

**World Crude Oil Markets: Monetary Policy
and the 2004-05 Oil Shock**

by

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Abstract

In this paper we examine the relationship between monetary policy and oil prices. Low price and high income demand elasticities and rigid supply explain high price volatilities and the market power of producers. Exchange and interest rates affect oil market equilibrium. The relationship between oil prices and interest rates is a two-way relationship that depends on the type of oil shock. Sustained world economic growth and price stability require stable oil markets and prudent monetary policy.

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I. INTRODUCTION

In this paper we analyze the relationship between monetary policy and oil prices and show that an oil demand shock, resulting from record low interest rates, led to the substantial oil price increases of 2004–05. Specifically, monetary policy, manifested 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 could be explained by an excessively expansionary monetary policy, with interest rates falling to record levels in the context of an integrated international capital market. As a result of low interest rates and a depreciating US dollar, demand for oil expanded faster than its supply. Given the short-run price inelasticity of both oil demand and supply, equilibrium was attained through large increases in the price of oil. As economic activity is heavily dependent on energy input, runaway energy prices could become inflationary and in turn result in a recession.¹

In section II we analyze crude oil futures' prices and present estimates of implied volatility and GARCH volatility.² In section III we analyze a simultaneous equations model (SEM) for demand and supply of oil, emphasizing the role of exchange and interest rates in influencing equilibrium in oil markets; we establish the empirical evidence on demand and supply elasticities, namely, price elasticities are very low, and income elasticity is relatively high and significant; and we also show that exchange and interest rates act negatively on oil demand and prices. In section IV we examine the role of monetary policy through the relationship between oil prices and interest rates; we show that this relationship is a two-way relation that depends on the type of oil shock. During an oil supply shock, oil prices lead interest rates; whereas during

¹ Hamilton (1983, 2003) observed that all post-war US economic recessions but one (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.

² Generalized Autoregressive Conditional Heteroskedasticity (GARCH).

an oil demand shock, interest rates lead oil prices.³ A vector autoregressive model (VAR) is used to analyze the effect of an interest rate shock on oil prices. In section V we present our conclusions.

Our main conclusion 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; it may require strict ceilings on monetary base, and may involve a trade-off between inflation and output. In the same vein, based on data for 1986–2000, sustained non-inflationary world economic growth would require a degree of stability in oil markets.

II. OIL PRICE VOLATILITY

Crude oil futures' prices increased rapidly from around US\$30/barrel (bl) in 2004 to nearly US\$70/bl in September 2005, for an increase of about 133 percent (Figure 1).⁴ 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 was almost stagnant at 80–81 million barrels a day, implying that crude oil production was constrained by resources availability.

A. Crude Oil Price 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.⁵ Oil futures prices implied volatility (Figure 2) reached high levels during February 2005–September 2005, averaging about 30 percent, and showing that the market was uncertain as to expected price developments. Volatility even increased during July–September 2005, rising to 40 percent, indicating that markets became very sensitive to small shocks and to news.⁶ High volatility increases speculative demand for futures contracts and contributes to higher volatility and volatility clustering. Volatility was also

³ An oil supply shock is defined as a disturbance in oil supply with normal demand conditions, often caused by exogenous factors. An oil demand shock is a disturbance in oil demand with normal supply conditions; it could result from endogenous factors.

⁴ Data on daily crude oil futures prices and implied volatility were obtained from Bloomberg.

⁵ Implied volatility is the volatility which equates the Black-Scholes option pricing formula to the call option's market value.

⁶ For instance, Hurricane Katrina (September 2005) took place at a time of very volatile markets. By causing temporary damage to US oil refineries in the Gulf of Mexico, oil prices soared beyond US\$70/bl.

Source: Bloomberg. Prices are in US\$ per barrel.

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: $dp_t = p_t - p_{t-1}$; the mean equation and the conditional variance equation are respectively:

$$dp_t = c + \varepsilon_t \quad (1)$$

$$\sigma_t^2 = \omega + \alpha\varepsilon_{t-1}^2 + \beta\sigma_{t-1}^2 \quad (2)$$

where $\varepsilon_t \sim N(0, \sigma_t^2)$ and $\sigma_t^2 = E(\varepsilon_t^2)$. 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 a level of 32.4 percent as oil prices were climbing; volatility receded in early 2005 as oil prices retreated, and then started rising again reaching 32.5 in September 2005 as oil prices resumed their upward trend.

