Modelling the World Oil Market
Assessment of a Quarterly Econometric Model

Stéphane Dées[a#], Pavlos Karadeloglou[a], Robert K. Kaufmann[b], Marcelo Sánchez[a]

[a] *European Central Bank*
[b] *CEES, Boston University*

Abstract

This paper describes a structural econometric model of the world oil market that can be used to analyse oil market developments and risks. Oil demand depends on domestic economic activity and the real price of oil. Oil supply for non-OPEC producers, based on competitive behaviours, is constrained by geological and institutional conditions. Oil prices are determined by a "price rule" that includes market conditions and OPEC behaviour. Policy simulations indicate that oil demand and non-OPEC supply are rather inelastic to changes in price, while OPEC decisions about quota and capacity utilisation have a significant, immediate impact on oil prices.

Keywords: Oil market; Econometric modelling; Forecasting

JEL codes: C51, Q41.

[#] Corresponding author: Stephane Dees, European Central Bank, Kaiserstrasse 29, 60311 Frankfurt-am-Main, Germany, Tel.: +49 69 13 44 87 84, Fax: +49 69 13 44 63 53, e-mail: stephane.dees@ecb.int.

We are grateful to Marc Dean, Conall MacCoille, Ivan Odonnat and Anne-Marie Rieu and colleagues from National Central Banks for helpful comments on a previous version. The views expressed in this paper are those of the authors and do not necessarily reflect the position of the European Central Bank.

1 Introduction

Standard practice models the world oil market in terms of a supply-demand equilibrium schedule (e.g. Bacon, 1991, Al Faris, 1991). This approach is difficult due to characteristics specific to the oil market. Although a demand curve that relates quantities to prices can accurately represent oil demand, modelling supply is more difficult because oil is supplied by both a cartel (OPEC) and a set of independent producers (non-OPEC nations). Moreover, oil prices react in a complex fashion to changes in market conditions and OPEC behaviour.

Here, we address these particularities with a quarterly model for the world oil market that includes a pricing rule and demand and supply schedules for different regions of the world. To model supply, we distinguish between non-OPEC and OPEC behaviours. While we assume that non-OPEC behaviour is competitive (but subject to geological and institutional constraints), OPEC behaviour is however more complex, as shown also by an extensive literature on the subject. The academic literature examines the nature and goals of OPEC by testing competing hypotheses for different behaviours (e.g. Griffin, 1985). Among the behaviours envisaged, two can be identified as corner solutions: a cartel model, where OPEC is price maker and a competitive model, where OPEC is price taker. Efforts to choose among these models focus in part on identifying the slope of OPEC's supply curve. A negative relationship between price and production has been interpreted as a backward bending supply curve, which indicates that OPEC sets production based on some type of non-competitive behaviour. However, econometric analyses of these relationships indicates that production by individual OPEC nations and OPEC as a whole ”Granger causes” oil prices but prices generally do not ”Granger cause” production (Kaufmann et al., 2004). These results imply that there is no backward bending supply curve. In other words, OPEC functions somewhere between the two corner solutions. To simulate this intermediate degree of ”real-world” control over the world oil market, the effect of both market conditions and OPEC behaviour on oil prices often is modelled with a “price rule.” Such a rule gives the price at which OPEC is ready to act as a swing producer, given new demand conditions and market indicators that reflect the effect of behaviour by the dominant producer.

This rest of this paper is organised as follows. Section 2 describes the general structure of the model and gives estimation results for the demand, supply and price equations. Section 3 assesses the model in terms of forecast performance and simulation properties. The final section summarises the major findings.

2 General Structure of the Model

Oil demand

Oil demand equations are estimated for the ten main trading partners of the euro area; the United States, Japan, United Kingdom, Euro area, Switzerland, other developed economies, non-Japan Asia, Transition economies, Latin America, and rest of the world. For each region, oil demand is a function of real GDP, real oil prices, and a time trend that represents technical changes that are linked to energy efficiency.

The general specification for the econometric equations of oil demand is given by:

$$DEM_i = \Phi\left(Y_i, \frac{POIL}{P_i^D}.E_i, time\right) \tag{1}$$

in which DEM_i is oil demand in physical units for each country/region i, Y_i is real GDP, $POIL$ is the Brent oil price in USD, E_i the exchange rate vis-à-vis the USD and P_i^D is the CPI index (the GDP deflator was also used, but did not yield statistically different results). The estimation sample includes quarterly data from 1984Q1 to 2002Q1 (due to data constraints, the sample starts later for emerging economies and other developed economies). The relatively small sample period may limit the robustness of the results, especially for the transition economies, whose sample includes only 24 observations. Nonetheless, we use the same methodology for all equations to ensure similar properties across countries and regions.

In equation (1), the price variable *POIL* corresponds to prices traded in the futures market and therefore does not include taxes. In many nations, taxes constitute a significant portion of the end-user prices, therefore changes in future prices may not measure exactly the percent change paid by consumers. To evaluate this effect on the econometric estimates for equation (1), we use a measure of oil prices calculated by the *International Energy Agency* that includes taxes for the United States, Japan, the United Kingdom and Switzerland. Although such a specification neglects any substitution effects among energy products, it captures the main factors, which influence the demand for oil[1].

Equation (1) is estimated using the two step dynamic ordinary least squares estimator. It includes a long-run equilibrium relationship and an error correction model that defines the dynamic adjustment to a long-run equilibrium relationship (see Table 1 for estimates

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[1] As we focus on macroeconomic aspects, we have deliberately excluded any distinction between sectors, although the sector-related behaviours might be strongly differentiated. We have also excluded any forward-looking variables (e.g. expectations about oil prices) in order to keep the model as simple as possible.

and Table 6a in Appendix for detailed results)[2]. The real price of oil does not enter any long-run relationship. We include this variable only among the dynamic terms in the error correction models. This is in line with unit root tests, which indicate that the real price of oil – which displays a high level of volatility – appears to be stationary.

The results show that the coefficient associated with the error correction term in the oil demand equation is significantly different from zero for all countries/regions but Latin America. The significance of this term indicates that oil demand is cointegrated with its long-run determinants. The long-run income elasticity of oil demand is less than one for all ten demand regions. It is very close to one in the US and Latin America, less than 0.2 in the UK and Switzerland, and between 0.39 and 0.77 in all other countries/regions. The long-run income elasticity for oil demand is smaller than the short-run income elasticity, which allows oil demand to adjust smoothly to income changes in the US, the euro area, other developed economies, and transition economies. The short-run elasticity is larger in the long-run elasticity in Japan, the UK, Switzerland, and Non-Japan Asia, which causes oil demand to over-react to changes in real GDP in the short run. Finally, the short-run and long-run elasticities are similar for Latin America and the rest of the world.

