Modelling the World Oil Market
Assessment of a Quarterly Econometric Model

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Abstract

This paper describes a structural econometric model of the world oil market intended to be used to assess oil price developments and to provide quantitative analyses of oil related risk assessments. In this model, oil demand is explained by behavioural equations that relate demand to domestic activity and the real price of oil. Oil supply for non-OPEC producers is derived from a competitive behaviour, taking into account the effect of geological and economic variables. Oil prices are defined by a "price rule" based on changes in market conditions and OPEC behaviour. In particular, OPEC acts according to a co-operative behaviour and ensures the global equilibrium at the price determined by the price rule. In-sample simulation results show that the model satisfactorily reproduces past developments in oil markets. Policy simulations show that the responses of demand and non-OPEC supply are rather inelastic to changes in price. Finally, 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.

Keywords: Oil market; Econometric modelling; Forecasting

JEL codes: C51, Q41.

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1 Introduction

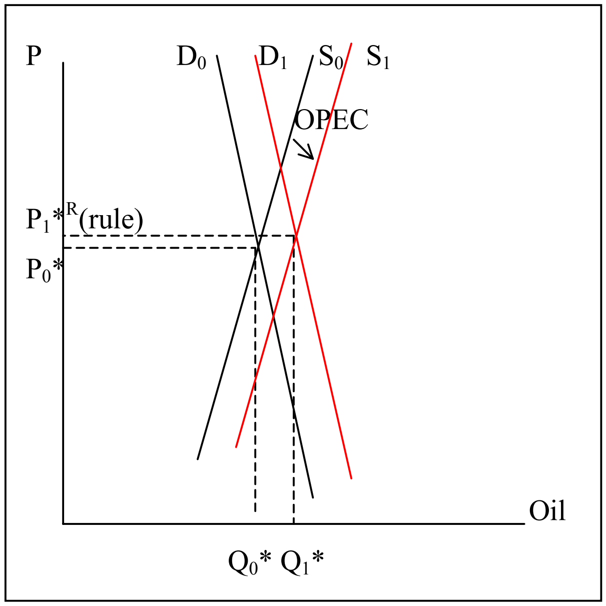
It is a standard modelling practice to represent the world oil market in terms of a supply-demand equilibrium schedule (e.g. Bacon, 1991, Al Faris, 1991). Still, the specific characteristics of the oil markets make its modelling a particularly complex endeavour. More specifically, although a demand curve that relates quantities to prices can be considered to correctly reflect the oil demand conditions, the modelling of supply is extremely difficult as oil markets are characterised by the existence of a cartel (OPEC) along with the presence of independent producers. Moreover, oil prices react in a complex fashion to changes in market conditions and OPEC behaviour. These particularities of the oil market are included in a full-fledged oil prices model, presented in this paper, which includes a pricing rule in addition to demand and supply schedules for different regions of the world.

To model supply, non-OPEC and OPEC behaviours need to be distinguished. While we assume non-OPEC behaviour to be competitive, OPEC behaviour is however much more complex to define, as shown also by the extensive literature on the subject. Some studies have questioned OPEC's ability to affect real prices (e.g. Belton, 1998), pointing out that the decline in real oil prices since the early 1980's coincides with a reduction in OPEC's market share. Others, in the academic literature, have examined the nature and goals of OPEC by testing competing hypotheses for different behaviours (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 the identification of the slope of OPEC's supply curve. A negative relation between price and production is interpreted as a backward bending supply curve, which indicates that OPEC sets production based on some type of non-competitive behaviour. However, the analysis of causality presented in Kaufmann et al. (2003) indicates that OPEC production 'Granger causes' prices but prices do not 'Granger cause' production indicating that there is no backward bending supply curve. In other words the functioning of world oil market is in reality between the two extreme cases of a competitive or completely dominant OPEC. As a result, an increase in demand can be considered to be followed by increases in both OPEC production and the world oil price.

The solution usually retained to model such a behaviour is to estimate this intermediary degree of market control with a "price rule", which depends on both demand conditions and OPEC variables. Such a model would give a price at which OPEC is ready to act as a swing producer, given new demand conditions and would include market indicators that reflect the effect of behaviour by the dominant producer.