B. Crude Oil Price Distribution

The returns of oil prices are plotted (Figure 4). It appears that oil price returns are not normally distributed as illustrated by the low probability value of the Jarque-Bera test which rejects normality at the 5 percent level. The empirical distribution has a large dispersion; the mean/standard deviation ratio is very low. The distribution is right skewed, implying that upward jumps were more frequent than downward movements, and has fat tails meaning that large jumps tended to occur more frequently than would be in the case of a normal distribution.

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

These empirical crude oil daily futures' price findings are typical of financial time series as noted by 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 difficult to handle.

III. THE DEMAND AND SUPPLY OF CRUDE OIL

The price and volatility developments described in Section II require further elaboration. In particular, 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 developed. Besides estimating elasticities, the SEM emphasizes the role of the exchange and interest rates. The general dynamic form of the model can be expressed as:

$$A(L)Z_t + B(L)X_t = U_t \quad (3)$$

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 crude oil demand and supply are described by equations (4) and (5), respectively:

$$q_t = \gamma_p p_t + \gamma_y y_t + \gamma_i i_t + \gamma_{neer} NEER_t + c_d + u_d \quad (4)$$

$$q_t = \delta_p p_t + \delta_v v_t + c_s + u_s \quad (5)$$

Except for the interest rate, all variables are in logarithm form:⁷

q_t = crude oil output, in millions of barrels per day, $lq_t = \log(q_t)$;

p_t = crude oil nominal price, in US\$ per bl, $lp_t = \log(p_t)$;

v_t = crude oil proven reserves, in billions of crude oil barrels, $lv_t = \log(v_t)$;

y_t = real GDP index for world economy, $ly_t = \log(y_t)$;

i_t = interest rate (chosen here to be the US federal funds rate (ff_t), or alternatively the three-month US Treasury bill rate and the US government ten-year bond yield);⁸

$NEER_t$ = the US dollar nominal effective exchange rate, $lNEER_t = \log(NEER_t)$.

The demand for oil is a function of own price and an indicator for world economic activity. Interest rates and the NEER are also added as explanatory variables. Interest rate has been recognized as an instrument for monetary policy, and a main variable in aggregate demand studies (McCallum and Nelson, 2000). Since energy demand is determined by the level of economic activity, it should also be influenced by interest rates as well as policy variables that affect aggregate demand.⁹ The inclusion of NEER is explained by the fact that oil prices are

⁷ Data sources are provided in the Appendix.

⁸ The choice of US interest rates is based on the fact that they are the main determinants of interest rates in world capital markets. Other interest rates can be used, namely the LIBOR (London inter-bank offered rate) rates.

⁹ Real interest rate, defined as nominal rate minus expected rate of inflation, is most appropriate as argument in the demand function. In this paper, however, nominal interest rate was used in the demand specification, with attendant mis-specification errors. This enables to avoid dealing with the interaction between nominal interest rate and expected rate of inflation and to keep the model tractable.

generally quoted in US dollar. Changes in exchange rates affect domestic prices of oil as well as the real value of financial assets, and therefore demand for oil.¹⁰ As interest and exchange rates may be related via uncovered interest rate parity (UIP), it may be hinted that either and not both variables should be in the demand function. Notwithstanding the UIP, and in line with open economy modeling (Williamson, 1983), these two variables appear distinctly in the demand function, because they operate via different transmission channels and have different lags. In the Mundell-Fleming-Dornbusch model, interest rate operates via the goods, money, and capital markets; whereas the exchange rate operates via the foreign trade and capital account sectors.¹¹

The supply of oil is a function of own price and oil proven reserves.¹² 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 equations. Given the dynamics of adjustment in

¹⁰ The exchange rate is an asset price, defined as the price of one unit of foreign exchange in terms of units of local currency. Changes in the exchange rate are different from changes in a tradable good price (e.g., oil price). While changes in one good's price affect only the relative price of the concerned good, a change in the exchange rate affects the price of all tradables and the relative price of tradables in terms of non-tradables; it also changes the real value of monetary assets and the real value of net holdings of foreign currency-denominated assets, and therefore has a wealth effect. For instance, holding money supply fixed, the real value of money declines in case of currency depreciation, and increases in case of appreciation, thus depressing, or stimulating a country's aggregate demand.

