

Spillover effect of US dollar exchange rate on oil prices

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Abstract

The US dollar is frequently used as the invoicing currency of international crude oil trading. Hence, the fluctuation in US dollar exchange rate is believed to underlie the volatility of crude oil price and especially its forecasting accuracy. Using econometric techniques including cointegration, VAR model, ARCH type models and a newly proposed approach to test Granger causality in risk, three spillover effects are explored, i.e., mean spillover, volatility spillover and risk spillover. Using rigorous appraisal, analysis is made of the influence of US dollar exchange rate on the international crude oil price from the perspective of market trading and several findings have been obtained.

Firstly, a significant long-term equilibrium cointegrating relationship can be identified between the two markets. This suggests a crucial reason for the fluctuation in crude oil price. But interestingly, the reverse does not work. Specifically, the influence of a standard deviation disturbance of US dollar exchange rate on oil price is increased quite slowly, and reaches its highest point, 1.0088 US dollars per barrel, after 1 year or so with a slightly and steadily diminishing process afterward. This implies that the US dollar depreciation for the years under investigation was a key factor in driving up the international crude oil price.

Secondly, there is apparent volatility and clustering for the two market prices, whereas their volatility spillover effect is insignificant, which reveals that their price volatility take relatively independent paths and the instant fluctuation in US dollar exchange rate will not cause significant change in the oil market.

Finally, their risk spillover effect appears quite limited, hence price risk influence of US dollar exchange rate on the oil market is not necessarily emphasized too much. Put it another way, compared with the powerful oil market, the impact of US dollar exchange rate is confirmed to be relatively partial.

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These results indicate that the influence of US dollar exchange rate on the international crude oil market proves quite significant in the long term; however, its short-term and instant influence turns out to be quite limited, which is noteworthy to be taken into account for oil market researchers, market trading analysts and traders.

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1. Introduction

Oil is commonly regarded to be a key strategic resource. Moreover, it is invariably argued that its market transaction and change in price are affected by numerous factors. Recently, the financial attribute of international crude oil markets has been increasingly emerging, and the growing interaction between oil markets and financial markets has been identified. Since 2002, international oil price has continuously risen with many new historic records. The price has risen from about 20 US dollars per barrel to the current over 90 US dollars per barrel. Such a change is the result of a confluence of many factors, such as the change of global oil demand and supply conditions, responses to geopolitics, institutional arrangements (such as OPEC), and the dynamics of the financial markets. One of the most important factors is the US dollar exchange rate, whose relatively recent depreciation has played a key role in the soaring oil price.

In retrospect, from the beginning of 2002 to the end of 2007, the US dollar has indeed fallen by 28% against the currencies of America's trading partners after adjusting for inflation, and what is more, it has also declined 41% against the euro. And in the future, according to the argument of US experts at the 2007 annual meeting of the American Economic Association, the US dollar would still have to depreciate by about 25% (Fink, Haiss, Oeberseder, & Rainer, 2007).

Since US dollar is the major invoicing currency in the international crude oil markets, it is probable that crude oil importing countries (except America) will be adversely affected by the rise in US dollar exchange rate. Also, the volatility of the US dollar exchange rate will render the international purchasing power of crude oil exporting countries more unpredictable. In the short term, the crude oil exporting countries may get anxious by a weak US dollar, whilst benefiting from a strong dollar. Conversely, an overvalued US dollar may lead to an adverse demand shock for them in the long term.

In fact, when the prospect of the US dollar is not considered promising, a large amount of money will flow to the oil market, thus oil price will be driven up. However, when the sizable sum of money departs from the oil market, the volatility of the US dollar exchange rate will be clearly seen. As a result, some new investment and speculation opportunities can be derived for traders based on the linkage between the oil market and US dollar exchange rate market. Moreover, as long as the invoicing and settlement currency of international oil markets is the US dollar, this kind of close linkage will remain.

Therefore, besides such qualitative comments, it is also essential to conduct quantitative research on the interactive relationship between international crude oil markets and the US dollar exchange rate. In particular, there is a need to investigate the influence of a continuing US dollar depreciating on oil price. The underlying rationale for this is not only for theoretical research but also for practical applications. And the outcomes of this work will bring further recognition of

the operating mechanism in the international oil market and also promote us to comprehend the fundamentals of its price volatility and risk.

2. Literature review

Hitherto, a rich body of literatures on oil market interaction can be found that are mainly involved with two aspects. One is to conduct empirical studies on interactions among diverse oil markets (Ewing, Malik, & Ozfidan, 2002; Hammoudeh, Li, & Jeon, 2003; Jiao, Fan, Wei, Han, & Zhang, 2007; Jiao, Fan, Zhang, & Wei, 2005; Lin & Tamvakis, 2001; Ng & Pirrong, 1996), and the other is concerned with the relationship between financial markets (especially the stock markets) and oil markets (Basher & Sadorsky, 2006; Chen, Roll, & Ross, 1986; Faff & Brailsford, 1999; Hamao, 1988; Hammoudeh & Eleisa, 2004; Huang, Masulis, & Stoll, 1996; Papapetrou, 2001; Sadorsky, 1999, 2003).

However, *less attention* has been paid to the interaction between international crude oil markets and the US dollar exchange rate, especially the influence of US dollar exchange rate on the crude oil price including its influencing way and extent. Chaudhuri and Daniel (1998) used the cointegration and causality tests to find the non-stationary behavior of US dollar real exchange rate, and concluded that it stemmed from the non-stationary behavior of real oil price. Amano and van Norden (1998) empirically studied the relationship between US dollar real effective exchange rate and oil price by means of cointegration theory, error correction model, and concluded that oil prices appeared to be the dominant source of persistent US dollar real exchange rate shocks. Indjehagopian, Lantz and Simon (2000) tested the interactive relationship between German, French and Rotterdam heating oil spot price and DM/US, FF/US exchange rates, using a vector error correction model (VECM); and their results indicated that variation in exchange rates had an instantaneous impact on the variations in oil price. Sadorsky (2000) examined the cointegrating and causal relationship between energy futures price for crude oil, heating oil and unleaded gasoline and the trade-weighted index of various US dollar exchange rates (i.e., effective exchange rate), and the results suggested that exchange rates transmitted a shock to energy futures price. Yousefi and Wirjanto (2004) investigated by means of GMM regression method the impact of US dollar exchange rate fluctuation on the formation of OPEC oil price.

