

A Short-run Crude Oil and Natural Gas Model Incorporating Monetary Policy

by

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Abstract

In this paper, we formulate a short-run model for analyzing world crude oil and natural gas markets with an explicit role for monetary policy. The parameter estimates show that short-run demand for oil and gas is price-inelastic, income-elastic, and is significantly influenced by interest and exchange rates; short-run supply is price-inelastic. Short-run price inelasticity could be the major explanation for high volatility in oil and gas prices, affording temporary market power to producers. Such a simultaneous model, explicitly incorporating interest and exchange rates effects, could be useful in short-term forecasting of oil and gas prices and output under different policy scenarios.

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I. INTRODUCTION

Recent developments in oil and gas markets have been marked by high price volatility, with oil prices hitting a record peak of U.S. \$78 per barrel in July 2006, then suddenly plummeting by about 25 percent toward the end of 2006. These developments may be linked to monetary policy stance. Indeed, nominal interest rates in most industrial countries fell to lowest post-war levels during 2003, resumed a slow upward move, then paused in 2006. Hence, excessively expansionary, then accommodative monetary policy seems to have caused strong world economic growth during 2003–2006,¹ which in turn placed pressure on oil and gas markets. Rising oil and gas prices can ignite inflation and cause recession. Yet, despite the macroeconomic importance of world oil and gas markets, little has been done in modeling world supply and demand for crude oil and natural gas, or in exploring the role of monetary policy in these markets.²

On the demand side, most studies have dealt with domestic demand for energy products, or sometimes the demand for energy products for a group of countries [Balestra and Nerlove (1966), Pindyck (1979), Pesaran et al. (1998), and Gately and Huntington (2002)] with no explicit role for monetary policy. On the supply side, most studies have followed Fisher's (1964) seminal work, concentrating on the supply of proven reserves of oil or gas instead of the supply of oil or gas output. Besides being country specific, Fisher's model formulates the supply process essentially from an engineering perspective, in three equations defined as wildcatting, success rate, and discovery rate equations, and does not have a direct output–price relation, as traditionally suggested by economic theory. Besides mis-specification, parameters from these country-specific energy supply or demand studies are not necessarily applicable to world oil and gas markets characterized by heterogeneous countries at different stages in economic development, and with different endowments of oil and gas resources.

In this paper we build a short-term model for world oil and gas, with an explicit role for monetary policy, to explain oil and gas prices.³ By incorporating the natural gas component,

¹ See the International Monetary Fund's World Economic Outlook, April 2007. World real economic growth averaged about 5 percent per year during 2003–2006.

² In view of full integration of capital markets, interest rates are reliable and readily available market indicators of underlying world demand conditions. A world measure for fiscal stance, however, is not available, and would be difficult to compute on a time series basis. For this reason, interest rates are highly relevant in explaining world oil and gas demand.

³ Long-run analysis is crucial for deeper understanding of oil and gas markets, and for energy policy design. In particular, long-term elasticities tend to be higher than short-term elasticities. However, for reason of space, long-term modeling has not been addressed in this paper.

the model could be highly relevant for the hydrocarbons industry and useful in many applications, including short-term forecasting under different scenarios for exogenous variables, evaluating the impact of monetary policy, and computing impulse response to shocks.

Supply and demand models are typically a set of simultaneous equations given the simultaneous determination of prices and quantities. Supply and demand equations are specified in structural form, according to traditional economic theory, defining aggregate demand by variables which are typically demand variables (e.g., prices, world income), and supply by variables which are typically supply variables (e.g., prices, world proven reserves).⁴ With regard to gas, special effort is given to estimating linkage with oil via cross-oil price elasticity.⁵ The reason for this linkage is the fact that the first oil shock in the fall of 1973, and subsequent oil shocks, might have caused considerable impact on the structure of supply and demand of natural gas; the latter is a close substitute to oil in many uses and can be directly influenced by developments in oil markets.

We analyze the effects of monetary variables, namely, the interest rate, given here by the LIBOR (London Inter-Bank Offered Rate, six-month U.S. dollar rate), and the U.S. nominal effective exchange rate (NEER) on world demand for oil and gas.⁶ The inclusion of these

⁴ While in this paper we study the impact of real GDP growth on oil demand and prices, the reader should be aware of a large body of literature which has analyzed the effect of oil prices on real GDP, following the seminal work of Hamilton (1983). See also Hamilton (2003) and the review article by Jones, et al. (2004). It should be noted, however, that a relationship between oil price and real GDP, estimated at a country level, cannot be extended in a straightforward manner to the world economy as changes in oil and gas prices affect countries that are net energy surplus and deficit economies differently.

⁵ Erickson and Spann (1971) modeled oil and gas as joint products and allowed for a cross-oil price elasticity in the discovery equation for natural gas.

⁶ Bernanke et al. (1997) have dealt with the role of monetary policy and the effect of an oil shock in a vector auto-regression (VAR) framework. While their model showed that most of the real GDP contraction was caused by the ensuing tightening of monetary policy following an increase in oil price, it did not deal with reverse causation from a monetary shock to oil prices, relevant for explaining developments in oil prices, including oil price trends observed in 1982–86 and 1999–2006. Furthermore, their model was essentially country-specific, and accordingly its results cannot be extrapolated to the world economy. Disagreeing with Bernanke et al. (1997), Hamilton and Herrera (2004) contended that an oil shock, and much less monetary policy responsiveness to an oil shock, which caused ensuing economic recessions. As regards exchange rate, it may be noted that inclusion of this variable in an oil model is not a novelty. For instance, Amano and van Norden (1998) claimed that oil price shocks could be a dominant source in real exchange changes.

variables stems from the notion that monetary policy might have a significant effect on oil and gas markets, and it would therefore be prudent to analyze the relationship between interest and exchange rates and oil and gas markets.⁷

To ascertain the robustness of parameters, estimation is done using annual data for 1970–2006, and quarterly data for 1984Q1–2006Q2. The findings show that short-run demand for oil is highly price inelastic, with price elasticity ranging between -0.01 and -0.04. The demand for gas is also highly price inelastic, with price elasticity ranging between -0.01 and -0.11. Oil supply is also highly price inelastic, with price elasticity ranging between 0.01 and 0.02. Similarly, gas supply is highly price inelastic, with price elasticity ranging between 0.03 and 0.05. The implication of low price elasticities is that any small excess supply or demand for oil or gas may require large movements in prices to clear oil and gas markets. As most of the burden for clearing oil and gas markets falls on prices, price inelasticity becomes a source for volatility in oil and gas prices. Income elasticities range between 0.12 and 0.44 for oil, and 0.11 and 0.48 for gas, showing that energy demand is mainly driven by economic activity.

The results demonstrate that oil and gas markets can be affected by shocks to monetary policy. Demand for oil and gas is significantly influenced by the interest rate (LIBOR) and the exchange rate (NEER). Interest rate semi-elasticity was estimated at -0.006 for oil and -0.005 for gas, while NEER elasticity was estimated at -0.17 for oil and -0.16 for gas. Henceforth, rising interest rates and an appreciating NEER tend to depress oil and gas prices, whereas declining interest rates and a depreciating NEER have the opposite effect.

The paper is organized as follows. In section II we present a simultaneous equation model (SEM) that describes supply and demand functions for oil and gas. In section III we estimate the SEM and discuss the findings. In section IV we evaluate simulations of the model over sample periods, and analyze the model's multipliers to assess the effect of exogenous variables on endogenous variables. In section V we perform impulse responses to assess the impact of shocks to endogenous variables. We present our conclusions in section VI.

II. MODELING DEMAND AND SUPPLY OF CRUDE OIL AND NATURAL GAS

We present the structural relationships of demand and supply for oil and gas in this section. While quantities and prices may be thought to correspond to equilibrium points, the identification of a demand or a supply relationship is made essentially through variables that

⁷ Dhal and Duggan (1998) have suggested inclusion of interest rates in the supply equation, as this variable has a significant effect on the cost of investment in the oil or gas industry. In this paper, however, we omit interest and exchange rates on the supply side and concentrate on their effect on the demand side.

are generally considered to shift demand or supply price-quantity schedules.⁸ Accordingly, the general form of the SEM for world oil and gas demand and supply can be stated in an implicit form as:

$$\text{Crude oil demand: } f_{od}(LQ, LP, LY, LIBOR, LNEER, \varepsilon_{od}) = 0$$

$$\text{Crude oil supply: } f_{os}(LQ, LP, LORSV, DUMO, \varepsilon_{os}) = 0$$

$$\text{Natural gas demand: } f_{gd}(LG, LPG, LP, LY, LIBOR, LNEER, \varepsilon_{gd}) = 0$$

$$\text{Natural gas supply: } f_{gs}(LG, LPG, LP, LGRSV, DUMG, \varepsilon_{gs}) = 0$$

Except for the interest rate, all variables are in logarithmic form.⁹ The dependent variables are:

Q = crude oil output, in millions of barrels per day, $LQ = \text{Log}(Q)$;

P = crude oil nominal price, in U.S. dollars per barrel, $LP = \text{Log}(P)$;

G = natural gas output, in billions of cubic meters per year (or quarter), $LG = \text{Log}(G)$;

PG = natural gas price, in U.S. cents per 1000 cubic feet, $LPG = \text{Log}(PG)$.

The exogenous variables are:

Y = real GDP index for world economy, $LY = \text{Log}(Y)$;

LIBOR = interest rate (London Inter Bank Offered Rate, six-month U.S. dollar rate);

NEER = U.S. dollar nominal effective exchange rate, $LNEER = \text{Log}(\text{NEER})$;

ORSV = crude oil proven reserves, in billions of crude oil barrels, $LORSV = \text{Log}(\text{ORSV})$;

GRSV = natural gas proven reserves, in trillions of cubic meters, $LGRSV = \text{Log}(\text{GRSV})$;

DUMO = dummy variable for large changes in oil price;

DUMG = dummy variable for large changes in natural gas price;

ε = disturbance term for oil demand (ε_{od}), oil supply (ε_{os}), natural gas demand (ε_{gd}), and

natural gas supply (ε_{gs}).