¹¹ UIP may weaken when there is a risk premium. Trade effect assumes that Lerner-Marshall condition holds.

¹² It may be tempted to include in the oil supply function the natural gas output, or natural gas price. There are many reasons for this temptation. First, these two products are close substitutes in many uses and constitute the hydrocarbons industry; they are often produced by the same firms. Second, exploration investment is generally indistinguishable; oil companies look for both products and not for one product; the discoveries, however, determine the respective size of proven reserves for oil and gas. Third, hydrocarbons may be associated products. Fourth, the first oil shocks in 1973 had certainly revived the gas industry and made natural gas a high valued product at the domestic and international levels. The subsequent expansion of natural gas had certainly alleviated pressure on demand for oil and oil prices; it might have, by way of implication, influenced oil supply. In the literature, Erickson and Spann (1971) contended that oil and gas evolve through identical stages at the level of exploration, development, and production. Eysell (1978), however, disagreed with this view and preferred to model oil and gas as unrelated products in all stages of drilling, development, and exploitation.

demand and supply, lagged variables have to be introduced. Tests on the length of the lag based on the Akaike information criterion indicated that the optimal lag would be two periods. The model was estimated using two-stage least-squares to obtain short-run estimates. Long-run elasticities were estimated using the error correction method (ECM) and co-integration analysis;¹³ these two methods were appropriate for finding long-run relations in each identified equation of the model. The model was estimated using quarterly data 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 get robust estimates.

Short-Run Demand for Crude Oil

Both quarterly and annual data supported the hypothesis of low short-run price demand elasticity, ranging between -0.01 and -0.02 , implying that changes in oil prices had a small effect on demand for crude oil (Table 1). This result is important and lies at the heart of the crude oil markets. It explains the volatility of oil markets and vulnerability to small shocks. Data also supported the hypothesis of a significant effect of economic activity on the demand for crude oil. Short-run income elasticity was statistically significant and ranged between 0.09 and 0.22 . This finding is particularly important as it demonstrates clearly that oil demand was responsive to changes in the economic activity.¹⁴ Namely, faster world economic growth might contribute to higher pressure on world oil demand; reciprocally, sluggish growth would depress oil markets.

Extension of the model to study the role of interest and exchange rates yielded interesting results. Interest rates tended to act negatively on the demand for crude oil; an increase in the interest rate would act to reduce the demand for crude oil and vice-versa. The interest rate semi-

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 $\Delta y_t = \delta_0 + \gamma_0 \Delta x_t + (\delta_1 - 1)y_{t-1} + (\gamma_0 + \gamma_1)x_{t-1} + \varepsilon_t$, or

$$\Delta y_t = \delta_0 + \gamma_0 \Delta x_t + (\delta_1 - 1)(y_{t-1} + \frac{(\gamma_0 + \gamma_1)}{(\delta_1 - 1)} x_{t-1}) + \varepsilon_t. \text{ The term } (y_{t-1} + \frac{(\gamma_0 + \gamma_1)}{(\delta_1 - 1)} x_{t-1}) = 0 \text{ represents}$$

the long-run relation.

¹⁴ 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 | | |
| Lagged dependent | 0.59 (6.49) | 0.59 (5.17) |
| Price elasticity | -0.02 (-1.81) | -0.01 (-0.86) |
| Income elasticity | 0.22 (4.17) | 0.09 (2.40) |
| Interest rate semi-elasticity | 0.001 (0.92) | -0.007 (-3.62) |
| NEER elasticity | -0.03 (-1.77) | -0.01 (-0.09) |
| R^2 | 0.97 | 0.96 |
| DW | 1.77 | 2.09 |
| Crude oil supply | | |
| Lagged dependent | 0.80 (14.11) | 0.71 (7.89) |
| Price elasticity | 0.02 (2.69) | 0.02 (1.26) |
| Oil reserves elasticity | 0.14 (3.33) | 0.14 (3.15) |
| R^2 | 0.97 | 0.94 |
| DW | 1.87 | 1.52 |