In addition to these aforementioned studies, there is literature related to the interaction between oil price and other kinds of exchange rates. Camarero and Tamarit (2002) found, using panel cointegration techniques, 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 the Spanish peseta. Zalduendo (2006) with VECM identified that Brent real oil price, amongst other factors, had become a significant cause in determining a time-varying equilibrium real exchange rate of Venezuela. Huang and Guo (2007) investigated, by constructing a structural VAR model, the extent to which oil price shock and three other types of underlying macroeconomic shocks, influence China's real exchange rate, and found that real oil price shocks, as opposed to nominal shocks, would lead to a minor appreciation of RMB in the long term. Chen and Chen (2007) used panel cointegration theory to test the relationship between real oil price and real exchange rate of G7 countries, suggesting that there exists a significant long-term equilibrium relationship between them. Meanwhile, in the end, real oil price was one of the main reasons for real exchange rate volatility and helped to forecast its future trend. All of this is very helpful for us to appreciate the relationship between oil markets and exchange rate markets, especially to examine whether, and how, exchange rate markets predict the future trend of oil markets.

Drawing together previous work it can be found that, on the one hand, literature was primarily inclined to discuss the interaction between real international oil price and real exchange rate. Invariably this was done by applying econometrical techniques, such as cointegration theory, Granger causality test, VAR model, and VECM, to explore the role of interaction in influencing the macroeconomics and currency policies. On the other hand, existing studies often focused on the real (or effective) exchange rate, and investigated the impact of real (or effective) oil price fluctuation on the adjusted real exchange rate. More interestingly, although different data sets are used in various literature, the results are basically consistent, that is, there can be found a long-term equilibrium cointegrating relationship between real oil price and real exchange rate and the former often plays a significant role in Granger-causing the latter; but the reverse does not appear to work.

However, current studies have not examined the influence of US dollar exchange rate on the international crude oil markets from the perspective of market trading, which is considered paramount for trading participants, especially oil market traders and researchers concerned. For this purpose, nominal oil price and exchange rate should be regarded as significant determinants of final price. Therefore, in view of the fact that the US dollar has been the main invoicing currency in international crude oil markets, this paper focuses on the market trading situation, investigates the interactive relationship, namely spillover effect, between nominal crude oil price and nominal US dollar exchange rate. The spillover effect investigation includes three aspects, namely, mean spillover, volatility spillover and risk spillover. Using these factors, the influential magnitude of the US dollar exchange rate on crude oil markets (especially its forecasting power towards the latter) will be assessed. It should be pointed out that all of previous literatures usually focus on the mean spillover effect based on real prices, whereas our research approach and perspective are unique.

The rest of the paper is organized as follows. In Section 2, the empirical study framework and methodologies are presented. Data definitions are described in Section 3. Section 4 discusses the empirical results. Concluding remarks and future work are provided in Section 5.

3. Empirical framework and methodologies

Empirical study on the interactive relationship between international crude oil market and US dollar exchange rate market is conducted using three facets, namely long-term price change, price volatility and market risk transmission. The purpose of this work is to thoroughly comprehend their relationship and to investigate the extent of influence of the US dollar exchange rate fluctuation on the change in crude oil price in a more accurate manner, thus providing support for forecasting oil price under macroeconomic conditions.

3.1. Mean spillover effect test of crude oil market and US dollar exchange rate

In terms of economics, mean spillover effect between two markets refers to the fact that the price in one market is affected not only by its own previous price movement but also by previous prices in other markets. In the long run, the test of mean spillover effect plays an important role in assessing whether the impact of change in US dollar exchange rate on crude oil price is significant, and whether the change in US dollar exchange rate can help to forecast future trends of the latter.

Mean spillover effect is based on a VAR model, that is, the standard linear Granger causality test. Therefore, according to the least values of AIC and SC in a VAR model, the optimal lagged order can be set, and then the Granger causality test is carried out to detect the mean spillover effect

between crude oil price and US dollar exchange rate. Specifically, let X_t denotes international crude oil price at time t and Y_t be the US dollar exchange rate (more accurately, that is the exchange rate of euro against US dollar in this paper) at time t , then a hypothesis $s_j = 0 (j = 1, 2, \dots, m)$ is tested in a bi-variable regression equation (like Eq. (1)). If the hypothesis is rejected, then we may say that the change of oil price is according to Granger, caused by the change of US dollar exchange rate. In the same way, we may also test whether US dollar exchange rate change Granger causes the change of oil price through Eq. (2). In both equations, the parameter m represents the largest lagged order

$$Y_t = k_0 + \sum_{i=1}^m k_i Y_{t-i} + \sum_{j=1}^m s_j X_{t-j} + \varepsilon_t \quad (1)$$

$$X_t = k_0 + \sum_{i=1}^m k_i X_{t-i} + \sum_{j=1}^m s_j Y_{t-j} + \varepsilon_t \quad (2)$$

3.2. Volatility spillover effect test between crude oil market and US dollar exchange rate market

The volatility spillover effect indicates that price volatility in different markets can be mutually affected. Specifically, the price volatility magnitude in one market may be affected not only by its own previous volatility but also by the price volatility of foreign markets. Put another way, their volatility information can be transferred among various markets. With respect to the two markets in this paper, market transaction situation changes so fast that their close relationship has raised great concern. Whether the US dollar exchange rate fluctuation will be transferred to the international crude oil market is the key concern related to volatility spillover effect under investigation here.

ARCH type models are first used to test and measure the volatility clustering, which is the basis of any volatility spillover effect investigation. GARCH model, provided by Bollerslev (1986), is based on the ARCH model (Engle, 1982) and its basic equations can be expressed as

$$Y_t = X_t' \theta + \varepsilon_t, \quad h_t = \alpha_0 + \sum_{i=1}^p \alpha_i \varepsilon_{t-i}^2 + \sum_{j=1}^q \beta_j h_{t-j} \quad (3)$$

where Y_t denotes the crude oil price or US dollar exchange rate and X_t the column vector consisting of independent variables, whereas θ is the column vector of coefficient and h_t is the conditional variance of the residual.

