Monetary Policies and Oil Price Fluctuations Following the Subprime Mortgage Crisis

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Abstract

This research examines how monetary policies have affected crude oil prices after the subprime mortgage crisis. Our earlier research (Taghizadeh and Yoshino (2014)) found a significant impact of easy monetary policies on energy prices during the period of 1980 to 2011. This current paper reports that the quantitative easing of US monetary policies weakened US dollar by shifting US investors to invest into oil market and other commodity markets. An empirical analysis shows that weaker exchange rate of US dollar pushed oil price in 2007-2012 period, World GDP which consists of demand for oil was not significant at all since the world economy was in recession in 2009-2012.

Key Words: oil prices, monetary policies, subprime mortgage crisis, exchange rate

1. Introduction

The sub-prime mortgage crisis began with the bursting of the housing bubble in the US and generated a global financial crisis in 2007 and 2008. During several years the housing prices increased and interest rates stayed low. Sub-prime mortgages were extensively available and refinancing was cheap. However, once housing prices started to drop which happened because of huge housing supply and once interest rates increased, refinancing became more difficult and the risks embedded in sub-prime mortgages could no longer be hidden. In August 2007 the problems hit the financial markets globally and caused enormous liquidity pressures within the interbank market. Due to the widespread dispersion of credit risk and the complexity of financial instruments, the mortgage crisis had a large impact on financial markets. Stock market indices have massively declined since July 2007. Several large banks, credit insurances and mortgage companies have reported significant losses and have lost much of their market value. Because of this drop in global output and reluctance in borrowing from banks, commodity markets including crude oil market demand also experienced a sharp drop and subsequently a huge decrease in the price of it.

In the US, the Federal Reserve held between $700 - $800 billion of Treasury notes on its balance sheet before the recession. In order to mitigate some of the adverse effects of the crisis in

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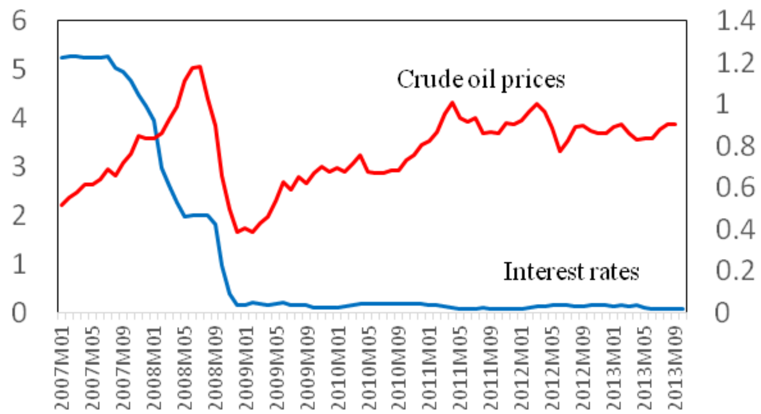
late November 2008, it started buying $600 billion in mortgage-backed securities.[1] By March 2009, it held $1.75 trillion of bank debt, mortgage-backed securities, and Treasury notes, and reached a peak of $2.1 trillion in June 2010. Further purchases were halted as the economy had started to improve, but resumed in August 2010 when the Fed decided the economy was not growing robustly. After the halt in June, holdings started falling naturally as debt matured and were projected to fall to $1.7 trillion by 2012. The Fed's revised goal became to keep holdings at $2.054 trillion. To maintain that level, the Fed bought $30 billion in two- to ten-year Treasury notes every month. In November 2010, the Fed announced a second round of quantitative easing, buying $600 billion of Treasury securities by the end of the second quarter of 2011. The expression "QE2" became ubiquitous nickname in 2010, used to refer to this second round of quantitative easing by US central banks.[2] Retrospectively, the round of quantitative easing preceding QE2 was called "QE1".[3] A third round of quantitative easing, "QE3", was announced on 13 September 2012. Additionally, the Federal Open Market Committee (FOMC) announced that it would likely maintain the federal funds rate near zero at least through 2015.

According to the IMF, these quantitative easing policies that undertaken by the central banks of the major developed countries like the example of US QE policies that mentioned in above have contributed to the reduction in systemic risks following the crisis. The IMF states that the policies also contributed to the improvements in market confidence and the bottoming out of the recession in the G7 economies in the second half of 2009 (Klyuev et al. 2009).

Fig. 1 Interest Rates and Crude Oil Prices 2007:01-2013:10



Note : crude oil prices are in constant dollars obtained using simple average of: Dubai crude oil prices in Tokyo market, Brent crude oil prices in London market, and WTI[4] crude oil prices in New York market, deflated by US consumer price index (CPI). Interest rates are the US money market rate, percent per annum. Left hand side scale is for is for the interest rate, and right hand side scale is for crude oil prices real prices.

[1] Harding, Robin. (3 November 2010), Quantitative easing explained, *Financial Times*.
[2] Authers, John (5 November 2010), Fed's desperate measure is a watershed moment, , The Long View, *Financial Times*
[3] Conerly, Bill (13 September 2012), QE3 and the Economy: It Will Help, But Not Solve All Problems, *Forbes*.
[4] West Texas Intermediate

In the critical side of these QE policies, there are several economists such as Ratti and Vespignani (2013), concluded that quantitative easing which done by central banks of different countries following by 2007-8 crisis, was important in fast recovery of commodity prices especially oil prices, a trend that imposed longer recovery time for the economy, since the price of oil as one of the most important production input started to increase rapidly, which is destructive for the economic growth and prolonged the economy recovery time. Hypothesis of this paper is also in line with this latter paper, we believe that US and other central banks QE policies following by the crisis pushed up the commodity markets prices robustly and rapidly including crude oil prices, a process that imposed longer recovery time for the global economy.

