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What Drives Long-term Oil Market Volatility? Fundamentals versus Speculation

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Abstract
This paper explores the role of speculation and economy fundamentals in the oil market using a two-component GARCH-MIDAS model. Particularly, the authors highlight the different role played by changing oil shocks on short-term and long-term components in terms of oil market volatility. The results show that the global demand shock is the only one factor found to be positive and significantly increasing long- or short-term oil volatility in the full sample. This is consistent with a classic host advocating that global demand dominates the oil market. However, impacts of other oil shocks are significantly weakened and even reversed since the year of 2004. In particular, the speculative demand shock plays a role in stabilizing long-term oil volatility during the post-2004 period. The results also suggest the existence of asymmetric impacts on the short-term oil volatility, particularly for shocks from oil supply, oil specific and oil speculative demand.

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Keywords Oil shocks; economy fundamentals; speculation; long/short-term oil volatility; GARCH-MIDAS model

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1. Introduction

Although the question as to whether fundamental factors actually anticipate changes in oil market volatility dates back to 1970s, the last run-up in oil prices since 2004 has put this issue back into the spotlight. Recent examples are Kilian (2009) who highlights that oil price shocks can have very different effects on the real price of oil depending on the origin of the shock, although oil prices have historically been driven by demand factors. Empirical results show that oil supply shocks have little explanatory power for the real oil price and aggregate demand shocks are the driving-force for oil price movements. Since this contribution, an impressive list of empirical studies has investigated the effects of different types of oil shocks, agreeing with Kilian's (2009) conclusion. See, among others, Lütkepohl and NetŠunajev (2014), Kilian and Murphy (2014), Baumeister and Peersman (2013), Kilian and Park (2009), Lombardi and Van Robays (2011) and Peersman and Van Robays (2009, 2012). Because of the importance of global demand in driving oil volatility, Aastveit and Bjørnland (2014) take a further step to explicitly analyze the contribution of demand from different geographical regions. Their results suggest that demand from emerging economies is more than twice as important as demand from developed countries in accounting for the fluctuations in the real oil price.

However, the developments in the oil market in the past decade have been so dramatic that growing flows of investment to commodity markets coincided with an increase in volatility of oil price. Some researchers find evidence that index investment directly or indirectly had an impact on volatility in oil prices (Einloth 2009; Medlock III and Jaffe, 2009; Kaufmann and Ullman, 2009; Irwin et al., 2009; Cifarelli and Paladino, 2010; Sanders and Irwin, 2010, 2011; Irwin and Sanders, 2012a, 2012b; Hache and Lantz, 2013). According to Tang and Xiong (2012), this speculative component may be behind the recent boom in oil prices. Hamilton and Wu (2014) argue that speculation have changed the nature of risk premia in the crude oil futures market. In particular, the compensation to the long position became smaller on average but more volatile.

However, recent studies that test for a bubble component or a strong global growth in oil prices are decidedly mixed (Phillips and Yu, 2011). Fattouh et al. (2013) find that the existing evidence is not supportive of an important role of speculation in driving the spot price of oil after 2003. Instead, they find strong evidence that the co-movement between spot and futures prices reflects common economic fundamentals. Manera et al. (2014) find that speculation presents a negative sign on volatility in oil futures markets, suggesting that it does not destabilize prices, in line with recent evidence. The robustness checks are enriched with alternative measures of speculation, based on CFTC data: the market share of non-commercial traders, the Working's T index, and the percentage of net long positions of non-commercials over total open interest in future markets. Juvenal and Petrella (2014) show that while global demand shocks account for the largest share of oil price fluctuations, speculative demand shocks are the second most important driver. These statements illustrate the acrimonious and heated nature of the public policy debate surrounding the role of index funds and economy fundamentals in oil markets. Even though over seven years have passed since the 2008 peak in commodity prices, the controversy surrounding the speculation activity and huge demand from emerging economy continues unabated. Therefore, this has led to an intense research effort to assess the role of fundamentals and speculations as drivers of volatility in oil prices.

To explore these questions, this paper complements the existing literature by employing the GARCH-MIDAS framework suggested in Colacito et al. (2011) and Conrad and Loch (2014), which enables us to directly identify the role of the speculation activity and economy fundamentals as drivers of the secular component of oil market volatility. Previous researches mainly focus on only one aspect of them while a combined consideration is still limited. In line with Kilian and Murphy (2014), the role of the speculation activity and economy fundamentals are identified as different types of oil shocks, namely, oil supply, oil-specific demand, global demand and speculative shocks.

Our contributions can be summarized as follows. First, we provide a detailed exploration of the relationship between various oil shocks and oil market in terms of volatility in a unified framework. To our best knowledge this is the first paper concentrating on the effect of various oil shocks in terms of volatility. Admittedly, the effect of oil shocks on oil market in terms of return or price level have been studied extensively, although with controversial results (Einloth 2009; Kaufmann, 2011), while relatively little attention has been paid to the level of volatility which should be paid the attention it deserves.

Second, we jointly model the dynamic volatility structure in oil prices. By employing the GARCH-MIDAS framework, we decompose the oil volatility into its short-run (conditional) and long-run (unconditional) components, where the latter is affected by oil shocks. This identification strategy adopted to isolate the long- and short- term components of oil market volatility is novel in the oil literature, as is the use of the GARCH-MIDAS model for this purpose. We also highlight the different role played by changing oil shocks on short-term and long-term dynamics.

