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On Oil-US Exchange Rate Volatility Relationships: an Intraday Analysis[1]

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On Oil-US Exchange Rate Volatility Relationships: an Intraday Analysis

Abstract

The aim of this paper is to investigate the dynamics of oil price volatility by examining interactions between the oil market and the US dollar/Euro exchange rate. Unlike previous related studies that focus on low frequency data and GARCH volatility measures; we use recent intraday data to measure realised volatility and to investigate the instantaneous intraday linkages between different types and proxies of oil price and US$/Euro volatilities. We specify the drivers of oil price volatility through a focus on extreme US$ exchange rate movements (intraday jumps). Accordingly, we found a negative relationship between the US dollar/euro and oil returns, indicating that a US $appreciation decreases oil price. Second, we show the presence of a volatility spillover from the US exchange market to the oil market. Interestingly, this spillover effect seems to occur through intraday jumps that take place simultaneously in both markets.

Keywords: Oil price volatility, realised volatility, intraday jumps, exchange rate, intraday data, GARCH model.
JEL: G15, C2.

1. Introduction

Oil is at the centre of various industry activities and is an important production factor. Accordingly, oil price shocks have had a significant impact on the real economy at least since the 1970s (i.e. oil shocks of 1973 and 1979). Hence, oil price changes have been the focus of a number of theoretical and empirical studies. In particular, since the seminal work of Hamilton (1983), several studies have examined the impact of oil price movements on economic activity in general and on financial markets in particular given the important role played by oil in real economy. Hamilton (1983) highlighted a significant link between the increase in crude oil prices and US recessions over the period 1948-1972. Focusing on the economies of the USA, UK, Japan, Germany and Canada, Burbridge and Harrison (1984) identified the considerable impact of oil price shocks on domestic economic variables. Based on Hamilton's data, Gisser and Goodwin (1986) found a positive link between oil prices and unemployment. Uri (1996) confirmed this finding for the agricultural sector. More recently, Lardic and Mignon (2006, 2008) found significant linkages between oil price and economic growth, while Arouri and Jawadi (2010) pointed to a significant correlation between oil price and exchange rate and to a nonlinearity in this relationship. Several studies have also investigated the linkages between oil price and stock markets (Arouri and Jawadi, 2010; Jawadi *et al*., 2010; Arouri and Rault, 2012; Ftiti et al., 2015, Pönkä, 2016, etc.).

While the impact of oil price movements on economic indicators has been widely investigated, there has been less interest in the determinants of oil price volatility. Indeed,there exists only few studies which look at this issue (De Truchis and Keddad, 2016; Zhang and Yao, 2016).

The present paper aims to fill this gap through the investigation of oil price volatility drivers. Our research question is firstly motivated by significant recent changes in oil prices.

Indeed, at the beginning of 2016, the price per barrel of West Texas Intermediate (WTI) crude oil reached 30 US dollars as opposed to 140 US dollars in June 2008. Interestingly, the decrease in oil price was accompanied by a historical US dollar appreciation against the euro, which raises the question of the link between these two variables: oil price and the US/€ exchange rate. Secondly, the dynamics of oil price is of great interest for investors as this helps them to better improve their investment and hedging strategies. It is also an important question for policymakers who can use such information to developed efficient monetary policies. Further, a precise analysis of oil price dynamics helps the oil exporters countries to better adjust their oil supply.

In the literature, several papers have examined the impact of dollar exchange rate variations on oil prices.[2] Bénassy-Quéré *et al.* (2007) found that a 4.3% appreciation of the dollar coincides with a 10% rise in oil price. Using a structural VAR model, Akram (2009) found that a weaker dollar exchange rate leads to an increase in oil price. Reboredo and Rivera-Castro (2013) investigated the link between oil price and US dollar exchange rates using a Wavelet multi-resolution analysis. They identified a negative dependence between the two markets during crisis periods. Turhan *et al*. (2014) analyzed the co-movements of oil price (in US dollar) and exchange rates (US dollar/local currency) of G20 members from 2000 to 2013 and showed that the link between oil prices and exchange rates has intensified in the last decade as they became strongly negatively correlated (which also associates an increase in the oil prices with the US dollar depreciation against other currencies).