Fig. 1 shows interest rate (here: US money market rate) and crude oil price (here: simple average of Dubai, Brent, and WTI crude oil prices in constant dollars) movements during 2007:01-2013:10. Expansionary monetary policies in US led to decrease in US money market rate from 5.25 percent per annum in January 2007, to 2 percent per annum in June 2008, at the same period time crude oil prices, increase from about US$ 53.35/barrel to beyond US$131.70/barrel. We believe a major cause of this skyrocketing increases was easy monetary policies. And on the other hand following by the financial crisis of 2007-8, because of decline in global demand for crude oil, prices dropped from US$ 133.11 in July 2008 to bellow US$ 42.01 in December 2008, and then it started to increase. A portion of this elevation was because of recovery of global economy that raised the demand, but we believe a significant reason for this sharp slop increasing was QE of monetary authorities which tend to elevation in crude oil demand and subsequently on the price of it robustly. Result was that in May 2009 although the global economy has not recovered completely, but crude oil prices almost passed the level that it was before the crisis in January 2007. Here in this paper we are going to answer to this question that whether monetary policies had significant impact on crude oil market following the subprime mortgage crisis.

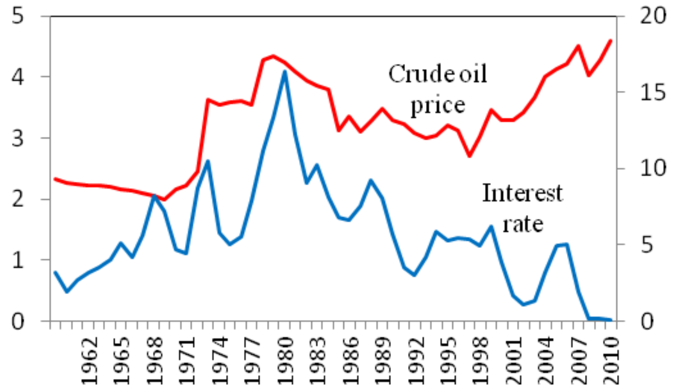
This paper is structured as follows: In the following section we review the literature, third section is for the theoretical background and the model, including: 3.1. Channels of transmission of monetary policies to oil demand, 3.2. The effect of monetary policy actions on exchange rates, 3.3. Definition of the Real Effective Exchange Rate (REER), 3.4. Theoretical framework and 3.5. The Model. The fourth section describes the Empirical results, including: 4.1. Data analysis, 4.2. The structural parameter estimates and 4.3. Structural Impulse Response (IR) analysis. The fifth section contains this paper’s concluding remarks.

2. Review of the Literature

In the literature of energy economics, there are several researches that found significant impact of monetary policies on energy markets specially on crude oil market; Barsky and Kilian (2002) argue that change in monetary policy regimes was a key factor behind the oil price increases of the 1970s and show that the substantial increase in industrial commodity prices that preceded the increase in oil prices in 1973-1974 is consistent with the view that rising demand based on increased global liquidity drove oil prices higher. Alquist et al. (2012) confirm the Gillman and

Nakov (2009) findings that monetary factors Granger cause oil prices in the post-war period up until 1997. Or in a more recent study by Taghizadeh and Yoshino (2014) which shows that global oil demand during 1960-2011 and 1980-2011 significantly influenced by monetary policies. They showed that Aggressive monetary policy stimulates oil demand, while supply is inelastic to interest rates. The result is skyrocketing crude oil prices, which inhibit economic growth.

Fig. 2 Interest Rates and Crude Oil Prices 1960-2011



Note : Crude oil prices are in logarithmic form.
Source of crude oil prices : 1960-1983 Arabian Light posted at Ras Tanura, 1984-2011 Brent dated. Interest rates are the US money market rate, percent per annum. Left hand side scale is for the logarithm of crude oil prices and the right hand side scale is for interest rates.
Source of figure : Taghizadeh & Yoshino (2014)

Fig. 2 illustrates the relationship between interest rates and crude oil prices. As can be seen in this figure, the relationship between interest rates and crude oil prices is asymmetric. For the period of 1981-2011, average oil prices accelerated from about $35/barrel in 1981 to beyond $111/barrel in 2011. At the same time, average interest rates subsided from 16.7 percent per annum in 1981 to about 0.1 percent per annum in 2011. Taghizadeh and Yoshino (2014) in their paper explained that this long-term price increase, especially after the year 2000, to be caused by expansionary monetary policies that led to lower interest rates, amplified both credit and aggregate demand. On the other hand, Bernanke et al. (1997) showed that expansionary monetary policies could have largely eliminated the negative output consequences of the oil-price shocks on the US economy. This view has, in turn, been also challenged by Hamilton and Herrera (2004), who argue that Bernanke, Gertler, and Watson's (BGW) empirical results are driven by model misspecification. Hamilton and Herrera reproduce the BGW experiment using a different model specification, and found that increases in the price of oil lead directly to contractions in real output. Tightening monetary policy in period that BGW considered in their paper, played only a secondary role in generating the downturn.

There are several other recent research studies that critically reevaluate Bernanke et al.'s (1997) results. For example, Leduc and Sill's (2004) findings approximated the Federal Reserve's behavior since 1979, showing that the monetary policies contributed to an approximate 40 percent of drop in output following a rise in oil prices. Hypothesis of this paper is in agreement with Barsky and Kilian (2002), Leduc and Sill (2004), Hamilton and Herrera (2004), Gillman and Nakov (2009), Askari and Krichene (2010), Kormilitsina (2011), Alquist et al. (2012), Ratti and Vespignani (2013), Taghizadeh and Yoshino (2013a, 2013b), and Taghizadeh and Yoshino's (2014) findings for the impact of monetary policies on crude oil prices. However innovation of this paper is that in this research we are going to test another channel of monetary policy transmission which is the exchange rate.

