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World Crude Oil Markets: Monetary Policy and the Recent Oil Shock

Noureddine Krichene

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Prepared by Noureddine Krichene[1]

Authorized for distribution by Abdoulaye Bio-Tchané

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Abstract

This paper examines the relationship between monetary policy and oil prices within a world oil demand and supply model. Low price and high income elasticities of demand and rigid supply explain high price volatilities and producers' market power. Exchange and interest rates do influence oil market equilibrium. The relationship between oil prices and interest rates is a two-way relationship that depends on the type of oil shock. During a supply shock, rising oil prices caused interest rates to increase; whereas during a demand shock, falling interest rates caused oil prices to rise. Record low interest rates led to high oil price volatility in 2005. Data shows that world economic growth and price stability require stable oil markets and therefore more prudent monetary policies.

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Keywords: Crude oil, demand, elasticities, exchange rates, impulse responses, interest rates, monetary policy, multipliers, oil shock, supply, volatility

Author(s) E-Mail Address: nkrichene@imf.org, nnkrichene@hotmail.com

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I. Introduction

Oil prices are of overriding concern. As economic activity is heavily dependent on energy use, runaway energy prices could become inflationary and cause an economic recession.[2] This paper analyzes the relationship between monetary policy and oil prices and shows that an oil demand shock, caused by record low interest rates, led to the exorbitant price increases noted in 2004–05. More specifically, monetary policy, conducted through changes in interest rates and monetary aggregates, has a significant and protracted effect on aggregate demand for goods and services as well as on asset prices such as exchange rates, housing prices, and stock prices. The sustained pressure on oil prices observed in 2004–05 can be explained by an excessively expansionary monetary policy, with interest rates falling to record levels in an integrated international capital market. Stimulated by low interest rates and a depreciating U.S. dollar, demand for oil has expanded faster than supply. Given the short-run price inelasticity of both oil demand and supply, equilibrium is obtained through a large increase in oil prices.

Based on time-series data for oil prices, exchange rates, and interest rates, this paper analyzes the influence of monetary policy on oil prices. The paper is organized as follows. Section II analyzes oil futures' prices and presents estimates of implied volatility and GARCH volatility.[3] Section III analyzes a simultaneous equations model (SEM) for demand and supply of oil, which emphasizes the role of exchange and interest rates in influencing equilibrium in oil markets. This section establishes empirical evidence on demand and supply elasticities; namely, price elasticities are very low, and income elasticity is relatively high and significant. It also shows that exchange and interest rates act negatively on oil demand and prices. Section IV analyzes the role of monetary policy by studying the relationship between oil prices and interest rates. It shows that this relationship is a two-way relation that depends on the type of oil shock. During an oil supply shock, oil prices led interest rates; whereas during an oil demand shock, interest rates led oil prices.[4] A vector autoregressive model (VAR) is used to analyze the effect

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[2] Hamilton (1983, 2003) observed that all post-war U.S. economic recessions, but one (that in 1960–61), were preceded by crude oil price increases. Asymmetric models for studying the relationship between oil shocks and the macroeconomy (e.g., Balke et al., 2002) show that oil price increases cause a contraction of GDP, whereas oil price declines tend to have a less noticeable effect. Jones et al. (2004) reported that best estimate of the oil price-GDP elasticity was –0.055. Oil price shocks are amplified through many channels. Most important among these channels is monetary policy as emphasized, for instance, in Bernanke et al. (1997). Rotemberg and Woodford (1996), however, have argued that an oil price shock is amplified through increases in mark-ups that depress output.

[3] GARCH stands for Generalized Autoregressive Conditional Heteroskedasticity.

[4] An oil supply shock is defined as a disturbance in oil supply in normal demand conditions, often caused by exogenous factors. An oil demand shock is a disturbance in oil demand in normal supply conditions; it could result from endogenous factors.

of an interest rate shock on oil prices. Section V deals with the reduced form of the SEM and shows that the model fits closely the data. It presents estimates of the model's multipliers and discusses impulse responses to oil price and interest rate shocks. Section VI concludes.

The main conclusion of the paper is that stabilization of oil markets requires a tightening of monetary policy and an increase in ex-ante real interest rates. Based on data for 1970–86, the degree of monetary tightening to rein in oil prices and their inflationary implications may be substantial and may involve a trade-off between inflation and output. In the same vein, based on data for 1986–2000, sustained noninflationary world economic growth would require a degree of stability in oil markets.

II. Oil Price Volatility

Crude oil futures' prices have rapidly increased from around US$30/barrel (bl) in 2004 to being close to US$70/bl in September 2005, equivalent to an increase of about 133 percent (Figure 1).[5] The upward trend was persistent and forecastable. Persistence was shown by the existence of a unit root in the AR1 process. Namely, daily crude oil prices tended to follow a random walk with an upward drift. In spite of this rapid price increase, crude oil supply has been almost stagnant at 84–85 million barrels a day, implying that crude oil production has been seriously constrained by resources availability.

A. Crude Oil Price Volatility

It is worthwhile studying the volatility of oil prices. Volatility measures the uncertainty in the oil prices. The higher the volatility, the greater is the uncertainty facing the market. There are many methods for measuring volatility. Two types of volatilities are studied here: the implied volatility from crude oil call options and volatility computed by a GARCH (1,1) model.[6] Oil futures prices implied volatility (Figure 2) has reached high levels during February 2005–September 2005, averaging about 30 percent, and showing that the market was experiencing big uncertainty regarding expected price developments. Volatility has even increased during July–September 2005, rising to 40 percent, indicating that markets have become very sensitive to small shocks and to news.[7] High volatility increases speculative demand for futures contracts and even contributes to higher volatility and volatility clustering. Volatility was also computed using a GARCH model for data on daily oil futures prices, denoted by p_t, and covering March 22, 2004–September 28, 2005. The oil price return was defined as: $dp_t = p_t - p_{t-1}$.

[5] Data on daily crude oil futures prices and implied volatility were obtained from Bloomberg.

[6] Implied volatility is the volatility which equates the Black-Scholes option pricing formula to the call option's market value.

[7] For instance, Hurricane Katrina (September 2005) took place at a time of already highly volatile markets. By causing temporary damage to U.S. oil refineries in the Gulf of Mexico, oil prices soared beyond the $70/bl mark.

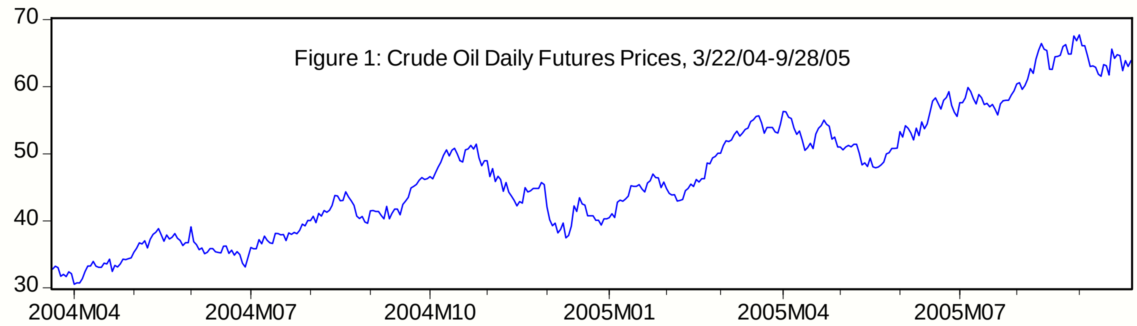
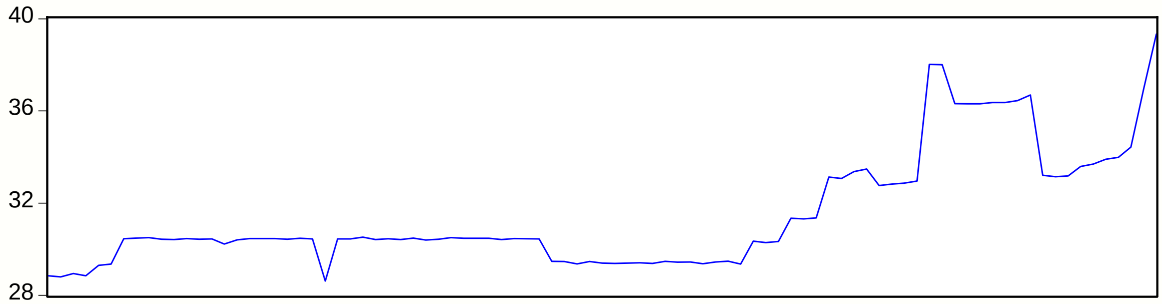


