a negative shock would be higher than the effect of a positive shock.

IV. Empirical Results and Analysis

The figure given below plots the monthly log returns based on the spot prices of WTI. A visual inspection of the plots shows some evidence of 'volatility clustering' during our study period. For analysing the data we used Eviews®.

Figure 8: Monthly Log return on WTI Spot Prices from February 2000 to October 2016



Source: Graph plotted by the author based on the calculation done on data taken from US. Energy Information Administration

The descriptive statistics for these monthly log returns are shown in the table given below. The mean is positive during the overall and the Pre 2008 period but negative during the Post 2008 period. This was expected because the oil prices have seen a steep fall since mid-2014 due to a variety of factors including shale gas production, oversupply and less demand by developing economies such as China. One can also note that the series during all the periods is negatively skewed. This points out that there were frequent small gains and a few extreme losses. This basically means that the oil prices saw a huge decline during some specific periods but incremental gains otherwise. The return series also shows non-normal kurtosis. The series is leptokurtic for Overall and Post 2008 period and platykurtic in the Pre 2008 period. As one can observe, the value of skewness is not zero and the series has a non-mesokurtic distribution, implying that it is not normally distributed. This is further confirmed by the significance of the Jarque-Bera (J-B) test statistic. In the case of the Pre 2008 series, the J-B test statistic is significant only at 10% level and not at 5% and 1%, indicating that the series shows characteristics of normal distribution during that period. This is supported by the fact that Kurtosis during that period is ~2.84 which is nearer to 3 when compared to the other two periods. Also, the negative skewness is less in this period when compared to the other two periods. The values inside the square brackets are the p-values for the J-B test statistic.

Table 1: Summary Statistics for Monthly Log Returns on WTI Spot Prices.

Period mm/yy	**Mean**	**Maximum**	**Minimum**	**Standard Deviation**	**Skewness**	**Kurtosis**	**Jarque-Bera**
Overall 02/00 to 10/16	0.002996	0.213866	-0.331981	0.089525	-0.831554	4.418657	40.020050 **[0.000000]**
Pre 2008 02/00 to 12/07	0.012768	0.168797	-0.190841	0.076817	-0.581212	2.843476	5.445592 **[0.065691]**
Post 2008 01/08 to 10/16	-0.005762	0.213866	-0.331981	0.099095	-0.821988	4.438689	21.078470 **[0.000026]**

The results obtained by applying the GARCH (1,1) model to the monthly log return series of WTI Spot Prices during the three periods: Overall, Pre 2008 and Post 2008 are given below. We took the World Production Index and the USD/Euro exchange rate as exogenous variables. As before the values inside the square brackets show the p-values for the coefficients. The coefficients of the chosen exogenous variables remain significant during the Overall and Post 2008 periods but not the Pre 2008 period (p-values of ~37.6% and ~26.9% for World Production Index and Exchange Rate respectively). We take a coefficient to be significant if the p-value is less than 10%.

Table 2: GARCH(1,1) results with World Industrial Production Index and Exchange Rate taken as exogenous variables Log returns taken as the dependent variable.

Period mm/yy	**Constant** (α_0)	**ARCH Coefficient** (α_1)	**GARCH Coefficient** (β_1)	**World Industrial Production Index**	**Exchange Rate**
Overall 02/00 to 10/16	0.001864 (1.615642) **[0.106200]**	0.250063 (2.593917) **[0.009500]**	0.499311 (2.334263) **[0.019600]**	-0.001291 (-3.355443) **[0.000800]**	0.109177 (3.490921) **[0.000500]**
Pre 2008 02/00 to 12/07	0.001256 (1.360345) **[0.173700]**	-0.140384 (-1.767259) **[0.077200]**	0.922332 (7.915321) **[0.000000]**	-0.000704 (-0.883884) **[0.376800]**	0.068723 (1.10451) **[0.269400]**
Post 2008 01/08 to 10/16	0.001491 (1.50854) **[0.131400]**	0.399580 (2.376431) **[0.017500]**	0.464770 (2.121325) **[0.033900]**	-0.001113 (-2.502852) **[0.012300]**	0.096681 (2.667777) **[0.007600]**