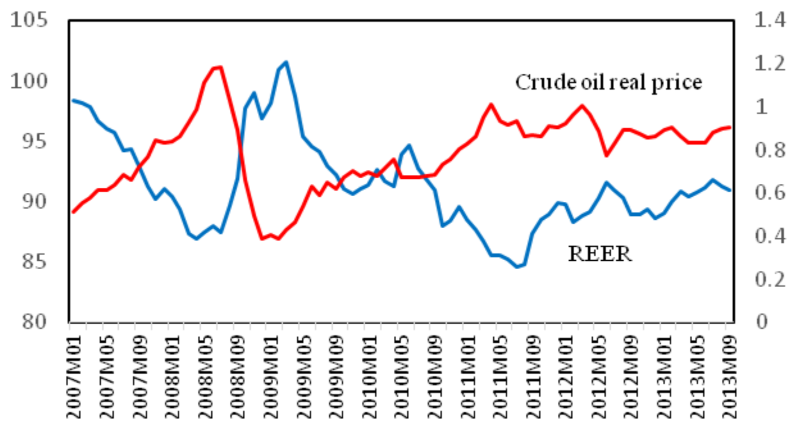
3. Theoretical Background and the Model

3-1 Channels of Transmission of Monetary Policies to Oil Demand

Monetary policies affect oil demand through a number of channels, including interest rates and exchange rates. Channels of interest rate transmission could be completely described by classical monetarism, as well as in modern literature such as the Keynesian IS-LM model. Easing interest rates increase the demand for credit and increase aggregate demand, including the demand for commodities. This increased demand for commodities also contains energy demand, especially for crude oil and derivatives because they are major energy carriers (Taghizadeh and Yoshino 2014). Keynes (1936) examined the effects that lowered interest rates have on aggregate demand. Expansionary monetary policy reduces the interest rate, and when the interest rate is lower than the marginal productivity of capital, it broadens investment demand until the marginal productivity of capital is equalized to a lower interest rate. The expansion of investment creates an accelerator-multiplier effect, causing aggregate demand to expand. This expansion of aggregate demand amplifies demand for commodities and puts pressure on commodity prices. This could be generalized for energy carriers as well, especially crude oil. In the end, this process leads to increased pressure on oil prices. In another word, lower interest rates will make the borrowing cheaper, this will push up the demand in commodities market including crude oil market.

As for the exchange rate transmission channel, most oil sales throughout the world are denominated in US dollars. This means that a depreciation of the US dollar would make oil imports cheaper in non-dollar-denominated currencies, raising oil imports and oil demand. Another exchange rate channel is as follows: A depreciation of the US dollar would cause an appreciation of non-dollar-dominated financial assets, majority of world financial assets are in non-dollar-denominated currencies and would, in turn, arouse world oil demand because of the *wealth effect*.

Fig. 3 Exchange Rate and Crude Oil Prices 2007:01-2013:09

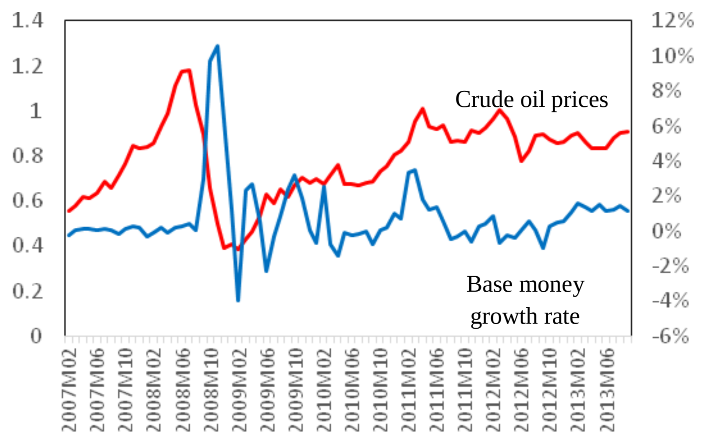


Note : crude oil prices are in constant dollars obtained using simple average of: Dubai crude oil prices in Tokyo market, Brent crude oil prices in London market, and WTI crude oil prices in New York market, deflated by US consumer price index (CPI). REER is for the US dollars. Left hand side scale is for REER and the right hand side scale is for crude oil real prices.

Source : International Energy agency (IEA) 2013, International Financial Statistics (IFS) 2013 and The Energy Data and Modelling Center (EDMC) database of the Institute of Energy Economics, Japan (IEEJ).

Fig. 3 shows REER and real crude oil price movements during the period of 2007:01-2013:09. The reverse movements between these two variables is apparent in this figure. In most cases following by the depreciation of US dollars, crude oil real prices started to raise and by the appreciation of it crude oil real prices dropped.

Fig. 4 Base Money and Crude Oil Price 2007:02-2013:09



Note : crude oil prices are in constant dollars obtained using simple average of: Dubai crude oil prices in Tokyo market, Brent crude oil prices in London market, and WTI crude oil prices in New York market, deflated by US consumer price index (CPI). Base money growth rate is for the US, seasonally adjusted. Left hand side scale is for the crude oil real prices and right hand side scale is for the base money growth rate.

Another way to verify our hypothesis is to see above figure. Fig. 4 illustrates Base money growth rate trend and the crude oil price movements during 2007:02-2013-09. As it is clear, in most cases they followed same path.