The implicit form of the above equations enables us to express demand and supply as a quantity schedule, i.e.: $quantity = q(price, \dots)$, and to compute, accordingly, price elasticities; or as a price schedule, i.e.: $price = p(quantity, \dots)$, called inverse demand or supply relation, and to compute, accordingly, quantity elasticities. For the resolution of the SEM, it is

⁸ Erickson and Spann (1971) noted that since demand variables such as income, population, urbanism, and industrialization are constantly evolving, the observed quantity-price data is likely to trace a supply curve.

⁹ Data sources are as follows: oil output is from the International Energy Agency; natural gas output is from the Oil and Gas Journal, various issues; oil and natural gas reserves are from British Petroleum and U.S. Department of Energy (U.S. DOE); oil prices, world economic activity, LIBOR, NEER are from the IMF International Financial Statistics (IFS); natural gas prices are from U.S. DOE and IFS.

necessary to estimate both a quantity schedule (demand or supply) and a price schedule (inverse demand or supply) as the SEM has to have an independent equation for each endogenous variable.

Our modeling of the demand for oil and gas follows traditional theory, as suggested by Working (1927). In line with Pindyck (1979), and Pesaran et al. (1998), demand is driven mainly by own price and income.¹⁰ The demand for oil is a function of own price and an indicator for world economic activity.¹¹ The demand for gas is a function of own price, oil price, and world economic activity. In particular, such specification responds to the need to examine the effect of oil prices on the gas markets. Interest and exchange rates are also added as explanatory variables. Interest rates have been recognized as an instrument for monetary policy, and as 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 by other policy variables that in turn affect aggregate demand.¹² The inclusion of NEER is explained by the fact that oil and gas prices are generally quoted in U.S. dollars. Changes in exchange rates affect domestic prices of oil and gas and the real value of financial assets, and therefore demand for these two products.

Traditional modeling of oil and gas supply in the literature has largely followed Fisher's approach (1964), analyzing the supply of proven reserves in three equations that describe closely the supply process for mineral resources encompassing the exploratory phase (wildcat drilling), the success phase, and the discovery phase; each equation has the price of oil among its explanatory variables. Fisher showed that wildcatting was highly influenced by oil prices; however, if drilling results in small prospects, the discovery ratio could have small, or even negative, price elasticity. Erickson and Spann (1971) have extended Fisher's

¹⁰ Population is also an important demand variable. For parsimony, it is omitted in the present formulation of demand for crude oil and natural gas.

¹¹ The exogeneity of real GDP is certainly not appropriate in this context, and is assumed only for the purpose of model simplification. Contrary to non-important commodities which have a small impact on GDP, and therefore exogeneity could be a valid assumption, in the case of oil and natural gas markets, prices and quantities exert a major influence on real GDP (see Hamilton, 1983 and 2003, and the literature on oil prices and the macro-economy). Similarly, the exogeneity of interest and exchange rates was assumed only for the purpose of simplifying the model. Bernanke et al. (1997) and others have shown that monetary policy variables were responsive to an oil price shock, and were, therefore, endogenous variables.

¹² Real interest rate, defined, as nominal rate minus expected rate of inflation, is most appropriate as an 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 us to avoid dealing with the interaction between nominal interest rate and expected rate of inflation and to keep the model tractable.

model to natural gas. Eyssell (1978), using Fisher's basic framework but with more disaggregated data and isolating predominantly natural gas producing districts, attempted to show that oil discoveries had higher price elasticity than implied by Fisher's estimates. Dhal and Duggan (1998) showed how Fisher's model can be derived from an optimization approach consisting of maximizing discounted net income stream. While fully in line with the stages through which the production of mineral resources evolve, Fisher's model and the body of literature built around it did not offer a direct relationship between supply and price as usually stipulated by economic theory. In fact, the purpose of modeling is to obtain a simple relation that can explain a given dependent variable, while discarding the vast complexity of the real world. Moreover, Fisher's model is country specific. As practically every country has undertaken exploratory drilling and or is searching for oil and gas deposits, the data requirement for Fisher's model, if extended to world economy, would be prohibitive.

Subsequently, and in line with standard production theory, oil supply is expressed as a direct function of own price.¹³ Oil reserves are included as a key variable in oil supply. Natural gas supply is specified in terms of own price, oil price, and gas reserves. This formulation of gas supply allows for the transmission of oil shocks to the gas sector. The model is recursive; the natural gas equations are affected by oil; feedback from gas to oil, although highly pertinent, is omitted in order to simplify the econometric analysis.¹⁴

The model is identified; no one equation can be obtained as a linear combination of two or more equations. The model is estimated using annual data for 1970–2006, and 1984–2006, and quarterly data for 1984Q1–2006Q2, and 1996Q1–2006Q2. The purpose of modifying both the frequency and the sample period of the data is to yield robust estimates. The regressions, presented in the Annex, are summarized in Table 1.¹⁵

¹³ The relationship between supply and own price is derived from profit maximization conditions, holding input prices and other variables appearing in the production (or cost) function fixed, (see McFadden and Fuss, 1977).

¹⁴ Besides the supply model retained in this paper, in the econometric work underlying this paper we estimated other supply models, yielding estimates close to the ones reported in Table 1. Among these models, Muth's (1961) rational expectations hypothesis was explored, where producers fixed supply at time $t - 1$, as a function of their expectations, at $t - 1$, regarding prices that may prevail at time t . Lucas-Rapping supply function was also estimated, where deviations from a desired output level are related to deviations of actual from expected price, yielding estimates similar to those reported here.

¹⁵ The method of estimation is the two-stage least squares when demand and supply are simultaneously determined; however, if supply and demand are recursive, standard ordinary least squares method is applied.

III. SHORT-RUN DEMAND AND SUPPLY ANALYSIS

Short-run demand and supply analysis are highly important in economic theory and account mainly for rigidities in preferences, technology, and fixed factors. The impact of changes in exogenous variables and of shocks is generally partial in the short run; full impact takes place in the long run. A short-run relation is a dynamic relation; it allows for the effect of lags of the dependent variable on its current value and for the speed of adjustment of the dependent variable toward equilibrium. It also enables us to solve the problem associated with non-stationarity of time series and to obtain coefficients, which are unbiased and consistent.¹⁶ A simple short-run relation can be stated as an autoregressive model:

$$z_t = \delta_0 + \delta_1 z_{t-1} + \gamma_0 x_t + \varepsilon_t$$

Where: z_t is a dependent variable, and x_t is an exogenous variable.

The coefficient δ_1 measures inertia or persistence; the smaller the value of δ_1 the faster the adjustment of the dependent variable to its long-term equilibrium. The coefficient γ_0 is short-run elasticity. Long-term impact of a unit change in x_t (multiplier) on z_t is given by

$\sum_{i=0}^{\infty} \delta_1^i \gamma_0 = \frac{\gamma_0}{1 - \delta_1}$.¹⁷ Transformed into an error correction form, the model becomes:

$$\Delta z_t = \delta_0 + \gamma_0 \Delta x_t + (\delta_1 - 1) \left(z_{t-1} + \frac{\gamma_0}{(\delta_1 - 1)} x_{t-1} \right) + \varepsilon_t$$

The term $(y_{t-1} + \frac{(\gamma_0 + \gamma_1)}{(\delta_1 - 1)} x_{t-1}) = 0$ represents long-run relation; the coefficient $-\frac{\gamma_0}{(\delta_1 - 1)}$ is long-run elasticity, and $(\delta_1 - 1)$ is the speed of adjustment toward equilibrium.

A. Short-run Crude Oil Demand Elasticities

Of far-reaching importance is the demand price elasticity for oil.¹⁸ Short-run oil demand price elasticity is estimated at -0.01 (insignificant) for 1970–2006 and -0.02 (significant) for 1984–2006 (Table 1). While consistently negative, this elasticity is, however, noticeably low. For quarterly data, demand price elasticity is estimated at -0.02 for 1984Q1–2006Q2,

¹⁶ See Favero (2001) for transformations which solve for spurious regressions. These transformations include auto-regression, error-correction, and co-integration analysis.

¹⁷ Computed by summing up the impact of one unit change in x_t on $z_t, z_{t+1}, z_{t+2}, \dots, z_{t+i}, \dots$, given by $\gamma_0, \delta_1 \gamma_0, \delta_1^2 \gamma_0, \dots, \delta_1^i \gamma_0, \dots$, respectively.

¹⁸ Oil prices operate also in an indirect way on oil demand via the relation between oil price and output. This relationship has been extensively analyzed in the literature since Hamilton's paper in 1983.