Thirdly, previous analyses (e.g., Kilian and Murphy, 2014) of the relationship between the oil returns and the oil shocks are mostly limited on monthly frequency data. However, the GARCH-MIDAS delivers a flexible methodology allows jointly modeling the daily observations of oil returns with data on oil shocks recorded at a lower frequency, in general monthly, in order to examine directly the oil shocks' impact on the oil volatility.

The remainder of the paper is structured as follows. Section 2 describes the model and the estimation procedure. Section 3 reports the data and shocks identification strategy. We report the results of the study and of our robustness checks in Section 4, while Section 5 concludes.

2. The GARCH-MIDAS model

To evaluate the role of different oil shocks on long-term volatility of spot oil price, we rely on the GARCH-MIDAS (mixed data sampling) model. The GARCH-MIDAS is attributed to the combine insights from Engle and Rangel (2008) and the work on mixed data sampling (MIDAS), as in e.g. Ghysels, Santa-Clara, and Valkanov (2005)[1]. The model uses a mean reverting unit daily GARCH process, similar with Engle and Rangel (2008), and a MIDAS polynomial that applies to lower frequencies macroeconomic or financial variables.

In our case, this model enables us to induce the monthly measures of oil supply shocks, as well as oil demand shocks which includes demand driven by economic activity, oil-specific demand, and the speculative oil demand shocks, directly into the specification of the long term component of daily spot oil returns. A log version of GARCH-MIDAS model can formally be described as below. Assume the spot oil return on day i in month t follows the following process:

$$r_{i,t} = u + \sqrt{\tau_t g_{i,t}}\varepsilon_{i,t}, \qquad (1)$$

$$\varepsilon_{i,t} \left| \phi_{i-1,t} \right. \sim N(0,1), \qquad (2)$$

where $t = 1,2,...T$ denotes the monthly period, and $i = 1,2,...,N_t$; N_t is the number of trading

[1] More details can be found in Engle, Ghysels and Sohn (2008).

days in month t and $\phi_{i-1,t}$ is the information set up to the $(i-1)th$ day of period t; u is the daily expected returns. Equation (1) expresses the that spot oil return volatility has at least two components, namely $g_{i,t}$ which accounts for daily fluctuations that are assumed short-lived, and a long-term component τ_t [2]. The short-term component here follows a mean-reverting GARCH(1,1) process:

$$g_{i,t} = (1-\alpha-\beta-\gamma/2)+(\alpha+\gamma\cdot 1_{\{r_{i-1,t}-u<0\}})\frac{(r_{i-1,t}-u)^2}{\tau_t}+\beta\cdot g_{i-1,t}\ , \tag{3}$$

with $\alpha>0, \beta>0$ and $\alpha+\beta+\gamma/2<1$. The choice of parameters in Equation (3) should ensure that $E[g_{i,t}]=1$. Note that the short-term component follows a mean-reverting asymmetric unit GARCH process in the model we use and the parameter γ contains the information about the asymmetry. The value of $\frac{\alpha+\gamma\cdot 1_{\{r_{i-1,t}-u<0\}}}{\theta} \square\ \lambda$ is the measure for the impact of oil shock on short-term oil volatility. Specifically, significant and negative value of γ indicates that when the value of $r_{i,t}$ is larger the fixed value u, the parameter $\frac{(r_{i-1,t}-u)^2}{\tau_t}$ in Equation (3) would be larger in magnitude, compared with the situation when the value of $r_{i,t}$ is less than the fixed value u.

With regard to the long-term component, following Engle, Ghysels and Sohn (2013), Asgharian et al. (2013) and Conrad and Loch (2014), we consider the alternative version of the MIDAS component τ_t which involving macroeconomic variable. In the empirical analysis, we focus on the version that directly incorporates monthly measures of oil shocks. In this version, we consider fixed span specifications and take a monthly frequency:

$$\log(\tau_t) = m+\theta_x\sum_{i=1}^{K_v}\varphi_l(w_1,w_2)X_{t-l}\ , \tag{4}$$

where X_{t-l} is the *level* and of different oil shock. To complete the model, we need to specific the weighting scheme which called Beta weights for Equation (4) as defined in Engle et al. (2013), namely:

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[2] Different from that in Engle and Rangel (2008), the τ_t component in Equation (1) is assumed constant throughout the month for simplicity reasons.

$$\varphi_l(w_1, w_2) = \frac{(\frac{l}{K_v+1})^{w_1-1}(1-\frac{l}{K_v+1})^{w_2-1}}{\sum_{j=1}^{K_v}(\frac{j}{K_v+1})^{w_1-1}(1-\frac{j}{K_v+1})^{w_2-1}}, \quad (5)$$

The weight attached to past oil shocks will depend on the parameters w_1, w_2 and K_v. The latter one determines the number of lagged oil shocks taken into account. The decay parameters w_1 and w_2 determine the weight attached to those past realized variance. In the case of $w_1 = w_2 = 1$, the past K_v will receive an equal weight of $1/K_v$. In the likely case of $w_1, w_2 > 1$, past oil shocks will gradually get less and less weight. The larger w_1, w_2, the faster the decay.