Oil supply

We distinguish between the supply behaviour of OPEC and non-OPEC nations. The former can be modelled using either a co-operative behaviour, in which OPEC matches production to demand or a competitive behaviour, in which OPEC produces oil commensurate with its operable capacity. Non-OPEC production has a significant effect on

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[2] The results using the tax-including end-use price variable (for the cases of United States, Japan, United Kingdom, Euro area, and Switzerland) are reported in Table 6b in Appendix. These results are roughly the same as those obtained using the real price of oil excluding taxes.

OPEC's share of the world oil supply and, as a consequence on OPEC's ability to influence prices. Production by non-OPEC countries is modelled using a technique that assumes competitive behaviour is constrained by geological and institutional factors.

Non-OPEC supply

Although most producers outside OPEC can be considered as price takers and profit maximisers, economic models of non-OPEC production generally have proved unreliable because there is no simple relation between real oil prices and production (Kaufmann and Cleveland, 2000). Instead, the effect of real oil prices on production is mediated by resource depletion, technical change, economic incentives, and political considerations. These factors must be included to simulate oil production by non-OPEC nations. To do so, we update a hybrid methodology developed by Kaufmann (1991) that combines the curve fitting technique developed by Hubbert (1962) with econometric models pioneered by Fisher (1981).

This hybrid methodology is estimated in three steps. First a logistic curve is estimated for cumulative oil production according to the method developed by Hubbert. The logistic curve is estimated using the following equation:

$$\ln\left(\frac{Q^{\times}}{Q_t-1}\right)=\ln(a)+b(t-t_0) \qquad (2a)$$

in which $Q^{\times}$ is the ultimate recoverable supply of oil, Q_t is cumulative oil production at time t, and t_0 is the start date of the analysis. The first difference of the logistic curve gives an estimate for the annual rate of production (ΔQt). This is Hubbert's bell shaped curve for the production cycle of a non-renewable resource, which we term the production curve.

Because the physical characteristics of the oil fields do not entirely determine production, the hybrid methodology also includes the effects of economic and political variables. These effects are included in the second step, in which the annual rate of production generated by the production curve (ΔQt) is used as an explanatory variable in a cointegrating relation for the economic, geological, and institutional determinants of production that is given as follows:

$$PROD_t = \alpha + \beta_1 \Delta Q_t + \beta_2 ROIL_t + \beta_3 Dummy + \beta_4 Asym + \mu_t \tag{2b}$$

in which $PROD_t$ is oil production, $ROIL$ is the real price of oil, *Dummy* is a dummy variable that may affect local production (e.g. prorationing by the Texas Railroad Commission in the US, the "Peso" crisis in Mexico), and *Asym* is a variable designed to test the assumption of symmetry that is implicit in the production curve. *Asym* is the product of ΔQ_t and a dummy variable, which is equal to one after the peak of the production curve. As such, the *Asym* variable can be used only for regions where production has continued beyond the peak of the production curve.

In the third step, the short-run dynamics of the supply equations are estimated using an error correction model that has the following specification:

$$\Delta PROD_t = \gamma + \delta_1 \mu_{t-1} + \underset{i}{\ } \delta_2 \Delta\Delta Q_{t-i} + \underset{i}{\ } \delta_3 \Delta ROIL_{t-i} + \underset{i}{\ } \delta_4 \Delta Asym + \varepsilon_t \tag{2c}$$

in which μ is the residual from equation (2b). The value of δ gives the rate at which oil production adjusts towards its long-run equilibrium.

The start date for the production curve t_0 and the value for $Q^{\times}$ are not known *a priori*. To identify these values, equations (2a)-(2c) are estimated using a range of values and the results reported in Tables 2a and 2b are chosen using the following criteria. First, the combination of t_0 and $Q^{\times}$ is chosen so that the residual in equation (2b) is stationary. This is done to identify the form of the production curve that cointegrates with production (and the other variables). Next, we retain combinations in which the regression coefficients have the correct sign and are statistically significant in both the long-term relationship (equation 2b) and the error correction model (equation 2c). Of these combinations, we chose the combination that has the highest R^2.

Because the geological and economic environments differ among non-OPEC nations, equations are estimated for nine regions: Lower 48 states (US), Alaska (US), Canada, Mexico, Brazil, Non-OPEC Latin America, Western Europe, Non-OPEC Africa, and Non-OPEC Asia. Other non-OPEC regions include the Former Soviet Union, China, and non-OPEC Middle East. Production by these regions is forecast exogenously due to the difficulties associated with market structure (Former Soviet and China) and/or geographical disparity (e.g. non-OPEC middle East includes non-contiguous nations such as Syria, Oman, etc.).

OPEC supply

The model is set up to simulate two forms of OPEC production behaviour: cooperative and competitive production. Cooperative behaviour can be used to describe OPEC production since the third quarter of 1986 (Kaufmann, 1995). During that period, OPEC generally set production to match the difference between world oil demand and non-OPEC production. This behaviour can be simulated with the following equation for OPEC production:

$$PROD^{opec} = \underset{i}{} DEM_{i} + \Delta Stocks^{oecd} - NGLS - \underset{j}{} PROD^{non\text{-}opec} - PG \tag{3a}$$

in which $\mathrm{Stocks}^{\mathrm{oecd}}$ is the level of stocks reported by OECD, NGLS is natural gas liquids and PG is processing gains.

Alternatively, the model can simulate competitive behaviour by OPEC nations. Following this behaviour, OPEC nations compete among themselves and with non-OPEC producers for market share. To compete for market share, OPEC increases production to rates that are consistent with operable capacity. To account for competitive production behaviours, OPEC production is simulated using the following equation:

$$PROD^{opec} = 0.95 * Capacity^{opec} \tag{3b}$$

in which *Capacity* is operable capacity (million barrels per day) of OPEC[3]. As described in the next section, OPEC capacity is exogenous to the model. The competitive behaviour described by equation (3’) implies that production will not match demand. Oil produced in excess of demand is put into stocks. This increase in stocks will depress oil prices via the price rule that is described in the next section. Conversely, the price rule does not use the 95 percent rate of capacity utilisation that is implied by equation (3). Instead, the rate of capacity utilisation used by the price rule is calculated based on the call for OPEC oil that is given by equation (3).

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[3] Data from Erik Kreil from the US Department of Energy

Oil price

Due to the presence of a dominant producer and a high degree of volatility, the real price of oil is difficult to model. Starting with Frankel (1946), several studies have tried to assess the factors that determine oil prices. In addition to market factors such as oil inventories, the behaviour of the dominant producer is an important determinant of oil prices. Between the late 1930's and the late 1960's the Texas Railroad Commission (TRC) acted as the dominant producer by prorationing Texas production to match demand. This reduced the volatility of real oil prices. Starting in the early 1970's OPEC became the dominant oil producer. OPEC has a different political agenda than the TRC and price volatility increased tremendously. Although the effect of behaviour by a dominant producer on the volatility of oil prices is relatively easy to see (Figure 4 from Kaufmann, 1995), modellers find it difficult to simulate their effect for two reasons: (i) the inability to forecast behaviour of the dominant producer; and (ii) the inability to translate a particular behaviour into a change in real oil prices (Kaufmann, 1995).