The above considerations are taken into account in the proposed model. Given a certain price, demand determines the optimal quantity of oil sold. Non-OPEC countries adapt their production to this new price and OPEC acts as a swing producer to equilibrate supply and demand consistent with the optimal price/quantity levels (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* – see Figure 1 –).

Figure 1: Model with price rule



The model of the world oil market presented here possesses several of the above desirable features. First, oil supply for non-OPEC producers is derived from equations including the effect of geological and economic variables. Second, oil demand is rather comprehensively modelled through a set of behavioural equations. Third, oil prices are defined by a price rule based on changes in market conditions and OPEC behaviour. Finally, two different OPEC behaviours are envisaged (co-operation and competition) resulting to two alternative closures of the model.

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 used in the model. Section 3 presents an assessment of 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

The demand for oil for each country/region is a function of economic activity, the real price of oil and a time trend representing technological developments linked to energy efficiency. Equations have been estimated for the main trading partners of the euro area namely United States, Japan, United Kingdom, Euro area, Switzerland, other developed economies, non-Japan Asia, Transition economies, Latin America and rest of the world. The estimation sample spans over the 1984-2002 period, except for some countries and regions for which, due to data constraints, the sample starts later. Although this may be problematic for the robustness of the results, especially for the transition economies, whose sample period includes only 24 observations, we have chosen to adopt the same methodology for all equations in order to get similar properties across countries and regions.

The general specification of the econometric equations used in the model is:

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

where 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). In addition to the real oil price variable in equation (1) – which does not include taxes and corresponds to prices traded in the futures market-, an alternative, tax–including measure (calculated by the *International Energy Agency*) has been used for the United States, Japan, the United Kingdom and Switzerland. Although such a specification neglects any substitution effects between different energy products, it captures the main factors, which influence the demand for oil[3].

The equation has been estimated as an error correction specification defining the dynamic adjustment to a long-run equilibrium relationship (see Table 1 for estimates and Table 6a in Appendix for detailed

[3] 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 in this first version.

results)[4]. Because unit root tests shows that the real price of oil is I(0) for all countries, this variable has been excluded from the long-run relationship and included only among the dynamic terms. This means that the real price of oil – which displays a high level of volatility - appears stationary, implying that it does not affect the long-run determination of oil demand.

The results show that the error correction term in the oil demand equation is significantly different from zero in all countries/regions but Latin America. The significance of this term indicates that the real price of oil is cointegrated with its long-run determinants. The long-run elasticity of oil demand to real GDP is lower than one for all countries. It is very close to one in the US and Latin America, less than 0.2 in the UK and Switzerland, and between ½ and ¾ in all other countries/regions. This elasticity of oil demand to real GDP is smaller in the short run than in the long run - thereby contributing to a smoother adjustment to changes in the latter variable - in the US, the Euro area, Other Developed Economies, and Transition Economies. This elasticity is larger in the short run than in the long run - thereby displaying a temporary over-reaction to changes in real GDP – in Japan, the UK, Switzerland, and Non-Japan Asia. Finally, the short run and long run elasticities are similar in the cases of Latin America and the Rest of the World.

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[5]
United States	0.67	1984:1-2002:1	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	1991:1-2002:1	0.55		0.58	

[4] 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.

[5] 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).

Oil supply

We distinguish different supply behaviour for OPEC and non-OPEC countries. The former is modelled based on a co-operative behaviour, in which OPEC matches production to demand. Non-OPEC production has had a significant effect on OPEC's share of the world oil supply and, as a consequence on OPEC's ability to influence prices. Production from non-OPEC countries is modelled using a technique that quantifies the effect of geological and economic 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 of the lack of a simple relation between real oil prices and production (Cleveland and Kaufmann, 1991). Indeed, to model non-OPEC production, a complex interrelation between resource depletion, technical change, economic incentives and political considerations has to be taken into account. The relation among these forces is modelled using a methodology developed by Kaufmann (1991) that combines the curve fitting technique developed by Hubbert (1962) with the econometric model of supply, pioneered by Fisher (1981) and called "hybrid methodology" (Kaufmann, 1995).