3. Data and shocks identification

3.1 Identifying oil shocks using sign restrictions

The analysis in this paper, builds on the structural oil shock, which is a vector of four oil price shocks (namely, supply-side shock, aggregate demand shock, specific demand shock and speculative demand shock). In line with Kilian (2009), Kilian and Murphy (2014) and Kilian and Lee (2014), the structural shocks are identified based on a combination of sign restrictions and bounds on the short-run price elasticities of oil demand and oil supply. The key identifying assumptions are the following set of restrictions on the signs of the impact responses of the four observables to each structural shock (Table 1)[3].

[Insert Table 1 here]

The first three shocks are proposed in the earlier work of Kilian (2009) who proposes a model that allows the identification of oil shocks and helps to understand their relative importance in determining the real price of oil. In their work, oil shocks are decomposed into three components: crude oil supply shocks; shocks to the aggregate global demand for industrial commodities; and global demand shocks that are specific to the crude oil market. Supply-side

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[3] The sign restrictions are imposed to hold for the first month. The sign restrictions are imposed to hold for the first month. To test the robust of the results, the sign restrictions are also imposed to hold for the first three month (see Paustian, 2007) and for the first six month (Barsky and Kilian, 2002) after the occurrence of the shocks which accounts for the delayed response of the oil market variables in the early period of our sample due to institutional arrangements.

shocks are associated with changes in the world oil production; e.g. overproduction or supply interruptions due to military conflicts or destruction of oil facilities. Oil specific demand shocks are associated with concerns about the future availability of oil, while aggregate demand shocks are associated with changes in the global economic activity. A change in the demand for commodities from emerging economics will shift word economic activity, oil price and oil production in the same direction. This identification has also been widely used in Peersman and Van Robays (2009, 2012), Baumeister and Peersman (2013) and Kilian and Murphy (2014).

The fourth one is the speculative-demand shock. Since the financialization of commodity markets, the coincident increase in oil prices and speculators in crude oil futures market has led to allegations that "speculators" drives crude oil prices. In the work of Kilian and Muphy (2014) and Kilian and Lee (2014), they refer to such a shock as a speculative demand shock in the spot market for crude oil, which is constructed by scaling U.S. crude oil inventory data by the ratio of OECD petroleum inventories over U.S. petroleum inventories. This focus on above-ground crude oil inventories is consistent with conventional accounts of speculation involving the accumulation of oil inventories in oil-importing economics. Hamilton (2009) and Alquist and Kilian (2010) argue that any expectation of a shortfall of future oil supply necessarily causes an increase in the demand for above-ground oil inventories and hence in the real price of oil. Kilian and Lee (2014) also empirically observe that this proxy based on readily available EIA data is likely to be accurate. Therefore, in order to distinguish speculative demand shocks from other shocks in practice, we follow Kilian and Lee (2014).

3.2 Data

The spot price for crude oil (US dollars per barrel) is provided by the Energy Information Administration (EIA). We employ daily data over the period from February 1990 to the end of year 2014. The log-returns of crude oil are displayed in Figure 1. Our measure of global real economic activity is the updated version of the index of global real economic activity in industrial commodity markets, as proposed in Kilian (2009), monthly percent deviations from trend, 1990.1-2014.12.The real price of oil is defined as the U.S. refiners' acquisition cost for imported crude oil, as reported by the EIA[4]. The refiners' acquisition cost for imported crude oil has been

[4] The Energy Information Administration (EIA) uses the imported refiner acquisition cost, the

argued as a better proxy for the price of oil in global markets than the U.S. price of domestic crude oil which was regulated during the 1970s and early 1980s (Kilian, 2009) and has been utilized in the work of Baumeister and Kilian (2012), Peersman and Robays (2012) and Baumeister and Peersman (2013).With regard to data on crude oil inventories, we follow Hamilton (2009) and Kilian and Murphy (2012, 2014) in using the data for total U.S. crude oil inventories provided by the EIA due to the lack of data for other countries. These data are scaled by the ratio of OECD petroleum stocks over U.S. petroleum stocks for each time period.

[Insert Figure 1 here]

4. Effects of oil shocks on the long/short-term volatilities of oil price

In this section, we examine the impacts of different types of oil shocks on oil market volatilities. Our analyses mainly focus on two aspects. Firstly, we investigate the long-term and short-term volatilities of spot oil price with the effect of different oil shocks as exogenous shocks in the GARCH-MIDAS model. Concerning on each of the four types of oil shock, we investigate how oil shocks affect long/short-term oil volatilities in terms of magnitude, significance and asymmetry. Secondly, we compare the responses of long/short-term oil volatilities towards these oil shocks before and after the year 2004 when significant index investment started to flow into commodity markets.

Empirical results are reported in Table 2-5 and long/short-term volatility components are shown in Figure 2. In order to make it clear expressed, the responses of oil price volatility to different types of oil shocks are summarized in Table 6.

4.1 Effects of oil supply shock

Table 2 provides parameter estimates for GARCH-MIDAS with oil supply shocks. In each case, we set one, two and three years of lags respectively.