Meanwhile, significant leverage effect often can be seen in the volatility of price series, that is, the current price volatility magnitude caused by the previous price increase and decrease is quite asymmetric. Therefore, the TGARCH (Zakoian, 1994) model is applied to discuss this topic, and its conditional variance can be depicted as follows

$$h_t = \alpha_0 + \sum_{i=1}^p \alpha_i \varepsilon_{t-i}^2 + \psi \varepsilon_{t-1}^2 d_{t-1} + \sum_{j=1}^q \beta_j h_{t-j} \quad (4)$$

where if $\varepsilon_{t-1} < 0$, $d_{t-1} = 1$; otherwise $d_{t-1} = 0$. Due to the introduction of d_{t-1} , different influence of price increase ($\varepsilon_{t-1} > 0$) and decrease ($\varepsilon_{t-1} < 0$) on the conditional variance (h_t) can be found distinct. Specifically, when the price increases, $\psi \varepsilon_{t-1}^2 d_{t-1} = 0$, and the influence magnitude can

be expressed by $\sum_{i=1}^p \alpha_i$; whereas if the price decreases, the influence should be $\sum_{i=1}^p \alpha_i + \psi$. In brief, so long as $\psi \neq 0$ in the model, then it can be said that the influence concerned appears asymmetric.

In order to select a model with the least AIC value, TGARCH(1,1) and GARCH(1,1) are singled out to model the international crude oil price and US dollar exchange rate, respectively. Under this circumstance, together with the ideas in Lin and Tamvakis (2001) and Hammoudeh et al. (2003) relating to the interaction between various oil markets, a model is constructed to test the volatility spillover effect

$$h_{1,t} = \alpha_{1,0} + \alpha_{1,1}\varepsilon_{1,t-1}^2 + \psi\varepsilon_{t-1}^2 d_{t-1} + \beta_{1,1}h_{1,t-1} + \gamma_1 h_{2,t-1} \quad (5)$$

$$h_{2,t} = \alpha_{2,0} + \alpha_{2,1}\varepsilon_{2,t-1}^2 + \beta_{2,1}h_{2,t-1} + \gamma_2 h_{1,t-1} \quad (6)$$

where $h_{i,t}$ denotes the conditional variance of market i (here, it relates to international crude oil market or US dollar exchange rate market) at time t , whereas $\alpha_{i,0}$, $\alpha_{i,1}$, ψ and $\beta_{i,1}$ are coefficients in (T)GARCH(1,1) model. As can be seen from Eqs. (5) and (6), a lagged conditional variance term of one market is appended to the conditional variance equation of another market, and γ_i is the coefficient of the regression term (that also can be viewed as the market volatility spillover term) in market i . Specifically, if γ_i can be proved statistically significant, then it may be said that volatility spillover effect from market i to another *does* exist. Put simply, the volatility information in market i will be transferred remarkably to another market. Otherwise, the volatility spillover effect cannot be addressed.

3.3. Risk spillover effect test between crude oil market and US dollar exchange rate market

The risk spillover effect between two markets means the historical information regarding extreme risk in one market helps to forecast its occurrence in another market. In fact, risk avoidance and control should be closely monitored by market participants, especially for bulk commodity trading such as crude oil trading. Additionally, crude oil trading almost goes hand in hand with US dollars all the time, which renders that their mutual penetration seems quite deep-rooted and their market risk transmission is worth noticing.

Therefore, crucial importance should be attached to the calculation and supervision of the extreme risk in the oil market and US dollar exchange rate market. The key point is how to measure the market risk quantitatively. Here, a concise but effective methodology, namely VaR, is introduced.

According to Hendricks (1996) and Hilton (2003), the idea of VaR implies the maximum amount of money that may be lost on a portfolio over a given period with a given confidence level, due to exposure to the market risk. Statistically, VaR refers to the quantile of a probability distribution function.

Actually, there are numerous methods to calculate market VaRs, for example, basic solution includes variance–covariance method, historical simulation approach, and Monte Carlo simulation method. Here, variance–covariance method is used. During the calculation, it is very important to estimate the parameters of VaR models. Given the leptokurtic distributions and fat tails in both oil price series and US dollar exchange rate series, the commonly used standard normal distribution assumption tends to underestimate the extreme market risk. Consequently, the generalized error distribution (GED) (Nelson, 1990) is presented here to estimate the residual series from GARCH type models.

The methodology of Granger causality in risk provided by Hong (2003) is employed here so as to examine the risk spillover effect between crude oil market and US dollar exchange rate especially the price risk influence of US dollar exchange rate on the oil market. Its essential argument requires that the time-varying VaR should be calculated for each price series at first, and then whether the historical information about risk in one market helps to forecast its occurrence in another market should be determined using the Granger causality test.

By introducing the sample cross-correlation function and kernel-based weighting function, Hong (2003) proposed two statistics Q_1 and Q_2 to test the one-way (unidirectional) and two-way (bidirectional) Granger causality in risk, respectively. In practice, we may test the two-way Granger causality in risk at first, if its null hypothesis is rejected (that means there exists a Granger causality in risk at least in one direction), then further hypothesis test can be conducted with respect to the one-way Granger causality in risk between the two markets.

4. Data definitions and selection

Our aim in this paper is to ascertain the spillover effect way and magnitude of US dollar exchange rate on the international crude oil market. Nominal prices have been used, which are market-trading prices but not real (effective) prices.¹

From the perspective of market trading, WTI crude oil price is supposed to be one of the primary representatives of an international crude oil benchmark price. Spot trading has been flourishing, and regarded as the principal facet in international oil markets (Yousefi & Wirjanto, 2004). Consequently, daily spot WTI crude oil price that is quoted in US dollars per barrel is used in this study. The exchange of euro against US dollar accounts for the largest market trades in the total international exchange. Under this circumstance, the spot (nominal) exchange rate of euro against US dollar is singled out here, which is also the daily price data.