1/ The t -statistics are between parentheses.

elasticity was statistically significant at -0.007 for annual data 1970–2005, implying that 100 basis point increase in the interest rate could depress world oil demand by -0.7 percent. The quarterly interest rate semi-elasticity showed an unexpected positive sign and was statistically insignificant. Recognizing that interest rates do influence world economic activity, a re-specification of the oil demand equation would therefore drop world real GDP from this equation; this re-specification yielded the following regression:

Sample: 1984Q1–2005Q2

$$LQ = 0.931 * LQ(-1) - 0.014 * (LP - LP(-1)) - 0.0025 * FF(-4) + 0.004 * LNEER + 0.288$$

(t=31.20) (t=-1.17) (t=-2.13) (t=0.21) (t=1.97)

$R^2 = 0.97$; DW=2.14

The significance of the interest rate semi-elasticity was essentially influenced by the intensity of monetary policy. Periods of highly active monetary policy would tend to yield significant impact for interest rates on oil demand. By narrowing the sample size to 1998Q1–2005Q2, which contained a sub period of highly active monetary policy, namely the sub period 2000–2005 when the federal funds rate fell to 1 percent and remained at this level from 2003M7 to 2004M6, the following regression was obtained:

Sample: 1998Q1–2005Q2

$$LQ = 0.741 * LQ(-1) - 0.019 * (LP - LP(-1)) - 0.005 * FF(-4) - 0.017 * LNEER + 1.211$$

(t=8.15) (t=-1.20) (t=-2.72) (t=-0.41) (t=2.51)

$R^2 = 0.92$; DW=1.91

Hence, re-specification of the demand function and selection of sub-periods of active monetary policy yielded significant interest rate semi-elasticities ranging between -0.0025 and -0.007.

These results are highly relevant and tended to establish that active monetary policy did in fact influence oil markets.

The demand for crude oil was related negatively to the NEER. The NEER elasticity tended to be statistically significant, although at a higher probability value, and ranged between -0.01 and -0.03 . An appreciation (depreciation) of the US dollar would tend to make oil more expensive and would reduce (increase) the demand for crude oil. Further, the exchange rate operated also via changes in value of financial assets. A NEER appreciation would cause a depreciation of non-dollar-dominated financial assets, depressing thus world oil demand. In contrast, a NEER depreciation would cause an appreciation of non-dollar-dominated financial assets and stimulate in turn world oil demand. The significance of the NEER depended on the sample period as shown by the two regressions below. Sub-periods characterized by wide movements in the exchange rate tended to yield higher elasticity for NEER ranging between -0.11 for quarterly data and -0.13 for annual data.

Sample: 1981–2005

$$LQ = 0.367*LQ(-1) - 0.015*(LP-LP(-1)) + 0.273*LY - 0.0002*FF(-2) - 0.131*LNEER + 1.738$$

(t=4.18) (t=-1.28) (t=6.58) (t=-0.12) (t=-2.02) (t=6.37)

$$R^2 = 0.99; DW = 2.19$$

Sample: 1998Q1–2005Q2

$$LQ = 0.467*LQ(-1) - 0.034*(LP-LP(-1)) + 0.329*LY + 0.001*FF(-1) - 0.108*LNEER + 1.201$$

(t=3.68) (t=-2.14) (t=3.52) (t=0.77) (t=-3.20) (t=2.69)

$$R^2 = 0.94; DW = 1.95$$

Hence, the significance and size of the interest and exchange rates elasticities depended on the specification of the demand function and the intensity of monetary policy. A parsimonious demand specification and choice of sub samples corresponding to highly active monetary policy tended to yield significant strong impact of interest and exchange rates on world oil demand. Note also that changes in interest rates were not transmitted instantaneously to the economic activity and oil prices and, as traditionally known in monetary economics, worked their effects with a lag. These findings will be crucial in examining the role of monetary policy in the next section; they demonstrate that the conduct of monetary policy has to pay heed to direct effects on world oil markets.