Table 1. Crude Oil and Natural Gas: Short-Term Demand and Supply Elasticities

Variable	1970–2006		1984–2006		84Q1–06Q2		96Q1–06Q2	
	Coeff.	T-Stat.	Coeff.	T-Stat.	Coeff.	T-Stat.	Coeff.	T-Stat.
Crude oil demand								
Lagged dependent	0.54	5.08	0.04	0.32	0.63	7.43	0.54	5.23
Crude oil price	-0.01	-1.28	-0.02	-2.17	-0.02	-1.30	-0.04	-1.15
World GDP	0.12	3.12	0.44	6.48	0.20	3.98	0.19	2.13
Interest rate	-0.006	-2.55	0.003	1.70	0.001	1.29	-0.002	-1.11
NEER	-0.023	-0.19	-0.17	-3.12	-0.03	-2.29	-0.07	-2.17
R^2	0.96		0.99		0.97		0.96	
DW	1.93		1.78		1.84		1.86	
Crude oil supply								
Lagged dependent	0.72	8.32	0.72	6.78	0.79	14.23	0.71	8.95
Crude oil price	0.02	1.29	0.02	1.76	0.01	2.67	0.02	2.45
Oil reserves	0.14	3.16	0.21	2.49	0.14	3.39	0.11	1.74
R^2	0.94		0.98		0.97		0.95	
DW	1.53		1.91		1.86		1.67	
Natural gas demand								
Lagged dependent	0.79	10.4	0.33	3.09	0.65	8.01	0.25	2.80
Natural gas price	-0.04	-3.29	-0.01	-1.02	-0.11	-2.70	-0.04	-1.63
Crude oil price	0.01	2.75	-0.02	-2.00	0.01	2.37	0.02	2.41
World GDP	0.11	1.84	0.41	5.72	0.26	4.25	0.48	4.23
Interest rate	-0.003	-2.14	0.001	0.71	0.001	1.21	-0.005	-2.55
NEER	0.10	1.18	-0.16	-2.21	-0.05	-3.53	-0.04	-1.51
R^2	0.99		0.99		0.99		0.98	
DW	2.37		2.58		1.96		1.54	
Natural gas supply								
Lagged dependent	0.84	8.72	0.75	7.10	0.79	16.2	0.75	9.56
Natural gas price	0.05	3.53	0.05	3.73	0.04	3.55	0.03	1.51
Crude oil price	-0.05	-3.83	-0.03	-1.86	-0.01	-1.95	-0.002	-0.26
Gas reserves	0.05	0.76	0.08	1.02	0.12	3.58	0.13	2.52
R^2	0.99		0.99		0.99		0.97	
DW	2.05		2.28		2.05		1.77	

and -0.04 for 1996Q1–2006Q2. Although negative, this elasticity is low and statistically insignificant. Exploiting the present sets of both annual and quarterly data and experimenting with alternative specifications of the demand for oil equation, the general finding is that the oil demand price elasticity can be significant or insignificant; often with the sign that is correctly negative; when significant, its effects often have lags which can extend up to six years; its magnitude, however, is small, ranging between -0.01 and -0.04. Further, the significance and size of this parameter changes with model specification and parsimony. As illustrated by the following two demand relationships for 1970–2006, a parsimonious oil demand equation tends to yield significant demand price elasticity:

$$LQ = 0.769*LQ(-1) - 0.0275*LP(-1) + 0.103*LY + 0.62; R^2 = 0.96; DW=1.9.$$

(t=8.43) (t=-3.64) (t=3.25) (t=2.33)

$$LQ = 0.733*LQ(-1) - 0.315*LQ(-2) - 0.0388*LP(-6) + 0.231*LY + 1.56; R^2 = 0.97; DW=1.82.$$

(t=5.30) (t=-2.42) (t=-5.14) (t=5.60) (t=5.10)

In the first demand relationship, demand price elasticity is estimated at -0.0275, significant at lag 1; in the second demand relationship, this elasticity is estimated at -0.0388, significant at lag 6, implying that a strong oil shock, such as the first oil shock, can have a significant effect on oil demand for several periods. Furthermore, in order to address multicollinearity in lagged prices, a polynomial distributed lag in oil prices, with 6 lags and polynomial degree equal to 2, is estimated for 1970–2006 yielding:

$$LQ = 0.532*LQ(-1) - 0.006*LP - 0.006*LP(-1) - 0.0065*LP(-2) - 0.0074*LP(-3) - 0.0087*LP(-4) - 0.0102*LP(-5) - 0.01256*LP(-6) + 0.196*LY + 1.297; R^2 = 0.97; DW=1.44;$$

(t=4.09) (t=-0.57) (t=-1.53) (t=-1.30) (t=-1.11) (t=-1.53)

(t=-3.08) (t=-1.55) (t=4.21) (t=3.52)

Sum of lags = -0.05776 (t=-4.62).

While price elasticities are consistently negative, they tend to be very small and statistically insignificant, except at lag 5. The sum of these elasticities, computed at -0.05776, is statistically significant, indicating a statistically significant cumulative effect of oil prices on oil demand.

These results are crucial for understanding world oil markets. World demand for oil seems to respond very little to oil price changes in the short-run. Despite changing data frequency and sample periods, regression analysis tends to consistently yield very low short-run demand price elasticities, often with insignificant contemporaneous effect, and significance achieved only with lags. Extreme demand price inelasticity can be given economic interpretations. First, crude oil is a basic commodity and thus shares the properties of basic commodities whose consumption cannot be reduced without dramatically impairing the welfare of consumers. Second, short-run demand for oil products is determined by fixed capital, including refining capacity, machinery, transport fleet, appliances, and by the state of arts; it cannot change instantaneously with changes in prices.¹⁹ Substitution, or energy-saving, effects are limited in the short-run; they become important only in the long-run.

This price inelasticity is a source of high price volatility, which could drive prices to extreme peaks or troughs, and has major implications. At the level of consumers, oil price increases will proportionally increase the budget share on oil spending, and will reduce the budget share for non-oil commodities; consequently, non-oil demand will be depressed; the

¹⁹ For instance a water desalination plant, or a power generation station, has to meet an average load demand, and does not cut or increase supply because of short-run fluctuations in fuel prices.

consumer's new commodity bundle will include approximately the same quantity of oil, however, fewer non-oil commodities. At the level of taxation, governments can levy high taxes on oil products without impairing the tax-yield. At the level of international trade, oil-importing countries have limited room for cutting oil imports, and therefore are forced to consent to larger imports bills. At the level of oil producers, this inelasticity may confer market power to oil producers, which in turn may allow them to influence oil prices.

The income effect is consistently significant. The income elasticity is estimated at 0.12 for 1970–2006, and 0.44 for 1984–2006. For quarterly data, the income elasticity is estimated at 0.20 for 1984Q1–2006Q2, and 0.19 for 1996Q1–2006Q2. Based on the present data sets and after running several regressions, the general finding is that the income elasticity is significant; however, it is sensitive to the sample period and frequency and to the specification of the oil demand relationship. A parsimonious demand model tends to yield higher, however, always less than unity, income elasticity.

The size and significance of the income elasticity imply that world economic growth exerts a significant positive effect on world demand for oil. The high value of the short-run income elasticity explains business cycles characterizing oil markets. International economic recession explains low oil demand and oil price downturn cycles. Hence, recessionary episodes during 1980–1982 and 1997–1998 may have contributed to the observed downturn cycles in oil prices. In contrast, an expanding world economy explains tight oil market conditions and upturns in oil prices; such was the case during 2000–2006. Although significant, income elasticity was less than unity. Subsequently, world oil demand would fluctuate less in magnitude compared to the case of income elasticity higher than unity. Contrary to price-elasticity, income elasticity exhibits considerable instability. It seems to have increased from 0.12 in 1970–2006 to 0.44 in 1984–2006. As income elasticity rises, oil markets become more sensitive to business cycles.

In this paper we were particularly interested in studying short-run implications of monetary policy on oil markets. Thus world demand for oil includes LIBOR and the U.S. effective nominal exchange rate; both variables exhibit wide movements and are indicators of monetary policy stance as well as the stability of major reserve currencies. Omission tests indicate that these two variables together have had a significant impact on oil demand. For annual data, LIBOR has a significant and negative effect, with a lag of 2 periods, on world demand for crude oil. The semi-elasticity is significant and is in the order of -0.006 for 1970–2006. For 1984–2006, the interest rate semi-elasticity, estimated at 0.003, has an unexpected sign and is statistically insignificant. For 1984Q1–2006Q2, the LIBOR coefficient, estimated at 0.001, also has an unexpected sign and is insignificant. For 1996Q1–2006Q2, the interest rate semi-elasticity, estimated at -0.002, is negative and insignificant. Based on the two data sets at hand, the general finding for the interest rate semi-elasticity is that this parameter could be significant or insignificant with expected (negative) or unexpected (positive) sign; its significance essentially depends on the sample period, namely, whether the sample period corresponds to a period of active monetary policy, and on the parsimony of specification of the demand relationship, as illustrated by the following two regressions, which include episodes of highly active monetary policies:

Sample 1970–2006

$$LQ = + 0.877 * LQ(-1) - 0.0107 * LP - 0.00559 * LIBOR(-2) + 0.601 ; R^2 = 0.95; DW=2.22.$$

(t=9.67) (t=-0.873) (t=-2.40) (t=1.64)

Sample 1996Q1–2006Q2

$$LQ = + 0.812 * LQ(-1) - 0.000104 * (LP - LP(-1)) - 0.00463 * LIBOR(-4) + 0.83$$

(t=13) (t=-0.718) (t=-3.23) (t=3.06)

$$R^2 = 0.94; DW=1.91.$$

The interest rate semi-elasticity implies that a one percent point increase in LIBOR (100 basis points) can reduce oil demand by -0.5 – -0.6 percent. This result is highly relevant showing that monetary policy may have a substantial effect on oil markets, as illustrated by the effect of active monetary policies in 1980–1982, and the recent experience in 2000–2006. In fact, monetary tightening in 1980–1982 contributed to depressing oil markets. In contrast, expansionary monetary policies in 2000–2006 stimulated oil markets considerably, pushing oil prices to unprecedented levels.²⁰

The exchange rate elasticity is significant and negative, estimated at -0.17 for 1984–2006, and at -0.03 for quarterly data 1984Q1–2006Q2, and -0.07 for 1996Q1–2006Q2. An appreciation of the NEER by one percent causes a decline by -0.17 percent and -0.03 to -0.07 percent in annual and quarterly demand, respectively. Depreciation has the opposite effect.²¹ The general finding for NEER elasticity is that this parameter could be both significant and insignificant, with correct or incorrect sign, and is sensitive to the specification of the oil demand equation. This is illustrated by the two equations below.

²⁰ Expansionary monetary policy, seemingly, stimulated also housing and commodity prices during 2000–2006. Credit was considered to be a main channel for monetary transmission (Bernanke and Blinder, 1992).

²¹ 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 the prices of tradable goods (e.g., oil price). While changes in one good's price affect only the relative price of the good in question, a change in the exchange rate, holding money supply fixed, 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.

