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Document de Travail
Working Paper
2017-11

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

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[1] This paper was presented at the first conference on Applied Financial Modelling in Melbourne (February 4, 2016) and at the extern seminar of Liverpool Management School (Feb, 29, 2016). The authors would like to thank Paresh Narayan, Jonathan Battern, Ruijun BuTimo Teräsvirta and the participants of the seminar and conference for their constructive and helpful comments on an earlier version of this paper.

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

Abstract

The paper investigates the dynamics of oil price volatility by examining interactions between the oil market and the US USD/EUR exchange rate. To this end, we use recent intradaily data to measure realised volatility and to investigate the instantaneous intradaily 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 (intradaily jumps). Accordingly, we find a negative relationship between the US USD/EUR and oil returns, indicating that a US $ appreciation decreases oil price. Second, we note the presence of a volatility spillover from the US exchange market to the oil market. Interestingly, this spillover effect seems to occur through intradaily jumps in both markets.

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

1. Introduction

Oil price shocks have had a significant impact on the real economy at least since the 1970s (e.g.. oil shocks of 1973 and 1979). Hence, oil price fluctuations 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 major role played by oil in the 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 compelling linkages between oil price and economic growth, while Arouri and Jawadi (2010) pointed to a significant correlation between oil price and exchange rate, with a nonlinear relationship. Several other studies have also explored 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, few studies have looked at this issue to date (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 oil price fluctuations. Indeed, at the beginning of 2016, the price per barrel of West Texas Intermediate (WTI) crude oil reached 30 US dollars compared to 140 US dollars in June 2008. Interestingly, the decline in oil price has been 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, oil price dynamics are of great interest to investors as a clearer understanding can help them to enhance their investment and hedging strategies. It is also an important issue for policymakers who can use such information to develop efficient monetary policies. Further, a precise analysis of oil price dynamics can help oil exporting countries to better adjust their oil supply.

Accordingly, our paper differs from previous related literature and makes at least three contributions. First, we use recent intradaily data to investigate instantaneous linkages between oil price and the US $/€ exchange rate, innovating through the application of a nonparametric approach to search for intradaily 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 intradaily jumps, while proposing a large number of econometric specifications. Third, we test the co-jump hypothesis between oil and foreign markets.

Our intradaily analysis offers several findings. First, we highlight a negative relationship between the USD/EUR exchange rate and oil returns, which means that a US dollar appreciation leads to a drop in the price of oil. Second, we identify significant volatility spillover from the foreign exchange market to the oil market. Indeed, intradaily jumps that occur in the foreign market have a real impact on oil market conditional volatility. Finally, we show that intradaily jumps occur simultaneously in the USD/EUR currency market and the oil market.

The remainder of the paper is organised as follows. Section 2 provides an overview on the related literature. Section 3 presents the data and the methodology. We discuss the main empirical results in Section 4. Section 5 concludes.

2. Literature

In the literature, several papers have examined the impact of dollar exchange rate variations on oil prices.[2] 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. Turhan *et al.* (2014) analyzed the co-movements of oil price (in US dollars) 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 have become strongly negatively correlated.

Beckmann and Czudaj (2013) focused on the causality pattern between oil price and currencies, concluding that, only in nominal terms, the most significant causality runs from exchange rates to oil price. Tantatape *et al.* (2014) investigated the relationship between U.S. imported crude oil prices and exchange rates. They showed that, in the short-run, exchange rates Granger-cause the price of crude. Moreover, this study revealed that the impulse response of crude oil price to exchange rate shock is negative and significant. However, oil price shocks apparently have no impact on the exchange rate. Recently, Jammazi *et al.* (2015) examined the link between US dollar exchange rates against 18 currencies and crude oil prices. The authors highlighted an asymmetric pass-through from exchange rates to oil prices in both the short and the long run, suggesting that negative exchange rate shocks have more impact on oil prices than positive ones.