3-2 The Effect of Monetary Policy Actions on Exchange Rates

The effect of monetary policy on exchange rates has been the subject of a large body of empirical research since the early 1990s ; Sims (1992), Clarida and Gali(1994), Grilli and Roubini (1995), Eichenbaum and Evans (1995), Clarida and Gertler (1997), Cushman and Zha (1997), Fungand Gupta (1997), Faust and Rogers (2003), Bonser-Neal et al. (1998), Bagliano and Favero (1999).

Several of these empirical studies found that a tightening of US monetary policy is associated with an appreciation of the dollar, while a loosening is associated with dollar depreciation. Using a VAR methodology, Eichenbaum and Evans (1995) find that contractionary shocks to monthly values of the federal funds rate, the ratio of non-borrowed reserves to total reserves, and the Romer and Romer (1989) index over the 1974 to 1990 period led to a sharp increase in the differential between US and foreign interest rates and to a sharp appreciation in the dollar. Clarida and Gali (1994), Evans (1994) and Lewis (1995) also find that contractionary US monetary policy is associated with a dollar appreciation using similar methods. Bonser-Neal el.al (1998) found that increases in the federal funds rate target during the 1974-79 and 1987-94 periods of interest-rate targeting are associated with significant increases in the value of the dollar. Zettelmeyer (2004) studied the impact effect of monetary policy shocks on the exchange rate for three small open economies[5] during the 1990s. They found that a 100 basis point contractionary shock will appreciate the exchange rate by 2-3 percent on impact. The association of interest rate hikes with depreciations that is sometimes observed during periods of exchange market pressure is mainly attributable to reverse causality.

While all of these studies estimate a dollar appreciation in response to contractionary monetary-policy shocks, they report different dynamic-response pattern. Bonser-Neal et al. (1998), for example, estimate spot and forward rate responses consistent with standard overshooting models in a majority of the cases they examine. In contrast, Clarida and Gali (1994), Eichenbaum and Evans (1995), and Evans(1994) estimate that it can take from one to three years for the maximal effect of the policy shock to be felt on exchange rates. Bonser-Neal et al. (1998) also estimate that the impact of a policy shock is expected to increase over time in the case of the yen/dollar exchange rate over the 1974-79 period. These latter results are clearly inconsistent with standard overshooting models. In overshooting models, Contractionary US monetary policy causes the dollar spot rate to temporarily appreciate beyond, or overshoot, its new higher equilibrium level. Future exchange rates are therefore expected to appreciate by less than the current spot rate in response to a tightening of monetary policy. Bonser-Neal et al. (2000) suggest that the standard overshooting model may be too restrictive to completely characterize the effects of monetary policy

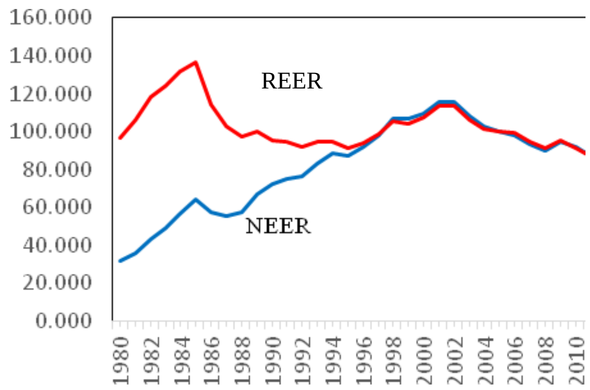
[5] Australia, Canada, and New Zealand

on exchange rates.

3-3 Definition of the Real Effective Exchange Rate (REER)

The relative attractiveness of domestic goods compared to foreign goods depends primarily on their relative price. We can think of this relative price as the number of domestic goods that must be given up to acquire one foreign good. This relative price is called the ***real exchange rate***. This real exchange rate, can be express in bilateral and multilateral (or effective) terms. ***The multilateral real exchange rate*** (or the real effective exchange rate – the two terms are synonymous and are both in common use) is constructed from bilateral real exchange rates. It is simply the geometrically weighted average of the relevant set of bilateral real exchange rates. Notice that a country's nominal and real exchange rates do not have to move in the same direction.

Fig. 5 Nominal Effective Exchange Rate (NEER) and the Real Effective Exchange Rate (REER) of the US $ 1980-2011



Note : both are consumer price index exchange rates, (2005=100)
Source : International Financial Statistics (IFS) 2013

Fig. 5. Shows that NEER and REER not necessarily follow the same path. As can be seen from the definition of the real exchange rate, changes in bilateral real exchange rate depends on two different factors: changes in the nominal exchange rate and changes in a country's price level relative to that of its trading partner. For example, in many developing countries that experiences high inflation during the decades of the 1980s and 1990s, it was not at all uncommon for their bilateral real exchange rates against the US dollars to appreciate significantly at the same time that their nominal exchange rates were depreciating (Montiel 2009), simply because their domestic inflation rates were so much higher than the inflation rate in the US.

Effective exchange rate indices are constructed in three steps. First the relevant bilateral exchange rates for a particular county are converted into indexes, using a common base year. Next, a set of weights is chosen to be applied to each of the bilateral indexes. Finally, the bilateral indexes are averaged together using these weights. This seems straightforward, however there are several issues that have to be taken into account, such as: geometric or arithmetic weighting, choice of weights, number of currencies and the base year for weights.