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.

(2a) $$Q_t = \frac{Q^{\infty}}{(1 + a\exp(-b(t - t_0))}$$

in which Q^{∞} 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 the Hubbert's bell shaped curve for the production cycle of a non-renewable resource, which is called a production curve. Because the physical characteristics of the oil fields do not entirely determine production, the hybrid methodology also incorporates the effects of economic and political variables.

In the second step, the annual rate of production generated by the production curve (ΔQt) is used as an explanatory variable in a cointegrating relation that is given as follows:

(2b) $$PROD_t = \alpha + \beta_1 \Delta Q_t + \beta_2 ROIL_t + \beta_3 Dummy + \beta_4 Asym + \mu_t$$

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. the Trans Alaskan Pipeline System), and *Asym* is a variable designed to test the symmetry of the production curve. *Asymt* is ΔQ_t times a dummy variable that equals 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:

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

Equations (2a)-(2c) are estimated using a range of assumptions for the start date of the production curve (t_0), the value for Q^∞ and the start date of the data sample used to estimate the cointegrating relation. The results reported in Tables 2a and 2b are chosen using the following criteria. First, the combination of t_0 and Q^∞ is chosen in order to generate a stationary residual in equation (2b). 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 coefficients have the correct sign and are statistically significant in both the long-term relation (equation 2b) and the error correction model (equation 2c). Finally, we chose the combination that has the highest R^2. These last two criteria identify an equation that is likely to generate an accurate forecast.

Because the geological and economic environments differ among non-OPEC countries, equations are estimated for nine regions: Lower 48 states (US), Alaska (US), Canada, Mexico, Brazil, Non-OPEC Latin America, 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.).

Table 2a: Results for equation (2a)

	Start date (t_0)	Q^∞	*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

OPEC supply

OPEC production is generally consistent with a co-operative behaviour and this is retained as the closure of the model (see Kaufmann, 1995). According to that, OPEC restrains production from existing capacity to match demand. The demand for oil is equal to the difference between demand and non-OPEC supply:

$$(3)\ PROD^{opec} = \sum_i DEM_i + \Delta Stocks^{oecd} - NGLS - \sum_j PROD^{non\text{-}opec} - PG$$

in which $Stocks^{oecd}$ is the level of stocks reported by OECD, NGLS is non gas liquid and PG net processing gains.

The model can also adopt the competitive behaviour as a closure rule, implying that OPEC countries compete not only among themselves but also with non-OPEC producers for market share leading OPEC to increase production to levels that are consistent with operable capacity. To simulate the lack of co-operation, the model sets OPEC production to 95% of capacity:

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

Oil produced in excess of demand is put into stocks.

Oil price

Due to a high degree of volatility, the real price of oil features is difficult to model. Starting with Frankel (1946), several other studies assess the different factors that imply fluctuation in oil prices, the most important being the behaviour of a dominant producer. In particular, when OPEC became the dominant producer in the early 1970s, price volatility increased tremendously. Although the effect of behaviour by a dominant producer on the volatility of oil prices is relatively easy to see, modellers find it difficult to simulate their effect for two reasons: (i) the inability to forecast behaviour of the dominant producers; and (ii) the inability to translate a particular behaviour into a change in real oil prices (Kaufmann, 1995). We have seen in Section 1 that the ability of OPEC to affect oil prices lies between that of a cartel and that of a price taker. Empirical analyses simulate this intermediate degree of control with a "price rule", which is a function that relates supply/demand balance to price (Gately, 1995). Rather than focus on general supply/demand conditions, price rules include market indicators that reflect the effect of behaviour by the dominant producer.

We estimate an econometric equation for the real price of oil from quarterly data, 1986:III through 2000:III, using the following specification:

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

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 oil stocks, which is calculated by dividing OECD 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 relation 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 diminishing reliance on current production and thereby reducing the risk premium associated with a supply disruption. Similarly, an increase in the OPEC quota tends to alleviate upward pressure on prices. An increase 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 –0.51, which indicates that 51 percent of the disequilibrium in equation (4) is eliminated after one quarter.