[Insert Table 2 here]

The results in the table show that the parameter u and m are both insignificant in all cases while the estimated α, β and γ parameters are highly significant. The sums of α, β and

weighted average cost of all oil imported into the US, as its "world oil price".

$\frac{\gamma}{2}$ are almost identical and always less than one[5], while in standard GARCH model the sum is typically 1. That is, in all specifications the short-run volatility component is mean reverting to the long-run trend. The same finding is also reported in Engle and Rangel (2008), Engle et al. (2013) and Conrad et al. (2014).

The most interesting parameter is the slope parameter θ in Equation (3), which represents the impacts of oil shock on the long-term oil volatility. Consider first the parameter estimators in the sub-periods. Take three years of lags for instance, θ range from 3.438 for the pre-2004 (1990-2003) sample to -5.235 for the post-2004 (2004-2014) sample. Since the parameter θ is positive and significant in the pre-2004 period, it means that more oil demand shock leads to high stock market volatility. We can get the information in Table 2 that the weighting function in Equation (5) with $w_1 = 20.576$ and $w_2 = 12.967$ puts 0.359 on the first lag (the maximum weights) of oil demand shock. If an oil demand shock took place at the current month, we would see a size of 2.429 increase in long term oil volatility next month[6]. For the post-2004 sample, the weighting function with $w_1 = 5.558$ and $w_1 = 7.206$ puts 0.071 on the first lag and 0.095 on the fifth lag (the maximum weights) of oil demand shock. Therefore, an oil demand shock taking place at the current month would lead to a size of 0.309 decrease in oil volatility while an oil demand shock taking place five month ago would lead to 0.391 decrease in oil volatility. Turning to the upper panel of Table 2, all the parameter estimates for θ are insignificant when we take one, two and three years of lags for the full sample. It is interesting to note that impact of oil demand shock on oil volatility behaves much different and even contrary before and after the financialization of commodities.

Next we turn to the impact of oil supply shock on short-term oil volatility.[7]. The most striking result is about its asymmetry as oil price moves up and down. The estimated parameter u is

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[5] Note that, the parameter γ for the full sample and α for the 2004-2015 sample is insignificant in results as shown in Table 2. The sum of α, β and $\frac{\gamma}{2}$ is calculated with the significant values only.

[6] Since $\Delta \log \tau_t = \theta\varphi_1(w_1, w_2)\Delta X_1$, increase in oil volatility would be calculated as $e^{\theta\varphi_1(w_1,w_2)\Delta X_1} - 1$.

[7] It should be noticed that response of short-term volatility to different oil shock is consistent with

insignificant while γ is negative – and in all but one case they are statistically significant. A quick computation revealed that the parameter λ is larger in absolute value when oil price increases (λ =0.033) than when oil price decrease (λ =0.020). This result indicates that oil supply shock would have larger affection on oil volatility when oil price increases. For the post-2004 sample, the estimated parameter γ is positive and in all cases they are statistically significant, the parameter λ is -0.003 and -0.016 with oil price increase and decrease respectively. The result suggests that, during the post-2004 period, oil supply shock would decrease more oil volatility when oil price decreases than when oil price increases. Although in the work of Herreraa et al. (2015) who argue that there is very little support for asymmety in the response of economic activity to oil price increases and decreases, we provide evidenct that oil price increases and decreases matters for the asymmetric impacts of economic factors on short-term oil volatility.

4.2 Effects of oil speculative demand shock

In this section, the contribution of specific oil demand shock to long/ short-term oil volatility is examined. The estimation results are shown in Table 3.

[Insert Table 3 here]

We first focus on the impact on long-term oil volatility. The parameter θ is statistically significant both for the pre-2004 sample and the post-2004 sample. However, the value of θ is positive with a value of 1.0133 with Lags=3 year during the pre-2004 period, and turns into negative with a value of -10.6964 after the year 2004. This observation suggests that oil speculative-shock would increase oil volatility before the year 2004 while decrease the fluctuations after the financialization of commodity markets. For the full sample, the effect of speculative demand shock is not observed significantly. This result is also consistent with Irwin and Sanders (2012).

The impact of the speculative demand shock on the short-term oil volatility also behaves differently in the pre-2004 sample and the post-2004 sample in terms of its asymmetry. Before the year 2004, there is no significant asymmetric effect to oil price increase and decrease. By contrast, the parameter γ is positive and significant with a value of 0.06 during the post-2004 period,

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that of long-term volatility since the value of $\alpha + \gamma \cdot 1_{\{r_{i-1,t} - u < 0\}}$ keeps positive in all cases.

suggesting that oil speculative demand shock would decrease more oil volatility when oil price decreases.

In short, our results provide evidence that speculative activities may stabilize the oil price, which complement the existing evidence that offer on support for the Masters Hypothesis[8].