While the above works focus on the first moment (returns), another corpus of studies has investigated volatility dependence between the oil market and the foreign exchange market. Zhang *et al.* (2008) found no volatility spillover from the US dollar exchange rate to the oil

[2] Another corpus of studies has focused on oil prices as an explanatory variable of exchange rate movements (Krugman, 1983; Golub, 1983; Chen and Chen, 2007; Coudert *et al.*, 2008, Narayan, 2008, among others).

market. Salisu and Mobolaji (2013), however, showed bidirectional returns and volatility between the oil market and the foreign exchange market. Using a GARCH model, Ding and Vo (2012) found no interaction between the two markets in the pre-crisis period (before 2008), while a bidirectional volatility interaction between the two markets during the financial crisis is not rejected. Recently, De Truchis and Keddad (2016) used the framework of copula techniques to test weak dependence between the foreign exchange market and the oil market, especially in the long term. Thus, overall, prior related studies offer heterogeneous findings, and the results appear to be sample and data dependent. Phan *et al.* (2016) however argued that understanding the determinants of intraday volatility is useful for investors and portfolio managers involved in high frequency trading to better forecast volatility. Caporin et al. (2016) higlighted intraday volatility spillover between S&P500 and leading energy commodities markets.

Accordingly, using available exchange rate and oil price intraday data, this paper extends previous studies while at the same time attempting to investigate whether intraday changes in the US/€ exchange rate might drive oil price. In other words, the aim is to determine whether financial investors' and speculators' behaviour might impact on oil price volatility (Du et al., 2011). This approach is original and interesting in that we not only investigate intraday volatility dependence between oil price and the dollar/euro exchange rate, but we also test the impact of abrupt jumps in the dollar/euro exchange rate on oil prices.

The correlation between oil price and US dollar exchange rate volatility is intuitively supported. Further, the economic theory seems to support both negative and positive relationships. Indeed, a negative relationship between oil and the US$ exchange rate can be justified by further hedging actions by investors when investing in oil and foreign markets. It can be also justified by the fact that with high weak dollar and high oil price, investors can invest in other currencies. As for the positive relationship, it is due to the fact that international crude oil trading is quoted in US dollars, and any abrupt change in the US $/€ exchange rate can positively affect oil transactions and consequently oil price, yielding co-jumps in both markets. We therefore expect to find a causality link between US dollar exchange rate volatility and crude oil prices. More specifically, an appreciation in the US dollar exchange rate will increase oil prices for foreigners in their local currencies, which in turn leads to a decrease in demand and a potential fall in the price of oil. Inversely, a weaker US dollar currency can trigger an increase in oil demand, leading to higher oil prices. We therefore expect a negative relationship between oil price and the US dollar exchange rate as documented by Narayan *et al.* (2008) and Wu *et al.* (2012).[3]

Accordingly, our paper differs from previous related literature and has at least three contributions. First, we use recent intraday data to investigate instantaneous linkages between oil price and the US $/€ exchange rate and innovate through the application of a nonparametric approach to assess for intraday jumps. Second, to our knowledge, our paper is the first attempt to investigate the spillover effect of extreme US exchange rate movements to oil prices through the intraday jumps, while proposing a large number of econometric specificationsThird, we propose to test the co-joump hypothesis between oil and foreign markets.

Our intraday analysis offers several findings. First, we highlight a negative relationship between the dollar/euro exchange rate and oil returns, which means that appreciation of the US dollar leads to a drop in the price of oil. This result confirms our preliminary suggestion and is in line with expectations of choice portofolio choice (Krugman, 1983; Golub, 1983). Second, we identify significant volatility spillover from the foreign exchange market to the oil market. Indeed, intraday jumps that occur in the foreign market have a real impact on oil market

[3] It is however important to note that some other studies including Dibooglu, 1996; Amano and van Norden, 1998; Bénassy-Quéré et al., 2007; Chen and Chen, 2007) found a positive relationship between oil prices and the exchange rate.

conditional volatility. Finally, we show that intraday jumps occur simultaneously in the dollar/euro currency market and the oil market.