Table 3: Estimates for price equation

Variables	**Coefficients**
Days	-6.88 (8.80)
Caputil	35.20 (10.95)
Cheat	-1.03 (6.62)
Quota	-1.34 (10.96)
Adjustment rate	-0.60 (3.24)
ΔPrice(-1)	0.27 (2.65)
ΔPrice(-2)	-0.33 (2.35)
ΔPrice(-3)	0.36 (1.98)

Figure 2: The model structure

Demand side

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

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

$$(2) PROD_j^{non\text{-}opec} = \Theta\left(\overline{Cost}_j , ROIL\right)$$

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

$$(3) PROD^{opec} = \sum_i DEM_i + \Delta \overline{Stocks}^{oecd} - \overline{NGLS} - \sum_j PROD^{non\text{-}opec} - \overline{PG}$$

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

PROD : Oil supply in mbd

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

ROIL : Real price of oil in USD

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

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

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

Oil Price

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

$\overline{Quota}$ *: 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.

3 Assessment of the model

Forecast performance of the oil model

To investigate the forecast performance of the model we carried out an in-sample static and dynamic simulation from 1995q1 to 2000q3.

Figure 3

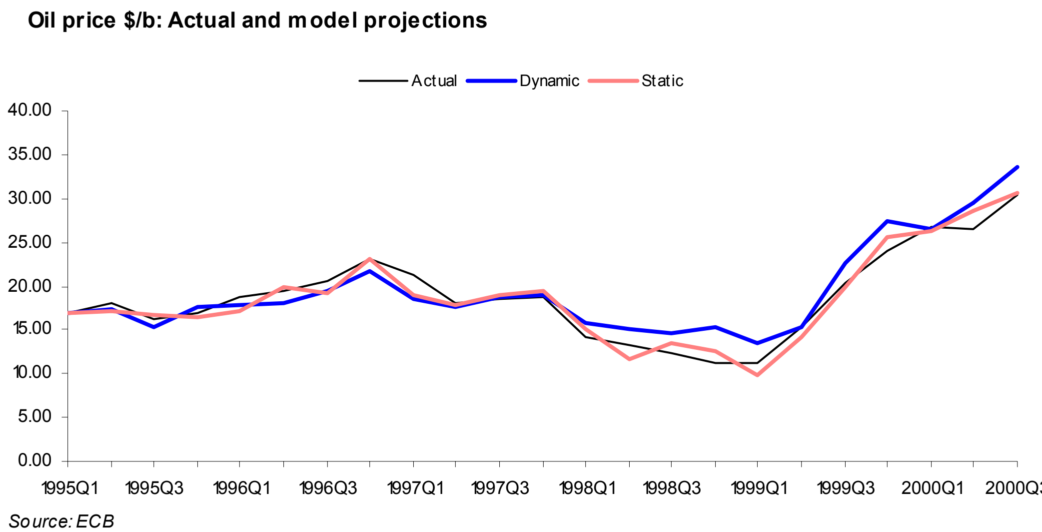


Figure 3 displays the actual and the fitted series for oil price over the simulation period. Standard measures of forecast accuracy suggest that the forecast errors implied by the model are small (see Table 4). The RMSE of the fully dynamic simulation is less than 2% after 1 quarter, around 2.5% after one year and is slightly less than 5% after 3 years.