Considering the fact that non-market factors, including geopolitics and speculative capital, have exerted a pronounced impact on the international oil market ever since the summer of 2005, we have taken a sample period that ranges from 4 January, 2000 to 31 May, 2005. This data set was selected to alleviate the influence of excessive intervention from non-market factors as much as possible and shed a more accurate quantitative light on the interaction between the oil price variation and US dollar exchange rate. Moreover, this sample set period includes both the fall and rise of both oil price and US dollar exchange rate; where the year of 2002 is supposed to be the principal turning point.

As a result, 1342 samples are obtained (which can be seen in Fig. 1). Broadly, from the year of 2000 to 2002, oil price was evidently slashed while the US dollar exchange rate against the euro continuously appreciated. Whereas, since the year of 2002, the picture has changed totally. Specifically, oil price has risen twice while the US dollar has increasingly depreciated. Hence, there are consistent trends between the two markets indicated by a strong correlation between them (with correlation coefficient 0.78). However, whether this kind of ostensible correlation *has* reflected their influencing mechanism in nature and whether the depreciation of US dollar *has* been one of the main reasons for the ever-increasing oil price, need further empirical study as follows.

¹ A large body of literature in the past tended to evaluate the influence of oil prices on exchange rates and even further on the macroeconomics. Hence real (effective) oil prices and exchange rates were used so as to reflect the relative price level between two countries, thus explaining their international competitive power in commodities.

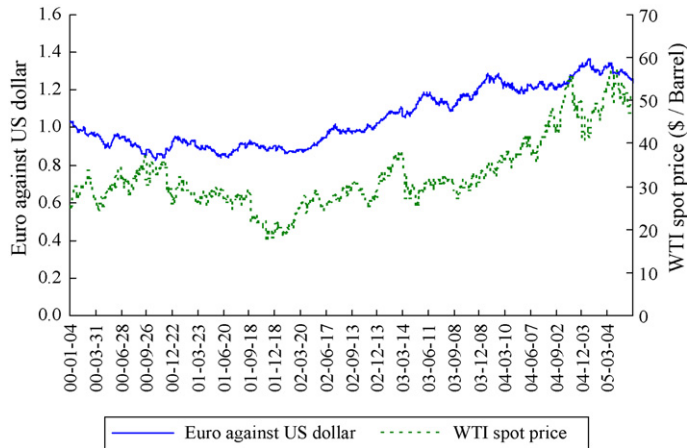


Fig. 1. WTI crude oil spot price and US dollar exchange rate (4 January 2000–31 May 2005).

5. Empirical results and discussion

5.1. Summary statistics of price series

Let PO_t and PE_t represent WTI crude oil price and euro exchange rate against US dollar on date t , respectively, whose statistical characteristics are shown in Table 1. From the summary statistics, several traits can be identified. Firstly, neither of the price series (the exchange rate can be regarded as a kind of relative price) follows a normal distribution. Secondly, there can be seen significant autocorrelation and heteroskedasticity in both price series; hence, volatility clustering does exist in both series. Additionally, from the results of an ADF test, it must be noted that at the significance level of 5%, both price series are non-stationary but their first-order difference series are stationary, so both are I(1) series. Finally, from standard deviation values, we may find

Table 1
Summary statistics for international crude oil price and US dollar exchange rate

Statistics	PO_t	PE_t
Mean	32.50352	1.048275
Std. Dev.	8.374317	0.155670
Skewness	1.032113	0.374490
Kurtosis	3.546463	1.657235
JB statistic	254.9604 (0.0000)	132.1863 (0.0000)
$Q(10)$	12,541 (0.0000)	13,254 (0.0000)
$Q^2(10)$	12,499 (0.0000)	13,248 (0.0000)
ADF statistics		
Level	−2.4048 (0.3768)	−3.1068 (0.1050)
FD	−38.2653 (0.0000)	−36.8002 (0.0000)

Note: JB statistic is used for normal distribution test. Statistic $Q(10)$ lagged from 1 to 10 periods is to test the autocorrelation of price series whereas its squared series $Q^2(10)$ is provided to check the heteroskedasticity of price series. ADF statistic is introduced to test the stationary properties of price series, and during the test, FD means the first-order difference. Finally, p -values for corresponding null hypotheses are reported in parentheses.

that, generally, the risk of oil price volatility is much larger than that of the US dollar exchange rate fluctuation.

5.2. Mean spillover effect between crude oil market and US dollar exchange rate market

5.2.1. Long-term equilibrium relationship of oil price and US dollar exchange rate

In order to use the notion of long-term elasticity, natural logarithmic values of both international crude oil price series and US dollar exchange rate series are calculated and two new price variable are obtained, namely \ln_PO and \ln_PE . From the statistical test result of stationary property, it has been found that both logarithmic price series are also $I(1)$ series. Hence, according to the cointegration theory, a regression model can be obtained as follows

$$\ln_PO_t = \underset{(42.9928^{**})}{1.2607} \ln_PE_t - \underset{(-770.8266^{**})}{3.4052} + \varepsilon_t \quad (7)$$

where values of t statistic are shown in parentheses and $**$ denotes that corresponding regression coefficient is significant at 99% confidence level. ADF test is conducted to determine the stationary property of residual series ε_t . The result indicates that at the significance level of 1%, the residual series is quite stationary. Therefore, we may say there is a long-term equilibrium cointegrating relationship between the oil price and US dollar exchange rate. And the cointegrating relationship appears positive according to the regression coefficient in Eq. (7). Moreover, the long-term elasticity coefficient of oil price over US dollar exchange rate is 1.2607, which means a 1% fluctuation of US dollar exchange rate will cause 1.2607% change of oil price in the long run. This finding suggests that the interaction between the two markets proves quite significant in the end and the influence of US dollar exchange rate on oil price should not be neglected. Thus, when analyzing and forecasting international oil price long-term trends, the influence caused by US dollar exchange rate change must be paid close attention.