The remainder of the paper is organised as follows. Section 2 presents the data and the methodology. We discuss the main empirical results in Section 3. Section 4 concludes.

2. Data and methodology

2.1. Data and preliminary analysis

Intraday data is obtained from the Bloomberg database. The sample under consideration covers a six-month period from August 2014 to January 2016. We computed 5-minute returns for WTI and for the US dollar/euro exchange rate during this period of study according to the logarithm formula. Table 1 presents the resulting descriptive statistics on returns in both the US/€ exchange rate and oil price.

Table 1: Descriptive statistics

	Oil returns	**Dollar/euro returns**
Mean	-9.62E-06	5.90E-07
Median	0.0000	0.0000
Maximum	0.0316	0.0129
Minimum	-0.0222	-0.0129
Std. Dev.	0.0016	0.0004
Skewness	0.219	0.215
Kurtosis	15.975	58.696
Jarque-Bera	575576.5	10593006
Probability	0.0000	0.0000

Note: This table gives descriptive statistics on 5-minute returns for WTI and the dollar/euro exchange rate. The returns are computed according to the logarithm formula over a six-month period from August 2014 to January 2016.

From Table 1, we note that oil returns exhibit higher standard deviation than dollar/euro returns, suggesting that oil price is more volatile than the US $/€ exchange rate. Further, the skewness coefficient positivity for both series indicates that both distributions are skewed right, while the positive excess of kurtosis –which is higher for the exchange rate- means that distribution has fatter tails than a normal distribution. Consequently, the Jarque-Bera test significantly rejects the normality hypothesis for both series.

2.2. Econometric methodology

2.2.1. Intraday jump detection

It is well-known that the logarithm price process can be expressed using the following continuous-time jump-diffusion model:

$$dP(t) = \mu(t)dt + \sigma(t)dW(t) + k(t)dq(t) \tag{1}$$

where: P(t) denotes the logarithmic asset price at time t; μ(t) is a continuous and locally bounded variation process; σ(t) denotes a strictly positive, right continuous and left limited stochastic volatility process; W(t) is a standard Brownian notion; and q(t) refers to a pure jump process with intensity λ(t) and jump size κ(t).

The usual quadratic variation of the cumulative return process is defined as

$$QV_t = \int_0^t \delta^2(s)ds + \sum_{0<s\leq t}^{N_t} k^2(s) \tag{2}$$

Equation (2) implies that the total price process variation (QV_t) is composed of the continuous Brownian component and the sum of the squared jumps.

Andersen and Bollerslev (1998) proposed an estimator for the quadratic variation (QV_t), called the realised variance (RV) that is defined as the following sum of intraday squared return:

$$RV_{t+1}(\Delta) \equiv \sum_{j=1}^{1/\Delta} r_{t+j\Delta,\Delta}^2 \tag{3}$$

Further, Barndorff-Nielsen and Shephard (2004) introduced the bipower variation (BV) as a robust estimator of jumps, defining it as follows:

$$BV_{t+1}(\Delta) \equiv \mu_1^{-2} \sum_{j=2}^{1/\Delta} \left| r_{t+j\Delta,\Delta} \right| \left| r_{t+(j-1)\Delta,\Delta} \right| \quad (4)$$

$$\mu_1 = \sqrt{2/\pi} \quad (5)$$

Such formulas (1-5) enable us to determine realised volatility, continuous volatility and daily jumps.