Long-Run Demand for Crude Oil

Long-run analysis is extremely important in the case of world oil markets.¹⁵ While there may be little leeway for short-run demand adjustment to large oil price changes, experience ensuing the

¹⁵ Long-run is determined by the coefficient of the lagged dependent variable in the demand equation $y_t = \delta_0 + \delta_1 y_{t-1} + \gamma_0 x_t + \gamma_1 x_{t-1} + \varepsilon_t$. The smaller this coefficient, the higher the speed of adjustment, and the shorter the period to return to long-run equilibrium. For instance if $\delta_1 = 0.75$, it will take four periods to return to long-run equilibrium, however if $\delta_1 = 0.25$, it will take only 1.33 periods to return to equilibrium.

first oil shock 1973 and the second oil shock 1979 indicated that demand for oil was responsive in the long-run to these shocks, and achieved considerable efficiency and substitution. If long-run demand-price elasticity is significant, it may imply that persistent trends in oil prices will end up influencing long-run demand for oil. In contrast, if this elasticity is insignificant, persistent trends in oil prices will have negligible long-run effect on oil demand. Disappointing as it may be, econometric analysis in this paper seemed to confirm elasticity pessimism. Indeed, the long-run demand for crude oil turned out to be price-inelastic (Table 2), and even though the long-run demand price elasticity was higher than the short-run one it was still low. For annual data, long-run price elasticity was estimated at -0.05 and was statistically significant; for quarterly data, it was estimated at -0.09, however, it was insignificant.¹⁶ These findings regarding the long-run demand price elasticity indicated that long-run world oil demand seemed to be in a price inelastic region of the long-run demand curve as considerably efficiency and substitution had been achieved during the seventies and eighties, and most of oil consumption had been confined to the transportation sector. They might imply continued price volatility, and could confer to oil producers some long-run market power.

Long-run income elasticity tended to be higher than the short-run elasticity and was statistically significant; it ranged between 0.32 for annual data and 0.83 for quarterly data. This implies that economic growth will be a main driving variable for oil demand, and that a sustained long-term growth will exert high pressure on long-run oil demand. The interest rates and the NEER were found to affect long-run demand for crude oil. The interest rate semi-elasticity was negative and significant, ranging between -0.027 (borderline significant) for quarterly data, and -0.007 (significant) for annual data. These findings imply that active monetary policy would shift significantly the long-run demand curve for crude oil, maintaining oil demand at higher level in case of expansionary monetary policy, or at a lower level in case of tight monetary policy. The long-run NEER elasticity was estimated at -0.35, borderline significant, for quarterly data, and at -0.16, insignificant, for annual data. This implies that large fluctuations in exchange rates can have an influence on long-run world demand for crude oil; namely, an appreciation of the

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

| | Quarterly: 1984Q1–2005Q2 | Annual: 1970–2005 |
|-------------------------------|---------------------------|---------------------------|
| Crude oil demand 2/ | | |
| Price elasticity | -0.09 (-1.23) | -0.05 (-5.24) |
| Income elasticity | 0.83 (4.15) | 0.32 (9.93) |
| Interest rate semi-elasticity | -0.027 (-1.91) | -0.007 (-2.39) |
| NEER elasticity | -0.35 (-1.90) | -0.16 (-1.11) |
| Trace statistic | Two CVs 48.4 (prob=0.045) | Two CVs 60.3 (prob=0.002) |

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.

| Maximum-eigenvalue stat. | Two CVs 30.6 (prob=0.02) | Two CVs 30.8 (prob=0.019) |
|--------------------------|--------------------------|---------------------------|
| Crude oil supply 3/ | | |
| Price elasticity | 0.07 (2.04) | 0.14 (4.63) |
| Oil reserves elasticity | 0.85 (9.32) | 0.30 (4.57) |

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

2/ Co-integration estimation, based on Johansen method; CV=cointegration vector.

3/ Error Correction Method estimation.

NEER would reduce demand for oil, and vice-versa. The results concerning the role of interest and exchange rates are important for appreciating the long-term impact of monetary policy on oil markets. They establish an extended effect over time of monetary policy on oil markets.