As we have discussed in the section on methodology, when the value of ARCH coefficient is high, it means there would be 'spikier' volatility patterns. In other words, the volatility shows less persistence and large reactions. On the other hand, when the value of GARCH coefficient is high it implies that shocks take longer to die out. In other words, volatility would show large persistence and small reactions. During all the three periods, the GARCH coefficient is larger than the ARCH coefficient. But the ARCH coefficient is comparatively larger among the three periods during the Post 2008 period. Also, the GARCH coefficient is the least during the Post 2008 period among all three periods. This leads us to believe that during the Post 2008, there should be 'spikier' volatility patterns. Also, since the ARCH term is the smallest during the Pre 2008 period, there should be 'persistent' volatility patterns in the Pre 2008 periods. This can also be observed from a visual inspection of the return series figure shown earlier. A visual inspection of that figure will show that up till around 2008, the spikes in returns were consistent but not high. In the Post 2008 period, there were more frequent higher spikes.

Another important aspect for a GARCH model is that typically for return data, ($\alpha_1 + \beta_1$) is close to 1. This indicates persistence in volatility. Expectedly this is true for all the three periods. Also, the coefficients for World Production Index and Exchange rates are small when compared to the ARCH and GARCH coefficients. So, they have a small impact on volatility when compared to the ARCH and GARCH parameters. Within the two exogenous variables, the Exchange Rate seems to have a higher impact. This can be seen by higher values of its coefficients. Also, an increase in World Production Index decreases volatility whereas an increase in Exchange Rate increases volatility.

The results obtained by applying the EGARCH (1,1,1) model to the monthly log return series of WTI Spot Prices for all the three periods, Overall, Pre 2008 and Post 2008, are given below.

Table 3: EGARCH(1,1,1) results with World Industrial Production Index and Exchange Rate taken as exogenous variables Log returns taken as the dependent variable.

Period mm/yy	**Constant** (α_0)	**ARCH Coefficient** (α_1)	**GARCH Coefficient** (β_1)	**Leverage Coefficient** (γ_1)	**World Production Index**	**Exchange Rate**
Overall 02/00 to 10/16	-1.389300 (-2.220008) **[0.026400]**	0.327046 (2.001235) **[0.045400]**	0.776602 (6.839595) **[0.000000]**	-0.173953 (-2.044663) **[0.040900]**	-0.001134 (-3.01216) **[0.002600]**	0.094602 (3.157342) **[0.001600]**
Pre 2008 02/00 to 12/07	-8.538071 (-3.793515) **[0.000100]**	0.321858 (0.949037) **[0.342600]**	-0.603114 (-1.289188) **[0.197300]**	-0.132060 (-0.959675) **[0.337200]**	-0.001430 (-1.60666) **[0.108100]**	0.122062 (1.776797) **[0.075600]**
Post 2008 01/08 to 10/16	-1.381227 (-2.152426) **[0.031400]**	0.466235 (1.809900) **[0.070300]**	0.799317 (7.462918) **[0.000000]**	-0.247398 (-1.932915) **[0.053200]**	-0.001200 (-2.96711) **[0.003000]**	0.100220 (3.061588) **[0.002200]**

As can be seen from the above table, the coefficient γ_1 is negative for all the three periods. It should be noted that it is significant for the Overall and Post 2008 periods but not for the Pre 2008 period. It implies that during these two periods, volatility for negative shocks (falling markets) was more compared to that for positive shocks (rising market). This won't be evident in the case of Pre 2008 period. This means that leverage effect is evident in the Overall and Post 2008 periods but not in the Pre 2008 periods.

One can also note that for the Post 2008 period the World Production Index becomes significant but is not significant for the Pre 2008 period. For Exchange rate, the significance substantially increases for the Post 2008 period when compared to the Pre 2008 period. This reaffirms the results obtained in the GARCH model.