In this paper, we identify intraday jumps rather than detecting trading days that contain jumps. To this end, we use the test proposed by Andersen et al. (2007).[4] The authors assess whether a randomly selected intraday return is subject to a jump using the following statistic:

$$r_{t+\xi.\Delta,\Delta} = \sum_{j=1}^{1/\Delta} r_{t+j.\Delta,\Delta} \coprod(\xi = j) \quad (6)$$

where: ξ is an independently drawn index (uniformly distributed) from the set $\langle 1,2,...,1/\Delta \rangle$ and $r_{t+j.\Delta,\Delta}$ has conditional mean and variance given by $Er_{t+j.\Delta,\Delta}$ and $vr_{t+j.\Delta,\Delta}$ respectively.

The above return is considered as a jump by comparing its absolute value to corresponding scaled return realisations, distributed as follows:

$$\Delta^{-1/2}\, r_{t+\xi.\Delta,\Delta} \to N(0, IV_{T+1}). \quad (7)$$

Thus, the multipleintraday jumps $k_s(\Delta)$ are detected based on the following rule:

[4] We also applied the tests of Lee and Mykland (2008). The two tests differ only in their critical values. Both tests give similar results.

2.2.2. GARCH Specifications

Numerous conditional volatility models have been developed to model the price variation dynamic since the seminal paper by Engle (1982) introduced the ARCH model. The clustering pattern of volatility is a well-known phenomenon in the financial literature. In fact, several empirical studies show that volatility time series are characterized by the presence of conditional heteroskedasticity. The family of ARCH models introduced by Engle (1982) and Bollerslev (1986), accounts for the volatility persistence effect and captures conditional heteroskedasticity patterns. The main property GARCH families is to specify time-conditional volatility while supposing that the current idiosyncratic variance depends on its past levels and past innovations. In this paper, the class of GARCH models is used to study oil price changes and volatility spillover between the crude oil market and the dollar/euro exchange rate. Moreover, the GARCH specification has been shown to provide a good fit for financial return time series (Bollerslev, 1987; Pyun et al, 2000; Han and Park, 2008). The autoregressive process accounts for the persistence and for the clustering pattern of volatility. It captures some statistical artifacts in returns as the nonstability of the distributions documented by Mandelbrot (1963) and Fama (1965).

In this paper, we compare several GARCH models using a battery of statistical tests, instead of imposing a specific model as in previous studies. The choice of a Jump-GARCH (1,1) specification, was motivated by the absence of asymmetry in conditional volatility responses to negative and positive shocks[5]. Moreover, according to the Q-statistics and ARCH-LM test presented in Tables 2, 3, 4 and 5, the GARCH (1,1) is sufficient to clean the autocorrelation of normalized residual series and squared standardized residuals.

[5] We validated this hypothesis by testing several asymmetric GARCH models (TGARCH, EGARCH).

The GARCH (1,1) model proposed by Bollerslev (1986) can be presented as follows:

$$OILR_t = \mu_0 + a_1 OILR_{t-1} + a_2 EXCHR_{t-1} + \varepsilon_t$$

$$VAR(\varepsilon_t | \varepsilon_{t-1}) = \sigma_t^2 \tag{9}$$

$$\sigma_t^2 = \omega + \alpha\ \varepsilon_{t-1}^2 + \beta\ \sigma_{t-1}^2$$

where $OILR_t$ and $OILR_{t-1}$ are the current and lagged oil returns respectively; $EXCHR_{t-1}$ refers to the lagged US dollar/euro return; the parameters $\mu_0, a_1, a_2, \omega, \alpha, \beta$ are the coefficients to be estimated. All returns are computed using a logarithm formula. The errors (innovations) ε_t are assumed to be identically and independently distributed. The degree of volatility persistence is measured by the sum of the ARCH and GARCH coefficients ($\alpha + \beta$). As the magnitude of persistence approaches unity, the persistence of shocks to volatility increases.

To test for spillover from a foreign exchange market to the oil market, we first adopted the approach proposed by Hamao *et al.* (1990), Baur and Jung (2006) and Miralles-Marcelo *et al.* (2010). Accordingly, the most recent squared dollar/euro returns are introduced as an exogenous variable in the conditional variance equation of the oil market. In addition, lagged returns from the oil market and the foreign exchange rate market are introduced in the mean equation in order to capture further persistence and memory effects in the oil return dynamics.