While the above studies focus on the first moment (returns), another corpus of research 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 market. Salisu and Mobolaji (2013), however, indicated bidirectional returns and volatility linkages between the oil market and the foreign exchange market. Using

[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).

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. 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 intradaily volatility is useful for investors and portfolio managers involved in high frequency trading to better forecast volatility, while Caporin et al. (2016) highlighted intradaily volatility spillover between the S&P500 and leading energy commodities markets.

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

The correlation between oil price and US dollar exchange rate volatility is intuitively supported. Further, 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 also be justified by the fact that with a highly weak dollar and high oil price, investors can invest in other currencies. The positive relationship 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]

3. Data and methodology

3.1. Data and preliminary analysis

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

Table 1: Descriptive statistics

	Oil returns	USD/EUR 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

[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.

Note: This table gives descriptive statistics on 5-minute returns for WTI and the USD/EUR 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 USD/EUR 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.

3.2. Econometric methodology

3.2.1. Intradaily jump detection

It is customary to assume 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, noted QV and often used as a one type of variation of a process, is defined as

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

where: the first term refers to the continuous volatility, while the second measures the jump part. N_t is a counting process.

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 realised variance (RV) that is defined as the following sum of intradaily squared return:

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

Further, Barndorff-Nielsen and Shephard (2004) introduced the bipower variation (BV) in order to be able to identify the contribution of jumps. The BV corresponds to:

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

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

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

In this paper, we identify intradaily 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 intradaily return is subject to a jump using the following statistic:

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

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.

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

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 multipleintradaily jumps $k_s(\Delta)$ are detected based on the following rule:

$$k_s(\Delta) = r_{t+s.\Delta,\Delta}.\Pi\left[\left|r_{t+s.\Delta,\Delta}.\right| > \phi_{1-\beta/2}.\sqrt{\Delta.BV_{t+1}(\Delta)}\right],\ s = 1,2,...,1/\Delta \quad (8)$$

We chose the level α=1% for the jump test at daily frequency, and define the corresponding confidence interval ($1-\beta$) for intradaily diffusive returns, where $\beta = 1-(1-\alpha)^{\Delta}$ and $\phi_{1-\beta/2}$ is the appropriate critical value from the standard normal distribution.[5]

3.2.2. GARCH specifications

Numerous conditional volatility models have been developed to assess 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 have shown 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 of 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 USD/EUR exchange rate. Moreover, the GARCH specification has been shown to provide a good fit for

[5] See Andersen et al. (2007) for more details about the application of this test.

financial return time series (Bollerslev, 1987; Pyun et al, 2000; Han and Park, 2008). The autoregressive process accounts for the persistence and 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 one 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.[6] 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 clear the autocorrelation of normalized residual series and squared standardized residuals.

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

$$
\begin{aligned}
& OILR_t = \mu_0 + a_1 OILR_{t-1} + a_2 EXCHR_{t-1} + \varepsilon_t \\
& VAR(\varepsilon_t | \varepsilon_{t-1}) = \sigma_t^2 \qquad (9) \\
& \sigma_t^2 = \omega + \alpha\, \varepsilon_{t-1}^2 + \beta\, \sigma_{t-1}^2
\end{aligned}
$$

where $OILR_t$ and $OILR_{t-1}$ are current and lagged oil returns respectively, $EXCHR_{t-1}$ refers to the lagged US USD/EUR return, and 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*

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

al. (2010). Accordingly, the most recent squared USD/EUR 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 crude oil market, we use the following GARCH specification:

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

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

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

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 USD/EUR return and lagged squared US USD/EUR 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 USD/EUR returns, we next introduce the intensity of the US USD/EUR intradaily jump as an exogenous variable in the oil market's conditional variance equation. 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[7]:

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

[7] The Jump variable use dis this regression is computed using the jump test discussed in the previous section.

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

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

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 USD/EUR returns and the intensity of the current US USD/EUR 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.