3-4 Theoretical Framework

In developing theoretical framework of this paper we inspired by Taghizadeh and Yoshino (2014). Our assumed oil importer country/region has a multi-input production function, with four production inputs[6]:

$$y_t = f(K_t, N_t, q_{1t}^d, q_{2t}^d) \tag{1}$$

where y_t is total production (the monetary value of all goods produced in a year; GDP), K_t is capital input (the monetary worth of all machinery equipment and buildings), N_t is labor input (the total number of man-hours worked in a year), q_{1t}^d is crude oil input (in barrels) and q_{2t}^d is natural gas input (in cubic feet). An oil importer's profit equation is:

$$Max\pi_t^d = P_{yt}.y_t - i_t K_t - w_t N_t - e_t p_{1t} q_{1t}^d - e_t p_{2t} q_{2t}^d \tag{2}$$

where P_{yt} is the output price level, w_t is the labor wage, i_t is borrowed capital rent, p_{1t} is the crude oil price in US$, p_{2t} is the natural gas price in US$ and e_t is the exchange rate. The Lagrange function is defined as:

$$L_t = \left(P_{yt} y_t - i_t K_t - w_t N_t - e_t p_{1t} q_{1t}^d - e_t p_{2t} q_{2t}^d\right) - \lambda\left[y_t - f(K_t, N_t, q_{1t}^d, q_{2t}^d)\right] \tag{3}$$

This produces the FOC for crude oil:

$$\partial L_t / \partial q_{1t}^d = -\left[e_t p_{1t} + \left(\partial p_{1t} / \partial q_{1t}^d\right) e_t q_{1t}^d\right] + P_{yt}\left(\partial f / \partial q_{1t}^d\right) = 0 \tag{4}$$

More specific results can be obtained by adopting the Cobb-Douglas production function:

$$y_t = f(K_t, N_t, q_{1t}^d, q_{2t}^d) = b_t K_t^{\alpha} N_t^{\beta} \left(q_{1t}^d\right)^{\gamma_1} \left(q_{2t}^d\right)^{\gamma_2} \tag{5}$$

where; $\alpha, \beta, \gamma_1, \gamma_2$ are the output elasticities of capital, labor, crude oil and natural gas, respectively. These values are constants determined by available technology and b is total factor productivity. We assumed that capital comes from the competitive market and the crude oil market is oligopolistic. For oligopolistic market we inspired by Revankar & Yoshino (2008). By rewriting Eq. 4 while accounting for our Cobb-Douglas production function, we get:

$$-\left[e_t p_{1t} + \left(\partial p_{1t} / \partial q_{1t}^d\right) e_t q_{1t}^d\right] + P_{yt}\gamma_1\left(y_t / q_{1t}^d\right) = 0 \tag{6}$$

In order to show that capital and labor inputs are function of what variables, we rewrite Eq.5 as bellow[7]:

[6] Taghizadeh and Yoshino (2014) used a production function, with five inputs; labor, capital, and three inputs for the energy; crude oil, natural gas and coal. For simplicity coal omitted from the model of this current paper.

[7] From Eq. 6 and Eq.7 we obtain an implicit function for crude oil demand as follows: $q_{1t}^d = h(p_{1t}/P_{yt}, p_{2t}/P_{yt}, y_t/P_{yt}, i_t, e_t)$ where $p_{1t}/P_{yt}, p_{2t}/P_{yt}, y_t/P_{yt}$ are crude oil prices, natural gas prices and the GDP of oil importer country all in real terms.

$$y_t = b_t K_t^{\alpha}{}_{(i_t, y_t)} N_t^{\beta}{}_{(\frac{w_t}{P_{yt}}, y_t)} \left(q_{1t}^d\right)^{\gamma_1} \left(q_{2t}^d\right)^{\gamma_2} \tag{7}$$

and as we know:

$$q_{it}^d = f(p_{it}/P_{yt}); \; (i = 1,2) \tag{8}$$

and for the estimation purposes we can express oil demand function in simplified log-linear form as bellow[8]:

$$\tilde{q}_{1t}^d = d_0 + d_1 \tilde{p}_{1t} + d_2 \tilde{p}_{2t} + d_3 \tilde{y}_t + d_4 \tilde{i}_t + d_5 \tilde{e}_t + u_{dt} \tag{9}$$

where $\tilde{q}_{1t}^d$ is logarithm of q_{1t}^d, $\tilde{p}_{it}$ is logarithm of $(p_{it}/P_{yt}); (i = 1,2)$, the coefficient d_1 is the price elasticity of crude oil demand, d_2 is the substitution elasticities of natural gas, which is the main substitution for crude oil. To demonstrate the effect of changes in the economic activity on the demand for oil, we use the real GDP in logarithmic format $(\tilde{y}_t = \log(y_t/P_{yt}))$. We also included two monetary policy factors: real interest rate $(\tilde{i}_t)$ and REER $(\tilde{e}_t)$. We expect negative values for d_4 and as for the exchange rate coefficient (d_5) we expect a negative value, implying that a depreciation of the US dollar would increase oil demand. d_0 is constant demand and u_{dt} is the random error term. We can write crude oil price equation as bellow:

$$\tilde{p}_{1t} = \vartheta_0 + \vartheta_1 D_t^{excess} + \vartheta_2 \tilde{p}_{2t} + \vartheta_3 \tilde{y}_t + \vartheta_4 \tilde{i}_t + \vartheta_5 \tilde{e}_t + u_{pt} \tag{10}$$

where $D_t^{excess} = \tilde{q}_{1t}^d - \tilde{q}_{1t}^s$ denotes the excess demand in crude oil market which obtained by deducting the crude oil supply from the demand of it and u_{pt} is the random error term.