Sample 1984–2006

$$LQ = - 0.00562*LP(-1) + 0.43*LY - 0.129*LNEER + 2.6; R^2 = 0.99; DW=1.89.$$

(t=-0.642) (32.5) (t=-2.35) (t=19.1);

Sample 1996Q1–2006Q2

$$LQ = + 0.547*LQ(-1) - 0.00028*(LP- LP(-1)) + 0.258*LY - 0.0914*LNEER+ 1.13$$

(t=4.95) (t=-1.88) (t=3.78) (t=-3.85) (t=4.08)

$R^2 = 0.95; DW=1.81.$

These results show that large exchange rate movements play an important role in oil markets, and influence oil demand by a non-negligible percentage, because of both wealth and price effects. In fact, a NEER depreciation causes an appreciation of non-dollar-dominated financial assets and at the same time makes imports, including oil imports, cheaper in non-dollar currencies, thus boosting world oil demand through higher real wealth and lower non-dollar currency oil prices. In contrast, a NEER appreciation causes a depreciation of non-dollar-dominated financial assets and makes imports, including oil imports, more expensive in non-dollar currencies, in turn depressing world oil demand through lower real wealth and higher non-dollar currency oil prices.

The coefficient of the lagged dependent variable describes a first-order difference equation in the dependent variable, giving the speed of adjustment toward full equilibrium, following a random shock or a change in any of the exogenous variables.²² For annual data, world demand for crude oil shows considerable stickiness during 1970–2006, which is captured by the significant coefficient of the lagged demand, estimated at 0.54. However, this inertia seems to have disappeared for annual data in 1984–2006. Annual world demand seems to be close to its long-run path during 1984–2006. For quarterly data, inertia remains significant and high. Estimates of the lagged dependent variable coefficient are 0.63 for 1984Q1–2006Q2, and 0.54 for 1996Q1–2006Q2. Quarterly world demand is, therefore, away from its long-run equilibrium, and may take two to three quarters to return to equilibrium following a shock.

B. Short-run Natural Gas Demand Elasticities

Natural gas demand is negatively affected by its own price. Own-price elasticity was estimated at -0.04 (significant) for 1970–2006, and -0.01 (insignificant) for 1984–2006. For quarterly data, demand price elasticity is estimated at -0.11 (significant) and -0.04

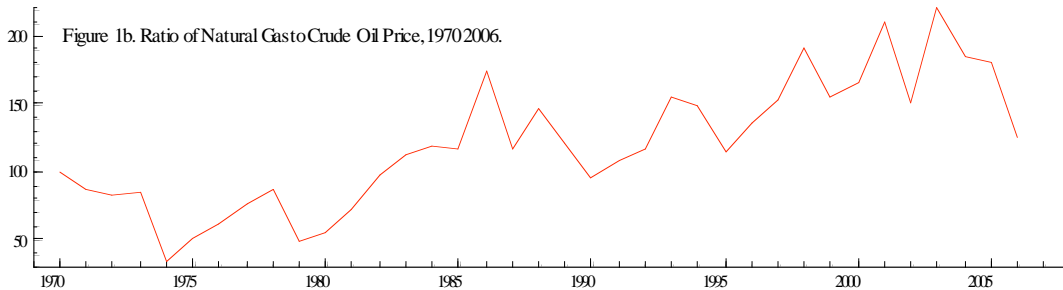
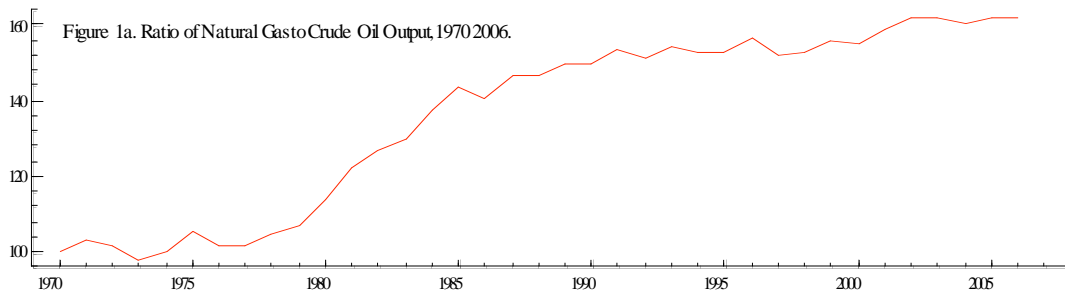
²² The effect of a random shock is given by the impulse response function. Indeed, if a vector auto-regression (VAR) system is written as: $y_t = \sum_{i=1}^L \Phi_i y_{t-i} + \varepsilon_t$, $E(\varepsilon_t \varepsilon_t') = \Sigma$, under invertibility condition, the VAR has a moving average representation defined as:

$$y_t = \sum_{i=0}^{\infty} \Psi_i \varepsilon_{t-i} .$$

The impulse response function consists of computing Ψ_i .

(insignificant), for 1984Q1–2006Q2 and 1996Q1–2006Q2, respectively. Hence, similar to oil demand, short-run gas demand may have only a small response to changes in own price. The same explanation applies, namely, gas consumption is determined by fixed physical capital which cannot be changed in the short-run in response to changes in prices. However, over the longer run, consumers do respond to persistent trends in prices and adapt their gas consumption accordingly.

Cross-price elasticity with oil price is an important parameter, enabling us to assess the degree of interaction between oil and gas markets. While there has been no noticeable natural gas shock, since gas is less tradable than oil, major oil shocks have had a strong impact on gas markets, affecting both quantity and price. The first oil shock displaced large oil demand toward gas wherever substitution was feasible in residential, commercial, and industrial uses. This is easily perceived from the increasing trend in natural gas to crude oil output and price ratios (Figure 1). For instance, associated natural gas is no longer flared and is recuperated; natural gas has become an important feedstock in petrochemicals; gas to liquids technologies are being developed with a view to reducing the cost for producing petroleum products from gas. In transportation, natural gas use is also increasing. Estimates for



1970–2006 show a significant positive effect of higher oil prices on gas demand. Cross-oil price elasticity, estimated at 0.01, has, however, been low, indicating that changes in oil price have had a significant, but small effect on natural gas demand in the short-run. In contrast, estimates for 1984–2006 show a negative cross-oil price elasticity, -0.02. This negative effect could illustrate an asymmetric response of gas demand to oil prices; in particular, large oil price downturns do not cause reverse substitution from gas toward oil. Estimates for 1984Q1–2006Q2 and 1996Q1–2006Q2, seem to indicate positive and significant cross-price elasticity, ranging between 0.01 and 0.02, indicating that higher oil prices tend to increase

demand for gas. The most plausible cross-oil price elasticity would be a positive one. Such a result would corroborate the significant substitution between gas and oil that has taken place since the first oil shock.

Similar to oil demand, gas demand has had significant income elasticity. For 1970–2006, short-run income elasticity is estimated at 0.11. However, for 1984–2006, it is estimated at 0.41, indicating a prominent role for world income in driving world demand for gas. This result is indicative of major structural changes in world demand for gas and the large substitution of natural gas in many energy uses. Thus, as gas use increases in many sectors of the world economy, the demand for gas has become more sensitive to world economic activity. Income elasticity is estimated at 0.26 for 1984Q1–2006Q2, and seems to have risen to 0.48 for 1996Q1–2006Q2. With gas use spreading to many sectors of the economy, world economic activity has become more gas intensive. Hence, gas will have an increasing role in influencing world activity.

The effect of monetary policy on gas markets has also been examined. Omission tests indicate that LIBOR and NEER have acted significantly on the demand for gas. The interest rate coefficient is highly sensitive to demand specification. A parsimonious model would yield a highly significant interest rate coefficient. For 1970–2006, interest rate semi-elasticity is estimated at -0.003 (significant). Thus, an increase in interest rates by 100 basis points could decelerate world demand for gas by -0.3 percent. For 1996Q1–2006Q2, interest rate semi-elasticity, at -0.005, is significant. Clearly, an active monetary policy would have a significant effect on demand for gas. Exchange rate may also have a significant effect on the demand for gas. The NEER elasticity is estimated at -0.16 for 1984–2006 (significant). For quarterly data, the NEER elasticity is estimated at -0.05 (significant) for 1984Q1–2006Q2, and -0.04 (insignificant) for 1996Q1–2006Q2. Thus, currency instability could affect world demand for gas, mostly via the wealth effect arising from changes in the real value of financial assets. Econometric analysis shows that both interest and exchange rates elasticities could be significant in more parsimonious specifications and through changing the sample period. For instance, for 1998Q1–2006Q2, as shown by the regression below, interest rate semi-elasticity is estimated at -0.004 (significant), and NEER elasticity is estimated at -0.06 (significant), indicating that active monetary policy significantly stimulated the demand for gas during this sample period.

Sample 1998Q1–2006Q2

$$\begin{aligned}
 LG = & 0.327*LG(-1) - 0.0034*(LPG-LPG(-1)) + 0.0359*LP(-2) + 0.276*LY - \\
 & (t=2.41) \quad (t=-0.50) \quad (t=3.78) \quad (t=2.04) \\
 & 0.00468*LIBOR(-2) - 0.060*LNEER + 3.21; \quad R^2 = 0.98; \quad DW=2.23. \\
 & (t=-3.59) \quad (t=-2.71) \quad (t=5.06)
 \end{aligned}$$

Gas demand exhibited high stickiness in 1970–2006, with the coefficient of the lagged dependent variable estimated at 0.79. Thus, the 1973 and 1979 oil shocks displaced demand for gas far away from long-run equilibrium. As structural adjustments in demand were taking place over time, inertia diminished. The auto-regression coefficient is estimated at 0.33 (significant) for 1984–2006, indicating much less displacement of the demand for gas from

long-run equilibrium and faster return to this equilibrium following shocks. For quarterly data, the lagged dependent variable coefficient is estimated at 0.65 (significant) for 1984Q1–2006Q2; demand for gas shows much less inertia in 1996Q1–2006Q2, with the lagged dependent variable coefficient dropping to 0.25 (significant), indicating substantial structural change in the demand for gas, and a faster return of this demand to long-run equilibrium following changes in driving variables or random shocks.

