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Empirical Analysis of Oil Price Determination Based on Market Quality Theory

TAGHIZADEH HESARY Farhad*
YOSHINO Naoyuki**

Abstract

Since the first oil shock in 1973 oil prices began to increase drastically. The 1973 and 1979 oil price shocks can be explained by supply reasons, but since the 80's, oil prices came under another type of increasing pressure. We argue that this latter with the exception of first Gulf War (1990-1991) oil price shocks, had another reason which was not a supply reason, and we found it on the demand side. Between 1981-2011, the 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. In this paper we will explain how this enduring price increase in most cases was caused by expansionary monetary policies that led to low interest rates, credit demand augmentation, and then aggregate demand which heightened crude oil prices. Simultaneously, this research looks at the time-series properties of crude oil and estimates a world demand-supply model and the determinants of crude oil prices along with price and income elasticities during 1960 -2011 and compares findings with two sub-periods, 1960-1980 and 1980-2011. Results show that demand is price elastic and unlike some earlier literature, supply is also affected by changes in oil price; however, income elasticity was significant only during 1980-2011. World crude oil demand was significantly influenced by interest rate, but impact of exchange rate depreciations on oil demand was not significant. Aggressive monetary policies would stimulate oil demand, but it would be met with oil supply which is rigid to monetary policies and would blow up the crude oil prices which are troublesome to economic growth. In last section we will attempt to shed light on the hypothesis of equilibrium vs. disequilibrium in the oil market, showing results that crude oil prices adjust instantly, declaring the existence of equilibrium in oil market during 1960-2011.

*TAGHIZADEH HESARY Farhad
GCOE, Keio University
**YOSHINO Naoyuki
School of Economics KEIO University

KEIO/KYOTO JOINT GLOBAL COE PROGRAM
Raising Market Quality-Integrated Design of "Market Infrastructure"

Graduate School of Economics and Graduate School of Business and Commerce,
Keio University
2-15-45 Mita, Minato-ku, Tokyo 108-8345, Japan

Institute of Economic Research,
Kyoto University
Yoshida-honmachi, Sakyo-ku, Kyoto 606-8501, Japan

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GCOE, Keio University, Mita 2-15-45 Minato-ku Tokyo Japan,108-8345

YOSHINO Naoyuki*

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Abstract:

Since the first oil shock in 1973 oil prices began to increase drastically. The 1973 and 1979 oil price shocks can be explained by supply reasons, but since the 80's, oil prices came under another type of increasing pressure. We argue that this latter with the exception of first Gulf War (1990-1991) oil price shocks, had another reason which was not a supply reason, and we found it on the demand side. Between 1981-2011, the 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. In this paper we will explain how this enduring price increase in most cases was caused by expansionary monetary policies that led to low interest rates, credit demand augmentation, and then aggregate demand which heightened crude oil prices. Simultaneously, this research looks at the time-series properties of crude oil and estimates a world demand-supply model and the determinants of crude oil prices along with price and income elasticities during 1960 -2011 and compares findings with two sub-periods, 1960-1980 and 1980-2011. Results show that demand is price elastic and unlike some earlier literature, supply is also affected by changes in oil price; however, income elasticity was significant only during 1980-2011. World crude oil demand was significantly influenced by interest rate, but impact of exchange rate depreciations on oil demand was not significant. Aggressive monetary policies would stimulate oil demand, but it would be met with oil supply which is rigid to monetary policies and would blow up the crude oil prices which are troublesome to economic growth. In last section we will attempt to shed light on the hypothesis of equilibrium vs. disequilibrium in the oil market, showing results that crude oil prices adjust instantly, declaring the existence of equilibrium in oil market during 1960-2011.

Keywords: oil market, monetary policies, interest rate, equilibrium vs. disequilibrium

1. Introduction

The descriptive analysis of crude oil markets enables us to observe oil price movements in two subperiods: 1960-1980 and 1980-2011. The initial period 1960–1980 witnessed a series of oil price

** Corresponding Author:
Email Add: Farhadth@gmail.com Farhadth@z3.keio.jp
* Professor of Economics

shocks. Price hikes culminated in 1980 at $36.83/barrel in nominal terms from $1.9/barrel in 1960. Fig.1 illustrates crude oil price movements in nominal and real terms during 1960-2011 and Fig.2 shows crude oil price growth rates in real and nominal terms during 1960-2011 and shows that both prices followed same path.

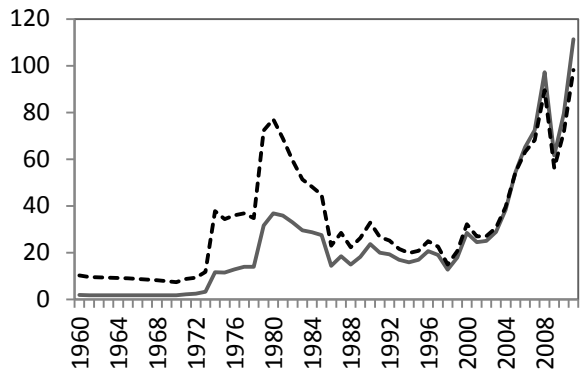

Fig 1. Crude oil price 1960 – 2011, Prices are in U.S. dollars per barrel. 1960-1983 Arabian Light posted at Ras Tanura.1984-2011 Brent dated. Dashed line is real price, and continuous line is nominal price.

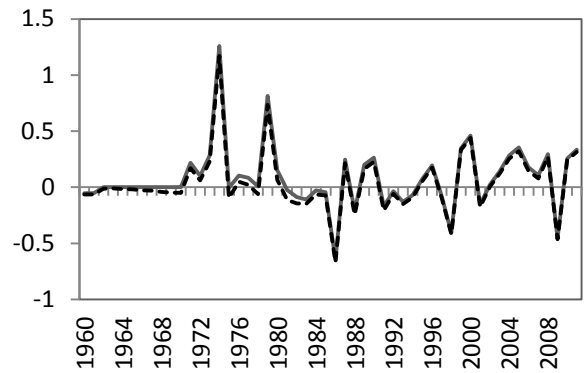

Fig2. Changes in crude oil price 1960 – 2011, $\Delta \ln poil$ used for changes in crude oil prices. Dashed line is real price, and continuous line is nominal price.