Short-Run Supply of Crude Oil

The short-run supply of crude oil tended to be price inelastic. Estimated at 0.02 for both quarterly and annual data, supply price inelasticity implied that producers did not expand output in response to a price increase because of short-run capacity constraints, fixed quotas, refining capacity, or to preserve significant price increases. Similarly, producers did not reduce output in response to large declines in prices. In some circumstances of depressed oil prices, some oil producers tended to supply more than their quota in order to generate badly needed budgetary revenues, particularly in the case of oil producers whose budgets relied heavily on oil revenues. This result concerning the supply-price inelasticity is important for comprehending the functioning of oil markets and explaining oil price volatility. Namely, short-run supply cannot expand in face of excess demand or large price increases. Oil supply rigidity would contribute to higher oil price volatility. Short-run crude oil supply was significantly influenced by available proven reserves; the elasticity coefficient for oil reserves was estimated at 0.14 for both quarterly and annual data.

Long-Run Supply of Crude Oil

Econometric modeling of oil supply (e.g. Fisher (1964), Erickson and Spann (1971), Eyssell (1978), and Dhal and Duggan (1998)) attempted to demonstrate that crude oil supply was responsive to persistent trends in oil prices, at least at the level of exploration (drilling). The oil exploration (drilling)-price elasticity was estimated by Fisher at 2.85, Erickson and Spann at 1.48, and Eyssell at 1.2. Analysis of world crude oil supply in this paper yielded significant long-run supply price elasticities, estimated at 0.14 for annual data and 0.07 for quarterly data; these estimates were, however, deceptively low and showed that long-run oil supply was determined by technological factors and discoveries, and was less responsive to prices.¹⁷ Proven

¹⁷ Fisher (1964) found negative values for discovery size-oil price elasticity, meaning that exploration was resulting in poorer prospects fields. Erickson and Spann (1971) estimated own price elasticity of supply of crude oil discoveries of 0.83. Eyssell (1978) improved on Fisher's estimates and found a value of 1.45 for the discovery size-oil price elasticity. The long-run price
(continued...)

oil reserves were a key determinant in long-run oil supply; estimated at 0.3 for annual data and 0.85 for quarterly data, this elasticity, although lower than unity, indicated that an increase in proven reserves would lead to an increase in oil supply.

In sum, oil 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 or supply would require a large change in prices to clear oil markets. Demand is, however, responsive to the income level, whereas supply can be influenced by oil proven reserves. Long-run demand and supply price inelasticities would imply continued oil price volatilities, and longer-term market power for oil producers. 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.¹⁸

Results regarding demand and supply price inelasticities suggested, indeed, estimating a time-varying volatility based on a GARCH(1,1) using monthly data 1970:1–2006:12. Figure 5 shows that oil markets were experiencing higher price volatility during 2000–2006, indicating that these markets were constantly out of equilibrium during this period. This may be an indication that demand and supply price inelasticities had increased compared to earlier periods. Had oil demand or supply been sufficiently elastic, equilibrium would have been restored and volatility would have reverted to low levels.¹⁹ Faster real world economic growth during 2003–2005 at about 5 percent per year kept pushing oil demand upward, with negligible negative price effect. The rising price trends indicated prevalence of excess demand in the oil markets, with the brunt

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).

¹⁸ Bernanke and Blinder (1992) showed that monetary policy is also transmitted via credit and deposits channels.

¹⁹ Daily volatility using daily oil prices was estimated for the same period 1970–2006. The results revealed a volatility pattern to the one reported here, namely volatility has increased during 2000–2006, implying considerable price inelasticities, in relation to earlier periods.

of clearing market falling essentially on prices.

IV. ROLE OF MONETARY POLICY IN THE OIL MARKETS

A standard model for analyzing monetary policy is composed of three equations (McCallum and Nelson, 2000), namely an IS curve, an aggregate supply (AS) curve (Augmented-Phillips curve), and an interest rate feedback policy equation (Taylor's rule), respectively:

$$y_t = -\sigma(i_t - E_t \Delta p_{t+1}) + E_t y_{t+1} + v_t \quad (6)$$

$$\Delta p_t = \lambda(y_t - \bar{y}_t) + \beta E_t \Delta p_{t+1} + \varepsilon_t \quad (7)$$

$$i_t = \mu_1 \Delta p_t + \mu_2 (y_t - \bar{y}_t) + \mu_3 i_{t-1} + \eta_t \quad (8)$$

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 v_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.