Oil and gas demand relationships exhibit close structural patterns. Both show the correct sign and significant demand price elasticity; however, this elasticity is extremely low. Both demands are driven by the level of economic activity, with rising income elasticities. With regard to monetary policy, both variables are significantly responsive to changes in interest and exchange rates. Thus, monetary policy can have a considerable effect on both oil and gas markets, resulting in significant changes in energy prices. Regarding the autoregressive coefficient (i.e., the inertia effect), gas demand seems to have higher stickiness. While both demands have undergone substantial structural adjustment, the demand for oil has become more flexible and faster to converge toward steady-state equilibrium than has the demand for gas.

C. Short-run Crude Oil Supply Elasticities

The ratio of gas to oil output has an increasing trend over time and may have a close relationship to the price ratio (Figure 1). Indeed, a simple regression relating the two ratios gives the following result:

$$L(Q/G) = 0.34 * L(P/PG) - 2.62; R^2 = 0.67; DW = 0.92.$$

(t=8.35) (t=-29.07)

The significance of the relationship between oil and gas output and price ratios calls for an exploration of the effects of gas variables on oil variables. However, to keep the model recursive, only the impact of oil on the gas sector has been studied.

For 1970–2006 and 1984–2006, oil supply–price elasticity is estimated at 0.02 (insignificant). For 1984Q1–2006Q2, oil supply price elasticity is estimated at 0.01 (significant). For 1996Q1–2006Q2, price elasticity is estimated at 0.02 (significant), indicating that oil supply showed a small response to increases in oil prices during 1999–2006. Thus, there is considerable short-run price inelasticity in oil supply. Oil production seems to be determined by installed production capacity, proven reserves, storage and refining capacity, and also by existing contracts and prevailing quotas for OPEC members, with oil prices having only a small influence. Since supply is price insensitive, shocks to oil demand lead to wide changes in oil prices, as witnessed during business cycles. Besides oil price, oil supply is also related to proven oil reserves. As increases in proven reserves stem partly from investment in the oil sector, conveying thus indirect information on capital spending and potential capacity, oil reserves seem to be a pertinent variable for explaining oil

supply [Fisher (1964), Erickson and Spann (1971), Eyssell (1978), and Dhal and Duggan (1998)]²³. Oil reserves elasticity is estimated at 0.14 (significant) for 1970–2006 and at 0.21 (significant) for 1984–2006, indicating more intensive pumping. For quarterly data, reserves elasticity is estimated at 0.14 (significant) for 1984Q1–2006Q2, and 0.11 (insignificant) for 1996Q1–2006Q2. These elasticities indicate that an increase in reserves leads to a significant increase in oil supply.

Considerable rigidity characterizes oil supply, as shown by high and significant coefficient of lagged supply, indicating that oil supply, once disturbed by a shock, has a slow adjustment speed toward equilibrium. For 1970–2006, the autoregressive coefficient is estimated at 0.72. For 1984–2006, oil supply continues to show high inertia. Similar inertia characterizes oil supply during 1984Q1–2006Q2, and 1996Q1–2006Q2, with autoregressive coefficients estimated at 0.79 and 0.71, respectively.

D. Short-run Natural Gas Supply Elasticities

The large magnitude of some past oil shocks seems to have substantially and positively influenced gas supplies. To the extent that oil price shocks contributed to a general appreciation of energy prices, including gas prices, they might also have made investment in the gas industry more appealing than before the shocks, thereby causing an expansion of gas supplies. Indeed, the under-supply of natural gas in the 1950s and 1960s and gas shortages in the 1970s could be attributed to low oil prices prior to the 1973 oil shock, which discouraged exploratory activities for gas. Following this shock, and with the subsequent appreciation of gas prices, a large world-wide effort was made for exploring and exploiting gas resources. Figure 1 shows a steady increase in the ratio of gas to oil supply, with natural gas gaining a higher share in the hydrocarbons industry. The price of natural gas appreciated significantly in relation to crude oil price during 1970–2006. As shown above, a regression of the supply ratio on the price ratio yielded significant elasticity, indicating that gas suppliers were responding to the appreciation of gas prices relative to oil prices.

Gas supply is positively influenced by own price. Supply price elasticity is estimated at 0.05 (significant) for 1970–2006 and 1984–2006. For quarterly data, it is estimated at 0.04 (significant) for 1984Q1–2006Q2, and 0.03 (insignificant) for 1996Q1–2006Q2. Similar to oil supply, short-term low gas supply price elasticity can be explained by installed production capacity and related facilities, including transport pipelines, liquid natural gas carriers, and port facilities. Cross-oil price elasticity is estimated at -0.05 (significant) for 1970–2006, and -0.03 (significant) for 1984–2006. For quarterly data, it is estimated at -0.01 (significant) for 1984Q1–2006Q2, and -0.002 (insignificant) for 1996Q1–2006Q2. Hence, gas–oil price ratio

²³ In Fisher (1964), Erickson and Spann (1971), Dhal and Duggan (1998), oil production is related to reserves, in the form of a depletion equation: $Q_t = e^{-\alpha t} ORSV_0$, $\alpha > 0$ is depletion rate. According to these authors, reserves are related to oil prices and drilling activities. Moreover, fields with depleting reserves had falling oil output.

is a significant determinant (with correct sign) of gas supply. An appreciation of gas price in relation to oil price leads to a higher gas supply; and vice-versa, depreciation of the price ratio leads to a lower gas supply.

The gas reserves coefficient is estimated at 0.05 (insignificant) for 1970–2006, and 0.08 (insignificant) for 1984–2006. For quarterly data, it is estimated at 0.12 (significant) for 1984Q1–2006Q2, and 0.13 (significant) for 1996Q1–2006Q2. The gas reserves elasticity is concomitant with the structural change in the gas industry. Prior to the first oil shock, gas was in large part an associated product with oil because the gas industry was in a lull state. Following the 1973 oil shock and reviving interest in natural gas, more gas fields were discovered and put into exploitation, explaining the rising elasticity of gas reserves. Regarding the dynamic adjustment of gas supply, the autoregressive coefficient seems to indicate slow speed of adjustment. This coefficient is estimated at 0.84 for 1970–2006, and 0.75 for 1984–2006. For quarterly data, the auto-regression coefficient is at 0.79 for 1984Q1–2006Q2, and 0.75 for 1996Q1–2006Q2. Thus, when disturbed, gas supply adjusts slowly to long-run equilibrium. This could be explained by technological considerations, such as more investment being undertaken in gas fields, more gas production coming on line, and more distribution network or processing facilities being installed. As the gas sector expands, convergence toward equilibrium remains slow.

Oil and gas supply equations display similar characteristics. They are positively influenced by own price, although with low elasticity. They are also positively influenced by own reserves. Interaction between the two equations is taken to be one way interaction; cross-oil price elasticity is shown to be small and negative.

IV. SIMULATION OF THE MODEL AND MULTIPLIER ANALYSIS

To serve as a tool for forecasting, an SEM has to closely fit the actual data. It would be interesting to see whether the model could produce the observed sharp fluctuations in oil and gas prices. The simulation exercise was undertaken for annual data 1970–2006, and for quarterly data 1984Q1–2006Q2. Both sets of data include episodes of oil shocks, large fluctuations in quantities and prices, and therefore provide a rich data set for evaluating the in-sample performance of the model. If performance is acceptable, meaning that the root of mean squared error is small, the annual model could be applied for annual forecasting, and the quarterly model for quarterly forecasting.

A. Simulation of the Annual Model: Sample 1970–2006

The structural form of the annual model can be stated as follows (SE=standard error):

Crude Oil Demand

$$\begin{aligned} LQ = & + 0.542 * LQ(-1) - 0.0111 * LP(-4) + 0.123 * LY - 0.00561 * LIBOR(-2) \\ (SE) & (0.107) \quad (0.00868) \quad (0.0395) \quad (0.0022) \\ & - 0.0231 * LNEER + 1.52; \text{sigma} = 0.0241663 \\ & (0.118) \quad (0.421) \end{aligned}$$

Inverse Crude Oil Supply

$$LP = + 0.713*LP(-1) + 1.16*LQ - 0.521*LORSV(-2) + 0.324*DUMO - 0.454$$

(SE) (0.0625) (0.672) (0.313) (0.0506) (1.26)

sigma = 0.167612

Natural Gas Demand

$$LG = + 0.792*LG(-1) - 0.0396*(LPG(-1) - LPG(-2)) + 0.0143*LP(-4) + 0.11*LY$$

(SE) (0.0762) (0.012) (0.0052) (0.0596)

$$- 0.00304*LIBOR(-2) + 0.0961*LNEER + 0.932; \text{sigma} = 0.0144985$$

(0.00142) (0.0813) (0.421)

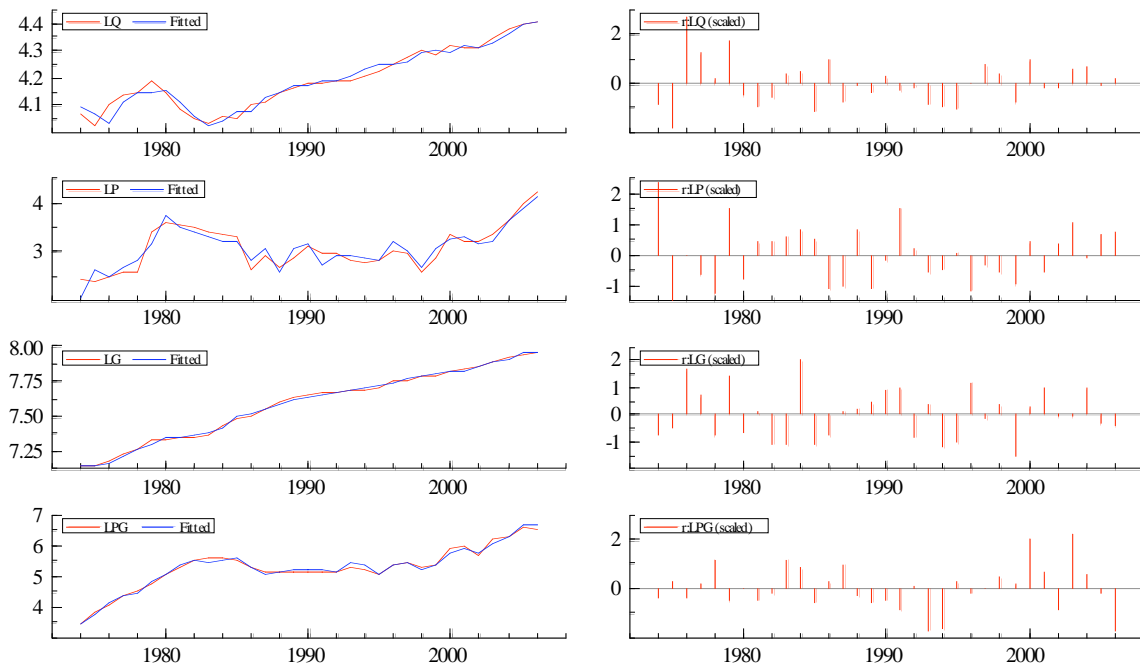
Inverse Natural Gas Supply

$$LPG = + 0.9*LPG(-1) + 0.514*LG + 0.0378*LP - 0.18*LGRSV + 0.26*DUMG - 2.6$$

(SE) (0.0654) (0.435) (0.0757) (0.327) (0.0301) (1.84)

sigma = 0.0864828.