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

Assessment of the model properties: Some basic simulations

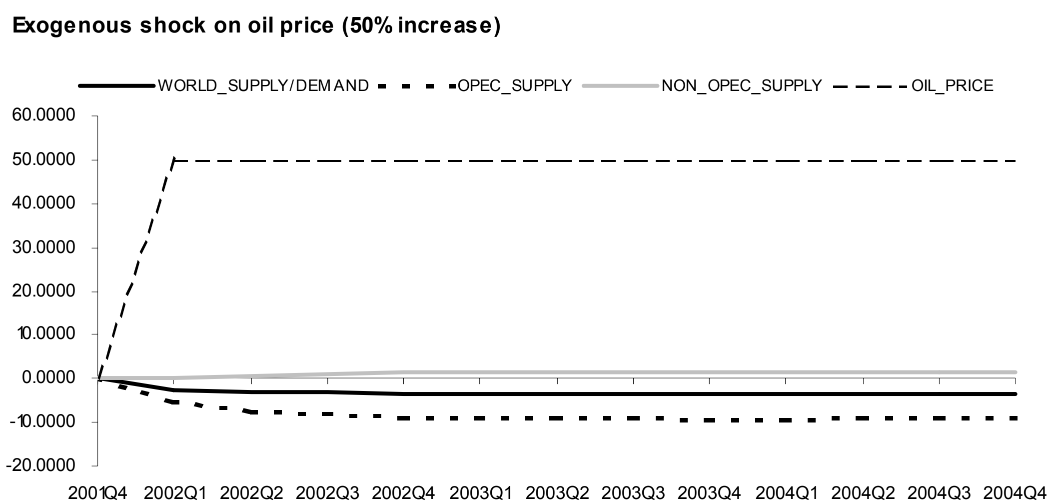
The main properties of the model are presented in this section with the help of four simulations. The first one, an exogenous oil price shock, helps understand the supply/demand behaviour without any price feedback. The three following simulations are related with each component of the price equation, namely OPEC quota, OPEC capacity and OECD stocks, while the demand side of the model and its interaction with the other parts are tested by two additional simulations: an increase in the US real GDP and a depreciation of the US dollar. Finally, an alternative behaviour of OPEC is presented in the last simulation.

In all the simulations, depending on the origin of the shock, the price rule gives the optimal price response, determined simultaneously with demand. Non-OPEC supply also reacts to this change in price with one-quarter lag, while OPEC produces the necessary quantity of oil, which together with non-OPEC supply, matches demand.

Exogenous oil price shock

The fist shock assumes a 50% permanent increase in the price of oil. As depicted in Figure 4, the 50% increase in the price of oil leads to a decrease in demand by 3% in the long run. Non-OPEC production tends to increase, although the response is quite inelastic to a change in price (non-OPEC supply increases by 1.75% relative to baseline). Because demand decreases and non-OPEC supply increases, OPEC needs to cut its production to balance supply and demand.