Compared with oil supply shock, a noteworthy fact is that the impact of oil-speculative demand shock on oil volatility is much similar with that of supply shock as discussed in Section 4.1. To explain this, we firstly turn to the definition of speculation. The most general economic definition of speculation is provided in Kilian and Murphy (2014) who note that anyone buying crude oil not for current consumption, but for future use is a speculator from an economic point of view. Therefore, oil speculative-demand is expected to be associated with oil supply closely since oil speculative demand would driven by poor supply of oil.[9] After 1973, when supply became restricted, the long-run relationships between oil inventories and the real price would be a function of the flexibility of oil supply in the future (Dvira and Rogoff, 2014). Supportive evidence can also be seen in the work of Kilian and Lee (2014) who find evidence that speculation may drive up the real price of crude oil in the physical market in the episodes with instability of oil supplies from the Middle East. An available explanation is that speculation may be conducted by oil producers who have the option of leaving oil below the ground in anticipation of rising prices, and this accumulation of below-ground inventories would be equivalent to a reduction in flow supply.

4.3 Effects of specific oil demand shock

In this section, the contribution of specific oil demand shock to long/ short term oil volatility is examined. The estimation results are shown in Table 4.

[Insert Table 4 here]

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[8] The "Masters Hypothesis" is a short-hand label for the claim that unprecedented buying pressure in recent years from commodity index investors created massive bubbles in commodity futures prices, argued by a hedge fund manager MichaelW. Masters (Irwin and Sanders, 2012).

[9] This phenomenon is consistent with the view that speculation activities in oil markets simply followed market trends set in motion by earlier shocks to economic fundamentals rather than creating market trends of their own.

Focusing on the long-term volatility, impact of oil specific demand shock behaves differently in the two sub-periods in terms of significance. For the post-2004 sample, oil specific demand shock shows significant impact on the long term oil volatility. For example, parameter θ is statistically significant with a value of -4.5618 with one-year lags and -5.3157 with 2-year lags. Note that θ is negative for the post-2004 sample, which suggests that oil specific demand shock would decrease oil volatility. Particularly, a specific oil demand shock at the current month would contribute to -0.013 decrease of oil volatility in next month. Turning to the top panel of Table 4, the impact is negative and significant for the full sample and looking at the sub samples we observe that this appears to be mainly due to the financialization of commodity markets.

With respect to the impact of global demand shock on short-term oil volatility, there is also a significant difference between the pre-2004 period and the post-2004 period, in terms of the asymmetry of the impact. For the pre-2004 sample, the parameter γ is insignificant that the impact on short-term volatility is symmetric with decrease and increase in oil price. However, for post-2004 sample, the estimated parameter γ is positive and significant in all case. The value of λ is -0.015 when oil price decrease and -0.003 when oil price increases. The results reveal that in this period specific oil demand shock would decrease more oil volatility when oil price decreases.

It should be mentioned that the empirical result for oil specific shock is much similar with that of oil supply shock or speculative demand shock. Evidence shows that these oil shocks enhance oil volatility during the pre-2004 period. Moreover, empirical results also suggest that the three oil shocks tend to decrease more short-term oil volatility when oil price decreases rather than oil price increases.

4.4 Effects of oil global demand shock

Table 5 provides parameter estimates for GARCH-MIDAS with global oil demand shock. There are two observations can be derived from the estimation results in Table 5.

[Insert Table 5 here]

First and most important, different from other oil shocks, the impact of global demand shock on long/short term volatility remains positive and statistically significant for both the pre-2004 period and the post-2004 period. This result is in line with Kilian and Murphy (2014) who find that the 2003-2008 oil price surges is mainly caused by unexpected increases in world oil consumption driven by the global business cycle. Take three years of lags for instance, θ range from 7.047 for the pre-2004 (1990-2003) sample to 3.803 for the post-2004 (2004-2014) sample. However, this impact becomes much weaker after the financialization of commodity markets. In the pre-2004 sample, a global oil demand shock occurs at the current month would lead to 0.338 increase in long-term oil volatility next month. However, this shock only contributes to 0.118 increases in long term volatility next month in the post-2004 period.

Second, regarding the asymmetry of impact of global demand shock on short-term oil volatility, the parameter γ is insignificant for the pre-2004 sample and the full sample while it is significant for the post-2004 sample. Focusing on the results in the bottom panel of Table 5, the estimated parameter γ is positive and in all cases they are statistically significant. Taking the specification with Lags=3 year for example, the value of λ is 0.022 and 0.003 with oil price decrease and increase respectively. Therefore, the results indicate that the asymmetric impact of global demand shock on short-term oil volatility exists significantly only during the post-2004 period. It means that the impact of global demand shock on short-run volatility would be larger when oil price decreases rather than oil price increases.

[Insert Table 6 here]

[Insert Figure 2 here]

5. Conclusion

In this paper, we aim at assessing the role of fundamentals and speculations, which have been controversial, as drivers of volatility in oil prices by employing the GARCH-MIDAS framework. Particularly, we examine the impacts of different types of oil shocks on oil market volatility before and after the year 2004, since Kilian (2009) highlights that oil price shocks can have very different effects on the real price of oil depending on the origin of the shocks. The main conclusions can be summarized as follows.

First, concerning on the impacts of different types of shocks, the global demand shock is the only one found to be positive and significantly affecting long/short-term oil volatility in all the sample periods we analyzed. The results indicate that global oil demand shock would increase oil volatility markedly. This supports the finding in Kilian (2009), Juvenal et al. (2014) and others of the importance of global demand in explaining oil price fluctuations.