4. Empirical Results

4.1. 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 relationship is negative, which shows that an appreciation (depreciation) in the US dollar leads to a decrease (increase) in oil prices. As the Eurozone 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 negative relationship observed 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, confirming the clustering pattern and persistence effect of oil volatility. This suggests that current idiosyncratic oil variance depends on its previous levels and past innovations. The sum (α+β) is close to the constraint, ensuring the stationarity of model ($\alpha+\beta<1$). The high degree of persistence 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). The results reported in Table 3 confirm the results from the GARCH model parameters. Introducing the squared exchange rate term in the conditional variance equation slightly decreases the level of persistence in volatility, as measured by the sum ($\alpha+\beta$). This confirms the hypothesis according to which volatility persistence 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.). In addition, the estimation of the variance equation indicates that the US USD/EUR squared returns coefficient is significant, showing evidence of volatility spillover from the US foreign exchange market to crude oil markets. This implies that changes to the US $ currency can drive oil price volatility. This finding is supported by the portfolio choice theory as well as by the monetary policy choice. Indeed, investors may choose to rebalance their portfolio when 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)

Coefficient	Estimator	P-value	Standard errors
Mean constant	-3.05E-06	0.229	2.53E-06
$OILR_{t-1}$	-0.053***	0.000	0.003

$EXCHR_{t-1}$	-0.04***	0.000	0.007
Variance constant	6.29E-09***	0.000	2.84E-10
ARCH	0.13***	0.000	0.002
GARCH	0.863***	0.000	0.001
ARCH-LM test	0.648	0.42	
Ljung-Box statistics j	1	2	12
$Q^2(j)$	0.648	4.674	14.214

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 USD/EUR exchange rate to oil prices

Coefficient	Estimator	P-value	Standard errors
Mean constant	-3.01E-06	0.227	2.49E-06
$OILR_{t-1}$	-0.054***	0.000	0.003
$EXCHR_{t-1}$	-0.037***	0.000	0.01

Variance constant	1.91E-09***	0.000	2.30E-10
ARCH	0.117***	0.000	0.001
GARCH	0.864***	0.000	0.001
$EXCHR^2_{t-1}$	0.207***	0.000	0.006
ARCH-LM test	0.304	0.581	
Ljung-Box statistics j	1	2	12
$Q^2(j)$	0.304	3.028	9.127

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 (intradaily 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 USD/EUR 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 USD/EUR 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 USD/EUR exchange rate jumps on conditional oil price volatility

Coefficient	Estimation	P-value	Standard errors

Mean constant	-2.83E-06	0.263	2.53E-06
$OILR_{t-1}$	-0.053***	0.000	0.003
$EXCHR_{t-1}$	-0.035***	0.000	0.008
Variance constant	6.11E-09***	0.000	2.78E-10
ARCH	0.13***	0.000	0.001
GARCH	0.865***	0.000	0.001
$EXCHJ_t$	3.30 E-04***	0.000	2.29E-05
ARCH-LM test	0.377	0.538	
Ljung-Box statistics j	1	2	12
$Q^2(j)$	0.377	3.784	12.808

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 our sample down 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 that there is no asymmetric reaction and no difference in the impact of positive shocks compared to negative ones. This implies that an appreciation in the dollar against the euro has the same impact on crude oil prices as a dollar depreciation. In order to check whether the coefficients associated with the effects of positive and negative jumps are statistically different, we re-estimated them using the confidence interval method. Basically, the idea is to check whether the intervals obtained overlap or not. If they overlap, this may indicate that the estimators are not statistically different and vice versa. Our results suggest that the two coefficients are not statistically different.