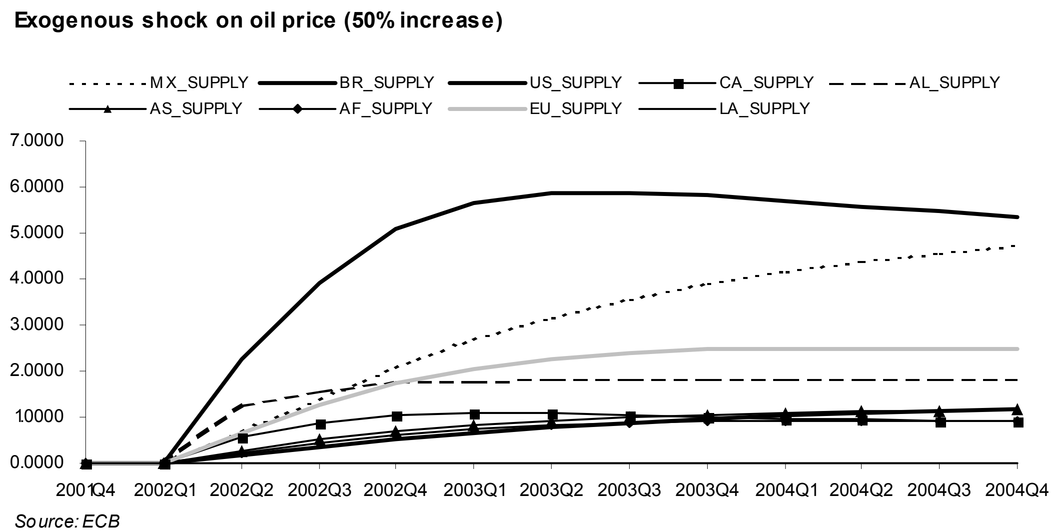
Figure 4



Source: ECB

Although the response of non-OPEC supply appears to be inelastic at an aggregate level, some differences across non-OPEC countries occur (Figure 5). The bulk of the supply responses to the 50% increase in oil price is around 1% with two countries departing significantly from this average, namely Mexico and the lower 48 US states whose response is around 5.5%. In Mexico, the significant response of production is due to the fact that Mexico is a relative new producer, with lots of unused capacities and a significant lack of cash to exploit those unused capacities. Hence, an increase in oil price would provide Mexican producers with the cash needed to pump more oil. For the US, the high response is due to the presence of a large number of producers who are able to increase quickly and strongly their production in case of a spike in oil prices that would increase profits.

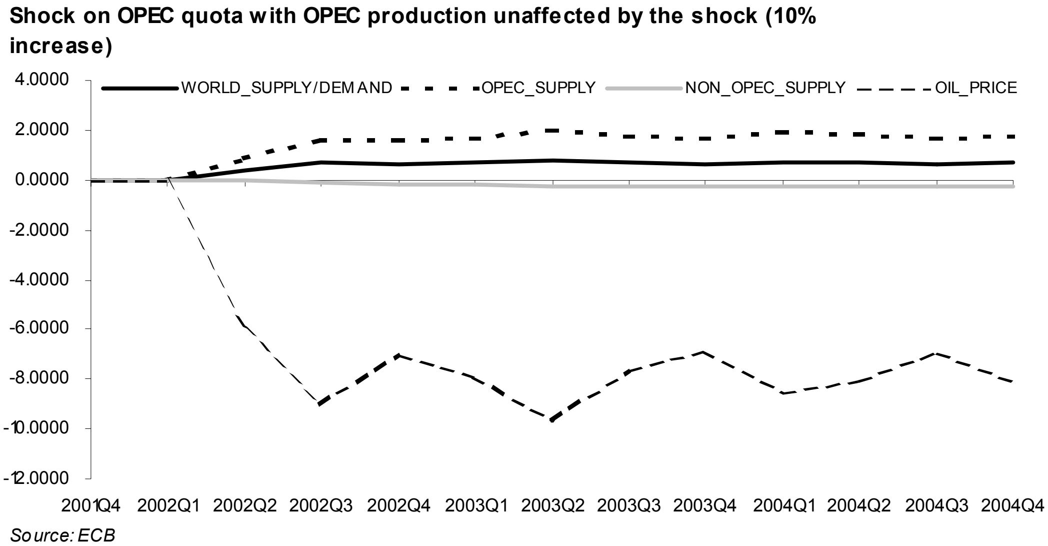
Figure 5



<u>*Shock on OPEC quota*</u>

The increase in OPEC quota by 10%, assumed in this simulation, can be interpreted only as an announcement effect. Indeed, OPEC production in the model is initially unaffected by the shock *per se*. Through the price equation, the increase in quota depresses significantly the price of oil (a 10% increase in quota leads to a immediate 6% decrease in oil price). As a result, demand increases and OPEC fills in the gap to balance demand and supply (see figure 6) causing a further lagged decrease in non-OPEC supply and price, while demand keeps on growing. Hence, OPEC needs to produce even more to absorb the increasing excess demand. However, this excess demand tends to influence the price of oil, which resumes an upward path. Demand reacts negatively to this price increase, which causes further oil price decrease in the following period. After a succession of oscillations, the price of oil reaches a long run effect close to a 10% permanent decrease.