5.2.2. Cross-correlation of oil market and US dollar exchange rate market

Although both international oil price series and US dollar exchange rate series are non-stationary, they have a cointegrating relationship, which satisfies the premise of constructing a vector auto-regression (VAR) model. In order to further ascertain whether it is appropriate to use the model, cross-correlation test is conducted with respect to the oil price and exchange rate series. When the lagged period is 2, the cross-correlation coefficients can be seen from Table 2. It should be noted that the entire cross-correlation coefficients are large and significant, which means there could be found significant leading and lagging relationship between the two markets. Consequently, it is imperative to construct a VAR model for them.

Table 2
Cross-correlation coefficients between oil price and US exchange rate

	\ln_PO	$\ln_PO.C1$	$\ln_PO.C2$
\ln_PE	0.7619	0.7606	0.7593
$\ln_PE.C1$	0.7626	0.7614	0.7601
$\ln_PE.C2$	0.7632	0.7620	0.7608

Note: $\ln_PO.C1$ and $\ln_PO.C2$ denote international oil price series lagged 1 and 2 periods, respectively, whereas $\ln_PE.C1$ and $\ln_PE.C2$ means the US dollar exchange rate series lagged 1 and 2 periods, respectively.

Table 3
Results of Granger causality test between oil price and US dollar exchange rate

Null hypothesis	F-Statistic	Probability
ln_PE does not Granger cause ln_PO	8.7447	0.0032
ln_PO does not Granger cause ln_PE	0.0071	0. 9329

5.2.3. Mean spillover effect

Through constructing a VAR model between oil price and US dollar exchange rate series, its optimal lagged period can be acquired according to the least AIC and SC values, which can be used for Granger causality test approach. The results of Granger causality test are shown in Table 3. From the significance probabilities, we may find that the change of US dollar exchange rate *does* Granger cause the volatility of international crude oil price, but the volatility of oil price *does not* significantly Granger cause the change of US dollar exchange rate. All of this implies that there only exists a one-way (unidirectional) mean spillover effect which is from the US dollar exchange rate to international oil price. Put it another way, the volatility of international oil price is markedly affected by the change of previous US dollar exchange rate, whereas the reverse does not work.

Since the year of 2002, the US dollar has experienced a constant depreciating process, and the reasons for that are quite complex. The most important one is that the US government desires to effectively pull its export, thus curtailing its international trade deficit. On the other hand, due to the comprehensive influence caused by oil market supply–demand situation, geopolitics, financial market volatility, etc., the international oil price has seen a great deal of historic break-through since 2002. Moreover, based on the empirical results of mean spillover effect, we can say that the depreciation of US dollar against euro (also depreciation against other main currencies) has helped to drive up the international oil price over the past few years. The most crucial reason is that the US dollar is the main invoicing currency of crude oil futures trading. Thus, the depreciation of US dollar motivated some foreign investors to buy an abundance of crude oil futures contracts to get greater profits, and then the rise of crude oil futures price will uncommonly promote the soaring of oil spot price. Additionally, it must be noted that this finding implies a long-term influence between them.

Compared with the conclusions of extant literature, in our work, using real oil price and real exchange rate, our empirical study using nominal prices indicates that there still exists an interactive equilibrium relationship between the two markets in the end. Nevertheless, the direction of interaction (i.e., causality) has totally changed. Consequently, it should be noted that the commodity price level (or consumer price index) in America and European countries, namely deflation situation, has altered this long-term interactive relationship between them to some extent.

5.2.4. Result analysis of impulse response function

During VAR modeling, the impulse response function can be used for dependent variables to measure the magnitude of response to the impulsion from one standard deviation of the random disturbance term. Impulse–response function graphs, based on international oil price and US dollar exchange rate, can be seen in Fig. 2, from which it can be identified that the influence magnitude of one standard deviation from US dollar exchange rate (with logarithmic value 0.1463 and its corresponding original exchange rate value 0.1557) on international oil price gradually increases. About 1 year (exactly 234 trading days) later, it gets to the largest that is about 0.00879\$/bbl (with its corresponding original oil price 1.0088\$/bbl), and then falls in a mild and slow manner.

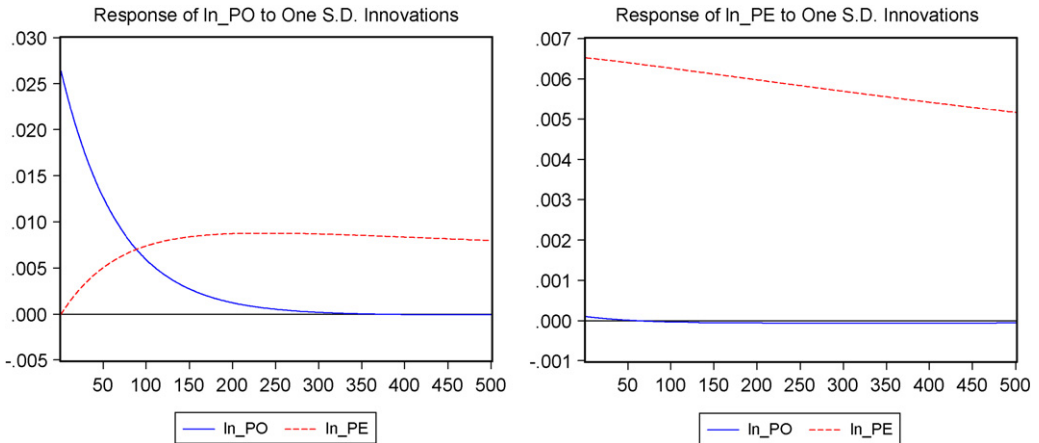


Fig. 2. Impulse response functions of oil price (ln_PO) and US dollar exchange rate (ln_PE).

Whereas the response of the US dollar exchange rate to one standard deviation disturbance of international oil price (with logarithmic value 0.2422\$/bbl and its corresponding original oil price 8.3743\$/bbl) is quite weak, close to zero all the time. This result further validates the unidirectional mean spillover effect between international oil price and US dollar exchange rate.