The production of crude oil increased during the first period (1960–1980) at an average rate of 4.95%[1], moving to 59.4 million barrels/day (mbd) in 1980 from 21mbd in 1960 (Fig. 3). In contrast to the stable crude oil output growth before 1973, the first oil price shock in 1973 initiated recurrent changes in oil production and a dissociation between OPEC and non-OPEC output. Fig.3 shows the remarkable asymmetry in the behavior of OPEC and non-OPEC production after the first oil price shock until 1985, after 1985 until 2011, both OPEC and non-OPEC output moved almost steadily parallel to each other. Growth rate of OPEC and world crude oil output is visible in Fig.4.

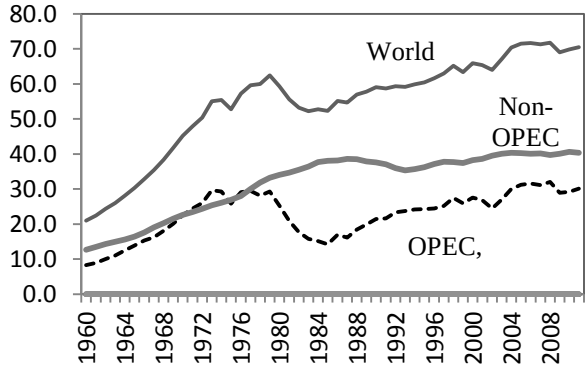

Fig3. Crude oil output 1960 – 2011, oil output is in million barrel/day

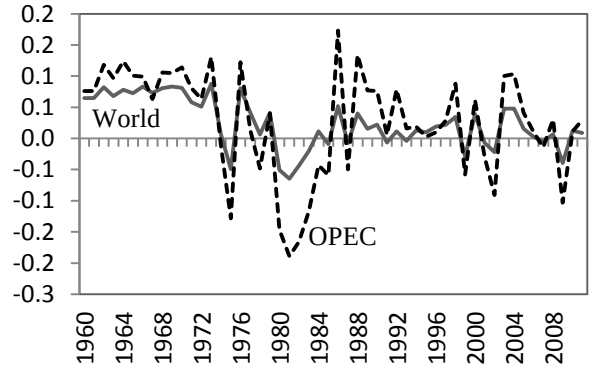

Fig4 Changes in OPEC and the World output 1960-2011, $\Delta \ln output$ used for changes in crude oil prices.

[1] Compound interest equation $A = ae^{in}$

During the second period (1980-2011) in the early 1980s, a recession reduced crude oil demand and had a significant negative impact on oil prices. By the end of decade, prices had declined substantially to below $25 U.S. per barrel. The 1990s brought the first Gulf War, (1990-1991) which had an impact on supply and prices. Despite the low prices for crude oil for most of the 1990's there was little interest within OPEC to try to raise prices. OPEC's lack of action kept oil prices low for an extended period. However, when crude oil prices descended to $10 U.S. per barrel following the Asian financial crisis in 1998, OPEC instituted a series of production cuts, starting in late 1999. This allowed OPEC to regain control over the oil market and began to result in higher oil prices. During the second period 1980-2011, average oil prices hoisted extensively from about $36/barrel in 1981 to beyond $111/barrel in 2011. At the same time, average interest rates devalued from 16.7 percent per annum in 1981 to about 0.1 percent per annum in 2011. We explain this inveterate price increase, especially after year 2000, to be caused by expansionary monetary policies that led to lower interest rates, amplification of credit demand and then aggregate demand, and made expanded demand for oil which elevated oil prices. Bernanke et al. (1997) stated that the Federal Reserve raises interest rates too much in response to high oil prices, which depresses economic activity beyond the negative effect of oil price shocks. They showed that expansionary monetary policies could have largely eliminated the negative output consequences of the oil-price shocks on the U.S. economy. This view has, in turn, been challenged by Hamilton and Herrara (2000), who argue that Bernanke, Gertler, and Watson's (BGW) empirical results are driven by model misspecification. Hamilton and Herrara reequip the BGW experiment using a different model specification and found that the increase in the price of oil that leads directly to contractions in real output. Tightening monetary policy plays only a secondary role in generating the downturn. There are several other recent researches that critically reevaluate Bernanke et al.'s (1997) results. For instance, Leduc and Sill's (2004) findings approximated the Federal Reserve's behavior since 1979, showing that the monetary policy contributes to about 40 percent drop in output following a rise in oil prices. Or, in a more recent research by Anna Kormilitsina (2011) within an estimated dynamic stochastic general equilibrium model with the demand for oil, the Ramsey optimal was contrasted with estimated monetary policy, finding that monetary policy amplified the negative effect of the oil price shock. Our results in this paper are also in line with these latter critical papers. We found that monetary policy indeed has negative effects on the demand side of the crude oil market and subsequently on oil prices. We argue that world oil demand was significantly influenced by interest rate. Aggressive monetary policy would stimulate oil demand; however, it would be met with rigid oil supply and would turn inflationary and disrupt economic growth.

In the last section of this research we attempted to shed light on the hypothesis of equilibrium vs. disequilibrium in oil market; the results showed that oil prices adjust instantly and declared the existence of equilibrium in the oil market during 1960-2011.

2. The theoretical framework

2.1 Oil consumption

Suppose that our assumed oil importer country has Eq.1 a multi-input production function, with 5 production inputs:

$$y = f(K, N, q_1^d, q_2^d, q_3^d) \tag{1}$$

Where y is total production (the monetary value of all goods produced in a year), K is capital input (the monetary worth of all machinery equipment and buildings), N is labor input (the total number of person-hours worked in a year), q_1^d is crude oil input (in barrels), q_d^2 is natural gas input (in cubic feet), q_d^3 is coal input (in short ton), and oil importer's profit equation is as Eq.2:

$$Max\pi^d = p_y.y - iK - wN - ep_1 q_1^d - ep_2 q_2^d - ep_3 q_3^d \tag{2}$$

Where p_y is the output real price level, w is the real labor wage, i is the rent of capital, p_1 is the crude oil real price in $ U.S., p_2 is the natural gas real price in $ U.S., p_3 is the coal real price in $ U.S., e is the exchange rate, Now define the Lagrange function in Eq.3,

$$L = \left(P_y y - iK - wN - ep_1 q_1^d - ep_2 q_2^d - ep_3 q_3^d\right) - \lambda\left[y - f(K, N, q_1^d, q_2^d, q_3^d)\right] \tag{3}$$

Now we get the FOC for capital and for crude oil:

$$\frac{\partial L}{\partial K} = -i + \lambda \frac{\partial f}{\partial K} = 0 \longrightarrow \lambda = \frac{i}{\partial f / \partial K} \tag{4}$$

$$\frac{\partial L}{\partial q_1^d} = -(ep_1 + \frac{\partial p_1}{\partial q_1^d}.eq_1^d) + \lambda \frac{\partial f}{\partial q_1^d} = 0 \tag{5}$$