We can also see that for the Overall and Post 2008 periods, the sum of the ARCH and GARCH coefficients is more than 1 (1.103648 and 1.265552). Also, in case of the Pre 2008 period, the GARCH coefficient is <0. However this is fine because unlike GARCH (1,1) model that puts some restrictions on coefficients (>0 and $\alpha_1 + \beta_1 < 1$), there are no such restrictions in case of EGARCH and hence, these do not warranty a deeper analysis for the same.

V. Conclusion

Oil price volatility plays a vital role for various microeconomic and macroeconomic considerations. This is because it is not just used as an input in many production processes but the health of economies of many oil-importing and oil-exporting countries is directly dependent on oil prices. Thus it becomes essential to estimate oil price volatility. In this regard, many attempts have been previously made to model and forecast oil price volatility and in the process, come out with some stylized facts shown by volatility in the oil prices. In this study, we make a modest attempt to explore oil price volatility before the 2008 crisis and after the 2008 crisis while trying to incorporate some stylized facts such as 'leverage effect' and 'clustering'. We use the GARCH and EGARCH models to model volatility in the monthly log return series of WTI spot prices, for the Overall, Pre 2008 and Post 2008 periods. We chose WTI because it is one of the most famous oil price benchmarks in the world.

We found some evidence of 'clustering' but this could have been more evident in the presence of more data points. The results from EGARCH model show the 'leverage effect' in the Overall and Post 2008 periods whereas leverage effect was not significant in the Pre 2008 period.

The impact of World Industrial Production and USD/Euro Exchange rate was also analysed. In this case both the models affirmed that these two exogenous variables were not very significant during the Pre 2008 period but became significant during the Post 2008 period. In fact both these models affirmed that the increasing World Industrial Production decreased volatility while increasing USD/Euro increased volatility.

With the world economy currently going through turbulent times and the fate of the US dollar only recently strengthening, this provides a potential policy challenge for policy makers around the world. We hope that they take privy to this matter and prepare will to cope with the uncertain times.

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Appendix: Data used for Analysis

Data Sources and Brief Explanation

Data Name	Source	Brief Explanation
*WTI Spot Oil Prices (Dollars/Barrel)	U.S. Energy Information Administration	WTI crude oil is an important oil benchmark. It serves as a reference price for buyers and sellers of crude oil and is often quoted as the price of oil in the market (along with other benchmarks as Brent). The data takes oil prices on the mid of month as the monthly prices.
*Log Returns	Calculated by the author	Log returns are a famous way for calculating returns instead of arithmetic returns because of two reasons. First, log return puts all numbers on a log plane, which normalises the returns to log normal. This removes any bias that Arithmetic Return may have. Second, the number of observations was high. The return was calculated as $ln\left(P_{i+1}/P_i\right)$.

Data Name	Source	Brief Explanation
*World Industrial Production Index	CPB Netherlands Bureau for Economic Policy Analysis	The Bureau publishes CPB World Industrial Production Index on a monthly basis. It has been doing so since January 2000. The data was accessed through the Bloomberg Terminal.
*Exchange Rate (USD/Euro)	European Central Bank	The data was accessed through the website of ECB's statistical warehouse. USD/Euro was chosen as these two currencies remain two of the most widely traded. Also, the United States and the European Union are the two largest economic entities in the world. The data takes the exchange rate at the end of month as the monthly data.