Second, by comparing the results in the pre-2004 period and post-2004 period, they exhibit exactly the reverse evidence about the impacts of oil shocks. According to our empirical results, all these oil shocks but the oil specific demand shock significantly exacerbate oil volatility during the pre-2004 period, however, the impacts on oil volatility have been significantly reduced (for global demand shock) and even reversed (for oil supply shock, specific oil demand shock and speculative shock) after the year 2004 when significant index investment started to flow into commodity markets.

In addition, our results also suggest the existence of asymmetric impacts on the short-term oil volatility, particularly for shocks form oil supply and oil specific/speculative demand. This asymmetry assumes that oil shocks tend to have larger affection on short-term oil volatility when oil price decreases rather than oil price increases. This result provides evidence for the argument that oil price increases are much more important than oil price decreases.

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Table 1 Identifying oil shocks using sign restrictions

	Oil supply disruption	Aggregate demand shock	Oil-specific demand shock	Speculative demand shock
Oil production	-	+	+	+
Real activity	-	+	-	-
Real oil price	+	+	+	+
Inventories				+

Table 2 Parameter estimates of GARCH-MIDAS with oil supply shocks

Full sample

Lags	μ	α	β	γ	m	θ	ω_1	ω_2
12 month	0.0015	0.0753***	0.9177***	-0.0014	0.4093	-2.0037	10.6115**	16.341*
	(0.0099)	(0.0213)	(0.0171)	(0.0169)	(0.3495)	(1.628)	(4.9276)	(10.015)
24 month	0.0024	0.0744***	0.9208***	-0.0029	0.2002	0.4101	26.9977**	55.2748**
	(0.0099)	(0.02)	(0.0164)	(0.0165)	(0.3336)	(0.5204)	(11.419)	(24.437)
36 month	0.0015	0.0753***	0.9177***	-0.0014	0.4093	-2.0037	10.6115**	16.341*
	(0.0099)	(0.0213)	(0.0171)	(0.0169)	(0.3495)	(1.628)	(4.9276)	(10.0145)

Pre-2004 sample

Lags	μ	α	β	γ	m	θ	ω_1	ω_2
12 month	-0.0015	0.1062***	0.906***	-0.0394	0.4313	-0.3292	22.8052	2.5547
	(0.0137)	(0.0321)	(0.0243)	(0.025)	(0.4013)	(0.3024)	(38.6091)	(5.5399)
24 month	-0.0003	0.1145***	0.9002***	-0.0437*	0.0694	2.5613*	10.9831	2.1366**
	(0.0135)	(0.032)	(0.0231)	(0.0258)	(0.4431)	(1.4968)	(7.3359)	(0.9362)
36 month	0.0006	0.113***	0.9026***	-0.0451**	-0.0534	3.4375**	20.576**	12.9568*
	(0.0136)	(0.0331)	(0.0244)	(0.0258)	(0.46)	(1.4952)	(9.9819)	(7.8087)

Post-2004 sample

Lags	μ	α	β	γ	m	θ	ω_1	ω_2
12 month	0.0067	0.0172*	0.9602***	0.043***	0.0062	3.4231	0.6661	1.4116
	(0.0145)	(0.0092)	(0.0112)	(0.0149)	(0.302)	(2.9467)	(0.5768)	(1.1)
24 month	-0.0044	0.0161	0.9357***	0.0669***	0.0597	-5.0848***	3.0133	1.802
	(0.0152)	(0.0129)	(0.0291)	(0.025)	(0.2599)	(1.3551)	(2.8541)	(2.3429)
36 month	-0.0038	0.0164	0.9355***	0.0655***	0.0454	-5.2345***	5.5582	7.2056
	(0.0151)	(0.0132)	(0.0291)	(0.0251)	(0.2348)	(1.2472)	(3.6781)	(5.5651)

Note: This table reports estimation results for parameters in Equations (3)-(5) with X being the oil supply shock; the value in parenthesis refers to the standard deviation. We take the lags for 1, 2, 3 years respectively. ***, ** and * indicate significance at 1%, 5% and 10% levels.

Table 3 Parameter estimates of GARCH-MIDAS with oil speculative demand shocks

Full sample

Lags	μ	α	β	γ	m	θ	ω_1	ω_2
12 month	0.0021	0.0747***	0.9202***	-0.0024	0.2161	0.5764	16.704	8.1625**
	(0.0099)	(0.02)	(0.016)	(0.0167)	(0.3321)	(0.689)	(13.481)	(3.3738)
24 month	0.0022	0.0742***	0.9208***	-0.0024	0.184	1.2367	1.8408	4.5859
	(0.0099)	(0.0198)	(0.0161)	(0.0166)	(0.336)	(1.9551)	(2.9639)	(12.259)
36 month	0.0022	0.0742***	0.9208***	-0.0024	0.1862	1.1773	2.0953	9.0113
	(0.0099)	(0.0197)	(0.0161)	(0.0166)	(0.3295)	(1.8049)	(2.4529)	(10.782)