The Cobb–Douglas production function is easy to analyze, and it appears to be a good approximation to actual productions (Romer, 2001). So the Cobb–Douglas production function was used and shown below:

$$y = f(K, N, q_1^d, q_2^d, q_3^d) = bK^{\alpha} N^{\beta} \left(q_1^d\right)^{\gamma_1} \left(q_1^d\right)^{\gamma_2} \left(q_1^d\right)^{\gamma_3} \tag{6}$$

Where; $\alpha, \beta, \gamma_1, \gamma_2, \gamma_3$ are the output elasticities of capital, labor, crude oil, natural gas and coal respectively. These values are constants determined by available technology. b is total factor productivity. We assumed that capital is from the competitive market and crude oil market is oligopolistic. By rewriting Eq.5, considering our Cobb-Douglas production function, we get Eq.7.

$$-(ep_1 - \frac{\partial p_1}{\partial q_1^d}.eq_1^d) + \lambda\gamma_1 \frac{y}{q_1^d} = 0 \tag{7}$$

By multiplying all variables to q_1^d, we write Eq.8.

$$\left(q_1^d\right)^2 e.\frac{\partial p_1}{\partial q_1^d} - ep_1 q_1^d + \lambda\gamma_1 y = 0 \tag{8}$$

Presently, we are rewriting our demand equation for crude oil, using antecedent results. $y(i, w, p_1, p_2, p_3)$ affects by interest rates, wages, the price of natural gas and the price of coal in addition to crude oil prices. Because of the significant impact of these factors in determining the price of crude oil, here we put

them disjoint, in our oil demand equation as in Eq.9, Except for wage that here omitted, since it does not have remarkable impact on crude oil demand:

$$q_1^d = d_0 + d_1 p_1 + d_2 p_2 + d_3 p_3 + d_4 y + d_5 i + d_6 e + u_d \tag{9}$$

Where d_0 is constant demand, the coefficient d_1 is the price elasticity of world demand for crude oil. d_2 And d_3 are substitution elasticities of natural gas and coal respectively which are two main substitutions for crude oil. These two values are anticipated to be negative. To demonstrate the effect of changes in the world's income on the demand for oil we use the real GDP of the world. As for the monetary policy factors we put two, interest rate and exchange rate. We expect negative values for d_5. We found a few papers that examined the impact of monetary policies on the oil market. In recent literature, Askari and Krichene (2010) used Libor as the key interest rate and found that an increase in interest rates by a 100 basis points would reduce oil demand by 0.1 to 0.5 percent. As for the channels of monetary policy transmission to oil consumption, it is comprehensively described in section 2.1.1 of our paper. As for the exchange rate, we expect a negative value for d_6. Askari and N. Krichene (2010) found a significant negative elasticity of demand with respect to exchange rate, implying that a depreciation of the U.S. dollar would increase oil demand.

2.1.1. Channels of transmission of monetary policies to oil consumption:

Monetary policies affect oil prices through a number of channels, including interest rate, exchange rate and speculative behavior. Channels of interest rate transmission could be completely described by, classical monetarism as well as in modern literature in the Keynesian IS-LM model. Easing interest rates increase the demand for credit and augment the aggregate demand, including the demand for commodities, which contains the energy demand especially for crude oil and derivatives as major energy carriers. Keynes (1936) examined the effect of easing interest rates on aggregate demand. Expansionary monetary policy reduces the interest rate, and when the interest rate is lower than the marginal productivity of capital, it will broaden investment demand until the marginal productivity of capital is equalized to a lower interest rate. The expansion of investment creates an acceleration-multiplier effect and causes aggregate demand to expand. The expansion of aggregate demand amplifies demand for commodities and puts pressure on commodity prices and this could be generalized for energy carriers, especially for crude oil. This aforementioned process puts pressure on oil prices as well. As for the exchange rate transmission channel, most of the world's crude oil demand is overshadowed by oil imports of non-producers or oil deficit producers, and a depreciation of the U.S. dollar would make oil imports cheaper in non-dollar-denominated currencies, raising oil imports and oil demand. Another channel is that the depreciation of the U.S. dollar would cause an appreciation of non-dollar-dominated financial assets and in turn arouse world oil demand because of the wealth effect. Ricardo (1817) studied the relationship between discount rates and commodity prices. He advanced that lower discount rates would lead to credit augmentation that would in turn, lead to higher commodity prices under the condition that we assume money velocity is constant.

There are pro and con researches for the impact of monetary policies on the oil market. Bernanke et al. (1997) states that the Federal Reserve raises interest rates too much in response to high oil prices, which depresses economic activity beyond the negative effect of oil price shocks. Anna Kormilitsina (2010) found that monetary policy amplified the negative effect of the oil price shock. Askari and Krichene (2010) measured that world oil demand was significantly influenced by interest and dollar exchange rates while oil supply was rigid. They found that oil supply and demand have very low price elasticity, and this characteristic makes oil prices highly volatile and subject to wider fluctuations than the prices of other commodities.

Fig.5 on the next page, illustrates the relationship between interest rates and crude oil prices. Here we used the Federal funds rate; a key interest rate, as a dominant interest rate. The Federal fund rate follows the same pattern as Libor rate; both are money market rates and are used as a benchmark for pricing loans by adding spreads that depend on risk and maturity. As it is noticeable in this figure, the relationship between interest rates and crude oil prices is asymmetric, but for the area which is our main scope, during 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. Here in this research we explain that this enduring price increase in most cases is caused by expansionary monetary policies that led to low interest rates, credit demand augmentation and then aggregate demand, increasing the demand for oil and therefore heightening oil prices.