As described in Section 1, the ability of OPEC to affect oil prices lies between that of a cartel and that of a price taker. Because no theory can explain such "intermediate behaviour," empirical analyses simulate this intermediate degree of control with a "price rule," which relates price to measures of OPEC behaviour and market indicators of the supply/demand balance (Gately, 1995). The use of a price rule to "solve" for oil prices can be explained as follows. At any given price, demand determines the optimal quantity of oil supplied. Non-OPEC countries adapt their production to this new price and OPEC acts as the swing producer to equilibrate supply and demand consistent with the optimal price/quantity levels (see Figure 1 – an increase in demand raises price to P_1*^R and the total supply curve moves from S_0 to S_1 leading to a new production level at Q_1*).

We use a price rule described by Kaufmann *et al*, (in press) that has the following specification:

$$\begin{aligned} ROIL_t &= \alpha + \beta_1 DAYS_t + \beta_2 Quota_t + \beta_3 Cheat_t + \beta_4 Caputil_t \\ &+ \beta_5 Q_1 + \beta_6 Q_2 + \beta_7 Q_3 + \beta_8 War + \mu_t \end{aligned} \tag{4}$$

in which *ROIL* is the US crude oil import FOB price and is measured in 1996 US $ per barrel (Monthly Energy Review, various months), *Days* is days of forward consumption of OECD crude oil stocks, which is calculated by dividing OECD crude oil stocks by OECD oil demand (Monthly Energy Review, various months), *Quota* is the OPEC production quota (million barrels per day), *Cheat* is the difference between OPEC production (Monthly Energy Review, various months) and OPEC quotas (million barrels per day), *Caputil* is capacity utilisation by OPEC, which is calculated by dividing OPEC production (mbd) by OPEC capacity (mbd), Q1, Q2, and Q3 are dummy variables for quarters I, II, and III, respectively, and War is a dummy variable for the Persian Gulf War (third and fourth quarters of 1990).

Dickey-Fuller tests indicate that the variables in equation (4), other than the dummies, are non-stationary. We use the dynamic ordinary least squares (DOLS) estimator developed by Stock and Watson (1993) to estimate the cointegrating relation given by equation (4) because it generates asymptotically efficient estimates of the regression coefficients for variables that cointegrate, it is computationally simple, and it performs well relative to other asymptotically efficient estimators. The coefficients estimated by DOLS represent the long run relationship among variables. To examine the short run dynamics in a second step, we use OLS to estimate an error correction model (ECM).

The signs on the regression coefficients estimated (Table 3) are consistent with previous results described by Kaufmann (1995) and Balabanoff (1995). The regression coefficient associated with *Days* is negative — an increase in stocks reduces real oil price by reducing reliance on current production and thereby lowering the risk premium that is associated with a supply disruption. Similarly, an increase in the OPEC quota tends to alleviate upward pressure on prices. An increase in the *Cheat* variable also tends to reduce price — an increase in OPEC production relative to their quota increases supply relative to the demand perceived by OPEC when setting the quota (perceived demand may not be the most important or only variable used to set the quota). The sign on the regression coefficient associated with *Caputil* is positive, which is consistent with those described by Gately and Kyle (1977) and Kaufmann (1995). The positive sign indicates that increases in capacity utilisation tend to increase prices. This effect is consistent with OPEC's role as the marginal producer during the 1986:III – 2000:III period. During this period, OPEC generally set production to match the expected difference between non-OPEC supply, which is determined largely by non-OPEC capacity (as price takers, non-OPEC producers generally operate at or near capacity), and demand (and to keep prices within a desired range). As demand for oil from OPEC increases production relative to capacity, utilisation rates rise, which signals a "tightness" in the market. The War variable has a positive effect on prices — prices rose after the Iraqi invasion of Kuwait in anticipation of a supply disruption, but this effect disappeared during the first quarter of 1991, when it became apparent that the war would have little effect on oil supplies from the Persian Gulf.

Results of the ECM estimate indicate that prices do not adjust immediately to the long-term relationship. Regression results indicate that the error correction coefficient is statistically significant (Table 4). This result is consistent with the interpretation of equation (4) as a cointegrating relation in which the right hand side variables “Granger cause” real oil prices. The point estimate of the error correction coefficient is –0.56, which indicates that 56 percent of the disequilibrium in equation (4) is eliminated after one quarter.

3 Assessment of the model

Forecast performance of the oil model

To evaluate the model’s ability to simulate the behaviour of the world oil market, we carried out an in-sample static and dynamic simulation from 1995q1 to 2000q3 (Figure 3). Standard measures of forecast accuracy suggest that the forecast errors generated by the model are small (Table 4). The RMSE of the fully dynamic simulation is less than 2% after 1 quarter, around 2.5% after one year and is slightly less than 5% after 3 years.

Assessment of the model properties: Some basic simulations

We illustrate the main properties of the model by running several simulations. The first simulates an exogenous oil price shock to illustrate its impact of the supply/demand behaviour in the absence of a price feedback. The remaining simulations illustrate the effect of three determinants of oil prices, namely OPEC quota, OPEC capacity, and OECD stocks. Finally, the effect of OPEC behaviour is examined with a simulation in which OPEC production is modelled using equation (3b).

The effect of oil price

To evaluate the effect of oil prices on supply and demand, the model is simulated with oil prices exogenous (the oil price rule is “turned off”). The first scenario assumes a 50 percent permanent increase in the price of oil. The 50 percent increase in the price of oil reduces demand by 3 percent in the long run. Higher prices do increase non-OPEC production, although the response is small (non-OPEC production increases by about 1.75% relative to baseline). This small response implies that supply is quite inelastic.

Although the aggregate response of non-OPEC supply is inelastic, there are differences among our non-OPEC regions (Figure 5). For most non-OPEC nations, the 50 percent increase in real oil prices generates a 1 percent increase in production. Two notable exceptions are Mexico and the lower 48 US states, where higher prices increase production by about 5.5 percent. In Mexico, the relatively elastic response is associated with its large undeveloped resource base and its significant lack of funds. Under these conditions, a large increase in oil prices would boost revenues and generate the capital needed to increase operable capacity. In the US, the relatively elastic response is associated with the presence of a large number of small producers who are willing and able to increase production in response to higher oil prices.

How does OPEC quota affect oil prices?