Figure 1: Crude Oil Daily Futures Prices, 3/22/04-9/28/05

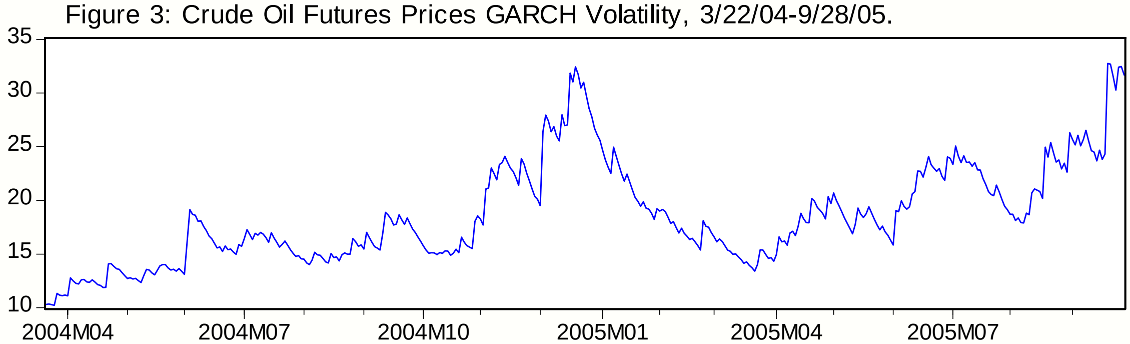
Source: Bloomberg. Prices are in U.S. dollars per barrel.

Figure 2: Crude Oil Implied Price Volatility, February, 2005-August, 2005.



Source: Bloomberg.

Figure 3: Crude Oil Futures Prices GARCH Volatility, 3/22/04-9/28/05.



The mean equation: $dp_t = c + \varepsilon_t,\ \varepsilon_t \sim N(0, \sigma_t^2)$

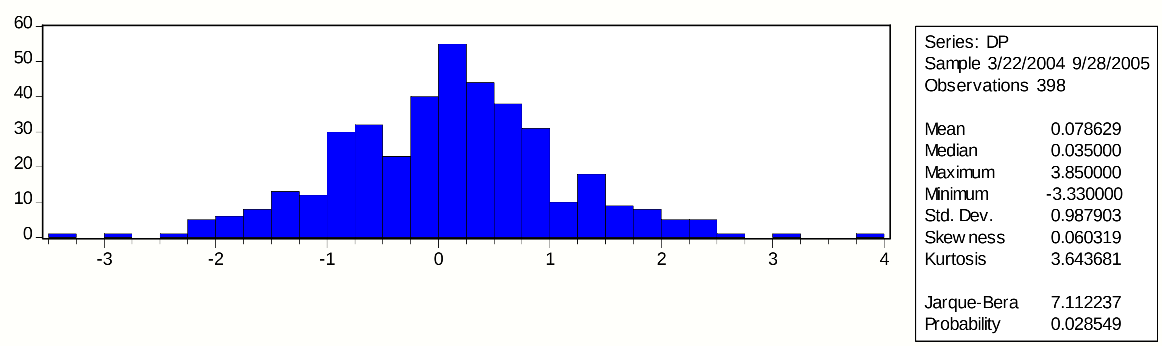
The conditional variance equation: $\sigma_t^2 = \omega + \alpha\varepsilon_{t-1}^2 + \beta\sigma_{t-1}^2$, where $\sigma_t^2 = E(\varepsilon_t^2)$

The fitting of the GARCH model showed high price volatility and periods of volatility clustering in the data sample under study. Volatility was rising during 2004, reaching an excessive level of 32.4 percent as oil prices were climbing to higher levels; volatility receded somehow in early 2005 as oil prices retreated; and then it started rising again reaching 32.5 in September 2005 as oil prices resumed their upward trend.[8]

B. Crude Oil Price Distribution

The returns of oil prices are plotted (Figure 4). It appears that oil price returns are not normally distributed. The empirical distribution has a large dispersion; the mean/standard deviation ratio is very low. The distribution is right skewed, implying that upward jumps are more frequent than downward jumps, and has fat tails meaning that large jumps tend to occur more frequently than in the normal case.

Figure 4: Crude Oil Price Returns Distribution, Daily, 3/22/2004–9/28/2005



These empirical findings about crude oil daily futures' prices are typical of financial time series as noted in Clark (1973), Fama (1965), and Mandelbrot (1963). These facts suggest modeling the oil price process as a jump-diffusion or, in a more general way, as a Levy process (Cont and Tankov, 2004). The estimation of these processes necessitates the knowledge of the probability density or the characteristic function of the process. Characteristic functions are easier to obtain and are available in closed forms. However, probability density may not be always available in closed forms, and even if they are available, they may involve special functions and may be complicated to handle.

[8] Volatility was also studied using a Kalman filter. A state space model can be expressed as:
Observation equation: $dp_t^2 = h_t + \varepsilon_t$, $\varepsilon_t \sim N(0, \sigma_\varepsilon^2)$

Transition equation: $h_t = \mu + \phi(h_{t-1} - \mu) + \eta_t$, $\eta_t \sim N(0, \sigma_\eta^2)$

Where h_t is a state variable (volatility). Application of Kalman filter confirms the volatility surges revealed in the GARCH model. Particularly, volatility was high in the fourth quarter of 2004 when prices were heading to \$50 per bl mark as well as in the third quarter of 2005 when prices quickly neared the \$70 per bl mark.

III. THE DEMAND AND SUPPLY OF CRUDE OIL

The price and volatility developments described in Section II deserve to be fully explained. Namely, what are the basic properties of oil markets that cause high volatility in oil prices? For this purpose, a simultaneous equations model (SEM) for world crude oil demand and supply is studied. The SEM emphasizes the role of the exchange and interest rates. Besides estimating elasticities, the purpose of the model is also to study the effect of the exchange and interest rates on the oil markets. The general dynamic form of the model can be expressed as: $A(L)Z_t + B(L)X_t = U_t$, where Z_t are the endogenous variables, X_t the exogenous variables, and U_t the error terms. $A(L)$ and $B(L)$ are linear lag operators. More specifically, the model can be defined as follows:

Crude oil demand: $qo_t = \gamma_p po_t + \gamma_y y_t + \gamma_i i_t + \gamma_{neer} NEER_t + c_d + u_d$

Crude oil supply: $qo_t = \delta_p po_t + \delta_{ng} ng_t + c_s + u_s$

Except for the interest rate, all variables are in logarithm form:[9]

qo_t = crude oil output, in millions of barrels per day;

po_t = crude oil nominal price, in U.S. dollars per bl;

ng_t = natural gas output, in billions of cubic meters per year;

y_t = real GDP index for the G7 countries;

i_t = interest rate (federal funds rate, the three-month U.S. Treasury bill rate, or the U.S. government ten-year bond yield);[10]

$NEER_t$ = the U.S. dollar nominal effective exchange rate.