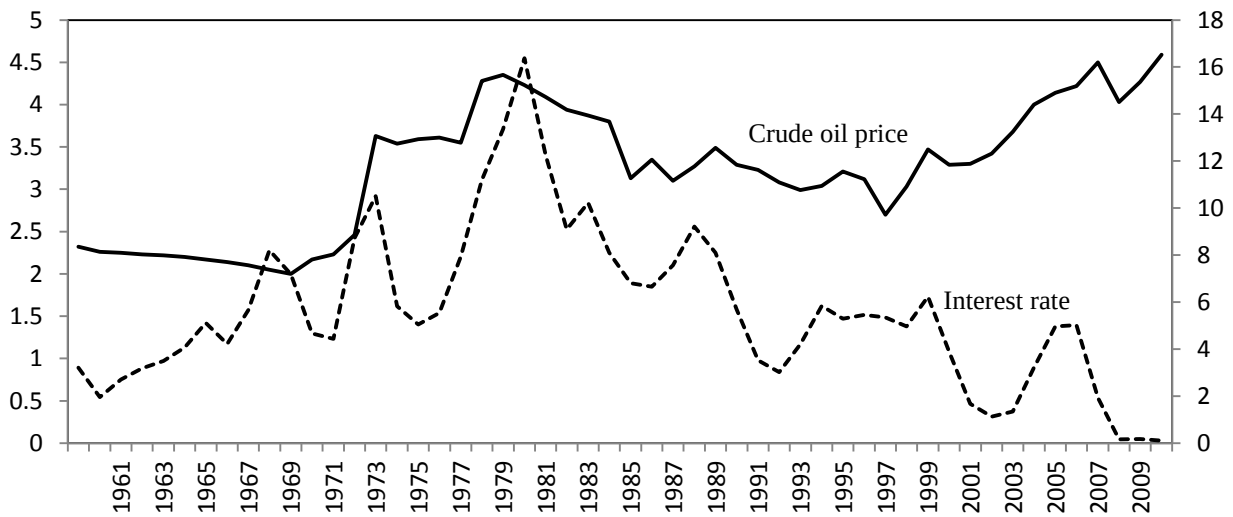

Fig5. Interest rate and crude oil price 1960 – 2011 Note: Crude oil prices are in logarithmic form, source of crude oil prices: 1960-1983 Arabian Light posted at Ras Tanura, 1984-2011 Brent dated. Interest rates are U.S. money market rate, percent per annum. Left hand side scale is for logarithm of crude oil price and right hand side scale is for interest rates.

2.2-Crude oil output

Suppose that over the period t-1 to t, crude oil output or extraction of crude oil is given by q_t^s ,and then we write the following equations:

$$Q_t^s = \sum_0^t q_t^s \tag{10}$$

$$TR_t \geq R_t + Q_t^s \tag{11}$$

$$R_t + Q_t^s = R_{t-1} + Q_{t-1}^s \tag{12}$$

$$R_t - R_{t-1} = Q_{t-1}^s - Q_t^s \tag{13}$$

$$dR_t = -q_t^s dt \tag{14}$$

Where: Q_t^s is the cumulative extraction at the end of period t. TR_t is the total amount of crude oil resources available, and R_t is amount of proven outstanding reserves. The above equations are under the condition that in the two following periods, no new resources has been added to proven inventory. Cost function is assumed to be given by a convex function, depending negatively on the amount of remaining proven reserves. The so-called stock effect is mainly because of the pressure dynamics affecting petroleum extraction. This type of cost specification is also considered by Livernois and Uhler(1987) , Farzin (1992) and Favero et al. (1994). The Favero cost function is as Eq.15:

$$C_t(q_t^s, R_{t-1}) = \alpha q_t^s + \frac{1}{2}\beta(TR_{t-1} - R_{t-1})^2 > 0\ , \alpha > 0, \beta > 0 \tag{15}$$

The first part of this cost function αq_t^s represents extraction cost, and the second part of it $1/2\,\beta(TR_{t-1} - R_{t-1})^2$ shows scarcity cost. Crude oil suppliers will choose an extraction profile to maximize the discounted stream of profits over the life of the field.

$$Max \sum_{t=0}^{T} \theta_t \left[\pi_t(q_t^s, R_{t-1})\right]\ \ 0 \leq \theta < 1 \tag{16}$$

$$\text{s.t. } (R_t - R_{t-1}) = -q_t^s \tag{17}$$

$$\left(\theta = \frac{1}{1+r} + \omega\right), r > 0\,. \tag{18}$$

Where θ is the subjective rate of discount, which we shall set equal to Eq.18, p^e is the expected real price of crude oil in U.S. $ per barrel and ω is the risk premium. In Eq.19, we write the profit equation for a crude oil producer, which is the function of expected own price at time *t*, the output of crude oil, extraction cost and scarcity cost:

$$\pi_t = ep_t^e q_t^s - \alpha q_t^s - \frac{1}{2}\beta(TR_{t-1} - R_{t-1})^2\,. \tag{19}$$

We awaken the assumption that the oil market is an oligopolistic market. First-order conditions for the optimization problem are given by:

$$\theta_t e p_t^e + \theta_t e \frac{\partial p_t^e}{\partial q_t^s} q_t^s - \theta_t \alpha - \lambda_t = 0 \quad . \tag{20}$$

$$C'_{R_t} = \lambda_t \quad . \tag{21}$$

Results in crude oil output equation*:*

$$\theta_t (e p_t^e + e \frac{\partial p_t^e}{\partial q_t^s} q_t^s - \alpha) - C'_{R_t} = 0 \tag{22}$$

A simultaneous supply and demand equations model (SEM) is developed for world crude oil incorporating monetary factors. The hypothesis of rational expectations is adopted; give the role of market information in determining the supply behavior (Muth, 1961)

$$q_1^d = d_0 + d_1 p_1 + d_2 p_2 + d_3 p_3 + d_4 y + d_5 i + d_6 e + u_d \tag{23}$$

$$q^s = s_0 + s_1 p^e + s_2 i + s_3 e + s_4 R + s_5 Z_1 + s_6 Z_2 + s_7 Z_3 + u_s \tag{24}$$

Where we have bellow variables, which are all in logarithmic form except exchange rates. All nominal values except exchange rates converted to real values using a U.S. GDP deflator (2005=100):

q_1^d is crude oil consumption, in million barrels per day. q^s is crude oil output, in millions of barrels per day. p_1 is crude oil real price[2], in U.S.$/barrel. p^e is the expected real price of crude oil in U.S.$ per barrel. p_2 is the U.S. Natural gas wellhead real price in U.S. cents per thousand cubic feet. p_3 is the American coal real price (F.O.B.) rail /barge prices in U.S.$ per short ton. y is the real GDP of the world. i is the U.S money market rate ; a key interest rates. e is the nominal effective exchange rate of U.S.$ unit labor costs. R is the amount of proven outstanding crude oil reserves. Z_1, Z_2, Z_3 are dummy variables for 3 major oil shocks. d_0 is constant demand. s_0 is constant supply. u_d is the demand residual. And u_s is the supply residual.