Pre-2004 sample

Lags	μ	α	β	γ	m	θ	ω_1	ω_2
12 month	-0.0007	0.114***	0.8989***	-0.041	0.3187	1.6125	3.6964	3.3915***
	(0.0137)	(0.0326)	(0.0242)	(0.026)	(0.4006)	(1.4808)	(2.3913)	(1.2684)
24 month	-0.0002	0.1122***	0.9007***	-0.0405	0.1045	4.4994**	2.2294	2.5919**
	(0.0136)	(0.0326)	(0.024)	(0.0263)	(0.4257)	(2.115)	(2.3415)	(1.2848)
36 month	-0.0005	0.1129***	0.8983***	-0.0386	0.3293	1.0133*	308.6306	329.8625
	(0.0136)	(0.033)	(0.0248)	(0.0261)	(0.3987)	(0.6051)	(217.0418)	(238.9528)

Post-2004 sample

Lags	μ	α	β	γ	m	θ	ω_1	ω_2
12 month	0.0022	0.0236**	0.9469***	0.0464**	-0.0999	-1.3837	10.5853**	17.7481**
	(0.0139)	(0.0108)	(0.0191)	(0.0214)	(0.2949)	(1.2946)	(5.4872)	(9.0129)
24 month	-0.0032	0.0168	0.9307***	0.0673***	-0.0092	-10.6815***	2.5273	1.9956*
	(0.0149)	(0.0142)	(0.0279)	(0.0228)	(0.1892)	(2.5051)	(1.7415)	(1.0318)
36 month	-0.0027	0.0176	0.9315***	0.065***	-0.0097	-10.6964***	4.876	6.9634
	(0.015)	(0.015)	(0.0322)	(0.0235)	(0.2154)	(2.9306)	(5.1818)	(6.3862)

Note: This table reports estimation results for parameters in Equations (3)-(5) with X being the oil speculative demand shock; the value in parenthesis refers to the standard deviation. We take the lags for 1, 2, 3 years respectively. ***, ** and * indicate significance at 1%, 5% and 10% levels.

Table 4 Parameter estimates of GARCH-MIDAS with oil specific demand shocks

Full sample

Lags	μ	α	β	γ	m	θ	ω_1	ω_2
12 month	0.0019	0.07**	0.9256***	-0.0018	0.1611	0.7607	6.4427	8.1226
	(0.01)	(0.0218)	(0.0204)	(0.0159)	(0.3414)	(1.3392)	(22.18)	(19.461)
24 month	0.0028	0.0742***	0.9188***	-0.0033	0.3557	-1.8664**	16.7173**	19.4785*
	(0.0099)	(0.0219)	(0.0181)	(0.017)	(0.3079)	(0.8082)	(8.4031)	(10.082)
36 month	0.0028	0.0742***	0.9189***	-0.0034	0.3543	-1.858**	21.5315*	47.1864*
	(0.0099)	(0.0219)	(0.0181)	(0.017)	(0.308)	(0.8207)	(11.543)	(25.915)

Pre-2004 sample

Lags	μ	α	β	γ	m	θ	ω_1	ω_2
12 month	-0.0016	0.1033**	0.909***	-0.0373	0.1934	1.3238	7.4917	9.3671
	(0.0138)	(0.0322)	(0.0261)	(0.0238)	(0.4128)	(0.9794)	(7.4044)	(7.6477)
24 month	-0.0017	0.1036***	0.9088***	-0.0374	0.1893	1.3744	8.721	28.5892
	(0.0139)	(0.0322)	(0.026)	(0.024)	(0.4135)	(1.0099)	(6.9709)	(19.448)
36 month	-0.0004	0.1101***	0.9048***	-0.0418*	0.1131	2.1466	22.3452	23.1777
	(0.0136)	(0.0309)	(0.0231)	(0.0248)	(0.4643)	(1.9371)	(14.9147)	(18.065)

Post-2004 sample

Lags	μ	α	β	γ	m	θ	ω_1	ω_2
12 month	-0.001	0.0129	0.9336***	0.0665***	-0.0932	-4.5618***	1.7925	1.3372**
	(0.014)	(0.013)	(0.025)	(0.022)	(0.147)	(1.137)	(1.549)	(0.680)
24 month	-0.0016	0.0115	0.9371***	0.0656***	-0.0651	-5.3157***	4.4555**	6.6391***
	(0.0139)	(0.0136)	(0.0249)	(0.0204)	(0.1602)	(1.3837)	(1.930)	(2.342)
36 month	-0.0009	0.0230*	0.9491***	0.0467**	0.2053	-1.5939	61.243	41.9226
	(0.0147)	(0.012)	(0.0213)	(0.0204)	(0.8468)	(1.1668)	(55.1086)	(40.5779)

Note: This table reports estimation results for parameters in Equations (3)-(5) with X being the oil specific demand shock; the value in parenthesis refers to the standard deviation. We take the lags for 1, 2, 3 years respectively. ***, ** and * indicate significance at 1%, 5% and 10% levels.