3-5 Model

In this section the objective is to examine the relationship between crude oil prices, natural gas price, REER, GDP and the excess demand[9]. To assess the relationship between the series we adopt the K variable SVAR[10] and start with bellow VAR model:

$$Y_t = A_1 Y_{t-1} + \ldots + A_p Y_{t-p} + u_t \tag{11}$$

where Y_t is a $(K \times 1)$ vector of variables and comprises of $\tilde{e}_t, \tilde{y}_t, \tilde{p}_{2t}, D_t^{excess}, \tilde{p}_{1t}$. $A_{i\,(i = 1,\ldots,p)}$ are $(K \times K)$ fixed coefficient matrices, p is the order of VAR model and u_t is a $(K \times 1)$ vector of VAR observed residuals with zero mean and covariance matrix $E(u_t u_t') = \sum_u$. The innovations of the reduced form model, u_t, can be expressed as a linear combination of the structural shock, ε_t, as in Breitung et al. (2004) and Narayan (2013):

8 Since the labor wage does not have a significant impact on crude oil demand, we omitted it from our demand equation.

9 in Eq. (10) shown that we included two monetary policy factors: real interest rate and REER in our crude oil price function, but since in the period that we focus on it (2007:01 - 2013:12), Federal Reserve and some other monetary authorities' behaviour kept the interest rates near to zero, so we limited our analysis to exchange rate as the only channel for transmission of monetary policy to crude oil market.

10 Structural Vector Autoregression (SVAR)

$$u_t = A^{-1}B\varepsilon_t \tag{12}$$

where, B is a structural form parameter matrix. Substituting Eq. (12) into Eq. (11) and following minor operations, we get bellow which is the structural representation of our model:

$$AY_t = A_1^*Y_{t-1} + \ldots + A_p^*Y_{t-p} + B\varepsilon_t \tag{13}$$

where $A_j^*{}_{(j=1,\ldots,p)}$ is a $(K \times K)$ matrix of coefficients; where $A_j = A^{-1}A_j^*{}_{(j=1,\ldots,p)}$ and ε_t is a $(K \times 1)$ vector of unobserved structural shocks, with $\varepsilon_t \sim (0, I_k)$. The structural innovation is orthonormal; that is the structural covariance matrix, $\sum_{\varepsilon} = E(\varepsilon_t \varepsilon'_t)$, I_K is the identify matrix,. This Model is known as the AB model and is estimated in the form bellow:

$$Au_t = B\varepsilon_t \tag{14}$$

The orthonormal innovations, ε_t ensure the identifying restriction on A and B:

$$A\sum A' = BB' \tag{15}$$

Both sides of the expression are symmetric which means that $K(K+1)/2$ restrictions need to be imposed on $2K^2$ unknown elements in A and B. at least $2K^2 - K(K+1)/2$ additional identifying restrictions are needed to identify A and B.

Considering 5 endogenous variables that we have in our model; $\tilde{e}_t, \tilde{y}_t, \tilde{p}_{2t}, D_t^{excess}, \tilde{p}_{1t}$, the errors of the reduced form VAR are : $u_t = u_t^{\tilde{e}} + u_t^{\tilde{y}} + u_t^{\tilde{p}_2} + u_t^{D_{excess}} + u_t^{\tilde{p}_1}$. The structural disturbances, $\varepsilon_t^{\tilde{e}}, \varepsilon_t^{\tilde{y}}, \varepsilon_t^{\tilde{p}_2}, \varepsilon_t^{D_{excess}}, \varepsilon_t^{\tilde{p}_1}$, are REER of US$, real GDP of total OECD, natural gas real prices, excess demand in the world crude oil market and crude oil real price shocks respectively. This model has a total of 50 unknown elements. A maximum number of 15 parameters can be identified in this system. Therefore, at least 35 additional identifiable restrictions are required to identify matrices A and B. The elements of the matrices that are estimated are assigned a_{rc}. All the other values in A and B matrices are held fixed at specific values. Since this model is over-identified, a formal likelihood ratio (LR) test is carried out in his case to test whether the identification is valid. The LR test is formulated with the null hypothesis that the identification is valid. Our system will be in bellow form:

$$\begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ a_{21} & 1 & 0 & 0 & 0 \\ a_{31} & a_{32} & 1 & 0 & 0 \\ a_{41} & a_{42} & 0 & 1 & 0 \\ a_{51} & a_{52} & a_{53} & a_{54} & 1 \end{bmatrix} \begin{bmatrix} u_t^{\tilde{e}} \\ u_t^{\tilde{p}_2} \\ u_t^{\tilde{y}} \\ u_t^{D_{excess}} \\ u_t^{\tilde{p}_1} \end{bmatrix} = \begin{bmatrix} b_{11} & 0 & 0 & 0 & 0 \\ 0 & b_{22} & 0 & 0 & 0 \\ 0 & 0 & b_{33} & 0 & 0 \\ 0 & 0 & 0 & b_{44} & 0 \\ 0 & 0 & 0 & 0 & b_{55} \end{bmatrix} \begin{bmatrix} \varepsilon_t^{\tilde{e}} \\ \varepsilon_t^{\tilde{p}_2} \\ \varepsilon_t^{\tilde{y}} \\ \varepsilon_t^{D_{excess}} \\ \varepsilon_t^{\tilde{p}_1} \end{bmatrix} \tag{16}$$

The first equation in this system represents the REER as an exogenous shock in the system. The second row in the system specifies natural gas real price responses to REER. The third equation allows real GDP to respond contemporaneously to REER and gas price shocks. The fourth equation exhibits excess demand in crude oil market responses to REER and gas price shocks. The last equation depicts crude oil real prices. REER, natural gas price, real GDP, and excess demand in crude oil market are determinants of crude oil prices; (see, *inter alia*, Askari and Krichene, 2010; Taghizadeh and Yoshino, 2013a, 2013b and 2014; Taghizadeh et al., 2013). On the other hand, focus of this paper is to evaluate impact of monetary policy on crude oil prices, REER is channel of transmission of monetary policies in our model, and in order to capture impact of it on crude oil price, REER should the most exogenous variable and crude oil prices should be the most endogenous variable.