This simulation increases the OPEC quota by 10% relative to base case. This simulation is designed to assess the effect of OPEC announcements regarding its quota. To isolate this effect, the change in quota initially has no affect on OPEC production. That is, OPEC increases its quota by 10 percent but production remains unchanged at the time of the announcement. OPEC production does change after prices change (via the price rule) because the change in price affects demand and non-OPEC supply, and these changes ultimately affect the amount of oil that OPEC must produce to balance supply and demand according to equation (3).

The 10 percent increase in OPEC quota leads to an immediate 6% decrease in oil price. In response, demand increases and non-OPEC production declines. OPEC fills the gap between demand and supply, which causes price to increase. Although this price increase is smaller than the immediate reduction, the rise is sufficient to reduce demand and increase non-OPEC production slightly. These two changes reduce the demand for oil from OPEC, which subsequently reduces the price for oil. After a succession of low amplitude oscillations, the price of oil reaches an equilibrium that is close to the immediate effect of 10 percent increase in the OPEC quota.

Change in OPEC capacity

A reduction in OPEC capacity was partially responsible for the oil price shock in 1979. At that time, the fall of the Shah plunged Iran into revolution and Iran's capacity was removed from the market for much of that year. To evaluate the effects of a change in OPEC capacity, we simulate a 5 percent increase in OPEC capacity. By definition, this increase reduces OPEC's rate of capacity utilisation, which reduces oil price. As with this previous scenario, the change in capacity has no immediate effect on OPEC production. Rather, OPEC production changes in response to the immediate effect on oil price. As indicated in Figure 7, the magnitude of the response as well as its dynamic pattern is very similar to the previous simulation.

The reduction in oil prices indicated in Figure 7 may explain why OPEC generally is unwilling to increase capacity (OPEC capacity in 2004 is essentially the same as it was in 1973). According to our simulation, increasing capacity depresses the real price of oil by about 12 percent immediately and by about 10 percent in the long term. The reduction in price causes the call for oil from OPEC to increase by about 2 percent. Together, these changes imply a reduction in OPEC revenues of about 8 percent. This reduction implies that it is not in OPEC’s interest to add capacity in a timely fashion. Rather, OPEC should not add capacity until the call for oil from OPEC approaches capacity and prices rise. OPEC could then use a portion of the additional revenue to fund additions to capacity. These additions would then lower price back towards the level that prevailed before the capacity induced price spike. This dynamic may foreshadow the ”solution” to the high price environment of 2004 that is caused in part by high rates of capacity utilisation.

Shock on OECD stocks

Kaufmann et al (2004) argue that changes in inventory practices that reduced OECD stocks of crude oil are responsible for a general increase in real oil prices from the early 1990’s forward. To evaluate the effect of changes in stocks, we simulate a 10 percent permanent reduction in stocks. Consistent with the sign of the regression coefficient associated with *DAYS* in equation (4), the 10 percent decrease in stocks increases real oil prices by about around 25 percent immediately and by 32 percent after one year (Figure 8). Assuming that the decrease in stocks is permanent, these increases in price decrease demand and increase non-OPEC supply, which tends to decrease the demand for oil from OPEC. Such reductions decrease price, but by a much smaller amount than the initial effect of the stock reduction. Under these conditions, the permanent decrease in stocks has a permanent, positive impact on real oil prices.

Alternative OPEC behaviour

The previous simulations assume that OPEC acts co-operatively to set production. This cooperation is coordinated by setting quotas. Without these quotas, operable capacity would allow OPEC to produce more oil than required by the market. The current quotas limit OPEC production to about 85 percent of operable capacity.

In this last simulation, we explore the effects of a break-down in OPEC cooperation. To do so, we assume that OPEC sets production at 95 percent of its operable capacity, regardless of the quantity demanded by the market. This would imply a significant increase in OPEC production, which exceeds current levels of demand. Under these conditions, the supply demand balance is maintained by putting excess quantities of OPEC oil into OECD stocks. The increase in stocks causes oil prices to decline sharply, by about 40 percent. In the longer term, lower prices increase demand and lower non-OPEC production. These changes increase the demand for oil from OPEC towards levels that are consistent with capacity. As OPEC production increases towards capacity, prices rise. This rise depresses demand and increases non-OPEC production. This reduces the demand for oil from OPEC, which causes prices to fall.

Because of this dynamic, prices fluctuate sharply around a lower midpoint for the remainder of the simulation (Figure 9). This volatility mirrors the high degree of volatility in prices that prevailed prior to the formation of the Texas Railroad Commission. The TRC was formed to damp the boom-and-bust cycle that characterised a “competitive” oil market. The boom-and-bust cycle is generated by the small price elasticities for oil supply and demand, the long life-times that are associated with energy using capital, and the high fixed costs of oil production relative to the operating costs (Kaufmann, 1995).

The high price volatility highlights the costs and benefits to consuming nations of OPEC acting cooperatively as the dominant producer. On average, real oil prices would be considerably lower if OPEC collapsed and individual members acted competitively. This would benefit oil-consuming nations. But such a change in OPEC behaviour would increase price volatility. And price volatility imposes costs to consuming nations. Specifically, it makes planning very difficult, which is especially important for energy markets where energy using capital devices have relatively long life-times. Hence these fluctuations make it difficult to choose the energy using technology that will maximise the net present value of profits or utility. In addition, the trough of the boom-and-bust cycle increases bankruptcies by high cost producers, like those most non-OPEC nations.

3 Concluding remarks

This paper describes a model of the world oil market that can be used to forecast oil supply, demand, and real prices and to analyse risks with each. The model simulates oil demand with behavioural equations that relate demand to domestic economic activity and the real price of oil. Oil supply for non-OPEC producers is simulated assuming a competitive behaviour that is constrained by geological and institutional factors. Real oil prices are simulated using a “price rule” that represents the effects of market conditions and OPEC behaviour. OPEC behaviour can be simulated using two modes, a cooperative behaviour that ensures a balance between supply and demand and a competitive behaviour that uses a rule that mimics basic petroleum economics.

Simulation results show that the model satisfactorily represents the underlying behaviour of the world oil market and this enables analysts to understand the basis on real-world events. As expected, the price response of oil demand and non-OPEC supply are rather inelastic. Although OPEC is assumed to “close” the model by absorbing any excess in supply or demand, the model shows that OPEC decisions about quota and capacity utilisation have a significant, immediate impact on oil price.