5.3. Volatility spillover effect between crude oil market and US dollar exchange rate market²

5.3.1. Volatility clustering effect analysis of price series

From the results in Table 1, it should be noted that the two price series take on significant volatility clustering properties. ARCH type models are introduced to depict these properties. Given the series autocorrelation, the random walk model is used here. After testing the residual series of the model, we find that there is significant high-order ARCH effect with respect to international oil price series; so a GARCH model is brought into play. Subsequently, according to the principle of least AIC value, a GARCH(1,1) model is singled out. Additionally, considering the asymmetric oil price volatility from ascending price and descending price, TGARCH(1,1) is put into use for the volatility clustering description in oil market ultimately, which also proves reasonable from the value of AIC. When examining the ARCH effect of the residual series of the TGARCH(1,1) model, we discover that ARCH effect has been filtered out. Besides, the results of $Q(10)$ and $Q^2(10)$ display that there hereafter are no longer extra series autocorrelation and volatility clustering. All of this indicates that TGARCH(1,1) can well fit the volatility characteristics of international crude oil price. In a similar way, it can be detected that the GARCH(1,1) model may depict the volatility clustering property of US dollar exchange rate in a favorable way. All the parameters of TGARCH(1,1) and GARCH(1,1) discussed above are shown in Table 4.

It should be noted that, given that residual series of GARCH type models concerned do not follow normal distributions, the generalized error distribution (GED) based (T)GARCH(1,1) model are adopted to characterize their leptokurtic distributions and fat tails. The estimation

² Considering the logarithmic calculation of price series will reduce their volatility magnitude, original price series are used here to conduct volatility spillover effect test.

Table 4
Parameter estimation of (T)GARCH model about international oil price and US dollar exchange rate

	PO	PE
θ	1.001405 (0.0000)	1.000165 (0.0000)
α_0	0.006967 (0.0903)	6.43E–07 (0.0733)
α_1	0.068833 (0.0006)	0.033913 (0.0015)
ψ	–0.046902 (0.0326)	–
β_1	0.949241 (0.0000)	0.953280 (0.0000)
GED degree	1.256753 (0.0000)	1.602860 (0.0000)
Adjusted R^2	0.9893	0.9981

Note: p -values are reported in parentheses.

in Table 4 indicates that both GED parameters are less than 2, which just validates the fat tail features of two residual series involved, respectively.

The estimation of volatility model TGARCH(1,1) implicates that significant asymmetry can be identified from international oil price volatility, namely leverage effect. The leverage coefficient ψ is negative, which means the influence of oil price rise on future oil price volatility appears larger than that of oil price fall with the same magnitude. Specifically, when oil price drops, the influence magnitude of ε_{t-1}^2 on h_t , namely $\alpha_1 + \psi$, is 0.0219; but when oil price upsurges, the influence magnitude, namely α_1 , is equal to 0.0688, which is about 3.1 times of that in the former scenario. There are a large number of reasons for this leverage effect, the most essential one of which is the non-renewable property of oil. Solely due to this natural property, the market position of oil suppliers is much superior to that of *demanders*. In this way, the rise of oil price will reinforce the expectation for oil supply deficit, which spurs market traders to buy oil as soon as possible thus the rise of oil price is exacerbated. Meanwhile, the speculation activities in the oil market, which is quite prevalent, add fuel to the fire, and all of this ultimately leads to the prominent volatility of rising oil price. However, when oil price sees a downward trend, oil producers reduce their production while oil dealers store their oil for future sales, which brings about the sharp drop of oil supply in oil market and thus promoting the rebound of oil price, in the end, further slashing of oil prices. Therefore, asymmetric positions of suppliers and demanders in oil markets determine that the rising magnitude of oil price when oil supply is deficient proves greater than its falling magnitude when oil supply is superfluous, and the leverage effect mentioned comes into being.

From the volatility model GARCH(1,1), it can be found that significant GARCH effect occurs for the volatility of US dollar exchange rate. In its variance equation, the sum of α_1 and β_1 depicts the decaying velocity of volatility shocks. The closer its value is to 1, the slower its decaying velocity appears. In the GARCH(1,1) model here, the sum is equal to 0.9872, which implies that US dollar exchange rate holds finite variance with a weak stable process and the volatility of US dollar exchange rate will be confronted with decaying ultimately, but its span will last for a relatively long time. Furthermore, the coefficient of h_{t-1} is 0.9533, revealing that 95.33% of current variance shocks will still stay on the next day, hence the half-life of its decaying is 14 days.

5.3.2. Volatility spillover effect

In light of the volatility spillover effect test models in Section 3, corresponding test results are shown in Table 5. Note that from the results, neither γ coefficient in international oil price volatility model nor that in US dollar exchange rate volatility model is statistically significant, therefore, it should be explicitly pointed out that, although there exists a long-term equilibrium

Table 5

Result of volatility spillover effect test between international oil price and US dollar exchange rate

	PO	PE
α_0	0.005681 (0.3771)	4.31E–07 (0.1840)
α_1	0.072854 (0.0004)	0.031151 (0.0027)
ψ	–0.047876 (0.0332)	–
β_1	0.942245 (0.0000)	0.954771 (0.0000)
γ	85.65198 (0.6066)	3.67E–07 (0.3291)

cointegrating relationship between international oil price and US dollar exchange rate and significant unidirectional mean spillover effect in the long run can be found between them, but their volatility spillover effect in any directions is insignificant enough, which means their price volatility information has independent paths to some extent and their price volatility magnitudes are not transferred to each other. It also can be concluded from the empirical study results that the impact of US dollar exchange rate on oil price proves fairly weak in terms of the price volatility.

5.4. Risk spillover effect between crude oil market and US dollar exchange rate market

In the market, volatility does not necessarily mean facing risk. Hence, the risk spillover effect should be the extension of volatility spillover. As far as different market participants, whether in downside or upside direction, both oil price and US dollar exchange rate are faced with extreme market risk. This is crucial in terms of risk management and can be adequately described using VaR methodology. Statistically, VaR implies the quantile of the distribution function. In this paper, the left quantile of international crude oil price is used to measure its downside risk, which means the loss of sales income for crude oil producers owing to the reduction of oil price. Whereas the right quantile is adopted to estimate the upside risk, which represents the extra expenditure for oil purchasers caused by the sharp rise of oil price. This logic of risk management also holds for US dollar exchange rate market. With regard to the euro exchange rate against US dollar in this paper, the up-and-downs of exchange rate cause different risks for different exchange rate market participants for many aspects. For one thing, when the international import and export trading happened in America is concerned, downside US dollar exchange rate means its appreciation, then exporters in America and importers in euro area face large market risk; whereas upside US dollar exchange rate represents its depreciation. American importers and European exporters may thereby have to handle remarkable market risk issues. Moreover, considering the matter of oil US dollars, US dollar appreciation signifies extra expenditure increase of oil importing countries (such as European countries), whereas its depreciation renders a great challenge for oil sales income of main oil exporting countries (such as OPEC).