The demand for oil is a function of own price and an indicator for world economic activity, which is approximated by the real GDP of the G7 countries. Interest rates and the NEER are also added as explanatory variables. The supply of oil is a function of own price and natural gas

[9] Data sources are described in the Appendix.

[10] The choice of U.S. interest rates can be explained by the fact that they are the main determinants of interest rates in World capital markets.

production.[11] c_d and c_s are constants. Each residual u_d and u_s is assumed to be serially uncorrelated, independently and identically distributed with mean zero and standard error σ_d and σ_s , respectively, and uncorrelated with the predetermined and exogenous variables. It may be further assumed that demand and supply disturbances are uncorrelated, implying $E(u_d u_s) = 0$. The model is identified: no one equation can be obtained as a linear combination of two or more equations.[12] Given the dynamics of adjustment in demand and supply, lagged variables have to be introduced. Tests on the length of the lag based on the Akaike information criterion seemed to indicate that the optimal lag would be two periods. The model was estimated by a two-stage least-squares method to obtain short-run estimates. Long-run elasticities were estimated with the help of the error correction method (ECM) and with cointegration analysis;[13] these two methods were appropriate for finding long-run relations in each identified equation of the model. Four versions of the model were considered, which extended the basic model to include progressively the exchange rates and the interest rates.[14] The model was estimated using quarterly data

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[11] Oil and natural gas are often modeled as joint products. Erickson and Spann (1971) expressed the supply of natural gas as a function of own price and the price of oil. The inclusion of natural gas output in the supply function for crude oil enables to identify the demand function and can be justified on the grounds that (i) the two products are often interdependent at the level of exploration, development, and production activities; and (ii) they are also close substitutes in many uses. The correlation coefficient between crude oil and natural gas production over 1970–2005 was 0.996. One can alternatively include the price of natural gas. The correlation between the price of crude oil and that of natural gas was of the order of 0.97 for the same period.

[12] In addition, the order condition for identification of an equation within a system requires the number of excluded predetermined variables to be equal to or higher than the number of included endogenous variables minus one; or, equivalently, the number of exclusions has to be higher than or equal to the number of endogenous variables minus one. Because the number of endogenous variables is two, and the number of instrumental variables is four, the order condition is satisfied in each equation of the model.

[13] Consider the lag model: $y_t = \delta_0 + \delta_1 y_{t-1} + \gamma_0 x_t + \gamma_1 x_{t-1} + \varepsilon_t$; in an error correction form, it becomes $\Delta \mathrm{y_t} = \delta_0 + \gamma_0 \Delta x_t + (\delta_1 - 1) y_{t-1} + (\gamma_0 + \gamma_1) x_{t-1} + \varepsilon_t$, or $\Delta \mathrm{y_t} = \delta_0 + \gamma_0 \Delta x_t + (\delta_1 - 1)(y_{t-1} + \frac{(\gamma_0 + \gamma_1)}{(\delta_1 - 1)} x_{t-1}) + \varepsilon_t$. The term $(y_{t-1} + \frac{(\gamma_0 + \gamma_1)}{(\delta_1 - 1)} x_{t-1}) = 0$ represents the long-run relation.

[14] Theoretically, the exchange and interest rates are related by the interest rates parity; namely, the expected change in the exchange rate is related to the interest rates differential. For this reason, it may be legitimate to include only the interest rates in the demand for crude oil equation. However, since the interest rates differential is not available in the data set, it was decided to include both the exchange and interest rates in the demand equation.

for 1984Q1–2005Q2, and annual data for 1970–2005. The purpose of modifying both the frequency and the sample period of the data was to yield robust estimates.

Short-Run Demand for Crude Oil

Both quarterly and annual data support the hypothesis of low short-run price demand elasticity, ranging between –0.02 and –0.03, implying that changes in oil prices have a small partial effect on demand for crude oil (Table 1). This result is extremely important and lies at the core of the crude oil market. It explains the volatility of oil markets and their vulnerability to small shocks. It is implied by the fact that energy consumption is determined in the short-run by fixed equipment and prevailing technologies and offers limited scope for substantial variation in relation to price movements. Data also supports the hypothesis of a significant effect of the economic activity on the demand for crude oil. Short-run income elasticity is statistically significant and ranges between 0.12 and 0.19. This finding is particularly important as it demonstrates clearly that oil demand is responsive to changes in the economic activity. Higher economic activity would entail an increase in demand for oil. This finding regarding income elasticities is also essential to explain the forces that affect the oil markets.[15]

The extension of the model to study the role of the NEER and the interest rates yields interesting results. The demand for crude oil is negatively related to the NEER. The NEER elasticity tends to be statistically significant, although at a higher probability value, and ranges between –0.03 and –0.09. An appreciation (depreciation) of the U.S. dollar would tend to make oil more expensive and would reduce (increase) the demand for crude oil. Regarding the role of the interest rate, the latter tends to act negatively on the demand for crude oil; however, the interest rate semi-elasticity is statistically significant only for the annual data. An increase in the interest rate would act to reduce the demand for crude oil and vice-versa. The quarterly interest rate semi-elasticity is negative, however, not statistically significant. This can be explained by the fact that interest rates work with a lag. Changes in interest rates are not transmitted instantaneously to the economic activity and prices; their effect is known to work with a delay. These results concerning the NEER and the interest rates will be quite relevant when studying the role of monetary policy in the next section. They show clearly that oil markets can be significantly influenced in the short-run by monetary policy.

[15] Similar modeling approaches and results can be found in Pindyck (1979), and Pesaran et al. (1998). Albeit using asymmetric oil demand models, Gately and Huntington (2002) reported, for a sample of 96 countries for the years 1971 to 1997, short-run price elasticities ranging between –0.04 (price cut) and –0.08 (price increase) for OECD countries, and –0.01 (price cut) and –0.03 (price increase) for non-OECD countries. However, attributing asymmetric response to omission of technical change, Griffin and Schulman (2005) demonstrated empirically, using a panel of OECD countries for the years 1961 to 1999, that symmetric price responses of energy and oil demand functions cannot be rejected after explicitly controlling for energy saving-technical change within fixed-effects models. Their preferred symmetric oil demand model implies a 0.37 income elasticity and a –0.09 short-run price elasticity.

Table 1. World Crude Oil: Short-Run Demand and Supply Elasticities 1/

	Quarterly: 1984Q1–2005Q2	Annual: 1970–2005
Crude oil demand: model 1: demand=f(crude price, GDP)		
Price elasticity	–0.02 (–1.59)	–0.03 (–3.41)
Income elasticity	0.19 (4.02)	0.12 (2.69)
Crude oil demand: model 2: demand=f(crude price, GDP, NEER)		
Price elasticity	–0.02 (–1.62)	–0.02 (–2.55)
Income elasticity	0.19 (3.98)	0.15 (2.66)
NEER elasticity	–0.03 (–1.87)	–0.09 (–1.71)
Crude oil demand: model 3: demand=f(crude price, GDP, interest rate)		
Price elasticity	–0.02 (–1.34)	–0.0003 (–0.20)
Income elasticity	0.18 (3.28)	0.10 (2.37)
Interest rate semi-elasticity	–0.001 (–0.63)	–0.004 (–2.50)
Crude oil demand: model 4: demand=f(crude price, GDP,NEER, interest rate)		
Price elasticity	–0.02 (–1.43)	0.005 (0.34)
Income elasticity	0.18 (3.35)	0.11 (2.66)
NEER elasticity	–0.03 (–1.79)	–0.09 (–1.85)
Interest rate semi-elasticity	-0.0008 (-0.39)	–0.004 (–2.62)
Crude oil supply		
Price elasticity	0.005 (0.91)	–0.03 (–3.70)
Natural gas elasticity	0.26 (4.08)	0.11 (2.42)

1/ The *t*-statistics are between parentheses.