*Monthly frequency

Raw Data

Month	WTI Spot Oil Prices	Log Returns	World Industrial Production	Exchange Rate (USD/Euro)
Jan-2000	27.26		77.7	0.9791
Feb-2000	29.37	7.46%	78.5	0.9714
Mar-2000	29.84	1.59%	78.7	0.9553
Apr-2000	25.72	-14.86%	79.4	0.9085
May-2000	28.79	11.28%	80	0.9303
Jun-2000	31.82	10.01%	80.1	10.9556
Jul-2000	29.7	-6.89%	80.4	0.9243
Aug-2000	31.26	5.12%	80.9	0.8906
Sep-2000	33.88	8.05%	80.7	0.8765
Oct-2000	33.11	-2.30%	81	0.8417
Nov-2000	34.42	3.88%	81.3	0.8684
Dec-2000	28.44	-19.08%	81.3	0.9305
Jan-2001	29.59	3.96%	80.6	0.9293
Feb-2001	29.61	0.07%	80.6	0.9248
Mar-2001	27.25	-8.31%	80.2	0.8832
Apr-2001	27.49	0.88%	79.7	0.8876
May-2001	28.63	4.06%	79.5	0.848
Jun-2001	27.6	-3.66%	79	0.848
Jul-2001	26.43	-4.33%	78.6	0.8755
Aug-2001	27.37	3.49%	79.1	0.9158
Sep-2001	26.2	-4.37%	78.3	0.9131
Oct-2001	22.17	-16.70%	78	0.9042
Nov-2001	19.64	-12.12%	77.9	0.8898
Dec-2001	19.39	-1.28%	77.5	0.8813
Jan-2002	19.72	1.69%	78.1	0.8637
Feb-2002	20.72	4.95%	78.3	0.8651
Mar-2002	24.53	16.88%	78.7	0.8724
Apr-2002	26.18	6.51%	79.1	0.9008
May-2002	27.04	3.23%	79.7	0.9387
Jun-2002	25.52	-5.79%	79.7	0.9975
Jul-2002	26.97	5.53%	80	0.9783
Aug-2002	28.39	5.13%	80.1	0.9833
Sep-2002	29.66	4.38%	80.5	0.986
Oct-2002	28.84	-2.80%	80.8	0.9864
Nov-2002	26.35	-9.03%	81.2	0.9927
Dec-2002	29.46	11.16%	79.8	1.0487
Jan-2003	32.95	11.20%	80.9	1.0816
Feb-2003	35.83	8.38%	81.6	1.0782
Mar-2003	33.51	-6.69%	82	1.0895
Apr-2003	28.17	-17.36%	81.6	1.1131
May-2003	28.11	-0.21%	81.5	1.1822

Month	WTI Spot Oil Prices	Log Returns	World Industrial Production	Exchange Rate (USD/Euro)
Jun-2003	30.66	8.68%	81.5	1.1427
Jul-2003	30.76	0.33%	82.1	1.1318
Aug-2003	31.57	2.60%	82.1	1.0927
Sep-2003	28.31	-10.90%	82.8	1.1652
Oct-2003	30.34	6.93%	83.7	1.1622
Nov-2003	31.11	2.51%	83.8	1.1994
Dec-2003	32.13	3.23%	84.6	1.263
Jan-2004	34.31	6.56%	85.1	1.2384
Feb-2004	34.69	1.10%	85.6	1.2418
Mar-2004	36.74	5.74%	85.5	1.2224
Apr-2004	36.75	0.03%	86	1.1947
May-2004	40.28	9.17%	86.3	1.2198
Jun-2004	38.03	-5.75%	86.6	1.2155
Jul-2004	40.78	6.98%	87	1.2039
Aug-2004	44.9	9.62%	86.8	1.2111
Sep-2004	45.94	2.29%	87.4	1.2409
Oct-2004	53.28	14.82%	87.8	1.2737
Nov-2004	48.47	-9.46%	87.6	1.3295
Dec-2004	43.15	-11.63%	88.1	1.3621
Jan-2005	46.84	8.21%	88.9	1.3035
Feb-2005	48.15	2.76%	89.1	1.3257
Mar-2005	54.19	11.82%	89.2	1.2964
Apr-2005	52.98	-2.26%	89.8	1.2957
May-2005	49.83	-6.13%	89.6	1.2331
Jun-2005	56.35	12.30%	90	1.2092
Jul-2005	59	4.60%	90.1	1.2093
Aug-2005	64.99	9.67%	90.4	1.2198
Sep-2005	65.59	0.92%	90.6	1.2042
Oct-2005	62.26	-5.21%	90.8	1.2023
Nov-2005	58.32	-6.54%	91.7	1.1769
Dec-2005	59.41	1.85%	92.2	1.1797
Jan-2006	65.49	9.74%	92.5	1.2118
Feb-2006	61.63	-6.07%	92.6	1.1875
Mar-2006	62.69	1.71%	93.1	1.2104
Apr-2006	69.44	10.23%	93.3	1.2537
May-2006	70.84	2.00%	93.9	1.2868
Jun-2006	70.95	0.16%	94.2	1.2713
Jul-2006	74.41	4.76%	94.3	1.2767
Aug-2006	73.04	-1.86%	94.8	1.2851
Sep-2006	63.8	-13.53%	95	1.266
Oct-2006	58.89	-8.01%	95	1.2696
Nov-2006	59.08	0.32%	95.9	1.32
Dec-2006	61.96	4.76%	96.6	1.317
Jan-2007	54.51	-12.81%	96.8	1.2954
Feb-2007	59.28	8.39%	97.1	1.3211
Mar-2007	60.44	1.94%	97.6	1.3318
Apr-2007	63.98	5.69%	97.8	1.3605
May-2007	63.46	-0.82%	98.6	1.3453
Jun-2007	67.49	6.16%	98.6	1.3505
Jul-2007	74.12	9.37%	99	1.3707
Aug-2007	72.36	-2.40%	99.7	1.3705
Sep-2007	79.92	9.94%	99.7	1.4179
Oct-2007	85.8	7.10%	100.4	1.4447
Nov-2007	94.77	9.94%	100.7	1.4761
Dec-2007	91.69	-3.30%	101.2	1.4721
Jan-2008	92.97	1.39%	102.1	1.487
Feb-2008	95.39	2.57%	102.3	1.5167
Mar-2008	105.45	10.03%	101.9	1.5812
Apr-2008	112.58	6.54%	102.2	1.554