Taking into account what has been discussed above, it is quite indispensable for both oil market and US dollar exchange rate market to estimate upside and downside extreme market risk at the same time, so as to provide pertinent and reliable decision support for different market participants. TGARCH(1,1) and GARCH(1,1) models based on GED mentioned above, plus variance–covariance method for VaR calculation, are adopted to measure the VaR risk in oil market and US dollar exchange rate market, respectively. Consequently, their market risk spillover effect test is conducted.

Table 6
GED parameters and quantiles for international oil price and US dollar exchange rate

Price	Parameter	95% quantile	99% quantile
PO _t	1.256753	1.642	2.580
PE _t	1.602860	1.647	2.434

5.4.1. Determination of GED quantiles

According to the probability density function of GED, we obtain the 95% and 99% quantiles under the calculated degree parameters (see Tables 4 and 6). The results in Table 6 show that the 95% quantiles are very close to that of standard normal distribution, namely 1.645, while the 99% quantiles are dramatically larger than that of standard normal distribution, namely 2.326, which also implies that both international crude oil price and US dollar exchange rate have marked fat tails.

5.4.2. Estimation of VaR risk of oil market and US dollar exchange rate market

Based on the meaning of VaR risk explained previously and its variance–covariance calculation method, two formulas of VaR risk estimation are obtained as follows. The formula of upside VaR risk can be expressed as

$$\text{VaR}_{m,t}^{\text{up}} = \mu_{m,t} + z_{m,\alpha} \sqrt{h_{m,t}} \quad (m = 1, 2) \tag{8}$$

where $\mu_{m,t}$ is the conditional mean of daily price in market m (referring to the oil market and US dollar exchange rate market here) at date t , and $z_{m,\alpha} > 0$, which denotes the GED quantile above of the (T)GARCH(1,1) model in market m at significance level α , whereas $h_{m,t}$ is their time-varying conditional variance series. Similarly, we can acquire the downside VaR according to

$$\text{VaR}_{m,t}^{\text{down}} = -\mu_{m,t} + z_{m,\alpha} \sqrt{h_{m,t}} \quad (m = 1, 2) \tag{9}$$

Through Eqs. (8) and (9), the upside and downside VaRs for international oil price and US dollar exchange rate are figured out at confidence levels of 95% and 99%, respectively. By means of the LR test (Kupiec, 1995), we find that the accuracy of these VaR series is quite practicable and satisfying, which is favorable for further study.

5.4.3. Risk spillover effect

After the upside and downside VaRs are obtained for the two markets, we constructed two statistics, namely $Q_1(M)$ and $Q_2(M)$, according to the idea of Granger causality in risk provided by Hong (2003). Next, we calculate their statistical values and their significance probability. Finally, both bidirectional and unidirectional risk spillover effect between the two markets are assessed. All the results can be seen from Table 7, in which M , the largest effective lag truncation order, is equal to 10, 20 and 30.

From the results of risk spillover effect test in Table 7, it should be noted that, as far as the downside risk (i.e., oil price decreases and US dollar appreciates) is concerned, there is bidirectional risk spillover effect between the international oil market and US dollar exchange rate market. Further study shows that at the 95% confidence level, unidirectional risk spillover effect from the US dollar exchange rate market to international oil market can be identified. However, the extreme risk of oil market *does not* transfer to the US dollar exchange rate significantly. Therefore, we may say that the appreciation risk of the US dollar *does* have an apparent

Table 7
Results of risk spillover effect between international oil price and US dollar exchange rate

Confidence level	Null hypothesis	Upside risk spillover			Downside risk spillover		
		<i>M</i> = 10	<i>M</i> = 20	<i>M</i> = 30	<i>M</i> = 10	<i>M</i> = 20	<i>M</i> = 30
95%	PO ⇌ PE	−0.6294 (0.7355)	−0.4370 (0.6689)	−0.2360 (0.5933)	2.7014 (0.0035)	1.9960 (0.0230)	1.5999 (0.0548)
	PO ⇏ PE	0.3311 (0.3703)	0.1898 (0.4247)	0.0234 (0.4907)	0.0816 (0.4675)	−0.3445 (0.6348)	−0.6715 (0.7491)
	PE ⇏ PO	−0.5425 (0.7063)	0.2793 (0.3900)	1.0902 (0.1378)	3.8867 (0.0000)	3.0383 (0.0012)	2.6992 (0.0035)
99%	PO ⇌ PE	−2.4071 (0.9920)	−2.7349 (0.9969)	−2.6128 (0.9955)	1.1209 (0.1312)	1.2139 (0.1124)	0.7934 (0.2138)
	PO ⇏ PE	−1.6326 (0.9487)	−2.2537 (0.9879)	−2.2171 (0.9867)	−0.1581 (0.5628)	−0.7030 (0.7590)	−1.3629 (0.9135)
	PE ⇏ PO	−1.3788 (0.9160)	−0.0231 (0.5092)	1.0441 (0.1482)	−0.5590 (0.7119)	−0.3419 (0.6338)	−0.5162 (0.6972)

Note: ⇌ represents there is no two-way Granger causality in risk, and ⇏ signifies there is no one-way Granger causality in risk from the former to the latter. The corresponding *p*-values are reported in parentheses.

influence on the decline of oil price. Additionally, at the confidence level of 99%, empirical study indicates that there is no risk spillover effect in any directions between the two markets. All of this implies that with respect to the downside risk, risk spillover effect between the two markets proves quite limited. Moreover, when the precision requirement is enhanced to a more precise extent, the influence in risk of appreciating US dollars on downside oil price can be negligible.