To test for volatility spillover from the US exchange rate to the oil crude market, we use the following GARCH specification:

$$OILR_t = \mu_0 + a_1 OILR_{t-1} + a_2 EXCHR_{t-1} + \varepsilon_t$$

$$VAR(\varepsilon_t | \varepsilon_{t-1}) = \sigma_t^2 \tag{10}$$

$$\sigma_t^2 = \omega + \alpha\ \varepsilon_{t-1}^2 + \beta\ \sigma_{t-1}^2 + \lambda\ EXCHR_{t-1}^2 + \vartheta_t$$

where $OILR_t$ and $OILR_{t-1}$ are the current and lagged oil returns respectively; $EXCHR_{t-1}$ and $EXCHR_{t-1}^2$ refer to the lagged US dollar/euro return and lagged squared US dollar/euro return respectively. The parameters $\mu_0, a_1, a_2, \omega, \alpha, \beta, \lambda$ are the coefficients to be estimated.

Using model (10), we study volatility spillover from the US foreign market to the oil market in line with the approach by Hamao et al. (1990), Baur and Jung (2006) and Miralles-Marcelo et al. (2010). We contribute to the above while testing for the jump component spillover effect. Hence, instead of considering the squared US dollar/euro returns, we introduce next the intensity of the US dollar/euro intraday jump as an exogenous variable in the conditional variance equation of the oil market. The GARCH specification to analyze the impact of jumps occurring on the US foreign exchange rate market on the conditional volatility of crude oil is now written as:

$$OILR_t = \mu_0 + a_1 OILR_{t-1} + a_2 EXCHR_{t-1} + \varepsilon_t$$

$$VAR(\varepsilon_t | \varepsilon_{t-1}) = \sigma_t^2 \qquad (11)$$

$$\sigma_t^2 = \omega + \alpha\ \varepsilon_{t-1}^2 + \beta\ \sigma_{t-1}^2 + \lambda\ EXCHJ_t + \vartheta_t$$

Where: $OILR_t$ and $OILR_{t-1}$ are the current and the lagged oil returns respectively; $EXCHR_{t-1}$ and $EXCHJ_t$ refer to the lagged US dollar/euro returns and the intensity of the current US dollar/euro exchange rate jump respectively. The parameters $\mu_0, a_1, a_2, \omega, \alpha, \beta, \lambda$ are the coefficients to be estimated. We estimate hereafter these specifications and discuss the main empirical results.

3. Empirical Results

3.1. Measuring spillover effects between the US $/Euro exchange rate and oil price

First, we estimated model (9) and reported the main results in Table 2. Overall, the GARCH estimation reveals the following points. From the mean equation, crude oil returns depend on past oil returns and past US exchange rate returns. This relation is negative, which shows that an appreciation (depreciation) of the US dollar leads to a decrease (increase) in oil prices. As the Euro zone is basically composed of oil-importing countries, this means that a rise in the US dollar exchange rate increases oil prices in the euro currency, leading to a fall in demand and lower oil prices. Inversely, a stronger euro against the US dollar increases European oil demand, which causes a rise in oil price and explains the observed negative relationship between oil price and the US dollar exchange rate.

Regarding the variance equation (in model (9)), we show that the ARCH and GARCH effects are statistically significant, which confirms the clustering pattern and persistence effect of oil volatility. This suggests that the current oil idiosyncratic variance depends on its previous levels and past innovations. The sum ($\alpha+\beta$) is close to the constraint ensuring the stationary of the model ($\alpha+\beta<1$). The high degree of persistent confirms the well-known clustering pattern of volatility.