The expected variable p^e is rationally formed: $p^e = E_{t-1}(p_1 | I_{t-1})$. I_{t-1} is the information set in the period $t-1$ in which expectations $E_{t-1}(p_1 | I_{t-1})$ were based. The supply of crude oil is a function of expected price. Proven crude oil reserves outstanding, monetary factors and dummy variables for large fluctuations in oil prices. Following McCallum (1976), the actual and expected prices are expressed as: $p_1 = p^e + \eta_s$, where η_s is a forecast error that is uncorrelated with I_{t-1}. In addition, as per Hausman et al., (1987), we can get the estimated residual from our crude oil demand equation as explanatory variable. Rearranging Eq. (26) by substituting for p^e and including $\hat{u}_d$, the two equations become as below. u_d and u_s are random residuals assumed to be serially uncorrelated, independently and identically distributed

[2] 1960-1983 Arabian Light posted at Ras Tanura.
1984-2011 Brent dated.

with mean zero and standard error s_d and s_s, respectively, and uncorrelated with the exogenous variables.

$$q_1^d = d_0 + d_1 p_1 + d_2 p_2 + d_3 p_3 + d_4 y + d_5 i + d_6 e + u_d \tag{25}$$

$$q^s = s_0 + s_1 p_1 + s_2 i + s_3 e + s_4 R + s_5 Z_1 + s_6 Z_2 + s_7 Z_3 + s_8 \hat{u}_d + (u_s - \eta_s) \tag{26}$$

3. Empirical Analysis

3-1. Data

We use annual data from 1960 to 2011. We define the crude oil prices in U.S. dollars per barrel, natural gas price in U.S. cents per thousand cubic feet, coal prices in U.S. dollar per short tons, and GDP, all in real terms as the ratio of nominal values to the U.S. GDP deflator (2005=100)[3]. From now on whenever we refer to the price of crude oil, price of natural gas, price of coal, and GDP, unless otherwise stated, it is their real values. As for crude oil output, crude oil consumption and GDP series, we used world data from The OPEC Annual Statistical Bulletin 2012. In earlier studies infrequently found researches that used world data. We believe by using world data, we could get more feasible results in order to generalize findings for most areas and countries. As for crude oil prices for 1960-1983, we used Arabian Light prices posted at Ras Tanura, and for the period 1984-2011, we used Brent dated rates released from BP [4]Statistical Review of World Energy 2012. For coal prices[5], because of lack of data, we used one of the world dominant source's rates, which are the U.S. total short ton prices. We got this series from the U.S. Energy Information Administration (EIA)[6]. For natural gas, likewise, due to lack of data for our period, we limited our references to one of the preeminent natural gas source and used U.S. natural gas wellhead prices, published by the U.S. Energy Information Administration**.** As oil prices are denominated in U.S. dollars, for the exchange rate series we used the U.S. dollar's nominal effective exchange rate (NEER) unit labor costs. For interest rates, we used the Federal fund rate[7] as a key interest rate that influences other key interest rates. By virtue of that, it is chosen to model world demand for crude oil. NEER, interest rates, world proven outstanding oil reserves, and the U.S. GDP deflator (2005=100) series are from International Financial Statistics (IFS) of International Monetary fund (IMF), OPEC Annual Statistical Bulletin 2012 and World Bank database 2012. Proven outstanding reserves at any given point in time are defined by quantities of oil that geological and engineering information indicate with reasonable certainty can be recovered in the future from known reservoirs under existing economic and operating conditions (Mohaddes 2012).

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[3] Other possible deflators are world commodities price index and world consumer price index.

[4] British Petroleum

[5] Prices are free-on-board (F.O.B.) rail/barge prices, which are the F.O.B. prices of coal at the point of first sale, excluding freight or shipping and insurance costs. For 1960-2000, prices are for open market and captive coal sales; for 2001-2007, prices are for open market coal sales; for 2008 forward, prices are or open market and captive coal sales.

[6] Sources: • 1960-1975—Bureau of Mines (BOM), Minerals Yearbook. • 1976—U.S. Energy Information Administration (EIA), Energy Data Report, Coal Bituminous and Lignite in 1976, and BOM, Minerals Yearbook. • 1977 and 1978—EIA, Energy Data Reports, Bituminous Coal and Lignite Production and Mine Operations, and Coal—Pennsylvania Anthracite. • 1979—EIA, Coal Production, and Energy Data Report, Coal—Pennsylvania anthracite. • 1980-1992—EIA, Coal Production, annual reports.• 1993-2000—EIA, Coal Industry Annual, annual reports and unpublished revisions. • 2001-2010—EIA, Annual Coal Report, annual reports. • 2011—EIA, Form EIA-7A, "Coal Production Report," and U.S. Department of Labor, Mine Safety and Health Administration, Form 7000-2, "Quarterly Mine Employment and Coal Production Report."

[7] Federal funds rate follows the same pattern as LIBOR rate. Both are money market rates and are used as benchmark for pricing loans by adding spreads that depend on risk and maturity.

We tested all series for unit roots (in logarithmic form), using the Augmented Dickey–Fuller test. Results are summarized in Table1.

Table 1.

Series: unit root tests, 1960-2011

	notation	*1960-2011*		*1960-1980*		*1980-2011*	
		ADF	*CV*	*ADF*	*CV*	*ADF*	*CV*
Test on level							
Crude oil consumption	q_1^d	-3.68**	-2.92	*-3.48**	*-3.03*	*0.71*	*-2.96*
Crude oil output	q^s	-5.94**	-2.92	*-3.12**	*-3.03*	*-0.22*	*-2.96*
Price of crude oil	p_1	-0.99	-2.92	*0.38*	*-3.03*	*-1.13*	*-2.96*
Price of natural gas	p_2	-1.87	-2.92	*0.44*	*-3.03*	*-2.38*	*-2.99*
Price of coal	p_3	-2.81	-2.92	*-0.27*	*-3.03*	*-2.92*	*-2.98*
Interest rate	i	-1.50	-2.92	*-0.29*	*-3.04*	*-2.50*	*-2.98*
Exchange rate	e	-2.34	-2.92	*-2.09*	*-3.03*	*-2.09*	*-2.99*
Oil reserves	R	-2.33	-2.92	*-1.86*	*-3.03*	*-1.60*	*-2.98*
Income	Y	-1.09	-2.92	*0.21*	*-3.04*	*-1.09*	*-2.92*
Test on first differences[8]							
Crude oil consumption	q_1^d	-2.70	-2.92	*-1.35*	*-3.03*	*-4.23***	*-2.96*
Crude oil output	q^s	-3.97**	-2.92	*-0.29*	*-3.08*	*-5.48***	*-2.96*
Price of crude oil	p_1	-6.95**	-2.92	*-4.21***	*-3.03*	*-3.96***	*-2.97*
Price of natural gas	p_2	-3.37*	-2.92	*-1.29*	*-3.03*	*-2.54*	*-2.99*
Price of coal	p_3	-4.54**	-2.92	*-3.18**	*-3.03*	*0.009*	*-2.98*
Interest rate	i	-6.53**	-2.92	*-2.99*	*-3.08*	*-4.65***	*-2.98*
Exchange rate	e	-5.27**	-2.92	*-3.41**	*-3.04*	*-0.98*	*-2.99*
Oil reserves	R	-2.93*	-2.92	*-2.84*	*-3.03*	*-2.80*	*-2.98*
Income	y	-4.46**	-2.92	*-4.60***	*-3.04*	*-4.46***	*-2.92*