Long-Run Demand for Crude Oil

The long-run demand for crude oil turns out to be price inelastic (Table 2). Even though the long-run demand price elasticity is higher than the short-run one, it is still low. It is statistically significant and ranges between –0.03 and –0.08, depending on the frequency and sample size.[16] Long-run income elasticity tends to be higher than the short-run one. It is statistically significant and ranges between 0.54 and 0.90; however, it is still less than unity. The NEER and the interest rates are found to affect long-run demand for crude oil. The long-run NEER elasticity is statistically significant and ranges between –0.26 and –0.29. An appreciation of the NEER would reduce demand for oil, and vice-versa. The interest rate semi-elasticity is significant and negative. It ranges between –0.01 and –0.06. An increase in the interest rates tends to affect

[16] Gately and Huntington (2002) reported, for long-run oil demand, a price elasticity of the order of –0.64 and an income elasticity of the order 0.56 for the OECD countries; the corresponding elasticities for the non-OECD countries were, respectively, –0.18 and 0.53. The differences with the long-run price elasticities in this paper are rather striking. They could originate from differences in data (time-series versus cross-section), sample period, and estimation techniques.

Table 2. World Crude Oil: Long-Run Demand and Supply Elasticities 1/

	Quarterly: 1984Q1–2005Q2	Annual: 1970–2005
Crude oil demand: model 1: demand=f(crude price, GDP)		
Price elasticity	–0.03 (–0.98)	–0.08 (–2.72)
Income elasticity	0.75 (14.16)	0.64 (9.88)
Crude oil demand: model 2: demand=f(crude price, GDP, NEER)		
Price elasticity	–0.05 (–0.78)	–0.06 (–3.02)
Income elasticity	0.90 (7.71)	0.54 (11.41)
NEER elasticity	–0.29 (–2.05)	–0.26 (–2.97)
Crude oil demand: model 3: demand=f(crude price, GDP, interest rate)		
Price elasticity	–0.06 (–1.18)	–0.01 (–0.58)
Income elasticity	0.25 (1.25)	0.26 (6.06)
Interest rate semi-elasticity	–0.06 (–3.77)	–0.01 (–6.64)
Crude oil supply		
Price elasticity	0.007 (1.24)	0.08 (2.63)
Natural gas elasticity	0.73 (50.7)	0.30 (4.23)

1/ The *t*-statistics are between parentheses.

negatively the demand for oil. The results concerning the role of the NEER and the interest rates are very relevant for the study of the role of monetary policy in influencing the oil markets. They demonstrate that monetary policy can have a long-term influence on oil markets.

Short-Run Supply of Crude Oil

The short-run supply of crude oil tends to be price inelastic. It seems to respond negatively to price changes, implying that producers do not expand output in the face of a price increase because of short-run capacity constraints, quota fixation, or to preserve significant price increases. Similarly, producers do not reduce output in the face of large declines in prices. In some circumstances of depressed oil prices, some oil producers tend to supply more than the quotas in order to generate badly needed budgetary revenues, particularly in the case of oil producers whose budgets rely heavily on oil revenues. This result concerning the price supply elasticity is extremely important to comprehend the functioning of the oil markets and to explain the volatilities of oil prices. Namely, supply is price-inelastic and cannot expand in face of excess demand or large price increases. Short-run crude oil supply is significantly influenced by the natural gas production. The short-run elasticity ranges between 0.11 and 0.26. Crude oil and natural gas are technically and economically interdependent. For this reason, an increase in natural gas production may be accompanied by an expansion in crude oil production.[17]

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[17] Erickson and Spann (1971) showed that supply curves for natural gas and crude oil are theoretically related and an increase in one leads to an increase in the other.

Long-Run Supply of Crude Oil

The long-run price elasticity is positive, but it remains low. It is significant and estimated at 0.08 for the annual data. This result shows that long-run oil supply is determined by technological factors and discoveries, and is less responsive to prices.[18] Natural gas continues to play an important role in the supply of crude oil. The long-run natural gas elasticity is statistically significant and ranges between 0.30 and 0.73.

The findings of this section represent basic properties of the oil markets. Particularly, these markets are characterized by price inelastic demand and supply. Many episodes of sizeable up-and-down jumps in prices and rising volatilities provide evidence of this inelasticity. The implication of the price inelasticity is that small excess demand would require a large change in prices to clear the market. Demand is, however, responsive to the income level, whereas supply can be influenced by the natural gas production. These two products are perfectly correlated over 1970–2005. A novelty in oil modeling in this section is to show that oil markets are vulnerable to macroeconomic policies, in particular to monetary policy that is transmitted to the oil markets via exchange and interest rates channels.[19]

IV. Role of Monetary Policy in the Oil Markets

Monetary policy is conducted by the monetary authorities through monetary instruments and also through controlling the monetary aggregates. A standard model for analyzing monetary policy is composed of three equations (McCallum and Nelson, 2000): an IS curve, an aggregate supply (AS) curve, and an interest rate feedback policy equation:

IS curve $y_t = -\sigma(i_t - E_t \Delta p_{t+1}) + E_t y_{t+1} + \nu_t$

Aggregate supply (AS) (Augmented-Phillips curve) $\Delta p_t = \lambda(y_t - \bar{y}_t) + \beta E_t \Delta p_{t+1} + \varepsilon_t$

Interest rate policy equation (Taylor's rule) $i_t = \mu_1 \Delta p_t + \mu_2 (y_t - \bar{y}_t) + \mu_3 i_{t-1} + \eta_t$

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[18] Erickson and Spann (1971) reported, for the period 1946–1958/59, own price elasticity of supply of crude oil discoveries at 0.83, and own price elasticity for natural gas discoveries at 0.69. The long-run price elasticity in this paper is rather dismal. Prices are the most important variable in a demand or supply model. While world crude oil supply grew at an average rate of 1.7 percent a year during 1970–2005, prices exhibited very wide fluctuations, which weaken the statistical relation between supply and prices. One way around this difficulty is to use asymmetric supply model with a filter for oil prices, which considers net oil price increase as in Hamilton (1983 and 2003), or which accounts for price volatility as in Lee et al. (1995).

[19] Bernanke and Blinder (1992) showed that monetary policy is also transmitted via credit and deposits channels.

Where y_t is aggregate output, $\bar{y}_t$ is potential or full employment output, p_t is the price level, Δp_t is the inflation rate, i_t is the nominal interest rate, and ν_t, ε_t, and η_t are shocks to aggregate demand, aggregate supply, and monetary policy, respectively. Finally, E_t is an expectation operator. In this model, monetary aggregates are omitted, and monetary policy is essentially based on Taylor's rule which consists of adjusting the interest rate in response to inflation or to the output gap. In the above model, aggregate demand responds negatively to ex-ante real interest rate and positively to expected output. A drop in ex-ante real interest rate will be expected to stimulate aggregate demand and, by the same token, aggregate demand for energy, as the latter is closely related to aggregate demand as shown in Section III. The AS equation describes the change in the aggregate price level as a function of expected future inflation and the deviation of output from its natural rate $\bar{y}_t$, which would obtain under fully flexible prices.[20] Accordingly, higher aggregate demand contributes to stimulate inflation.