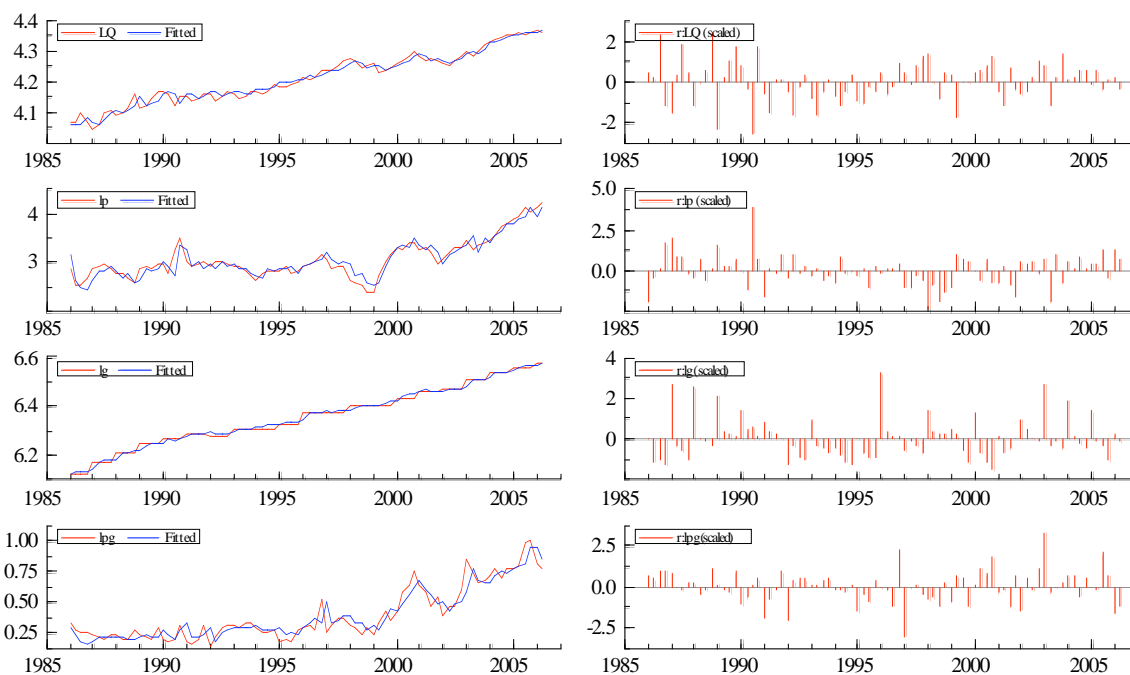
Figure 2: Annual Simulation of the Oil and Natural Gas Model, 1970–2006.



The model closely tracks the data (Figure 2). The residuals are white noise. The respective values for the standard error of the regression residuals (sigma) are 0.02 for oil demand, 0.168 for inverse oil supply, 0.014 for gas demand, and 0.086 for inverse gas supply. Hence, oil and gas outputs have a close fit with the actual data. However, due to their high volatility, oil and gas prices tend to exhibit a higher standard error for the residuals. The implication for forecasting is to allow for larger errors for price forecasting. Assessing the in-sample forecast, the model seems to replicate fluctuations in oil and gas prices; however, large fluctuations might be underestimated by the model. For instance, gas prices are excessively volatile during 2000–2006, rising suddenly by 68 percent in 2000, falling by 26 percent in

2002, and then rising sharply by 69 percent in 2003, by 37 percent in 2005, and falling by 9 percent in 2006. These wide gyrations in gas prices cause the model's in-sample forecast to become less precise. With regard to oil prices, in-sample forecast during 2000–2006 is quite satisfactory due to the continued rising trend during this period. In light of the in-sample forecast performance, it seems that wider error margin should be allowed for prices compared to quantities in future short-term forecasting.

Figure 3: Quarterly Simulation of the Oil and Natural Gas Model, 1984Q1–2006Q2.



B. Simulation of the Quarterly Model: Sample 1984Q1 2006Q2

The structural form of the quarterly model can be stated as follows (SE=standard error):

Crude Oil Demand

$$LQ = + 0.628 * LQ(-1) - 0.0152 * (LP - LP(-1)) + 0.204 * LY + 0.00124 * LIBOR(-2) - 0.034 * LNEER + 0.774; \text{sigma} = 0.0151522$$

(SE) (0.0866) (0.0131) (0.0518) (0.00109) (0.0159) (0.183)

Inverse Crude Oil Supply

$$LP = + 0.941 * LP(-1) + 0.529 * LQ(-2) - 0.229 * LORSV + 0.181 * DUMO - 0.448$$

(SE) (0.0286) (0.301) (0.239) (0.0141) (0.665)

sigma = 0.0847762.

Natural Gas Demand

$$LG = + 0.649 * LG(-1) - 0.107 * (LPG - LPG(-1)) + 0.0132 * LP + 0.257 * LYW$$

(SE) (0.0818) (0.0393) (0.0051) (0.0614)
 + 0.000989*LIBOR(-2) - 0.0524*LNEER + 1.24; sigma = 0.0142549
 (0.000812) (0.0149) (0.278)

Inverse Natural Gas Supply

LPG = + 0.58*LPG(-1) + 0.687*LG(-1) + 0.138*LP - 0.311*LGRSV - 3.07
 (SE) (0.0768) (0.257) (0.0359) (0.175) (0.836)
 sigma = 0.0745424

The quarterly model closely fits the actual data (Figure 3). The residuals are white noise. The respective values for the standard error of the regression residuals are 0.015 for oil demand, 0.085 for inverse oil supply, 0.014 for gas demand, and 0.075 for inverse gas supply. Because of their low volatility, oil and gas outputs have a close fit with the actual data. However, due to their high volatility, oil and gas prices tend to exhibit a higher standard error for the residuals. Nonetheless, the model replicates the trend for oil and gas prices during 1984Q1–2006Q2. The performance of the model during 2000Q1–2006Q2 could be considered satisfactory because the residuals are tightly contained in a small error margin.

C. Multiplier Analysis

Model multipliers are key parameters that compute the effect of a change in exogenous variables on endogenous variables; they may be derived directly from the model’s long-run reduced form, assuming lagged endogenous variables to be at steady–state equilibrium. If stylized values are assigned to multipliers, one can rapidly evaluate the impact of changes in exogenous variables on oil and gas output and prices. Given the noted instability of structural parameters over sample periods and frequencies, it is important to examine the multipliers over the four sample periods considered for the model (Table 2).

The multiplier for world income shows that a one percent increase in income could easily induce a 0.5 percent increase in oil demand, and a 0.9 percent increase in gas demand. Consequently, this may cause an increase in oil prices by 7 percent and in gas prices by 8 percent. The multiplier for interest and exchange rates are generally negative, indicating that expansionary monetary policy leading to lower interest rates and depreciating NEER might stimulate oil and gas markets. Inversely, tight monetary policy leading to higher interest rates and appreciating NEER might depress oil and gas markets. The multiplier for oil reserves tends to stimulate oil output and to depress oil prices; its effect on gas output is ambiguous; however, it seems to depress gas prices. The multiplier for gas reserves does not impact oil markets due to the recursive nature of the model. Nonetheless, it tends to stimulate gas output, and to depress gas prices.

Table 2. Multiplier Analysis

Variable	Sample Period	World Income	Interest Rate	Exchange Rate	Oil Reserves	Gas Reserves
Crude	1970–2006	0.246	-0.011	-0.046	0.040	0.000
Oil	1984–2006	0.330	0.002	-0.129	0.128	0.000
Output	84Q1–06Q2	0.548	0.003	-0.091	0.000	0.000
	96Q1–06Q2	0.462	-0.004	-0.169	-0.008	0.000
Crude	1970–2006	0.991	-0.045	-0.185	-1.654	0.000
Oil	1984–2006	6.853	0.043	-2.690	-6.940	0.000
Price	84Q1–06Q2	4.921	0.030	-0.820	-3.882	0.000
	96Q1–06Q2	3.251	-0.031	-1.192	-0.487	0.000
Natural	1970–2006	0.593	-0.018	0.448	-0.114	0.000
Gas	1984–2006	0.428	0.001	-0.163	0.182	0.000
Output	84Q1–06Q2	0.917	0.004	-0.180	-0.146	0.000
	96Q1–06Q2	0.714	-0.007	-0.094	-0.013	0.000
Natural	1970–2006	3.433	-0.108	2.239	-1.211	-1.809
Gas	1984–2006	7.674	0.045	-3.005	-6.882	-0.423
Price	84Q1–06Q2	3.122	0.016	-0.565	-1.519	-0.739
	96Q1–06Q2	1.957	-0.019	-0.398	-0.115	-0.039

V. STRUCTURAL VECTOR AUTO-REGRESSION ANALYSIS

After having analyzed the model multipliers, it would be useful to examine the impact of random shocks, and to learn more about the historic dynamics of oil and gas markets. Such an analysis is undertaken by viewing the SEM as a near-vector autoregressive (VAR) model comprising four variables: oil output, oil price, gas output, and gas price. Four shocks are identified: an oil demand shock operating through the oil demand function, an oil supply shock operating through the oil supply function, a gas demand shock operating via the gas demand function, and a gas supply shock operating through the gas supply function. Impulse responses of VAR to shocks are shown in Figure 4 and 5. The first row in Figure 4 and 5 describes the impact of an oil demand shock, the second describes the impact of an oil supply shock, the third describes the impact of a gas demand shock, and the fourth describes the impact of a gas supply shock on successively oil output, oil price, gas output, and gas price.