4. Empirical Results

4-1 Data Analysis

We use monthly data from 2007:01 - 2013:12 which is the period leading up to and following the subprime mortgage crisis. Crude oil prices obtained using simple average of: Dubai crude oil prices in Tokyo market, Brent crude oil prices in London market, and WTI crude oil prices in New York market all in constant dollars. The reason we used Dubai crude oil prices in Tokyo market is because Japan is the third largest importer of crude oil following by the US and China. Natural gas prices are in constant dollars obtained using simple average of three major natural gas price; US henry hub, UK NBP[11] and Japanese imported LNG average prices. GDP is for the OECD in constant US dollars, fixed PPPs, seasonally adjusted[12]. All above three data series deflated by US consumer price index (CPI), as most crude oil, and natural gas markets are denominated in US dollars and the amount of GDP of OECD was also in US Dollars. For the exchange rate series we used the US dollar’s REER (2005=100) Consumer Price Index. From now on whenever we refer to the price of crude oil, price of natural gas, and GDP, unless otherwise stated, we refer to their real values. The last variable which is the excess demand for crude oil shows the excess demand of crude oil in global market, obtained by deducting the global crude oil supply from the global crude oil consumption. We believe that, by using global data, we can obtain more feasible results in order to generalize findings for most areas and countries. Source of data are: International Energy agency (IEA) 2013, International Financial Statistics (IFS) 2013, The Energy Data and Modelling Center (EDMC) database of the Institute of Energy Economics Japan (IEEJ) and Monthly Energy Review of DOE[13].

In order to evaluate the stationarity of all series, we used an Augmented Dickey-Fuller (ADF) test. The results that we found imply that, with the exception of crude oil prices, which was stationary in log-level, all other variables are non-stationary in log-level. These variables include REER, natural gas real prices, real GDP of the OECD, excess demand in global crude oil market. However, when we applied the unit root test to the first difference of log-level variables, we were

[11] National Balancing Point

[12] Original data was quarterly but since our work file is monthly basis we converted them to monthly data and have done exponential smoothing on the released data

[13] US. Department of Energy (DOE)

able to reject the null hypothesis of unit roots for each of the variables. These results suggest that the REER, natural gas real prices, real GDP and excess demand in crude oil market variables each contain a unit root. Once the unit root test was performed and it was discovered that the variables are non-stationary in level and stationary in first differences level, they were integrated of order one. Hence they will appear in the SVAR model in first differenced form.

4-2 The Structural Parameter Estimates

The structural parameter estimates of the A and B matrices are presented in bellow table. The LR test does not reject the under-identifying restrictions at the 5 percent level as the $\chi^2(1)$ test statistic is 3.62 and the corresponding p-value is 0.06, implying that identification is valid.

Table 1 Structural Parameter Estimates of Matrices -A and B

	-A matrix					B matrix				
	$\tilde{e}$	$\tilde{p}_2$	$\tilde{y}$	D_{excess}	$\tilde{p}_1$	$\tilde{e}$	$\tilde{p}_2$	$\tilde{y}$	D_{excess}	$\tilde{p}_1$
$\tilde{e}$	1	0	0	0	0	0.01 (0.001)	0	0	0	0
$\tilde{p}_2$	0.01 (0.02)	1	0	0	0	0	0.002 (0.0002)	0	0	0
$\tilde{y}$	-1.31 (-2.61)	2.52 (0.96)	1	0	0	0	0	0.06 (0.005)	0	0
D_{excess}	-1.47 (1.44)	-9.20 (7.53)	0	1	0	0	0	0	0.16 (0.01)	0
$\tilde{p}_1$	-2.46 (0.58)	7.71 (2.92)	-0.06 (0.13)	0.10 (0.05)	1	0	0	0	0	0.06 (0.005)

Note : Standard errors (S.E.) are presented in parentheses. T-statistics can be calculated as $(\hat{\alpha}/SE(\hat{\alpha}))$ where $\hat{\alpha}$ is the estimated coefficient. The critical value at the 5 percent and the 1 percent levels are 1.96 and 2.58 respectively.