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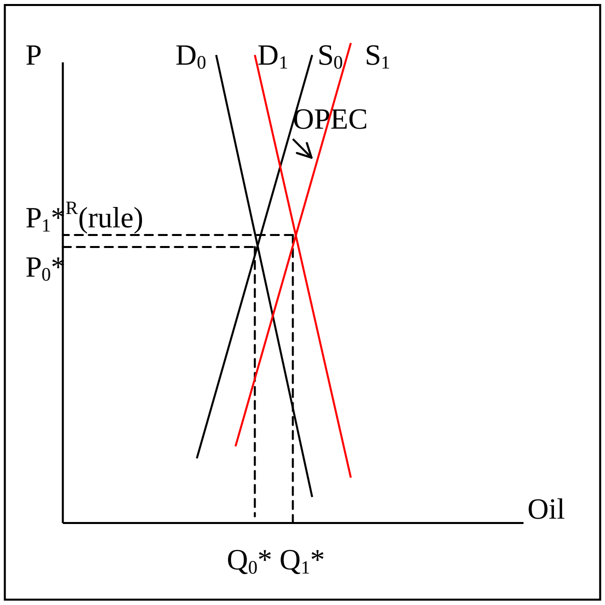
Tables and figures

Table 1: Results of oil demand estimations

	Adjustment coefficient of the ECM	Estimation period	Long term coefficients		Short-term dynamics	
			Real GDP	Time trend	Real GDP	Real oil price[4]
United States	0.67	1984:1-2002:2	0.98	-0.004	0.77	-0.02
Japan	0.25	1984:1-2002:1	0.61		0.89	-0.03
Euro area	0.82	1984:1-2002:1	0.57		0.45	-0.03
United Kingdom	0.14	1985:2-2002:1	0.17		0.65	-0.05
Switzerland	0.93	1984:1-2002:1	0.18		1.08	-0.08
Non-Japan Asia	0.34	1993:1-2002:1	0.77		1.73	-0.02
Other Dev. Eco.	0.83	1993:1-2002:1	0.39		0.001	-0.01
Transition eco.	0.004	1995:1-2002:1	0.51	-0.010	0.002	-0.02
Latin America	0.23	1993:1-2002:1	0.85		0.82	-0.00
Row	0.51	1991:1-2002:2	0.55		0.58	

Figure 1: Model with price rule



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[4] Defined as the oil price in national currency deflated by a domestic price index for each country. CPI has been used as a proxy for domestic price index. It can been shown that the results obtained with CPI are more satisfactory than the ones obtained with other domestic price proxies (GDP deflator in particular).

Table 2a: Results for equation (2a)

	Start date (t_0)	$Q^\times$	a	b	R^2
Lower 48 (US)	1858	170000	161.0	-0.08	0.954
Alaska (US)	1948	15000	435.3	-0.21	0.995
Canada	1940	50000	235.8	-0.12	0.961
Western Europe	1908	90000	246.0	-0.12	0.995
Non-OPEC Asia	1877	67000	181.2	-0.09	0.887
Non-OPEC Africa	1932	27000	222.3	-0.11	0.996
Non-OPEC Latin America	1940	30000	128.8	-0.06	0.999
Mexico	1904	80000	151.4	-0.07	0.700
Brazil	1948	34000	321.3	-0.16	0.861

Table 2b: Results for equation (2b)

	ΔQ_t	*ROIL*	*Cost*	*Dummy*	*Asym*	R^2
Lower 48 (US)	0.62 (23.32)	1.36 (2.69)			0.17 (10.43)	0.96
Alaska (US)	0.53 (20.26)	993.2 (2.71)		282098.5 (18.0)	-0.07 (-3.57)	0.99
Canada	0.50 (10.32)	1.77 (2.45)	-170.77 (-7.01)			0.85
Western Europe	0.84 (47.29)	6.03 (4.72)				0.98
Non-OPEC Asia	0.67 (53.19)	1.30 (2.69)				0.99
Non-OPEC Africa	1.04 (67.17)	0.84 (2.59)				0.99
Non-OPEC Latin America	0.94 (53.93)				0.37 (14.56)	0.98
Mexico	0.15 (9.04)	7.18 (9.71)		500.66 (14.55)		0.70
Brazil	0.30 (24.36)	0.79 (2.25)				0.93

Table 3: Estimates for price equation

Variables	**Coefficients**
Days	-1.45 (3.35)
Caputil	32.47 (2.30)
Cheat	-2.00 (2.87)
Quota	-2.05 (2.85)
Adjustment rate	-0.56 (2.85)

Values in parenthesis are t statistics that are calculated using the Newey-West (1987) estimator.

Figure 2: The model structure

Demand side

$$DEM_i = \Phi\left(Y_i, \frac{POIL}{\overline{P_i^D}}.\overline{E_i}, time\right) \qquad (1)$$

for i = US, euro area, UK, Switzerland, Other Dev. Eco. NJA, Transition, Latin America, Rest of the world

DEM : Oil demand in mbd

Y : Real GDP

POIL : Oil price in USD

$\overline{P^D}$ *: Domestic price index*

$\overline{E}$*: Exchange rate vis - a - vis USD*

time : time trend

Supply side

$$PROD_j^{non\text{-}opec} = \Theta\left(\overline{Cost}_j, \frac{POIL}{\overline{P_i^D}}\right) \qquad (2)$$

for j = US (lower 48 + Alaska), Canada, Asia, Africa, Europe, Latin America (Brazil, Mexico and others)

$$PROD^{opec} = \underset{i}{}\, DEM_i + \Delta\overline{Stocks}^{oecd} - \overline{NGLS} - \underset{j}{}\, PROD^{non\text{-}opec} - \overline{PG} \qquad (3)$$

$$PROD^{opec} = 0.95 * \overline{Capacity}^{opec} \qquad (3')$$

PROD : Oil supply in mbd

$\overline{Cost}$ *: Measure of production costs*

$\overline{Stocks}^{oecd}$ *: Oil stocks reported OECD*

$\overline{NGLS}$ *: Non Gas Liquid in mbd*

$\overline{PG}$ *: Processing Gains in mbd (net)*

Oil Price

$$POIL = \Psi\left(\underset{i \in oecd}{}\frac{\overline{Stocks}^{oecd}}{DEM_i}, \overline{Quota}^{opec}, \left(PROD^{opec} - \overline{Quota}^{opec}\right)\frac{PROD^{opec}}{\overline{Capacity}^{opec}}\right) \qquad (4)$$