Notation: *ADF, augmented Dickey–Fuller statistics; CV, critical value at 5% significance level; * indicates significance at 5%; ** indicates significance at 1%*

We have done ADF[9] test on level and on first differences. Both crude oil consumption and crude oil output reveal an interesting feature: they were stationary on level during 1960-2011 and 1960-1980. This

[8] Gas price series for 1980-2011 became stationary with -3.11 value (CV=-2.99) in 2nd differences. Coal price series for 1980-2011 became stationary with -5.27 value (CV=-2.98) in 2nd differences. Exchange rate series for 1980-2011 became stationary with -5.53 value (CV=-2.99) in 2nd differences. Oil reserves series for 1960-1980 became stationary with -5.94 value (CV=-3.04) in 2nd differences. Oil reserves series for 1980-2011 became stationary with -11.91 value (CV=-2.98) in 2nd differences.

[9] Augmented Dickey–Fuller

shows a stable structure that helped to maintain consumption and output around a stationary level. Most series, except crude oil consumption and crude oil output were non-stationary in level, but almost all series became stationary in first differences.

3.2. Empirical Results

It would be didactic to run regression in order to assess the basic properties of oil markets, determinants of crude oil prices, and evaluate the impact of monetary factors such as interest rates and exchange rates on the oil market. For this reason, we ran the regression for our SEM using the weighted two-stage least squares (W2SL) method. Results summarized in Table 2.

Table 2.Empirical results[10]
Simultaneous weighting matrix & coefficient iteration[11]
Convergence achieved after: 1 weight matrix, 2 total coefficients iterations

	Notation	*1960-2011*	*1960-1980*	*1980-2011*
Demand Side q_1^d				
Price elasticity of demand	p_1	*-0.05*(2.31)*	*-0.10*(-3.06)*	*-0.05(-1.04)*
Price of natural gas	p_2	*0.02(1.17)*	*0.02(0.55)*	*0.05*(2.55)*
Price of coal	p_3	*0.04(1.21)*	*0.07(1.19)*	*0.04(0.57)*
Income elasticity of demand	y	*0.03(0.67)*	*0.25(1.54)*	*0.17**(3.01)*
Interest rate	i	*-0.003*(-2.24)*	*-0.001(-0.4)*	-1.4e-05(-0.008)
Exchange rate	e	*-0.07(-1.33)*	*0.10(0.72)*	*0.04(1.00)*
		R-squared:0.99	*R-squared:0.99*	*R-squared:0.99*
Supply Side q^s				
Price elasticity of supply	p_1	*0.24*(2.15)*	*0.05(1.34)*	*0.12*(2.00)*
Interest rate	i	*0.01(0.80)*	*-.0.01(-1.45)*	*0.01(1.21)*
Exchange rate	e	*0.37(1.06)*	*0.19(0.39)*	*0.19(1.43)*
Oil reserves	R	*0.22(1.04)*	*1.13**(15.78)*	*0.23(0.84)*
		R-squared:0.76	*R-squared:0.98*	*R-squared:0.76*

t-statistics are in parentheses
** indicates significance at 5%,*
*** indicates significance at 1%*

[10] Since there is a sluggish adjustment in oil demand, it forced us to insert q_{1t-1}^d in right hand side of our demand equation, hence the SEM that we done our estimations based on it is below:

$$\begin{cases} q_{1t}^d = d_0 + d_1 p_{1t} + d_2 p_{2t} + d_3 p_{3t} + d_4 y_t + d_5 i_t + d_6 e_t + d_7 q_{1t-1}^d + u_{dt} \\ q_t^s = s_0 + s_1 p_{1t} + s_2 i_t + s_3 e_t + s_4 R_t + s_5 Z_1 + s_6 Z_2 + s_7 Z_3 + s_8 \hat{u}_{dt} + u'_{st} \end{cases}$$

the estimated coefficient for q_{1t-1}^d in 1960-2011is 0.93** (t=14.03), S.E: 0.07, for 1960-2011 is 0.80** (t=6.03) S.E: 0.13 and for the last sub period (1980-2011) is 0.66** (t=3.88), S.E: 0.17

[11] The Akaike Information Criterion (AIC) has been used to select the lag orders for each SEM in which the maximum lag is set to two.

As it is clear our results for oil demand price elasticity agree more with those results that found low values for oil demand price elasticities in the short-run and long-run. For the short-run, our results suggest a demand price elasticity of -0.05 (significant), -0.10(significant) and -0.05(insignificant) for 1960-2011, 1960-1980 and 1980-2011 respectively. And for the long-run, our calculations show a -0.33 value which is in line with Bentzen and Engsted (1993) who found short-run and long-run price elasticities of -0.13 and -0.46 respectively. Pesaran et al. (1998) found aggregate and sectorial long-run price elasticities of energy demand for Asian countries:-0.33; industry, -0.52; transport, -0.36; residential, -0.47; and commercial, -0.08. Gately and Huntington (2002) found between -0.12 and -0.64 for both OECD and non-OECD countries, and Krichene's (2006) results were between -0.03 and -0.08 for various countries in the short-run. His long-run price elasticity was significantly low: 0.05 in 1918–1999, 0.13 in 1918–1973 and almost zero during 1973–1999. Askari and Krichene (2010) found -0.009 to -0.008 for short-run elasticities and Mohaddes (2012) found -0.15 for the short-run price elasticity of world oil demand. Demand for crude oil administrated a large structural change after the 70's oil shocks, high energy-taxation in oil importing countries, establishment of the Strategic Petroleum Reserve (SPR), and the raise in share of other energy carriers such as natural gas in energy importing countries energy basket, contributing to the significant reduction in the demand elasticity by compacting through energy saving and substitution. This is the reason that oil price elasticity decreased from -0.10 in 1960-1980 to -0.05 in 1980-2011.