A. Technical Chart of the Crude Oil Price, Interest Rates, and the NEER

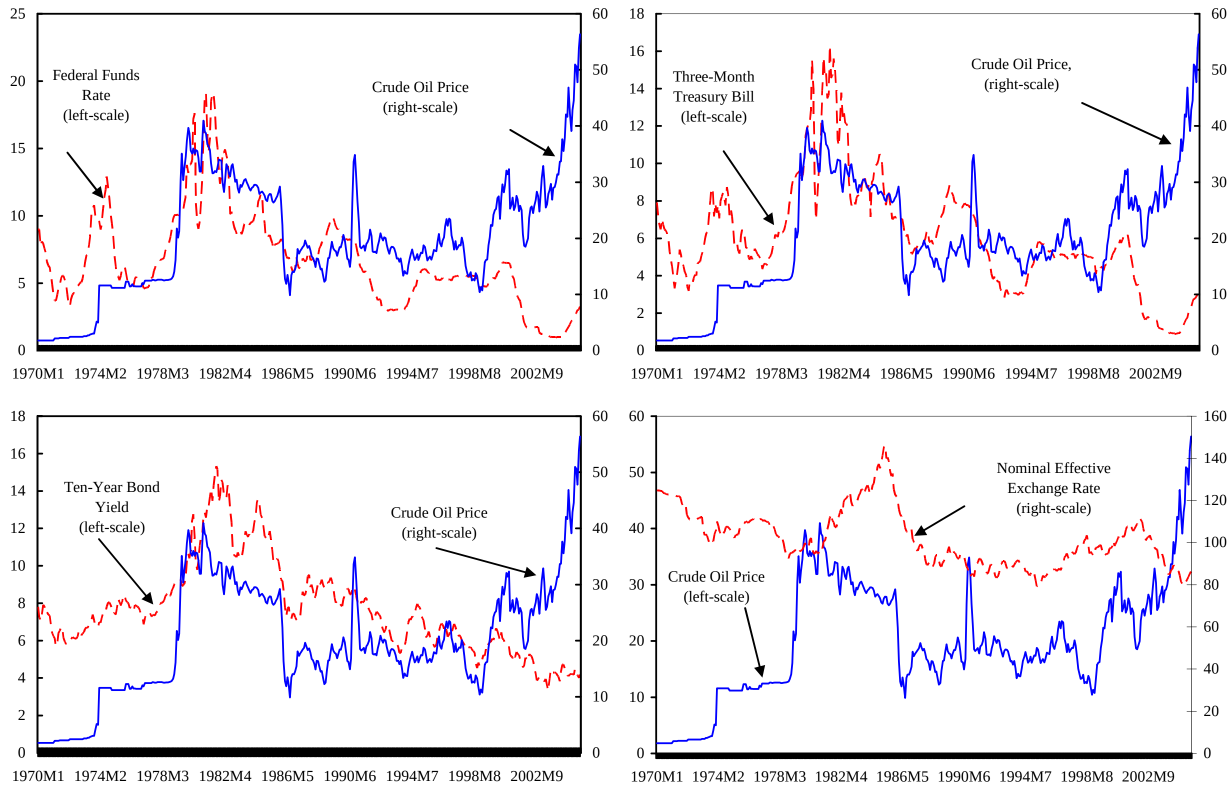
Monthly time series spanning 1970–2005 for crude oil prices, interest rates, and the NEER is plotted in Figure 5. Broadly, three epochs can be distinguished. The first epoch spans 1970–1986; the second epoch spans 1986–1999; and the third spans 1999–2005. The first period was obviously characterized by oil supply shocks. Oil prices kept rising and peaked at US$41/bl in 1980M11. As a result, world inflation rose to two-digit levels, peaking at 13.5 percent in 1974 and 13.2 percent in 1980, and averaging 10.1 percent during 1974–81.[21] Monetary policy had to be deployed to cope with the oil shock and the oil-induced inflationary pressure. Monetary policy was obviously counterreacting to the oil supply shock.[22] The response aspect

[20] The solution for this rational expectations model is described in Blanchard and Kahn (1980).

[21] World inflation and oil prices were highly correlated during the period 1970–2005. A regression equation gives the following result: $\log(p) = 1.03\log(po) + 0.91\mathrm{Re}\,sidual(-1) + 4.93$, $R^2 = 0.91$, $DW = 1.92$. The *t*-statistics are 12.3, 12.07, and 45.94, respectively, showing that the coefficients are statistically significant and that oil prices have strong impact on world inflation.

[22] Based on Hamilton's findings that post-war U.S. recessions, namely those prior 1972 and the recessions of 1973-75, 1980-82, and 1990-91, were preceded by crude oil price increases, Bernanke et al. (1997) found a significant role for endogenous monetary policy, and that total effect of oil price shocks on the economy was strongest during the Volcker era when the monetary response to inflationary shocks was the strongest. They observed that a number of most significant tightenings of U.S. monetary policy has followed on the heels of major increases in the price of oil.

Figure 5. Crude Oil Price, U.S. Interest Rates, and U.S. Dollar NEER, 1970M1-2005M7.



Source: International Financial Statistics, International Monetary Fund.

is demonstrated by the fact that interest rates kept chasing oil prices and peaked only after oil prices reached a peak. Indeed, the federal funds rate peaked at 19.08 percent in 1981M1, the U.S. Treasury bill rate at 16.29 percent in 1981M5, and the ten-year government bond yield at 15.32 percent in 1981M9.[23] Because of high interest rates, the NEER appreciated significantly,

[23] Because inflationary expectations became self-fulfilling, Clarida et al. (2000) argued that monetary policy adopted a strictly non-accommodative stance and targeted the non-borrowed reserves during 1979:10–1982:10, which explains the big jumps in the federal funds rate during this period. They noted, however, that monetary policy was accommodative in the pre-Volcker era; more specifically, nominal interest rates rose by less than the expected inflation, contributing thus to a decline in the real interest rates and a further rise in aggregate demand and inflation. Bernanke and Mihov (1998) and Strongin (1995) indicated that, during 1979:10 and 1982:10, monetary policy was targeting non-borrowed reserves, causing an increase in real interest rates which brought down inflation from 10 percent in 1980 to 4 percent in 1983. Bernanke and Mihov (1998) reported that monetary policy was not accommodating shocks to demand for banks' reserves during this period. Their coefficient of accommodation fell to 0.1.

making oil more expensive. Ultimately, world economic growth contracted sharply to a meager average growth rate of 0.8 percent during 1980–82, forcing a sustained decline in both crude oil prices and world inflation rate during 1981–86.

The second period spanning 1986–99 was a period of relative stability for oil prices. A unit root test shows that oil prices were stationary during this period. The NEER also tended to be stationary. Interest rates were, however, highly nonstationary, implying that monetary policy remained active during this period. Nonetheless, monetary policy was neither too loose nor too tight to cause upward or downward pressure on oil prices, and was mainly geared toward maintaining the growth and price stability momentum. The monetary policy was eased during 1992–93, but then it was tightened without a sensible impact on oil prices. The third period spanning 1999–2005 was characterized by historically record low interest rates and by a depreciating NEER. Interest rates were ostensibly taking the lead over crude oil prices. The federal funds rate was maintained at 1 percent during 2003M7–2004M6, while the U.S. Treasury bill rate was less than 1 percent during most of this period. In the event, crude oil prices started rising rapidly, exceeding the mark of US$70/bl in September 2005.

B. Regression Analysis

Besides chart analysis, econometrics can be applied to study the relationship between crude oil prices, interest rates, and the NEER. Based on the above analysis, this relationship is characterized by a two-way causality, depending on the type of shock. During an oil supply shock, causality could be seen as running from oil prices to interest rates; whereas during a demand shock, causality seems to run from interest rates to crude oil prices.