A demand shock increases the demand for oil. At the same time, it contributes to a gradual increase in oil prices, and to gas output and price. This seems to have been the experience during 2000–2006 when a demand shock caused an increase in oil demand, and at the same a progressive increase in oil price, gas output, and gas price. In contrast, a supply shock seems to act abruptly, causing a sharp increase in oil prices, depressing in turn oil demand. It causes, however, an increase in gas output and prices, essentially via a displacement of the demand for oil toward gas. A gas demand shock increases the demand for gas as well as gas prices. A gas supply shock increases gas prices, and depresses at the same time the demand for gas. It operates along the same pattern as an oil supply shock. Because of assumed recursiveness, shocks from the gas sector are not transmitted to the oil sector. As mentioned

earlier, recursiveness is assumed only to simplify modeling; a reverse relationship would be worth analyzing, because developments in the gas sector do affect the oil sector.

Figure 4: Annual Structural VAR: Impulse Responses

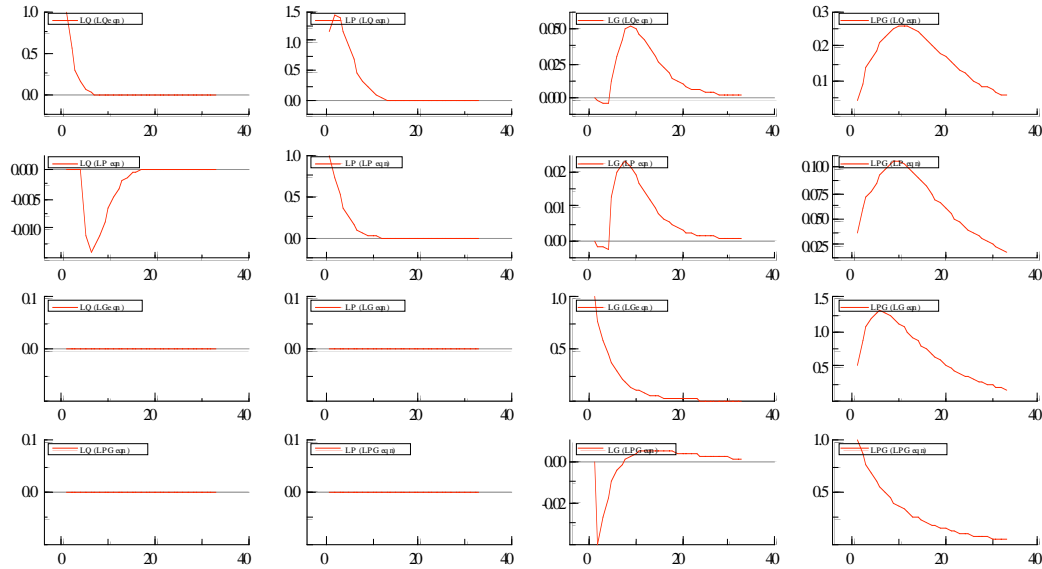
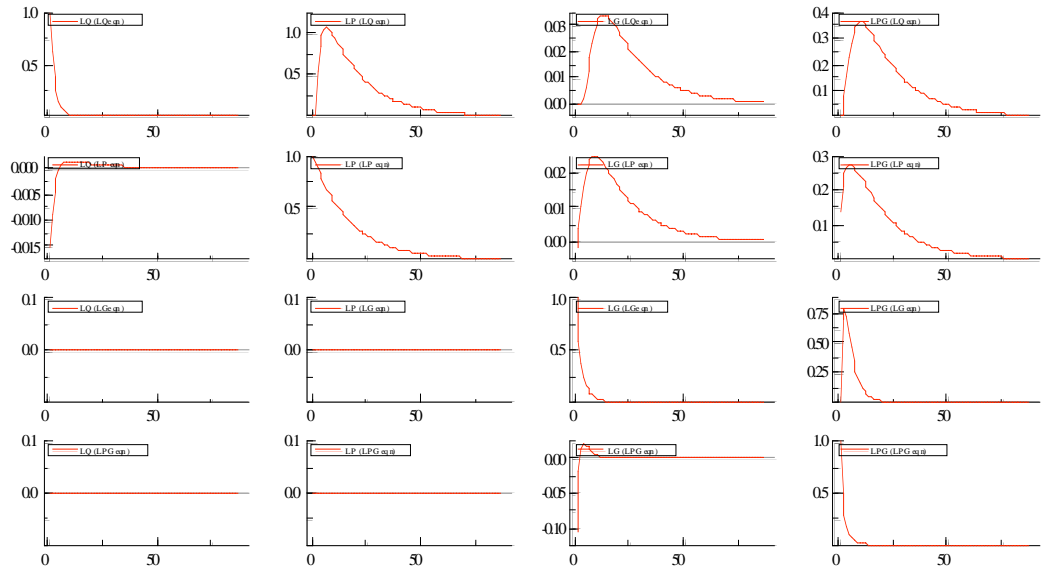


Figure 5: Quarterly Structural VAR: Impulse Responses



VI. CONCLUSION

Recent instability in oil and gas prices, coupled with expansionary monetary policies and the re-emergence of inflationary expectations, motivated us to build a model for analyzing oil

and gas markets, incorporating the role of monetary policy. Using annual data for 1970–2006 and quarterly data for 1984Q1–2006Q2, short-term oil demand price elasticity turns out to be small, ranging between -0.01 and -0.04, often contemporaneously insignificant and significant only with a lag, showing a highly price inelastic world demand for oil. Short-term oil supply-price elasticity also turns out to be small. Similarly small demand and supply elasticities are obtained for the gas sector. The implication of these findings is that any small imbalance in the demand for hydrocarbons or their supply could lead to large changes in respective prices. In examining oil-gas linkage, cross-oil price elasticity is shown to be small, positive in the gas demand equation, and negative in the gas supply equation. Oil and gas demands are driven by world economic activity. Income elasticity has always been significant and is in the range of 0.11 and 0.48. It has systematically been less than unity. An implication of these findings is that changes in the rate of world economic growth cause significant changes in the demand for oil and gas and could subsequently cause large upturns or downturns in oil and gas prices.

We were particularly interested in the role of monetary policy in oil and gas markets. We show that interest rates, given by LIBOR, have a significant and negative semi-elasticity, which implies that an active monetary policy significantly influences, with some delay, the demand for oil and gas. Similarly, using the U.S. nominal effective exchange rate as a measure for exchange rate stability, we conclude that exchange rate movements have had a significant and negative effect on the demand for oil and gas. A depreciation of the U.S. dollar exchange rate would stimulate world demand for hydrocarbon, and vice-versa. An implication of these findings is that a highly active monetary policy would have a significant effect on oil and gas markets. In the same vein, stable monetary conditions would contribute to stable oil and gas markets. These findings suggest that monetary policy should include the impact of monetary instruments (e.g., interest rates, monetary base) on oil and gas prices.

Historical simulations show that the model gives a good fit; its dynamics was able to retrace turning points in actual quantity and price data. In-sample quantity forecasts have a very small margin of error. Price forecast, however, deteriorate when there are wild fluctuations in prices. If applied as a forecasting tool, the model has to assume a wider margin of error for prices. We analyzed the model's multipliers and impulse responses to demand and supply shocks. In this regard, an oil demand shock has a typical response consisting of an increase in the demand for oil and gas, and a gradual increase in prices which taper off progressively. An oil supply shock has a typical response consisting of a price increase, a depressed demand for oil, and increased gas output and prices.

As in any econometric model, further modeling improvements would be desirable; in this case addressing the exogeneity of income, interest rates and exchange rates, and bringing in expected inflation rates and using real interest rates as an argument in demand equations. Nonetheless, the SEM, being a structural model and involving key macroeconomic variables, has many potential applications for industry analysts and policymakers. It could be used as a forecasting tool for oil and gas markets. It could also simulate the impact of random shocks on the supply and demand of oil and gas via impulse responses.

Estimated Regressions, Annual Data:

Crude Oil Demand, Sample 1970 2006

$$\begin{aligned} \text{LQ} = & + 0.542*\text{LQ}(-1) - 0.0111*\text{LP}(-4) + 0.123*\text{LY} - 0.00561*\text{LIBOR}(-2) \\ (\text{SE}) & (0.107) \quad (0.00868) \quad (0.0395) \quad (0.0022) \\ & - 0.0231*\text{LNEER} + 1.52; \text{sigma} = 0.0241663. \\ & (0.118) \quad (0.421) \end{aligned}$$

Crude Oil Demand, Sample 1984 2006

$$\begin{aligned} \text{LQ} = & + 0.044*\text{LQ}(-1) - 0.0177*\text{LP}(-2) + 0.437*\text{LY} + 0.00273*\text{LIBOR}(-2) \\ (\text{SE}) & (0.141) \quad (0.00817) \quad (0.0673) \quad (0.0016) \\ & - 0.171*\text{LNEER} + 2.49; \text{sigma} = 0.0104882. \\ & (0.0549) \quad (0.354) \end{aligned}$$

Crude Oil Supply, Sample 1970 2006

$$\begin{aligned} \text{LQ} = & + 0.717*\text{LQ}(-1) + 0.0207*(\text{LP} - \text{LP}(-1)) + 0.137*\text{LORSV}(-2) + 0.27; \text{sigma} = 0.061. \\ (\text{SE}) & (0.0861) \quad (0.016) \quad (0.0433) \quad (0.179) \end{aligned}$$