$\overline{Quota}$ *: OPEC quota in mbd*

$\overline{Capacity}$ *: OPEC capacity in mbd*

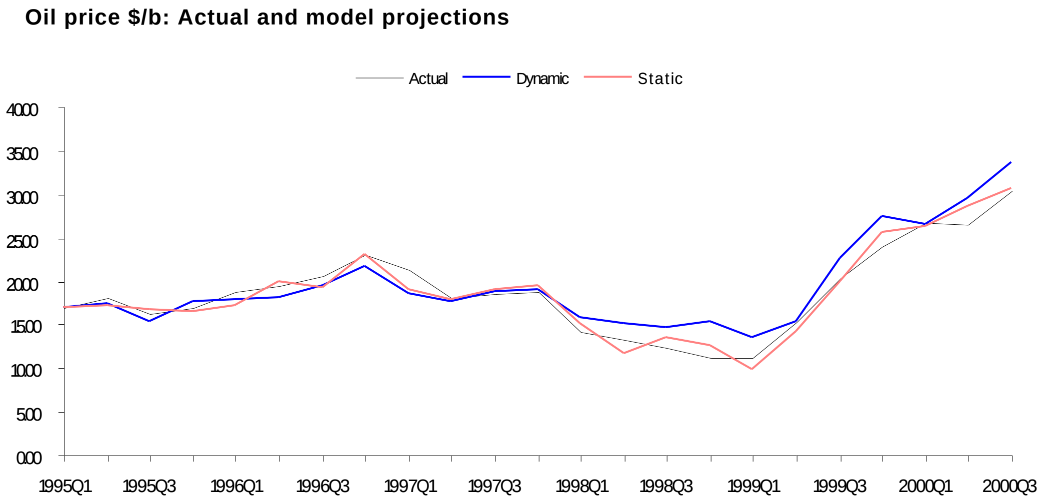
Closure of the model

The model is closed by OPEC behaviour :

cooperation [equation (3)] or *non - cooperation* [equation (3') + stocks used as residuals]

Note: A bar over a variable means it is determined exogenously.

Figure 3



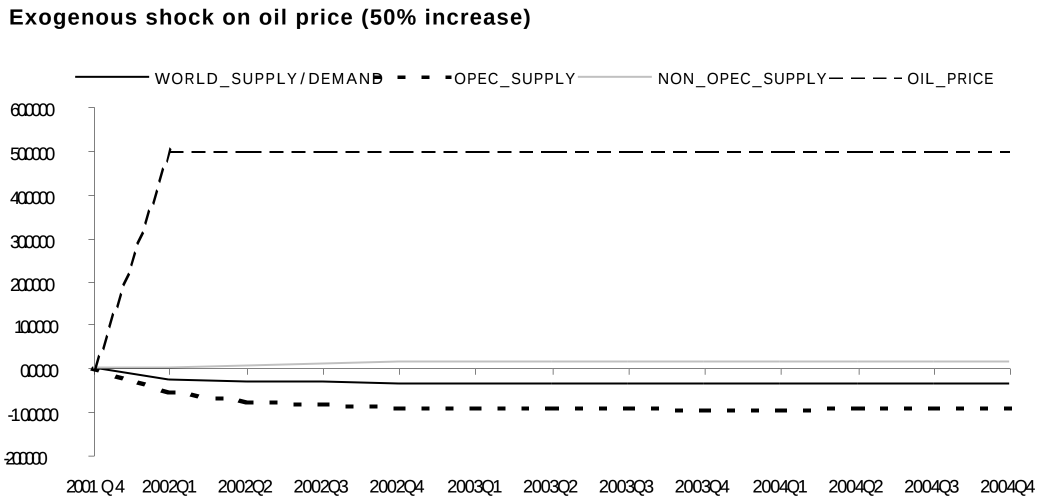
Source: ECB

Table 4: Computations of the in-sample forecasting performance for oil price

(Root mean squared errors in percentage of the baseline value)

	1 quarter	1 year	2 years	3 years
Dynamic simulation	1.90	2.46	3.70	4.97
Static simulation	1.39	2.23	3.40	4.63

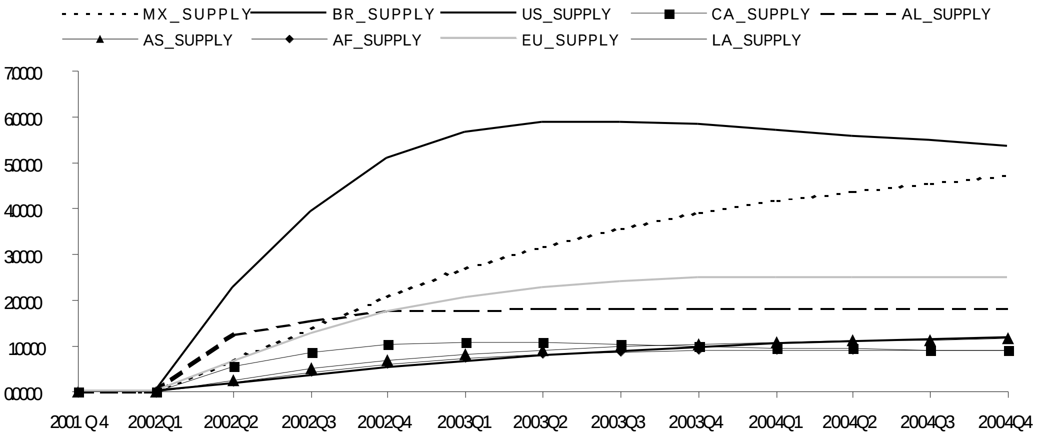
Figure 4



Source: ECB

Figure 5

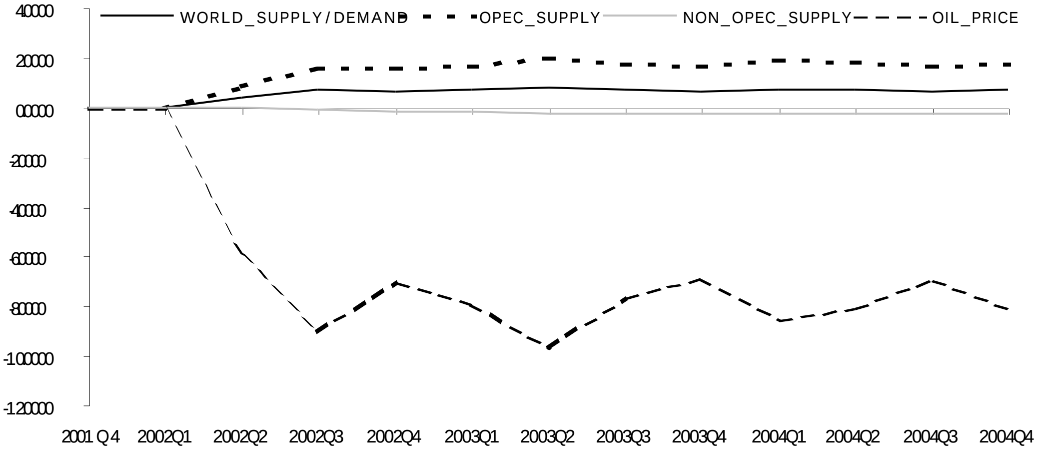
Exogenous shock on oil price (50% increase)



Source: ECB

Figure 6

Shock on OPEC quota with OPEC production unaffected by the shock (10% increase)