Next, to test the spillover hypothesis between the oil market and the exchange rate market, we estimate model (10). Results reported in Table 3 confirm the results concerning the GARCH model parameters. Introducing the squared exchange rate term in the conditional variance equation has decreased slightly the level of persistence in volatility, as measured by the sum ($\alpha+\beta$). This result confirms the hypothesis according to which the persistence in volatility is reduced when an information proxy is introduced in the GARCH model (Lamoureux and Lastrapes, 1990; Bohl and Henke, 2003; Kalev et al., 2004; Louhichi, 2011, etc.). Also, the estimation of the variance equation, indicates that the coefficient of the US dollar/euro squared returns is significant, showing evidence of volatility spillover from the US foreign exchange market to crude oil markets, and indicating that changes to the US $ currency can drive oil price volatility. This finding is supported by theportfolio choice theory as well as by the monetary policy choice. Indeed, investors can have tendency to rebalance their portfolio while buying and selling on oil and foreign exchange markets. Further, in the short term, the US dollar plays a major role in oil price movements as in the oil trade globally, with the US dollar often used as a medium. In the long term however, the Federal Reserve's monetary policy that affects inflation rate and the dollar exchange rate has an impact on oil prices. For example, a stronger dollar compounds the disinflationary impact from a drop in oil prices.

Table 2: Modelling oil volatility with GARCH (1,1)

Note: significance at 10% level is marked by (*), 5% level by (**) and 1% level by (***). Q^2(j) are the Ljung-Box statistics of order j (j = 1, 2 or 12), respectively, for standardized residuals.

Table 3: Volatility spillover from the US dollar/euro exchange rate to oil prices

Note: significance at 10% level is marked by (*), 5% level by (**) and 1% level by (***). Q^2(j) are the Ljung-Box statistics of order j (j = 1, 2 or 12), respectively, for standardized residuals.

Next, after testing the volatility spillover hypothesis, we estimated model (11) to investigate the transmission of abrupt price shocks (intraday jumps) from the US foreign market to the oil market. Table 4 summarises the main results of model (11). First, we note that these findings confirm the above results regarding the negative relationship between the dollar/euro returns and oil returns. Second, we note that the ARCH and GARCH effects remain statistically significant. Finally, we show that jumps occurring in the US dollar/euro exchange market positively impact on the oil market's conditional volatility. This means that abrupt shocks occurring in the exchange rate markets are immediately transmitted to the oil market.

Table 4: Impact of US dollar/euro exchange rate jumps on oil price conditional volatility

Note: significance at 10% level is marked by (*), 5% level by (**) and 1% level by (***). Q^2(j) are the Ljung-Box statistics of order j (j=2, 2 or 12), respectively, for standardized residuals.

Next, to take the analysis further, we break down our sample into two sub-samples, namely, jumps initiated by positive returns and jumps initiated by negative returns, and we re-estimate model (11) while introducing positive jumps and negative jumps separately in the variance equation. The main results are reported in Table 5. Accordingly, we show that the two types of jumps cause an increase in oil market volatility. However, we can note an asymmetric reaction as the impact of positive shocks is higher than that of negative shocks. This implies that a dollar appreciation against the euro has a greater impact on crude oil prices than a dollar depreciation. in order to check whether the coefficients associated with the effects of positive and negative jumps are statistically different, we reestmated them by the confidence interval method. Basically, the idea is to check whether the obtained intervals overlap or not. If they overlap, this may indicate that estimators are not statistically different and vice versa. Accounrding to our results show that (I WILL COMPLETE IT)

Table 5: Impact of positive and negative US dollar/euro exchange rate jumps on oil price conditional volatility

Note: significance at 10% level is marked by (*), 5% level by (**) and 1% level by (***). $Q^2(j)$ are the Ljung-Box statistics of order j (j = 1, 2 or 12), respectively, for standardized residuals.

4. Conclusion

This paper investigates oil price volatility through an analysis of the relationship between the crude oil market and the US dollar/euro exchange rate market. Prior studies have also examined volatility spillover between these two markets, often using low frequency data and usual GARCH volatility proxies. In this paper, our contribution is twofold. On the one hand, we rely on high frequency data and develop more precise measures of continuous and discontinuous volatility. On the other hand, in addition to the investigation of volatility spillover, we contribute by considering the intraday jump component of volatility. Accordingly, we decompose realised volatility and detect intraday jumps in both the foreign exchange market and the oil market.

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