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

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

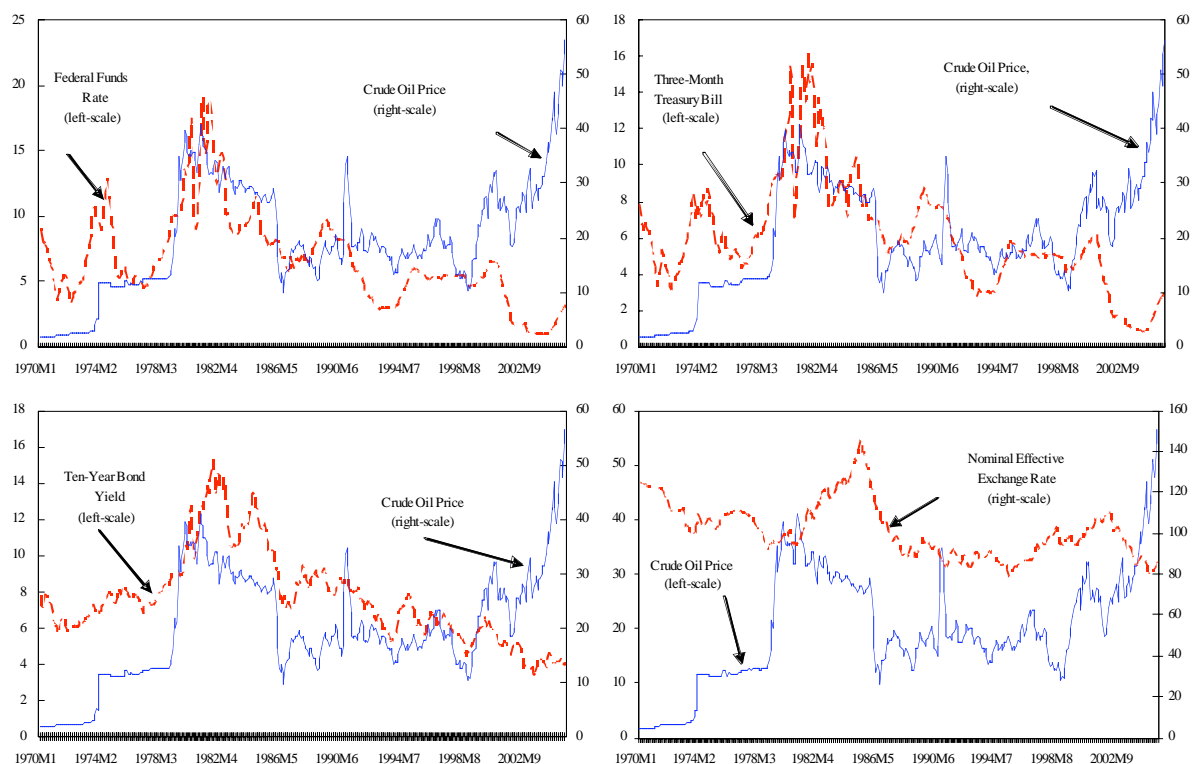
Monthly time series spanning 1970–2005 for crude oil prices, interest rates, and the NEER is plotted in Figure 6. Broadly, three time periods can be distinguished: 1970–1986, 1986–1999 and 1999–2005. The first period was characterized by oil supply shocks. Oil prices kept rising and peaked at US\$41/bl in 1980M11. As a result, world inflation rose to double-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 was used to address the oil shock and the oil-induced inflationary pressure. Monetary policy was counteracting the oil supply shock.²² The response 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 US 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, 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.

²¹ World inflation and oil prices were highly correlated during the period 1970–2005. A regression equation gives the following result:
 $\log(\text{world_cpi}) = 1.03\log(\text{oil_price}) + 0.91\text{Residual}(-1) + 4.93, R^2 = 0.91, DW = 1.92$. 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 US 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 US monetary policy has followed on the heels of major increases in the price of oil.

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.

Figure 6. Crude Oil Price, U.S. Interest Rates, and U.S. Dollar NEER, 1970M1-2005M7.