Table 3.Long-run crude oil demand and supply elasticities
World crude oil, long-run elasticities (normalized cointegrating coefficients)
1960-2011[12]

Demand Side q_1^d	*Notation*	*C.E.*	*S.E.*
Price elasticity of demand	p_1	-0.33	0.09
Price of natural gas	p_2	0.27	0.08
Price of coal	p_3	0.51	0.09
Income elasticity of demand	y	0.005	0.04
Interest rate	i	-0.03	0.005
Exchange rate	e	-0.14	0.18
Supply Side q^s			
Price elasticity of supply	p_1	*-0.40*	0.05
Interest rate	i	-0.06	0.007
Exchange rate	e	-0.26	0.18
Oil reserves	R	-0.59	0.08

We used Johansen Cointegration test in order to get long-run elasticities.
Notation*: C.E, coefficient; S.E, Standard error.*

Oil supply price elasticity for crude oil in the short-run is small but significant in 2 out of 3 periods. We calculated 0.24(significant) for 1960-2011, 0.05(insignificant) for 1960-1980, and for the last period

[12] Because of short period for two subperiods, we limited long run elasticity estimation to main period 1960-2011 only.

(1980-2011) 0.12(significant). Long-run oil supply price elasticity for 1960-2011 computed -0.40. This negative oil supply price elasticity is in line with several studies. Griffin (1985) calculated -0.48 to 0.19 for OPEC member countries and -0.06 to 3.36 for 11 non-OPEC countries for 1973-1997. He found a negative price elasticity of oil supply for five OPEC member countries[13], while negative and significant elasticity coefficients were also obtained for the other five non-OPEC countries[14]. Jones (1990) found -0.229 to 0.048 for OPEC member countries, Krichene (2002) computed oil supply short-run price elasticity from -0.08 to 0.08 for 1918–1999 and long-run price elasticities of 0.10 to 1.10. Ramcharran (2002) obtained negative and significant supply elasticity for 7 of the 11 OPEC members[15]. Moreover, at the aggregate level, a negative and significant elasticity coefficient was obtained for OPEC nations. Askari and Krichene's (2010) experiment results showed short-run oil supply price elasticity of -0.48 to 0.660 for 1970Q1–2008Q4, long-run price elasticity of -0.02 to 0.008. Oil supply price elasticities could be thought-out to be deliberately low, reasoning that oil supply was determined by oil discoveries and technological factors. For long-run price elasticity of supply, we computed a negative value; possibly derived from the long-run price elasticity of the demand function. Crude oil Producers may emphatically abstain from increasing production at the time of a price rise in order to preserve the gain in price, as experienced in 2002–2008 that in order to yield much higher revenues, supplies were reduced. Oil proven outstanding reserves, had a significant positive impact on oil supply during 1960-1980 with a large coefficient of 1.13, but in second sub period and in the main period its influence was slight and not significant.

For the income elasticity of demand our findings suggest 0.03(insignificant), 0.25(insignificant) and 0.17(significant) for 1960-2011, 1960-1980 and 1980-2011 respectively, and in long-run for 1960-2011 decreased to 0.005. Our findings are in line with Askari and Krichene (2010), who reported 0.02 to 0.327 and lower than the estimated value of 0.678 by Mohaddes (2012). 1.0-1.2 was suggested by Pesaran et al (1998) for Asian developing countries, 0.95 by Gately and Huntington (2002), and 0.54 to 0.90 in Krichene's (2006) estimations. Our result for the income elasticity of world crude oil demand matches the reality. Dependency on crude oil decreased following the 70's oil price shocks, due to aforementioned structural changes in the oil demand framework. As a result, share of other energy carriers, such as natural gas, brightened. All these factors contributed to lessening the influence of total economic output on the demand of crude oil.

4. Testing for Equilibrium vs. Disequilibrium in Oil Market

The literature on disequilibrium in the oil market has grown recently. In this section we attempt to shed light on the following question how can one test the hypothesis of equilibrium vs. disequilibrium in oil models? The simple version of the disequilibrium oil model based on our findings is given in Eq.27 to 29.

[13] Indonesia, Iran, Iraq, Saudi Arabia and UAE
[14] Algeria, Kuwait, Libya, Qatar and Venezuela
[15] Iran, Kuwait, Libya, Nigeria, Qatar, UAE and Venezuela

$$\begin{cases} q_{1t}^{d} = d_0 + d_1 p_{1t} + d_2 p_{2t} + d_3 p_{3t} + d_4 y_t + d_5 i_t + d_6 e_t + u_{dt} \\ q_t^{s} = s_0 + s_1 p_{1t} + s_2 i_t + s_3 e_t + s_4 R_t + s_5 Z_1 + s_6 Z_2 + s_7 Z_3 + s_8 \hat{u}_{dt} + u'_{st} \\ q_{1t}^{*} = \min(q_{1t}^{d}, q_t^{s}) \end{cases} \tag{27}$$

$$u'_{st} = u_s - \eta_s \tag{28}$$

$$\Delta p_1 = \lambda (q_{1t}^{d} - q_t^{s}) \tag{29}$$

Where we call q_t^* *equilibrium quantity,* we assumed that the price equation is non-stochastic. This type of testing for the hypothesis of equilibrium vs. disequilibrium in the oil market by incorporating monetary factories is another unique part of this paper that has not been found in earlier studies. Various estimating methods have been proposed for model27, and maximum likelihood methods are available. In addition, several two-stage, three–stage and instrumental-variable estimators are possible, according to Amemya (1974), Ito and Ueda (1979), Laffont and Monfort (1979), Golfeld and Quandt (1980). Here in this paper we follow Golfeld and Quandt (1980) and Bowden's (1978) methods.

If we solve for the reduced form of the price equation in our model, we obtain:

$$p_{1t} = \frac{1}{\frac{1}{\lambda} + (s_1 - d_1)} \begin{bmatrix} (d_0 - s_0) + (d_5 - s_2) i_t + (d_6 - s_3) e_t \\ + d_2 p_{2t} + d_3 p_{3t} + d_4 y_t - s_4 R_t - s_5 Z_1 \\ - s_6 Z_2 - s_7 Z_3 - s_8 \hat{u}_{dt} + (u_{dt} - u'_{st}) \end{bmatrix} + \frac{p_{1t-1}}{1 - \lambda (d_1 - s_1)} \tag{30}$$

Now we write the equilibrium model as below:

$$\begin{cases} q_{1t}^{d} = d_0 + d_1 p_{1t}^{*} + d_2 p_{2t} + d_3 p_{3t} + d_4 y_t + d_5 i_t + d_6 e_t + u_{dt} \\ q_t^{s} = s_0 + s_1 p_{1t}^{*} + s_2 i_t + s_3 e_t + s_4 R_t + s_5 Z_1 + s_6 Z_2 + s_7 Z_3 + s_8 \hat{u}_{dt} + u'_{st} \\ q_{1t}^{*} = q_1^{d} = q^{s} \end{cases} \tag{31}$$