Crude Oil Supply, Sample 1984 2006

$$\begin{aligned} \text{LQ} = & + 0.7225*\text{LQ}(-1) + 0.02088*\text{LP}(-1) + 0.2113*\text{LORSV} - 0.3438; \text{sigma} = 0.02882. \\ (\text{SE}) & (0.107) \quad (0.0118) \quad (0.0848) \quad (0.223) \end{aligned}$$

Natural Gas Demand, Sample 1970 2006

$$\begin{aligned} \text{LG} = & + 0.792*\text{LG}(-1) - 0.0396*(\text{LPG}(-1) - \text{LPG}(-2)) + 0.0143*\text{LP}(-4) \\ (\text{SE}) & (0.0762) \quad (0.012) \quad (0.0052) \\ & + 0.11*\text{LY} - 0.00304*\text{LIBOR}(-2) + 0.0961*\text{LNEER} + 0.932; \text{sigma} = 0.0144985 \\ & (0.0596) \quad (0.00142) \quad (0.0813) \quad (0.421) \end{aligned}$$

Natural Gas Demand, Sample 1984 2006

$$\begin{aligned} \text{LG} = & + 0.327*\text{LG}(-1) - 0.0108*(\text{LPG}(-1) - \text{LPG}(-2)) - 0.0177*\text{LP}(-2) \\ (\text{SE}) & (0.106) \quad (0.0107) \quad (0.00882) \\ & + 0.409*\text{LY} + 0.00119*\text{LIBOR}(-2) - 0.157*\text{LNEER} + 3.75; \text{sigma} = 0.0097947 \\ & (0.0715) \quad (0.00168) \quad (0.0713) \quad (0.616) \end{aligned}$$

Natural Gas Supply, Sample 1970 2006

$$\begin{aligned} \text{LG} = & + 0.839*\text{LG}(-1) + 0.0485*\text{LPG} - 0.0459*\text{LP}(-1) + 0.0511*\text{LGRSV} + 0.879 \\ (\text{SE}) & (0.0963) \quad (0.0137) \quad (0.0119) \quad (0.0674) \quad (0.416) \\ & \text{sigma} = 0.01182. \end{aligned}$$

Natural Gas Supply, Sample 1984 2006

$$\begin{aligned} \text{LG} = & + 0.754*\text{LG}(-1) + 0.0463*\text{LPG} - 0.0259*\text{LP}(-1) + 0.0844*\text{LGRSV} + 1.33 \\ (\text{SE}) & (0.106) \quad (0.0124) \quad (0.0139) \quad (0.0824) \quad (0.416) \\ & \text{sigma} = 0.0102. \end{aligned}$$

Estimated Regressions, Quarterly Data:

Crude Oil Demand, Sample 1984Q1 2006Q2

$$\begin{aligned} \text{LQ} = & + 0.632*\text{LQ}(-1) - 0.0165*(\text{LP}-\text{LP}(-1)) + 0.204*\text{LY} + 0.00137*\text{LIBOR}(-2) \\ (\text{SE}) & (0.0851) \quad (0.0127) \quad (0.0511) \quad (0.00106) \\ & - 0.0356*\text{LNEER} + 0.766; \text{sigma} = 0.0150062. \\ & (0.0156) \quad (0.179) \end{aligned}$$

Crude Oil Demand, Sample 1996Q1 2006Q2

$$\begin{aligned} \text{LQ} = & + 0.539*\text{LQ}(-1) - 0.0373*\text{LP} + 0.0443*\text{LP}(-1) + 0.193*\text{LY} - 0.00191*\text{LIBOR}(-4) \\ (\text{SE}) & (0.103) \quad (0.0324) \quad (0.0301) \quad (0.0906) \quad (0.00173) \\ & - 0.0674*\text{LNEER} + 1.35; \text{sigma} = 0.0102828 \\ & (0.031) \quad (0.275) \end{aligned}$$

Crude Oil Supply, Sample 1984Q1 2006Q2

$$\begin{aligned} \text{LQ} = & 0.793*\text{LQ}(-1) + 0.014*\text{LP}(-1) + 0.139*\text{LORSV}(-2) - 0.132; \text{sigma} = 0.032. \\ (\text{SE}) & (0.056) \quad (0.005) \quad (0.041) \quad (0.104) \end{aligned}$$

Crude Oil Supply, Sample 1996Q1 2006Q2

$$\begin{aligned} \text{LQ} = & 0.714*\text{LQ}(-1) + 0.017*\text{LP}(-1) + 0.114*\text{LORSV}(-2) + 0.366; \text{sigma} = 0.058. \\ (\text{SE}) & (0.079) \quad (0.007) \quad (0.066) \quad (0.356) \end{aligned}$$

Natural Gas Demand, Sample 1984Q1 2006Q2

$$\begin{aligned} \text{LG} = & + 0.647*\text{LG}(-1) - 0.113*(\text{LPG} - \text{LPG}(-1)) + 0.0117*\text{LP} + 0.258*\text{LY} + \\ (\text{SE}) & (0.0808) \quad (0.0147) \quad (0.00492) \quad (0.0607) \\ & 0.00096*\text{LIBOR}(-2) - 0.0521*\text{LNEER} + 1.25; \text{sigma} = 0.0144115 \\ & (0.000793) \quad (0.0417) \quad (0.275) \end{aligned}$$

Natural Gas Demand, Sample 1996Q1 2006Q2

$$\begin{aligned} \text{LG} = & + 0.249*\text{LG}(-1) - 0.0432*(\text{LPG} - \text{LPG}(-1)) + 0.019*\text{LP}(-2) \\ (\text{SE}) & (0.135) \quad (0.0265) \quad (0.0079) \\ & + 0.479*\text{LY} - 0.00471*\text{LIBOR}(-4) - 0.0441*\text{LNEER} + 2.73 ; \text{sigma} = 0.010683 \\ & (0.113) \quad (0.00185) \quad (0.0293) \quad (0.488) \end{aligned}$$

Natural Gas Supply, Sample 1984Q1 2006Q2

$$\begin{aligned} \text{LG} = & + 0.79*\text{LG}(-1) + 0.0427*\text{LPG}(-1) - 0.0112*\text{LP}(-4) + 0.122*\text{LGRSV} + 0.75 \\ (\text{SE}) & (0.0486) \quad (0.012) \quad (0.00575) \quad (0.0341) \quad (0.156) \\ & \text{sigma} = 0.011. \end{aligned}$$

Natural Gas Supply, Sample 1996Q1 2006Q2

$$\begin{aligned} \text{LG} = & + 0.752*\text{LG}(-1) + 0.0281*\text{LPG}(-1) - 0.00226*\text{LP}(-4) + 0.133*\text{LGRSV} + 0.918 \\ (\text{SE}) & (0.0787) \quad (0.0186) \quad (0.00854) \quad (0.0528) \quad (0.373) \\ & \text{sigma} = 0.031. \end{aligned}$$

References

- Amano RA, van Norden S. Exchange Rates and Oil Prices. *Review of International Economics* 1998; 6; 683-694.
- Balestra P, Nerlove M. Pooling Cross Section and Time Series Data in the Estimation of a Dynamic Model: The Demand for Natural Gas. *Econometrica* 1966; 34; 585-612.
- Bernanke BS, Blinder AS. The Federal Funds Rate and the Channels of Monetary Transmissions. *American Economic Review* 1992; 82; 901-921.
- Bernanke, BS, Gertler M, Watson M. Systematic Monetary Policy and the Effects of Oil Shocks. *Brookings Papers on Economic Activity* 1997; 1997; 91-157.
- Dhal C, Duggan TE. Survey of Price Elasticities from Economic Exploration Models of US Oil and Gas Supply. *Journal of Energy Finance and Development* 1998; 3; 129-169.
- Erickson, EW, and Spann RM. Supply Response in a Regulated Industry: The Case of Natural Gas. *The Bell Journal of Economics and Management Science* 1971; 2; 94-121.
- Eyssell, JH. The Supply Response of Crude Petroleum – New and Optimistic Results. *Business Economics* 1978; 1393; 338-346.
- Favero, CA. *Applied Macroeconometrics*. Oxford University Press: Oxford; 2001.
- Fisher, FM. *Supply Costs in the United States Petroleum Industry*. John Hopkins University Press: Baltimore; 1964.
- Gately D, and Huntington HG. The Asymmetric Effects of Changes in Price and Income on Energy and Oil Demand. *The Energy Journal* 2002; 23; 19-55.
- Hamilton, JD. Oil and the Macroeconomy since World War II. *Journal of Political Economy* 1983; 91; 228-48.
- Hamilton, JD. What Is an Oil Shock. *Journal of Econometrics* 2003; 113; 363-98.
- Hamilton, JD, Herrera AM, 2004, “Oil Shocks and Aggregate Macroeconomic Behavior: The Role of the Monetary Policy,” *Journal of Money, Credit, and Banking* 2004; 36; 265-86.
- International Monetary Fund. *World Economic Outlook*. International Monetary Fund: Washington DC; April 2007.

Jones, DW, Leiby PN, Paik IK. Oil Price Shocks and the Macroeconomy: What Have We Learned Since 1996? *The Energy Journal* 2004; 25; 1-32.

McCallum B, Nelson W. Performance of Operational Policy Rules in an Estimated Semi-Classical Structural Model. In: Taylor J (Ed.), *Monetary Policy Rules*_Chicago: University of Chicago Press: Chicago; 2000. P. 15-45.

McFadden D, Fuss M (Eds). *Production Economics: A Dual Approach*. North-Holland Publishing Co: Amsterdam; 1977.

Muth, JF. Rational Expectations and the Theory of Price Movements. *Econometrica*, 1961; 29; 313-335.

Pesaran, MH, Smith RP, Akiyama T. *Energy Demand in Asian Developing Economies*. Oxford University Press/World Bank: New York; 1998.

Pindyck, RS. *The Structure of World Energy Demand*. MIT Press: Cambridge; 1979.

Working, EJ. What Do Statistical Demand Curves Show. *Quarterly Journal of Economics* 1927; 41; 212-235.