The Supply Shock Period

The supply shock period has two phases: the rising phase and the declining phase of oil prices. During the rising phase 1974–81, interest rates can be looked at as a policy variable geared toward containing unprecedented upward jumps in oil prices and their ensuing inflationary effect. The dependent variable is therefore the interest rate, which was responding to oil prices. During the descent phase 1982–86, monetary policy was being relaxed cautiously after oil prices were effectively contained and started a rapid descent. Interest rates were being lowered progressively after having achieved their objective of reversing the fast trend in oil prices and world inflation. The policy relation can be seen as a partial Taylor equation:

$$i_t = \alpha_1 \log(po_t) + \alpha_2 \operatorname{Re}sidual(-1) + \alpha_3 \operatorname{Re}sidual(-2) + c\,,\ \ \alpha_1 > 0$$

Where $\operatorname{Re}sidual$ is obtained from the regression $i_t = \alpha_1 \log(po_t) + c$ to correct for the Durbin-Watson statistic. The regression is estimated using both monthly and quarterly data which provides sufficiently large samples for obtaining asymptotically efficient estimators. The regression results show a strong positive response with monetary policy being vigorously and consistently tightened in order to rein in huge oil price increases (Table 3). The regression coefficient was estimated at 6.04. In percent, interest rates would increase by 6 percentages

Table 3. World Crude Oil: Relationship between interest rates and oil prices 1/

Oil Supply Shock: Tightening Monetary Policy: interest rates responding to rising oil prices						
Treasury bill rate	Crude oil price	Residual(-1)	Residual(-2)	R^2	D–W	Sample
	6.04 (28.84)	1.11 (10.6)	–0.38 (-3.60)	0.93	1.87	1975M1–1981M12
	6.04 (12.20)	0.76 (3.73)	–0.48 (0.23)	0.88	1.86	1975Q1–1981Q4
Oil Supply Shock: Relaxing Monetary Policy: interest rates responding to abating oil prices						
	4.56 (18.63)	0.89 (8.09)	–0.10 (–0.96)	0.89	1.98	1982M1–1986M12
	4.83 (10.57)	0.80 (4.94)	–0.52 (–4.94)	0.87	1.94	1982Q1–1986Q4
Oil Demand Shock: Lax Monetary Policy: oil prices responding to declining interest rates						
Crude oil price	Treasury bill rate	Residual(-1)	Residual(-2)	R^2	D–W	Sample
	–0.09 (–17.11)	1.14 (10.71)	–0.16 (–1.50)	0.95	2.01	1998M1–2005M7
	–0.09 (–6.02)	1.33 (7.21)	–0.47 (–2.46)	0.86	2.13	1998Q1–2005Q2

1/ The *t*-statistics are between parentheses.

points (600 basis points) for each 100 percent increase in oil prices. Indeed, data shows that crude oil prices went up from US$11.17/bl to US$40.97/bl during this period, while the federal funds rate went up from 4.61 percent to 19.1 percent and the U.S. Treasury bill rate from 4.35 percent to 16.29 percent. The second phase spanning 1982–86 could be seen as a progressive easing of monetary policy in response to the abatement of oil prices. Estimated at 4.56, the regression coefficient was significant and positive; however, its value was less than in the upward phase, indicating that monetary policy was cautiously relaxed.[24]

The Oil Demand Shock

When oil prices are exposed to a demand shock, the causality could be seen as running from interest rates to oil prices. The relationship between oil prices and interest rates could be seen as

[24] Granger causality test, using quarterly data on crude oil price and the federal funds rate for 1970Q1–1986Q4 and with a number of lags equal to four, gives for the null hypothesis: federal funds rate does not Granger–cause crude oil price: F–Statistic=0.75, probability=0.57; crude oil price does not Granger–cause federal funds rate: F–Statistic=4.07, probability=0.006. The test shows that causality is running from crude oil price to the federal funds rate.

a version of an aggregate supply curve. Low interest rates cause excess demand which feeds into higher prices. The dependent variable is therefore crude oil price and the forcing variable is the interest rate.

$$\log(po_t) = \beta_1 i_t + \beta_2 \operatorname{Re}sidual(-1) + \beta_3 \operatorname{Re}sidual(-2) + c\,,\ \ \beta_1 < 0$$

Where $\operatorname{Re}sidual$ is obtained from the regression $\log(po_t) = \beta_1 i_t + c$ to correct for the Durbin-Watson statistics. The regression coefficient is significant and negative, showing that lower interest rates were causing excess demand for crude oil and, therefore, causing oil prices to rise rapidly.[25]

C. Vector Autoregression (VAR) Analysis

The regression analysis has helped to determine the nature of the relationship between interest rates and crude oil price according to the type of shock and causality. VAR analysis can be useful to simulate impulse responses to shocks affecting endogenous variables. A trivariate VAR formed of crude oil price, interest rates, and NEER is estimated for evaluating the impact of innovations affecting each of these variables respectively. The VAR is estimated on monthly and quarterly data. The impulse responses are portrayed in Figure 6. For the period 1974–86, which corresponds to the oil supply shock period, the ordering of variables is: interest rates, NEER, and crude oil prices. A positive shock to oil price has a positive impulse response on interest rates as shown in the regression analysis.[26] A positive shock on the NEER has a negative impulse response on the oil price. For the period 1998–2005, which corresponds to an oil demand shock period, the ordering of variables is: crude oil, NEER, and interest rates. The impulse response shows that a negative innovation in interest rates has a positive response in oil prices.[27] In the same vein, a negative innovation in NEER has a positive effect on oil prices. The inverse relation among oil price, interest rates, and NEER is borne out by both monthly and quarterly data.