Where p_{1t}^* denotes the market clearing price of crude oil:

$$p_{1t}^{*} = \frac{1}{s_1 - d_1} \begin{bmatrix} (d_0 - s_0) + (d_5 - s_2) i_t + (d_6 - s_3) e_t + d_2 p_{2t} + d_3 p_{3t} \\ + d_4 y_t - s_4 R_t - s_5 Z_1 - s_6 Z_2 - s_7 Z_3 - s_8 \hat{u}_{dt} \end{bmatrix} + \frac{u_{dt} - u'_{st}}{s_1 - d_1} \tag{32}$$

$$q_{1t}^{*} = \frac{\begin{bmatrix} (s_1 d_0 - d_1 s_0) + (s_1 d_5 - d_1 s_2) i_t + (s_1 d_6 - d_1 s_3) e_t + s_1 d_2 p_{2t} \\ + s_1 d_3 p_{3t} + s_1 d_4 y_t - d_1 s_4 R_t - d_1 s_5 Z_1 - d_1 s_6 Z_2 - d_1 s_7 Z_3 - d_1 s_8 \hat{u}_{dt} \end{bmatrix}}{s_1 - d_1} + \frac{s_1 u_{dt} - d_1 u'_{st}}{s_1 - d_1} \tag{33}$$

The equilibrium is close to the disequilibrium model, in which prices adjusts instantly. We judge the result of testing equilibrium vs. disequilibrium by looking at the size of λ which is "Adjustment speed". If it is large, the process of adjustment is rapid. In another word: $\lim_{\lambda \to \infty} p_{1t} = p_{1t}^{*}$ and $\lim_{\lambda \to \infty} q_1^{d} = \lim_{\lambda \to \infty} q^{s} = q_{1t}^{*}$,

But since it is shiftless to test whether λ is large enough to accept the hypothesis of equilibrium in the market, Bowden (1978) provided a more convenient formulation of this method:

$$p_{1t} = \delta p_{1t-1} + (1-\delta) p_{1t}^{*} \tag{34}$$

$$p_{1t} = \delta p_{1t-1} + (1-\delta)\left[\frac{1}{s_1 - d_1}\begin{bmatrix}(d_0 - s_0) + (d_5 - s_2)i_t + (d_6 - s_3)e_t + d_2 p_{2t} + d_3 p_{3t} \\ + d_4 y_t - s_4 R_t - s_5 Z_1 - s_6 Z_2 - s_7 Z_3 - s_8 \hat{u}_{dt}\end{bmatrix} + \frac{u_{dt} - u'_{st}}{s_1 - d_1}\right] \tag{35}$$

Bowden (1978) formulated this above equation using $\delta = 1/1 - \lambda(d_1 - s_1)$.In the above equation p_{1t}^{*} is given by Eq.32, and $\lim_{\delta \to 0} p_{1t} = p_{1t}^{*}$, and $\lim_{\delta \to 0} q_1^d = \lim_{\delta \to 0} q^s = q_{1t}^{*}$, equilibrium occurs when $\lambda = \propto$ or as per the Bowden (1978), when $\delta = 0$. Now by testing the null hypothesis that $\delta = 0$, we can evaluate the equilibrium vs. disequilibrium in the oil market. Table 4 shows the results of estimated coefficients for a reduced form equation. We could not reject the null hypothesis for p_{1t-1}'s coefficient in Eq.35 (t=1.50). This suggests rapid adjustment in the oil market and equilibrium during 1960-2011, which means we can retain our empirical results in section 3.2.

Table 4. Reduced form equation with substituted coefficients:
1960-2011

$$p_1 = 0.19 p_1(-1) - 0.02 I - 1.65 e^{**} - 0.026 y + 0.57 p_2^{**} + 0.46 p_3^{**} + 0.47 R - 0.23 Z_1 + 0.33 Z_2^{*} + 0.21 Z_3 + 1.87 \hat{u}_{dt}$$

(1.50)	(-1.15)	(-5.25)	(-0.22)	(4.29)	(2.89)	(1.85)	(-1.07)	(2.04)	(1.01)	(1.05)

R-squared= 0.95
Durbin-Watson stat= 1.62

t-statistics are in parentheses,
** indicates significance at 5%*
*** indicates significance at 1%*

5. Conclusion

In this paper we examined the world crude oil market over the period 1960-2011. We analyzed properties of oil markets and determinants of crude oil prices during this period. In order to reach worthwhile analytical results, we have done our estimations during the main period above and two sub-periods, 1960-1980 and 1980-2011. The reason for classifying in this way is that most price volatilities during 70's have supply reasons, however, we believe in the second period, crude oil prices blew up mainly due to another type of inflating pressure. We argued that this latter with the exception of first Gulf War (1990-1991) oil price shock, had another reason which was not a supply reason, but we found it on demand side. Here in this research, we explained that in most cases, this uninterrupted price increase was caused by expansionary monetary policies that led to low interest rates, credit demand augmentation and then aggregate demand which heightened oil prices. Monetary policy affects oil prices through two main channels, interest rate and exchange rate. We found that world oil demand was significantly influenced by interest rate, but the impact of exchange rate depreciations on oil demand was not significant, and on the other hand supply was adamant. Aggressive monetary policy would stimulate oil demand; however, on the other

hand, supply is inelastic to interest rates. The result is blown up crude oil prices which is troublesome to economic growth. We argue that stability in oil markets cannot be achieved unless monetary policy is restrained and real interest rates become significantly positive. Simultaneously we reviewed crude oil price determinants and price properties, as well as elasticities during the main period and two sub-periods. We found that price elasticity and income elasticity of crude oil demand decreased in the second sub-period, because the crude oil market administrated a large structural change after the 70's oil shocks: high energy-taxation in oil importing countries, the establishment of the Strategic Petroleum Reserve (SPR), and a raise in share of other energy carriers such as natural gas in the energy importing countries energy basket, contributing significantly to the reduction in demand elasticity. Unlike earlier researches, we found that oil supply is elastic to prices in short-run, and during the second sub-period, the price elasticity increased compared to the first sub-period. Our attempts to test the hypothesis of equilibrium vs. disequilibrium in the oil market showed that crude oil prices adjust instantly and the results declare the existence of equilibrium in the oil market during 1960-2011.

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