Source: ECB

Figure 7

Shock on OPEC capacity with OPEC production unaffected by the shock (5% increase)

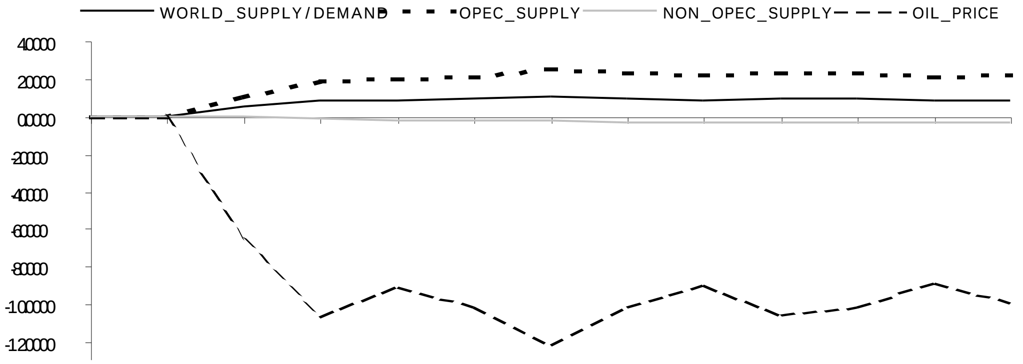
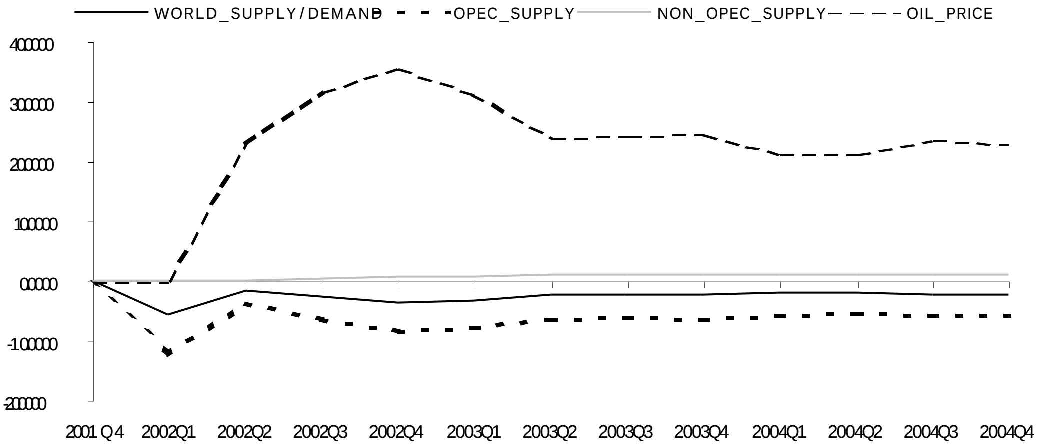


Figure 8

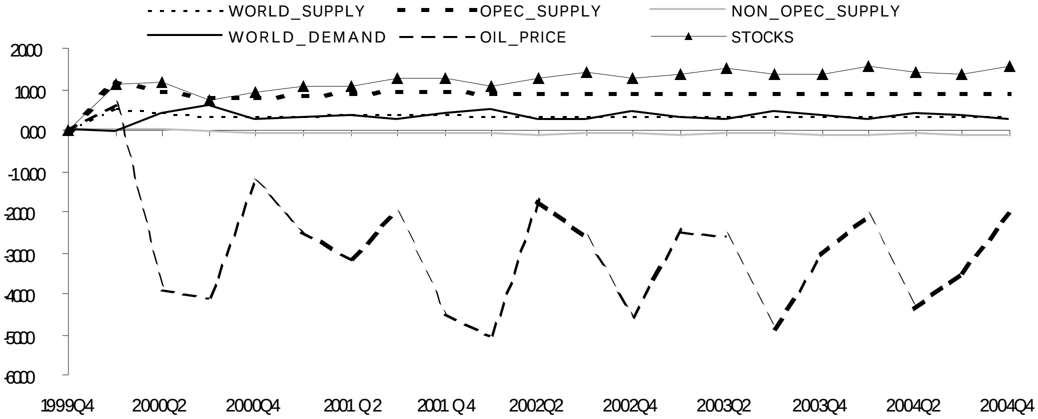
Shock on oil stocks (10% decrease)



Source: ECB

Figure 9

Non-cooperative behaviour of OPEC



Source: ECB

Appendix : Oil demand equation results

This appendix presents detailed econometric results of the demand equations presented in the main text. Table 5 presents unit root tests of the variables and Tables 6a and 6b give the complete estimation results.

Table 5: Unit root tests

	ADF - constant and trend		ADF - constant		ADF - without constant	
	DEM	ΔDEM	DEM	ΔDEM	DEM	ΔDEM
US	-1.88	-3.41*	-0.37	-3.49***	2.27	-2.77***
Japan	0.42	-4.22***	-1.75	-3.25**	0.93	-3.13***
UK	-4.83***	-6.77***	-2.53	-6.87***	-0.56	-6.98***
Euro area	-2.36	-14.95***	-1.75	-14.84***	3.28	-3.92***
ODE	1.56	-2.63	-2.78*	-1.52	1.77	-1.48
Transition	-1.81	-3.05	-2.93**	-2.03	-0.90	-1.94**
NJA	-0.46	-10.42***	-3.96***	-3.26**	2.32	-1.74*
Lat. America	-0.60	-2.77	-1.64	-2.29	1.18	-1.95**
RoW	-3.71**	-9.50***	-4.32***	-3.16***	2.64	-1.51
	Y	ΔY	Y	ΔY	Y	ΔY
US	-2.18	-3.86**	-0.41	-3.89***	3.27	-1.95**
Japan	-1.24	-2.70	-2.51	-1.63	0.82	-1.51
UK	-2.76	-2.90	-1.01	-2.86*	2.35	-1.55
Euro area	-2.50	-7.69***	-0.97	-7.58***	8.82	-1.36
ODE	-3.21*	-4.98***	-2.22	-4.43***	13.41	-1.18
Transition	-0.07	-3.75**	0.65	-3.16**	1.73	-1.51
NJA	-2.52	-3.27*	-1.81	-2.89**	2.48	-1.09
Lat. America	-2.16	-4.06***	-1.79	-3.36**	1.79	-2.73***
RoW	-1.99	-2.19	-0.11	-2.26	4.21	-0.75
	ROIL	ΔROIL	ROIL	ΔROIL	ROIL	ΔROIL
US	-3.70**	-4.87***	-3.34**	-4.76***	-0.70	-4.74***
Japan	-2.63	-5.20***	-3.37**	-4.71***	-0.87	-4.66***
UK	-3.61**	-4.86***	-3.72***	-4.49***	-0.95	-4.43***
Euro area	-3.79**	-7.23***	-2.99**	-7.28***	-0.62	-7.29***
ODE	-2.59	-5.17***	-3.15**	-4.77***	-0.64	-4.76***
Transition	-3.74**	-2.93	-3.35**	-2.96**	0.43	-2.48**
NJA	-3.35*	-3.26**	-3.12**	-3.17**	-0.40	-3.23***
Lat. America	-3.36*	-5.13***	-2.51	-5.01***	-0.64	-5.00***

Note: We use data-driven lag selection procedures in the ADF tests, taking 1.645 as the critical value used for significance of lagged terms and 4 as the maximum number of lags allowed in these procedures into account. We denote with */**/** the rejection of the null hypothesis at a 10%/5%/1% critical levels.