On the other hand, from the perspective of upside risk (i.e., oil price soars while US dollar depreciates), whether at the confidence of 95% or 99%, none risk spillover effect can be detected in any directions between the two markets. Hence, in recent years, although US dollar has been continuously depreciating and international oil price has been increasing in a surprising way. The US dollar's depreciation has not formed a significant impetus to the sharp rise of oil price with respect to market risk. Put it another way, although the upsurge of oil price has led to the evident increase of extra expenditure for those main purchasers in international oil markets, such as China and India, the depreciation of US dollar exchange rate should not be responsible for this cost increase.

In a word, greater attention should be paid to the risk influence of that US dollar appreciation on the downside oil price when market transactions are conducted and measures should be taken to shun the market extreme risk. In recent years, although there have been numerous ups and downs of US dollar exchange rate in daily trading, its depreciation is the main trend overall. Historically new records of its weakness can be frequently identified. This situation, however, has not exerted significant influence on the upside risk of oil price. Therefore, in the current environment, risk spillover effect empirical study results here should be considered a desirable signal for traders.

6. Concluding remarks and future work

The US dollar is used for the invoicing currency of international oil trading as a consequence of world economic development and international politics. The concentration on the interaction of the oil market and US dollar exchange rate market, therefore, is of great importance not only for practical market trading, but also for the stability of oil dollar and the international political environment, and even the continuing prosperity of the world economy.

Based on the discussion above, in this paper, three aspects, including market price, price volatility, and price risk of interaction between international crude oil market and US dollar exchange rate market, have been empirically studied from the perspective of market trading. Consequently, some interesting findings are obtained as follows.

- (1) The depreciation of the US dollar should be considered a crucial reason for the astonishingly soaring oil price. Hence, in the recent years, the promoting influence of continuous depreciation of the US dollar on constantly record-breaking oil prices has been demonstrated. This is because a long-term equilibrium and positive cointegrating relationship can be identified between oil price and the exchange rate for the euro against US dollar. Moreover, there is a unidirectional mean spillover effect from the US dollar exchange rate to the oil price. Specifically, the influence of a standard deviation disturbance of US dollar exchange rate on oil price appears increased relatively slowly, and reaches the highest point 1.0088\$/bbl after about 1 year and then starts a slightly and steadily diminishing process.
- (2) As far as the market price volatility is concerned, both international crude oil price and US dollar exchange rate take on remarkable fluctuation. Yet their volatility is relatively independent. Such knowledge provides some support for market traders and researchers when judging

the interaction between the two markets. Empirical studies show that volatility clustering has been identified for both market prices. Furthermore, oil price volatility has an apparent leverage effect, which means the influence of oil price rises on future oil price volatility proves larger than that of oil price fall with the same magnitude, namely 3.1 times. On the other hand, US dollar exchange rate volatility experiences slow decaying velocity and its decaying half-life equals 14 days. However, our empirical study reveals that the volatility spillover effect between the two markets is statistically insignificant. Consequently, the influence of US dollar exchange rate volatility on the change of the international oil price is quite weak, and its price volatility information appears relatively independent.

- (3) From the perspective of market risk, it can be seen that the interaction between oil price and US dollar exchange rate does not seem strong, and their leading and lagging effect are fairly restricted. Empirical research implies that the extreme risk spillover effect between the two markets proves quite limited. Specifically, at the confidence level of 95%, the appreciation risk of US dollar exchange rate against euro helps to forecast the downside risk of oil price. However, when the confidence level is enhanced to 99%, this spillover effect turns insignificant. Furthermore, neither of their risk spillover effect in other directions is notable. Hence, market participants *do not* have to worry about the risk spillover from the dollar exchange rate to the oil markets.

The empirical results of our study as discussed above have several important policy implications for traders and researchers involved.

- (1) When long-term oil price forecasting is conducted and its long-term affecting factors are explored, the trend of US dollar exchange rate must be attached great importance. Since the year of 2002, the dollar has continuously been depreciating, and whereas the status quo of American macroeconomy and its future expectation, basically, the dollar will continue to be weak, hence we may say that there exists some force to keep the international oil price in a high level.
- (2) Although in recent years, the dollar has declined overall with a large oscillating magnitude sometimes; meanwhile, the rising oil price frequently fluctuates at a high level. However, the oscillation of the dollar *does not* form a driving force for that of the oil price, hence we cannot judge the future fluctuating trend in oil markets from the volatility of the dollar.
- (3) It should be pointed out that although continuous depreciation has been the main feature of the US dollar in the past few years, its influence on the extreme market risk of constantly sharp rising oil price is very partial. At the same time, although the surging oil price has led to apparent cost increases for oil importers such as China and India, their expenditure increases cannot be explicitly attributed to the depreciation of the dollar. In our opinions, main reasons for their cost increases should take into account the skyrocketing of oil price and their importing volume.
- (4) In the long term, US dollar exchange rate proves one of the crucial factors affecting the oil price trend, however, the short-term especially instant influence of US dollar exchange rate is quite limited. Hence, when analyzing short-term volatility of international oil price is concerned, the influence of US dollar exchange rate is not necessarily emphasized too much. From this, we also may find that the fundamental reasons for oil price change are the supply-and-demand situation and its future expectation, while the impact of financial markets does not turn out to be considerable.

Empirical studies on the interaction of the two markets, especially the spillover effect of US dollar exchange rate on the oil price, are conducted in this paper. However, there is still a long way to go for work in this field. In the wake of an emerging non-US dollar as the invoicing currency in international oil markets, the consequences are significant and market players face huge challenges. More importantly, even a change of international politics and the economic environment may occur. Consequently, the influence of exchange rates on the oil market becomes more complex. Additionally, oil markets encompass not only crude oil markets but also refined oil markets. Moreover, the representative benchmark for crude oil price not only includes WTI crude oil price, but also the Brent crude oil price and the increasingly outstanding Dubai crude oil price. The net effect may be that the US dollar exchange rate may witness diverse features. All of this needs further study so that greater insight can be gained on the volatility characteristics of oil markets and interaction among various oil prices and the US dollar exchange rate.

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