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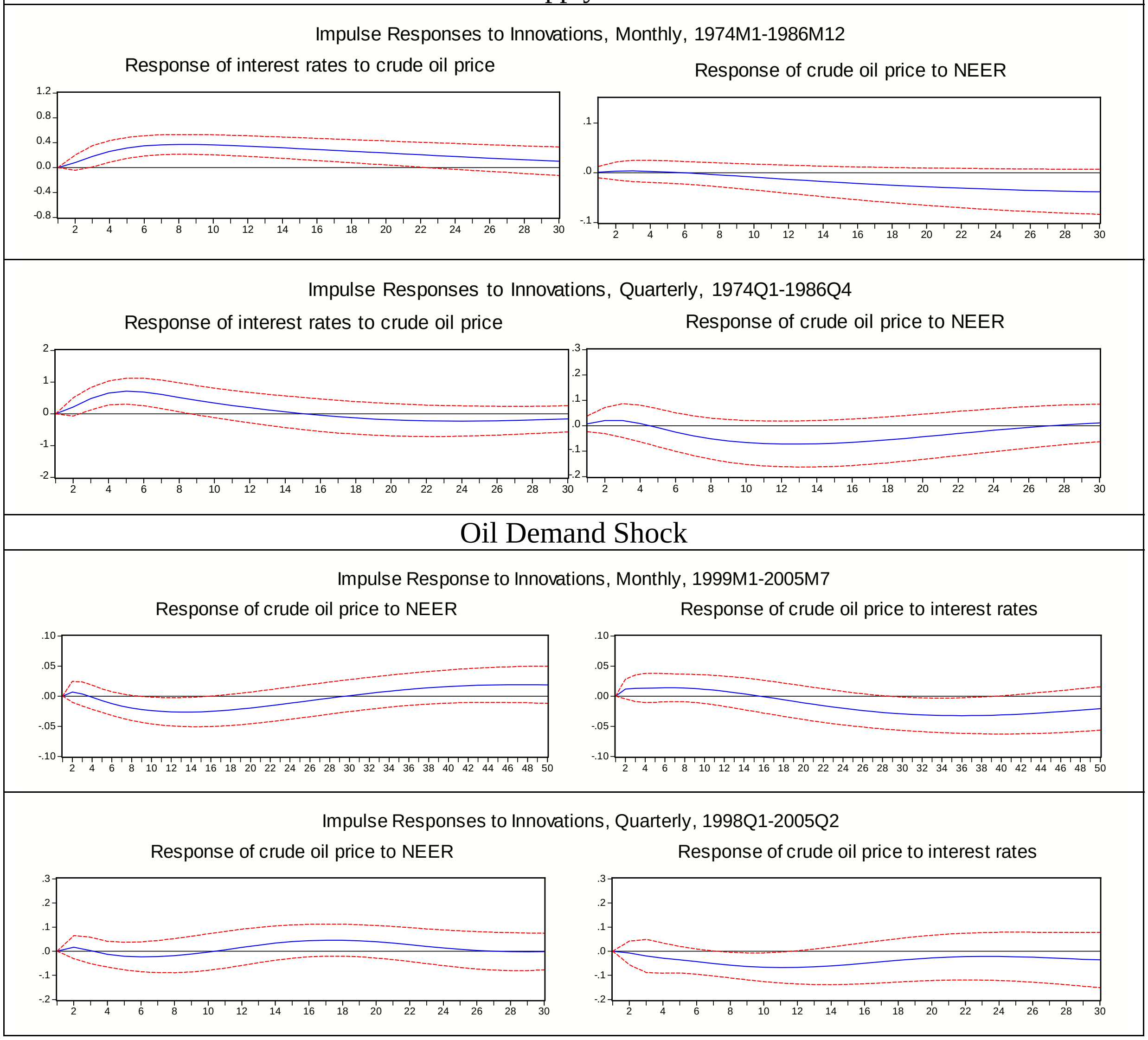
[25] Granger causality test, using quarterly data on crude oil price and the federal funds rate for 1999Q1–2005Q2 and with a number of lags equal to two, gives for the null hypothesis: federal funds rate does not Granger–cause crude oil price: F–Statistic=3.86, probability=0.04; crude oil price does not Granger–cause federal funds rate: F–Statistic=2.46, probability=0.11. The test shows that causality is running from the federal funds rate to crude oil price.

[26] This is a stylized finding of VAR models dealing with the oil shocks and the macroeconomy. Bernanke et al. (1997) reported that short- and long-term interest rates are positively affected by a positive innovation to oil prices. Dealing with asymmetric responses, Balke et al. (2002) showed that interest rates rise in response to a positive oil shock.

[27] In the same vein, Bernanke et al. (1997) showed, in a counterfactual simulation, that an increase in the federal funds rate causes a depressing effect on oil prices.

Figure 6: Impulse Responses from a VAR for Crude Price, NEER, and Interest Rates

Oil Supply Shock



The VAR analysis is further substantiated by reporting the results of vector error correction analysis for each shock period separately (Table 4). For the oil supply shock period 1974–1986, the relationship between interest rates, NEER, and crude oil prices can be described by a cointegration relation normalized on the interest rate and with coefficients that indicated that interest rates were moving in the same direction as crude oil prices. Similarly, for the crude oil demand shock period 1999–2005, the relationship between crude oil price, NEER, and interest rates can be described by a cointegrating vector normalized on the crude oil price and with coefficients that indicated that crude oil prices were moving in an inverse manner with the interest rates.

Table 4. Cointegrating Relations Between Crude Price, the NEER, and Interest Rates 1/

Oil supply shock period				
Treasury Bill Rate	NEER	Crude Oil Price	Constant	Sample
1	10.54 (3.80)	–4.69 (–7.08)	–43.57	1975M1–1987M12
1	8.62 (2.96)	–5.50 (–8.29)	–32.15	1975Q1–1987Q4
Oil demand shock period				
Crude Oil Price	NEER	Treasury Bill Rate	Constant	Sample
1	1.88 (2.14)	0.18 (4.0)	–12.44	2000M1–2005M7
1	0.82 (0.44)	0.34 (5.07)	–8.02	1998Q1–2005Q2

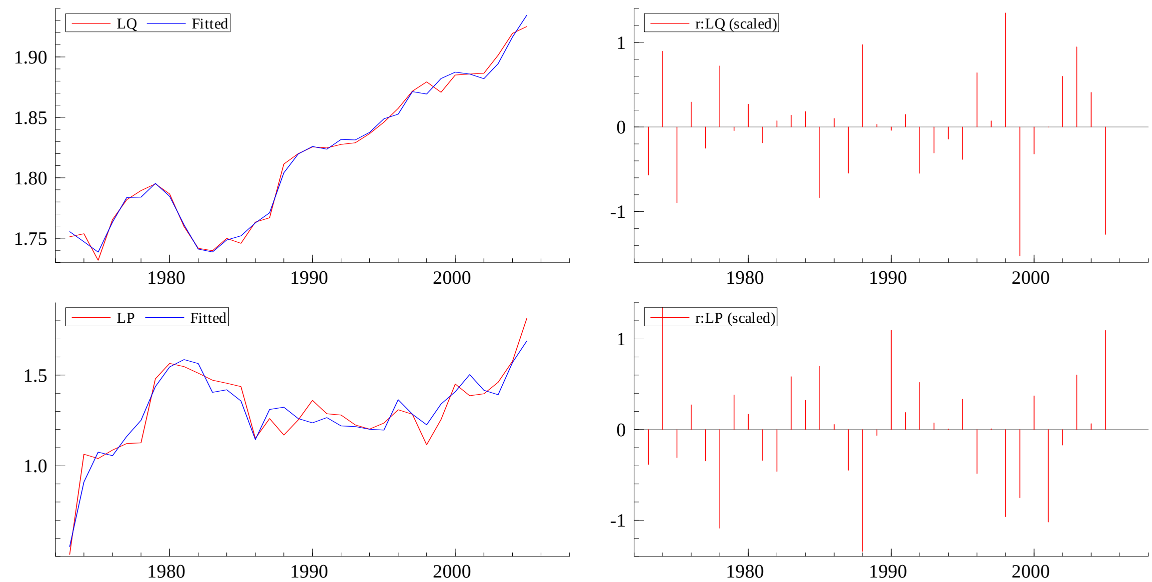
1/ The *t*-statistics are between parentheses.

The findings of this section are very relevant for policy analysis. During the oil supply shock period, it was evident from data on interest rates and crude oil prices that powerful actions on interest rates had to be undertaken to choke off oil price increase, thereby causing a severe contraction of world economic growth. These actions were reinforcing other measures that were simultaneously adopted to curb oil prices, such as high taxes on petroleum consumption, energy substitution and conservation, and technological change oriented toward higher energy efficiency. During the oil demand shock period, oil prices were responding powerfully to historically record low interest rates. Noting that crude oil supply is rigid in the short run, small excess demand for crude oil both for consumption or speculation purposes will cause, in view of the low price elasticities, large changes in oil prices. Being obviously a policy variable, strong action on interest rates, as shown by empirical evidence during the oil supply shock period, will be required to contain the oil price increase. These actions may cause a temporary contraction in world economic growth.