Critical levels used for ADF are the following:

- In the model with constant and trend: -4.05 (1%), -3.45 (5%) and –3.15 (10%).
- In the model with constant: -3.50 (1%), -2.89 (5%) and –2.58 (10%).
- In the model without constant: -2.59 (1%), -1.94 (5%) and –1.62 (10%).

Table 6a: Econometric results

	United States	Japan	U. Kingdom	Euro area	Switzerland
Long-term equation					
Constant	5.49 (11.27)	5.78 (15.87)	6.67 (28.07)	6.59 (41.1)	4.74 (16.18)
GDP	0.98 (8.61)	0.61 (7.61)	0.17 (3.36)	0.57 (16.32)	0.18 (2.89)
Time trend	-0.004 (-4.99)				
Short-term equation					
Adj. Coef.	-0.67 (-5.37)	-0.25 (-2.72)	-0.14 (-2.17)	-0.82 (-6.89)	-0.93 (-7.84)
Constant	-0.01 (-1.73)	0.07 (8.37)	0.00 (0.52)	0.02 (2.79)	-0.04 (-2.48)
ΔGDP	0.77 (2.29)			0.45 (0.85)	1.08 (0.70)
ΔGDP(-1)		0.89 (2.63)	0.65 (1.21)		
ΔROIL			-0.05 (-2.73)	-0.03 (-1.45)	-0.08 (-2.01)
ΔROIL(-1)	-0.02 (-1.78)	-0.03 (-1.63)			
Q2	-0.01 (-2.20)	-0.26 (-24.2)	-0.05 (-5.40)	-0.06 (-7.50)	-0.00 (-0.13)
Q3	0.01 (1.99)	-0.06 (-3.46)	0.00 (0.14)	-0.03 (-2.63)	0.08 (4.15)
Q4	0.01 (2.65)	0.02 (1.64)	0.02 (2.18)	0.01 (1.06)	0.05 (2.91)
Sample	84:1-02:2	84:1-02:1	85:2-02:1	84:1-02:1	84:1-02:1
Nb of obs.	72	72	67	72	72
ADF resid.	-8.40	-9.77	-8.39	-8.24	-8.73
Adj. R2	0.54	0.95	0.57	0.77	0.62

Table 6a: Econometric results (continued)

	NJ Asia	Transition	Latin America	ODE	RoW
Long-term equation					
Constant	5.77 (35.27)	6.67 (0.88)	4.81 (22.89)	6.41 (27.91)	6.25 (123.2)
GDP	0.77 (22.33)	0.51 (2.49)	0.85 (18.80)	0.39 (7.90)	0.55 (50.66)
Time trend		-0.01 (-5.27)			
Short-term equation					
Adj. Coef.	-0.34 (-1.88)	-0.83 (-4.75)	-0.004 (-0.64)	-0.23 (-1.98)	-0.51 (-3.65)
Constant	-0.02 (-1.69)	0.01 (0.83)	0.10 (0.57)	-0.01 (-1.66)	-0.00 (-0.41)
ΔGDP	1.73 (2.75)		0.82 (3.03)	0.001 (0.49)	0.58 (1.56)
ΔGDP(-1)		0.002 (0.48)			
ΔROIL		-0.01 (-1.55)	-0.01 (-0.51)		
ΔROIL(-1)	-0.02 (-0.84)				
Q2	-0.01 (-1.13)	-0.04 (-5.27)	0.03 (4.14)	-0.02 (-2.41)	0.01 (1.22)
Q3	-0.01 (-1.04)	-0.03 (-2.83)	0.03 (3.56)	0.03 (3.39)	0.01 (2.21)
Q4	0.06 (3.76)	0.02 (1.80)	-0.01 (-0.87)	0.03 (5.10)	-0.01 (-1.52)
Sample	93:1-02:1	95:1-02:1	93:1-02:1	93:1-02:1	91:1-02:2
Nb. of obs.	36	28	36	35	45
ADF resid.	-7.14	-4.89	-7.43	-6.39	-5.80
Adj. R2	0.74	0.90	0.56	0.75	0.46

Table 6b: Econometric results with tax-including oil prices

	United States	Japan	U. Kingdom	Euro area	Switzerland
Long-term equation					
Constant	5.49 (11.27)	5.78 (15.87)	6.67 (28.07)	6.59 (41.1)	4.74 (16.17)
GDP	0.98 (8.61)	0.61 (7.61)	0.17 (3.36)	0.57 (16.32)	0.18 (2.89)
Time trend	-0.004 (-4.99)				
Short-term equation					
Adj. Coef.	-0.67 (-5.79)	-0.27 (-2.88)	-0.12 (-1.68)	-0.81 (-7.01)	-0.96 (-8.28)
Constant	-0.01 (-2.01)	0.06 (8.02)	0.01 (0.72)	0.02 (2.80)	-0.04 (-2.67)
ΔGDP	0.86 (2.57)			0.002 (0.37)	0.82 (0.55)
ΔGDP(-1)		0.78 (2.34)	0.61 (1.11)		
ΔROIL			-0.16 (-2.12)	-0.17 (-2.71)	-0.30 (-2.65)
ΔROIL(-1)	-0.03 (-1.03)	-0.07 (-1.84)			
Q2	-0.01 (-2.94)	-0.25 (-23.9)	-0.05 (-5.51)	-0.06 (-7.13)	0.00 (0.16)
Q3	0.01 (2.24)	-0.05 (-3.53)	-0.001 (-0.10)	-0.03 (-2.56)	0.08 (4.21)
Q4	0.01 (2.56)	0.02 (1.52)	0.02 (2.04)	0.01 (1.37)	0.06 (3.28)
Sample	84:1-02:2	84:1-02:1	85:2-02:1	84:1-02:1	84:1-02:1
Nb. of obs.	72	72	67	72	72
ADF resid.	-8.69	-9.84	-7.59	-8.41	-8.97
Adj. R2	0.54	0.94	0.56	0.79	0.65