Source: International Financial Statistics, International Monetary Fund.

The second period spanning 1986–99 was a period of relative oil price stability. 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 non stationary, implying that monetary policy remained active. 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 growth and price stability. Monetary policy was eased during 1992–93, but then it was tightened without a significant 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 led crude oil prices. The federal funds rate was maintained at 1 percent during 2003M7–2004M6, while the US Treasury bill rate was less than 1 percent during most of this period. Crude oil prices started rising rapidly, exceeding the mark of US\$70/bl in September 2005.

B. Regression Analysis

The relationship between crude oil prices, interest rates, and the NEER is characterized by 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 instrument to contain unprecedented upward jumps in oil prices and the 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:

$$i_t = \alpha_1 \log(oil_price_t) + \alpha_2 Residual(-1) + \alpha_3 Residual(-2) + c, \alpha_1 > 0 \quad (9)$$

Where *Residual* is obtained from the regression $i_t = \alpha_1 \log(oil_price_t) + c$ to correct for the Durbin-Watson statistic. The regression is estimated using both monthly and quarterly data, providing 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 oil price increases (Table 3). The regression coefficient was estimated at 6.04. In percent, interest rates would increase by 6 percentage points for each 100 percent increase in oil prices. Crude oil prices climbed 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 US 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. The conduct of monetary policy moved from non-borrowed reserves targeting to interest rates targeting during this period. 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 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:

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, supports 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.

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.

$$\log(oil_price_t) = \beta_1 i_t + \beta_2 Residual(-1) + \beta_3 Residual(-2) + c, \beta_1 < 0 \quad (10)$$

Where $Residual$ is obtained from the regression $\log(oil_price_t) = \beta_1 i_t + c$ 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 revealed the nature of the relationship between interest rates and crude oil price depending on 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

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, supports 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.

| Figure 7: Impulse Responses from a VAR for Crude Price, NEER, and Interest Rates |
|--|
| Oil Supply Shock |
| |
| |
| |
| Oil Demand Shock |
| |
| |
| |

affecting each of these variables respectively. The VAR is estimated on monthly and quarterly data. The impulse responses are portrayed in Figure 7. For the period 1974–86, which corresponds to the oil supply shock period, the ordering of variables is: crude oil prices, interest rates, and NEER. 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

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.

response on the oil price. For the period 1998–2005, which corresponds to an oil demand shock period, the ordering of variables is: interest rates, NEER, and crude oil prices. The impulse response shows that a negative innovation in interest rates has a positive effect on 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.

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, a co-integration relation normalized on the interest rate can describe the relationship between interest rates, NEER, and crude oil prices 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, a co-integrating vector normalized on the crude oil price can describe the relationship between crude oil price, NEER, and interest rates and with coefficients that indicated that crude oil prices were moving in an inverse manner to 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 highly relevant for policy formulation. 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 adopted to choke off oil price increases, thereby causing a severe contraction in 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 will cause, because of the low price elasticities, large changes in oil prices. Strong action on interest rates, as shown by empirical evidence during the oil supply shock period, will be required to contain oil price increases. As shown by experience in 1979–1982, ceilings on money base may be

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.

required for effective control of inflation. These actions may cause a temporary contraction in world economic growth.

V. CONCLUSION

We have examined the effect of monetary policy on oil prices and highlighted the risk of a subsequent world economic contraction and inflation that could result from high oil prices.²⁸ 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. We have proposed a model for studying demand and supply in the oil markets with emphasis on the role of exchange and interest rates. Particularly relevant for policy purpose 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 influenced by proven reserves. 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.

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 conditions, oil prices led interest rates. Monetary policy was used to force oil prices down through 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 non-borrowed 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 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 oil demand in line with oil supply and contain the inflationary effect of high oil prices.

The model, being simultaneous, can be useful in numerous applications for policy analysis. For instance, monetary policy may have to be tightened to reduce oil prices to a stable path, consistent with overall price stability. 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 change in oil prices results in a pure relative price change to 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,

²⁸ 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.

additional measures to contain oil demand, such as 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.

Appendix. Data sources

Arthur Andersen/Cambridge Energy Research Associates, *Natural Gas Trends, 1985-2004*.

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