V. Solution of the SEM

The SEM can be written as $BZ_t + CX_t = U_t$, where Z_t is the vector of endogenous variables, X_t is the vector of exogenous and predetermined variables, and U_t is the vector of error terms satisfying $E(U_t) = 0$ and $E(x_{jt}u_{it}) = 0$. The solution of the model can be written in reduced form as: $\hat{Z}_t = -\hat{B}^{-1}\hat{C}X_t$. Knowledge of the exogenous variables will enable one to forecast the endogenous variables, particularly oil demand. The actual and fitted values for the endogenous variables are shown in Figure 7. The SEM closely fits the data. The residuals are serially uncorrelated; their standard errors are small and estimated at 0.007 for crude oil output, and 0.103 for crude oil price. The model predicts closely the quantities for crude oil; however, price prediction is less precise, particularly for the crude oil price, since the latter has shown large fluctuations in the period 1970–2005. The multipliers of the SEM give the long-run effect of a unit change in an exogenous variable on the endogenous variables. In this respect, a 1 percent increase in income leads to an increase in crude oil output by 0.49 percent and crude oil price by 2.8 percent. Thus, an expansion of world economic growth could exert a strong upward pressure on oil prices. For the natural gas production, a 1 percent increase leads to an increase by 0.30 percent in the crude oil production and a decline in oil price by 1.47 percent. An increase in the interest rate leads in the long-run to a decline in both crude oil demand and prices, with multipliers equal respectively to –0.004 and –0.02. The model can be re-specified to include interest rates as endogenous variables. The following specification is considered, along the lines of the model shown in Section IV.[28]

Figure 7: Actual and Fitted Values and Residuals of the SEM



Crude oil demand: $qo_t = \gamma_p po_t + \gamma_y y_t + \gamma_i i_t + \gamma_{neer} NEER + c_d + u_d$

Crude oil supply: $qo_t = \delta_p po_t + \delta_{ng} ng_t + c_s + u_s$

Interest rate policy equation $i_t = \mu_1 po_t + \mu_2 (qo_t - \overline{qo}_t) + \mu_3 (y_t - \overline{y}_t) + \mu_4 i_{t-1} + \eta_t$

Where $\overline{qo}_t$ is potential crude oil output. Again, the model closely fits the data, except for large deviations in quantities and prices (Figure 8). Since the interest rate is now an endogenous variable, the effect of its innovations is apprehended via impulse responses. Computations show that impulse responses from shocks affecting interest rates in the SEM are similar to those reported in the VAR analysis (Figure 6). Namely, a positive shock to interest rates tends, on impact, to depress both crude oil demand and prices. However, a positive shock to oil prices tends, on impact, to increase interest rates.

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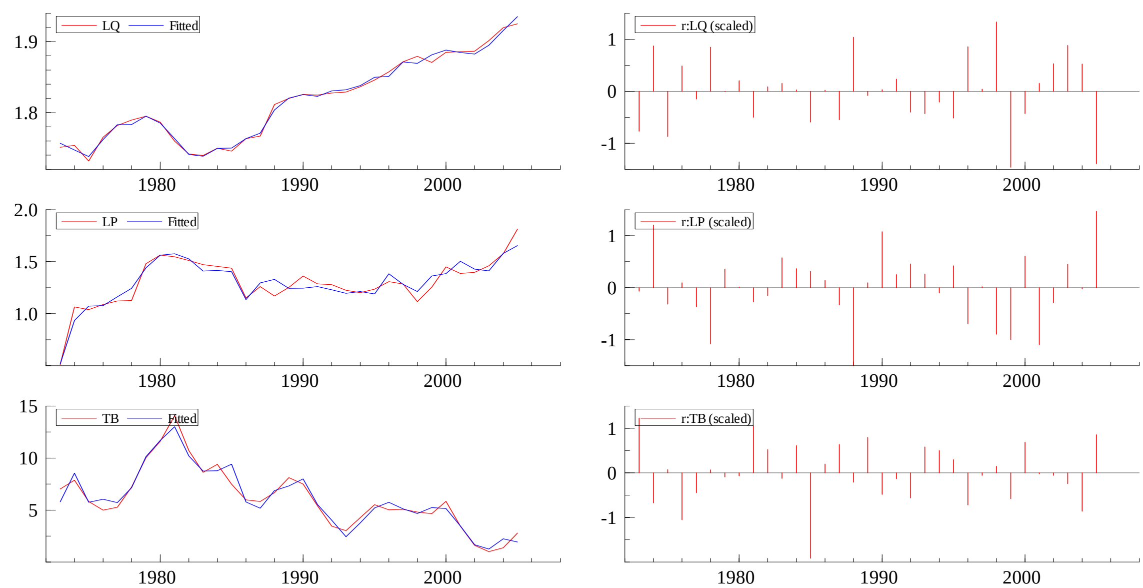
[28] The model can also be rewritten in a similar form as in Section IV in terms of percent price changes and in rational expectations form.

Figure 8: Actual and Fitted Values and Residuals of the SEM (interest rate endogenous)



VI. Conclusions

This paper has studied the effect of monetary policy on oil prices and highlighted the risk of a subsequent world economic contraction and inflation that could be caused by high oil prices.[29] Indeed, oil markets were highly volatile during most 2005 and oil prices were following a persistent upward trend in the midst of rising world demand for oil, stimulated by exceptionally low interest rates and a rigid oil supply. The paper has proposed a model for studying demand and supply in the oil markets with emphasis on the role of exchange and interest rates. Estimation shows that demand is price inelastic; it is, however, significantly influenced by the level of economic activity. Particularly relevant for policy purposes is the finding that oil demand is negatively influenced by interest rates and the NEER. Oil supply is also highly price inelastic in the short run, but it is strongly correlated with natural gas production. The parameter estimates describe basic properties of the oil markets. It is the combination of low price, high income elasticities, and rigid supply that explains high and persistent volatility in the oil markets and the market power of producers.

Based on monthly and quarterly time-series on interest rates and oil prices, the paper has shown that the relationship between oil prices and interest rates is a two-way relationship. During an oil supply shock—characterized by perturbations in oil supply, under stable oil demand

[29] Hamilton and Herrera (2004), and the literature cited therein, emphasized that oil shocks have a sizable recessionary effect of their own, and noted the long lag characterizing transmission and amplification of the contraction effect in the economy.

conditions—oil prices led interest rates. Monetary policy was deployed to compel oil prices down by forcing a downward adjustment in the demand for oil commensurate with the supply disturbances. Such an adjustment was brought about by substantial increases in real interest rates through targeting nonborrowed reserves. However, during a demand shock, characterized by major shifts in oil demand, under stable oil supply conditions, interest rates led oil prices. The regression coefficients in the relation between oil prices and interest rates showed that the response of one variable to the other was significantly high during major shocks. Consequently, an important increase in real interest rates, similar to those experienced during the oil supply shock, might be required to bring demand in line with supply and contain the inflationary effect of high oil prices.

The model was shown to track closely oil output and prices as well as interest rates. It can have many applications in policy analysis. For instance, monetary policy may have to be tightened to reduce oil prices to a stable path, consistent with overall price stability with an inflation rate not exceeding 2–3 percent a year, which is the inflation target in many inflation targeting models. For this purpose, the model can simulate the effect of interest rates on oil prices and determine an appropriate interest rate response for each desirable oil price path. Contrary to a supply shock, where the change in oil prices results in a pure relative price change that will help bring about stronger energy substitution and savings, in a demand shock most asset prices are moving upward with a general increase in the price level. Consequently, the relative change in oil prices becomes less noticeable, and therefore the energy substitution and energy savings effect could be less important than under a supply shock. In particular, additional measures to contain oil demand, such us higher taxes, may be overshadowed by the general price increase and will have a limited effect on oil demand. If greater energy substitution and savings are to be achieved during a demand shock, an appropriate tightening of monetary policy, strong enough to uproot inflationary expectations, will be required.

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