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

Coefficient	Estimation	P-value	Standard errors
Mean constant	-2.83E-06	0.263	2.53E-06
$OILR_{t-1}$	-0.054***	0.000	0.003
$EXCHR_{t-1}$	-0.036***	0.000	0.008
Variance constant	6.11E-09***	0.000	2.78E-10

ARCH	0.131***	0.000	0.002
GARCH	0.865***	0.000	0.002
Positive $EXCHJ_t$	3.29 E-04***	0.000	3.3E-05
Negative $EXCHJ_t$	3.31 E-04***	0.000	3.3E-05
ARCH-LM test	0.378	0.538	
Ljung-Box statistics	1	2	12
$Q^2(j)$	0.378	3.786	12.809

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.

4.2. Modelling jump spillover effects between the oil market and the US USD/EUR exchange rate

Overall, our findings show that US$ exchange rate volatility and, in particular, US$ exchange rate jumps, significantly affect oil price volatility. This implies that abrupt changes in the US$ currency can drive oil price changes because investors invest in both markets and can immediately react to any change in either of the markets. In order to clarify this volatility effect and check whether jumps in the US$/Euro exchange rate imply jumps in oil markets, we estimated the following Tobit model:

$$OILJ_t = \sigma_1 + \sigma_2 EXCHJ_t + \sigma_3 OILV_t + \varepsilon_t \quad (12)$$

where: $OILJ_t$ is the intensity of the jump occurring on the crude oil market during a 5-minute interval t; $OILV_t$ denotes oil market trading volume, and σ_1, σ_2, and σ_3 are regression coefficients.

If the coefficient σ_2 is statistically significant, it would suggest that jumps occurred simultaneously on the crude oil market and on the exchange rate market, supporting the idea that similar information drives both markets. We also introduced oil trading volume as a control variable as recommended by Giot et al. (2010), Chevallier and Sévi (2012), Shahzad et al. (2014) and Jawadi et al. (2016), in line with the MDH theory. Accordingly, we estimated model (12) and reported the main results in Table (6). These findings indicate a significant contemporaneous relationship between jumps in the exchange market and the oil market. This means that jumps occur simultaneously in foreign exchange and oil markets. We also confirm the positive relationship between volume and jumps (Jawadi et al., 2016).

Table 6: Tobit model estimation

$OILJ_t = \sigma_1 + \sigma_2\ EXCHJ_t + \sigma_3\ OILV_t$

Dependent variable/independent variable	Estimation	P-value
Constant	-0.036***	0.000
$EXCHJ_t$	2.033***	0.000
$OILV_t$	2.56E-06***	0.000
Log likelihood	84.749	

This table reports the estimation of Table 11. Significance at 10% level is marked by (*), 5% level by (**) and 1% level by (***).

5. Conclusion

This paper investigates oil price volatility through an analysis of the relationship between the crude oil market and the US USD/EUR exchange rate market. Prior studies have also examined volatility spillover between these two markets, often using low frequency data and usual GARCH volatility proxies. Our contribution is twofold. First, we use high frequency data to develop more precise measures of continuous and discontinuous volatility.

Second, in addition to the investigation of volatility spillover, we consider the intradaily jump component of volatility. Accordingly, we decompose realised volatility and detect intradaily jumps in both the foreign exchange market and the oil market.

Our intradaily analysis reveals several interesting findings. First, we confirm previous results which identify volatility spillover from the US foreign exchange rate market to the oil market, suggesting that information arriving in the exchange rate market can also be interesting for investors in the oil market and drive its price. Second, we show a negative relationship between USD/EUR returns and oil returns, which means that a US dollar appreciation results in a drop in oil prices. This negative relationship can be seen in the fact that investors may rebalance their portfolio and diversify it in order to obtain higher performance. Third, we focused on abrupt (extreme) shocks to show that intradaily jumps occurring in the exchange rate market impact and drive market volatility. Furthermore, our results indicate that both positive and negative shocks impact volatility. Finally, we found a significant contemporaneous relationship between the jumps occurring every 5 minutes in both markets.

A future extension of this study would be to investigate the economic justification of market jumps through an examination of the effect of news, for example. It might also be interesting to check whether the consideration of jumps can enhance oil price volatility forecasts.

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