Month	WTI Spot Oil Prices	Log Returns	World Industrial Production	Exchange Rate (USD/Euro)
May-2008	125.4	10.78%	101.5	1.5508
Jun-2008	133.88	6.54%	101.4	1.5764
Jul-2008	133.37	-0.38%	101.1	1.5611
Aug-2008	116.67	-13.38%	100.2	1.4735
Sep-2008	104.11	-11.39%	99.3	1.4303
Oct-2008	76.61	-30.67%	98.1	1.2757
Nov-2008	57.31	-29.03%	95	1.2727
Dec-2008	41.12	-33.20%	92.1	1.3917
Jan-2009	41.71	1.42%	89.7	1.2816
Feb-2009	39.09	-6.49%	89.3	1.2644
Mar-2009	47.94	20.41%	89.4	1.3308
Apr-2009	49.65	3.50%	89.8	1.3275
May-2009	59.03	17.30%	90.5	1.4098
Jun-2009	69.64	16.53%	91.2	1.4134
Jul-2009	64.15	-8.21%	92.1	1.4138
Aug-2009	71.05	10.22%	92.7	1.4272
Sep-2009	69.41	-2.34%	94	1.4643
Oct-2009	75.72	8.70%	94.6	1.48
Nov-2009	77.99	2.95%	95.4	1.5023
Dec-2009	74.47	-4.62%	95.9	1.4406
Jan-2010	78.33	5.05%	97	1.3966
Feb-2010	76.39	-2.51%	97.4	1.357
Mar-2010	81.2	6.11%	98.4	1.3479
Apr-2010	84.29	3.73%	99.1	1.3315
May-2010	73.74	-13.37%	99.8	1.2307
Jun-2010	75.34	2.15%	99.9	1.2271
Jul-2010	76.32	1.29%	100.2	1.3028
Aug-2010	76.6	0.37%	100.6	1.268
Sep-2010	75.24	-1.79%	101.1	1.3648
Oct-2010	81.89	8.47%	101.5	1.3857
Nov-2010	84.25	2.84%	102.1	1.2998
Dec-2010	89.15	5.65%	102.9	1.3362
Jan-2011	89.17	0.02%	103.7	1.3692
Feb-2011	88.58	-0.66%	103.5	1.3834
Mar-2011	102.86	14.95%	102.9	1.4207
Apr-2011	109.53	6.28%	102.8	1.486
May-2011	100.9	-8.21%	103.6	1.4385
Jun-2011	96.26	-4.71%	104.3	1.4453
Jul-2011	97.3	1.07%	104.7	1.426
Aug-2011	86.33	-11.96%	105.3	1.445
Sep-2011	85.52	-0.94%	105.2	1.3503
Oct-2011	86.32	0.93%	105.1	1.4001
Nov-2011	97.16	11.83%	105.3	1.3418
Dec-2011	98.56	1.43%	106.1	1.2939
Jan-2012	100.27	1.72%	106.2	1.3176
Feb-2012	102.2	1.91%	107	1.3443
Mar-2012	106.16	3.80%	106.9	1.3356
Apr-2012	103.32	-2.71%	106.6	1.3214
May-2012	94.66	-8.75%	107.1	1.2403
Jun-2012	82.3	-13.99%	107	1.259
Jul-2012	87.9	6.58%	107.1	1.2284
Aug-2012	94.13	6.85%	107.2	1.2611
Sep-2012	94.51	0.40%	106.8	1.293
Oct-2012	89.49	-5.46%	107.2	1.2993
Nov-2012	86.53	-3.36%	107.5	1.2986
Dec-2012	87.86	1.53%	107.8	1.3194
Jan-2013	94.76	7.56%	107.9	1.355
Feb-2013	95.31	0.58%	108	1.3129
Mar-2013	92.94	-2.52%	108.4	1.2805