Table 5 Parameter estimates of GARCH-MIDAS with global demand shocks

Full sample

Lags	μ	α	β	γ	m	θ	ω_1	ω_2
12 month	0.0024	0.0766***	0.9156***	0.0001	0.0077	1.7986***	7.8826**	2.8069**
	(0.0098)	(0.021)	(0.0161)	(0.0175)	(0.3548)	(0.6789)	(3.7444)	(1.2300)
24 month	0.0023	0.0766***	0.9155***	0.0004	0.002	1.8996**	19.4501*	28.7975*
	(0.0098)	(0.0209)	(0.016)	(0.0175)	(0.3594)	(0.749)	(12.105)	(17.628)
36 month	0.0023	0.0767***	0.9155***	0.0004	0.0007	1.9196**	22.6071*	59.8713*
	(0.0098)	(0.0209)	(0.016)	(0.0175)	(0.3599)	(0.7579)	(14.07)	(36.981)

Pre-2004 sample

Lags	μ	α	β	γ	m	θ	ω_1	ω_2
12 month	-0.0011	0.1098***	0.9006***	-0.0358	0.3653	1.6636	1.7332	9.1048*
	(0.0137)	(0.0343)	(0.0264)	(0.0261)	(0.422)	(1.1504)	(1.9365)	(5.009)
24 month	-0.001	0.1068**	0.9036***	-0.036	0.3562	6.8745*	36.4847	17.5175
	(0.0137)	(0.0341)	(0.0264)	(0.0258)	(0.4123)	(3.8953)	(27.1774)	(16.2746)
36 month	-0.001	0.1066**	0.9038***	-0.0359	0.3553	7.0473*	60.5962	71.7431
	(0.0137)	(0.0339)	(0.0263)	(0.0256)	(0.4123)	(3.9216)	(38.7786)	(53.3899)

Post-2004 sample

Lags	μ	α	β	γ	m	θ	ω_1	ω_2
12 month	-0.0007	0.0137	0.9359***	0.0647***	-0.9485***	2.7227***	2.0147	1.2373**
	(0.0139)	(0.0136)	(0.0225)	(0.02)	(0.210)	(0.604)	(2.0834)	(0.697)
24 month	-0.0006	0.0128	0.9286***	0.073***	-1.1577***	3.4778***	4.4551*	5.4195
	(0.0139)	(0.0129)	(0.023)	(0.0201)	(0.2534)	(0.9045)	(2.7139)	(3.8464)
36 month	-0.0013	0.0112	0.93***	0.0742***	-1.2306***	3.8027***	3.8986	7.5089
	(0.0139)	(0.0132)	(0.0232)	(0.0196)	(0.3200)	(1.2356)	(3.5797)	(9.3704)

Note: This table reports estimation results for parameters in Equations (3)-(5) with X being the global demand shock; the value in parenthesis refers to the standard deviation. We take the lags for 1, 2, 3 years respectively. ***, ** and * indicate significance at 1%, 5% and 10% levels.

Table 6 The response of oil price volatility to different types of oil shocks.

	Long/short-term volatility		
	Full period	Pre-2004	Post-2004
Oil supply shock		+	-
Speculative demand shock		+	-
Specific oil demand shock	-		-
Global demand shock	+	++	+

Note: This table is extracted from the results of the response of oil price volatility to different types of oil shocks as shown in Table 2-5. The "+" indicates that oil shock would increases oil price volatility. The "-" indicates that oil shock tends to stabilize oil price. The "++" indicates that global demand shock has a larger impact for the pre-2004 period than other periods.

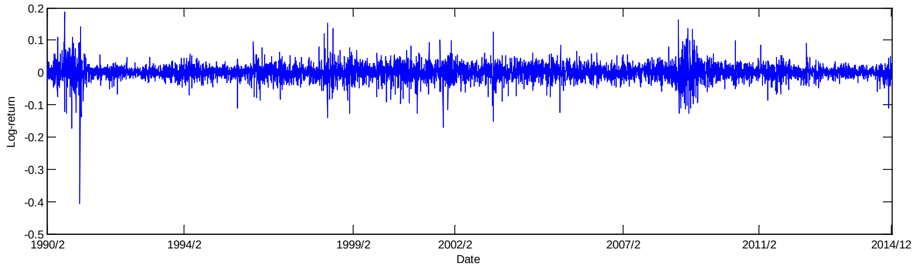

Figure 1 Evolution of daily log-returns of crude oil

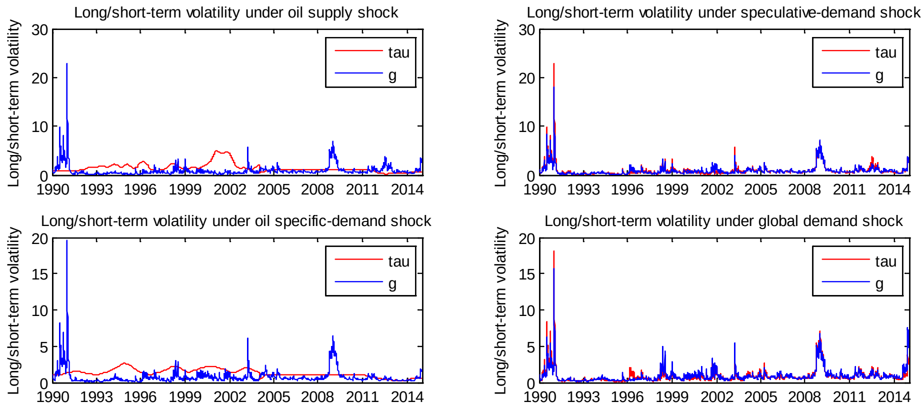

Figure 2 Long and short run volatilities under different oil shocks