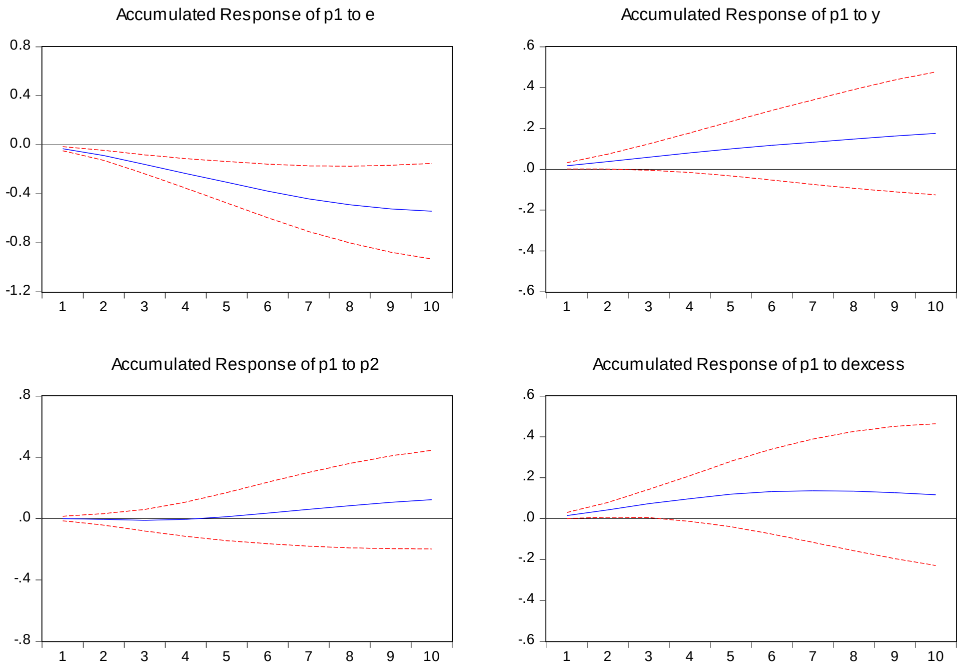
The signs and the significances of contemporaneous impacts on crude oil prices, deserve discussions as they have important policy and theoretical implications. To get an interpretation of the contemporaneous coefficients, the signs of A matrices are reversed; this follows from Eq. 13 (also see Narayan, 2013). The key results are as follows. For this interpretation, the most important row in -A matric is the last row, which shows determinants of crude oil real prices over the period of 2007:01 - 2013:12 leading up to and following the subprime mortgage crisis. As it is clear impact of REER of the US dollar on the crude oil real prices was significant and the sign of coefficient is negative, implying that by depreciation of the US dollars, crude oil prices will raise. As assumed earlier, during 2007:01 - 2013:12 US QE transferred to crude oil prices, through exchange rate channel. It means that following the US QE policies, US dollars depreciated, which made the oil prices cheaper in non-dollar-denominated currencies, result was higher demand for the crude oil in the global market and higher prices for it, our estimations confirm this hypothesis.

Other findings are impact of changes in natural gas prices on crude oil prices, which shows positive sign. Meaning that higher natural gas prices, will raise the price of other substitute energy carriers, including the crude oil. As for the impact of GDP of OECD on crude oil prices, sign of coefficient shows negative value, because in that period, global economy, especially the OECD was in recession however this result is not significant. And finally the last coefficient which is the excess demand in global market shows positive sign and is statistically significant, meaning that higher excess demand in the global oil market will raise the crude oil prices. By running the Impulse Response analysis in Section 4.3, we will be able to define the period that each of these impacts were significant during 2007:01 - 2013:12.

4-3 Structural Impulse Response (IR) Analysis

The Structural Impulse response analysis is performed in this part, in order to provide further evidence on the dynamic responses of crude oil real prices to REER, natural gas real prices, real GDP, and the excess demand in crude oil market shocks.

Fig. 6 The Impulse Response Effects of the Structural Shocks: 2007:05-2012:12



Notes : p1 is crude oil real prices, e is the REER of the US$, p2 is natural gas real prices, y is real GDP of the OECD, dexcess is the excess demand of crude oil in global market, all variables are in first differences of log form. The dashed lines represent one standard error (S.E.) confidence bands around the estimates of the coefficients of the impulse response functions. The confidence bands are obtained using Monte Carlo integration.

Fig. 6 shows the responses of the crude oil real prices in our SVAR model to one-standard deviation structural innovations. In the left column are shown the responses of crude oil real prices to structural (positive) innovations in REER and natural gas real prices. The effect of an unanticipated positive shock to REER (appreciation of US dollars) on crude oil real prices is very persistent and highly significant, it diminish crude oil real prices. An unanticipated positive innovation in natural gas real prices does not cause a significant effect on the real price of crude oil.

In the right column of Fig. 6, a positive shock to the real GDP of OECD has a positive effect on crude oil real prices that is statistically significant from beginning for about 2 months and after that the effect become non-significant. An unanticipated positive shock to excess demand of crude oil in global market, has a statistically significant positive effect on crude oil real prices builds up over the first 3 months and after that it become non-significant.

5. Concluding Remarks

This paper evaluates how monetary policies have affected crude oil prices leading up to and following the subprime mortgage crisis. This analysis concludes that aggressive monetary policies following the 2008 subprime mortgage crisis, inflated oil prices, mainly through the exchange rate channel, by making oil cheaper in non-dollar dominated currencies. Most of the world's crude oil demand is overshadowed by oil imports of non-producers or oil deficit producers. This means that a depreciation of the US dollar would make oil imports cheaper in non-dollar-denominated currencies, raising oil demand and the price of it. Our results show that the sharp shoot up in crude oil prices by early 2009 right after the crisis happened in 2007-8 was not because of the recovery of the economy, for the reason that as data shows the world economy has not recovered at that time, however crude oil prices increased sharply. We found that one of the reasons for this elevation in crude oil prices is because of QE that Federal Reserve and various central banks followed. The trend that led to slower economic growth and imposed a longer recovery time for the global economy following the crisis. This research provides several other findings, among which are the relationship between gas prices and crude oil prices and the impacts of GDP growth and excess demand in crude oil market on crude oil prices. Our results for the dynamic responses of crude oil prices to natural gas price, GDP and excess demand impacts during 2007:05 - 2012:12 show that: an unanticipated positive shock in natural gas real prices does not cause a significant effect on the real price of crude oil. A positive shock to the real GDP of OECD has a positive effect on crude oil real prices that is statistically significant from beginning for about 2 months and after that the effect become non-significant. An unanticipated positive shock to excess demand of crude oil in global market, has a statistically significant positive effect on crude oil real prices builds up over the first 3 months and after that it become non-significant.

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