Month	WTI Spot Oil Prices	Log Returns	World Industrial Production	Exchange Rate (USD/Euro)
Apr-2013	92.02	-0.99%	108.7	1.3072
May-2013	94.51	2.67%	108.9	1.3006
Jun-2013	95.77	1.32%	108.9	1.308
Jul-2013	104.67	8.89%	109.4	1.3275
Aug-2013	106.57	1.80%	109.9	1.3235
Sep-2013	106.29	-0.26%	110.1	1.3505
Oct-2013	100.54	-5.56%	110.4	1.3641
Nov-2013	93.86	-6.88%	111	1.3611
Dec-2013	97.63	3.94%	111.2	1.3791
Jan-2014	94.62	-3.13%	111.6	1.3516
Feb-2014	100.82	6.35%	111.9	1.3813
Mar-2014	100.8	-0.02%	111.9	1.3788
Apr-2014	102.07	1.25%	112.5	1.385
May-2014	102.18	0.11%	112.5	1.3607
Jun-2014	105.79	3.47%	112.5	1.3658
Jul-2014	103.59	-2.10%	112.9	1.3379
Aug-2014	96.54	-7.05%	112.4	1.3188
Sep-2014	93.21	-3.51%	113.5	1.2583
Oct-2014	84.4	-9.93%	113.6	1.2524
Nov-2014	75.79	-10.76%	113.8	1.2483
Dec-2014	59.29	-24.55%	114.7	1.2141
Jan-2015	47.22	-22.76%	114.1	1.1305
Feb-2015	50.58	6.87%	114.3	1.124
Mar-2015	47.82	-5.61%	114.3	1.0759
Apr-2015	54.45	12.98%	114.5	1.1215
May-2015	59.27	8.48%	114.1	1.097
Jun-2015	59.82	0.92%	114.8	1.1189
Jul-2015	50.9	-16.15%	115	1.0967
Aug-2015	42.87	-17.17%	115	1.1215
Sep-2015	45.48	5.91%	115.2	1.1203
Oct-2015	46.22	1.61%	115.5	1.1017
Nov-2015	42.44	-8.53%	115.2	1.0579
Dec-2015	37.19	-13.21%	115.4	1.0887
Jan-2016	31.68	-16.04%	115.9	1.092
Feb-2016	30.32	-4.39%	115.4	1.0888
Mar-2016	37.55	21.39%	115.6	1.1385
Apr-2016	40.75	8.18%	115.9	1.1403
May-2016	46.71	13.65%	115.7	1.1154
Jun-2016	48.76	4.30%	116.7	1.1102
Jul-2016	44.65	-8.81%	116.3	1.1113
Aug-2016	44.72	0.16%	117.2	1.1132
Sep-2016	45.18	1.02%	117.1	1.1161
Oct-2016	49.78	9.70%	117.2	1.0946