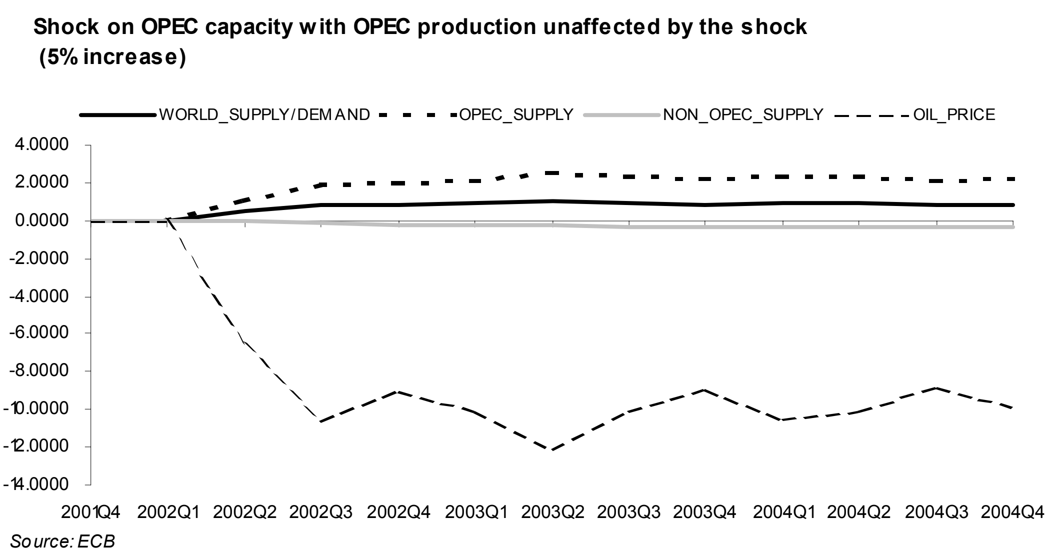
Figure 6



<u>*Shock on OPEC capacity*</u>

A 5% increase in OPEC capacity decreases automatically OPEC's rate of capacity utilisation, which acts negatively on oil price leaving OPEC production initially unaffected by the shock. Only demand and non-OPEC supply, in reaction to price developments, determine the response of OPEC. As we can see in Figure 7, the magnitude of the response as well as its dynamic pattern is very similar to the previous simulation.

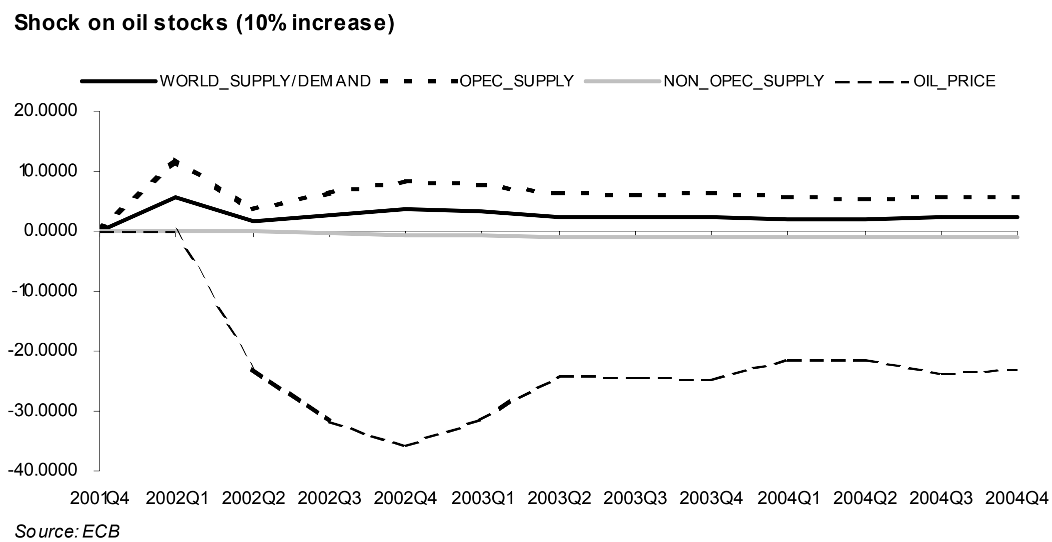
Figure 7



Shock on OECD stocks

The availability of stocks covering a longer period of consumption exerts downward pressures to the price of oil. Indeed, the price of oil decreases sharply (by around 25% initially and by a maximum of 32% after one year) and demand tends to increase, reducing as a consequence the initial negative price impact (see Figure 8). However, this shock has a permanent, negative impact on oil price because demand does not increase enough to absorb all the increase in stocks. Non-OPEC supply is slightly reduced by the decrease in price and OPEC supply has to increase to eliminate the excess demand.

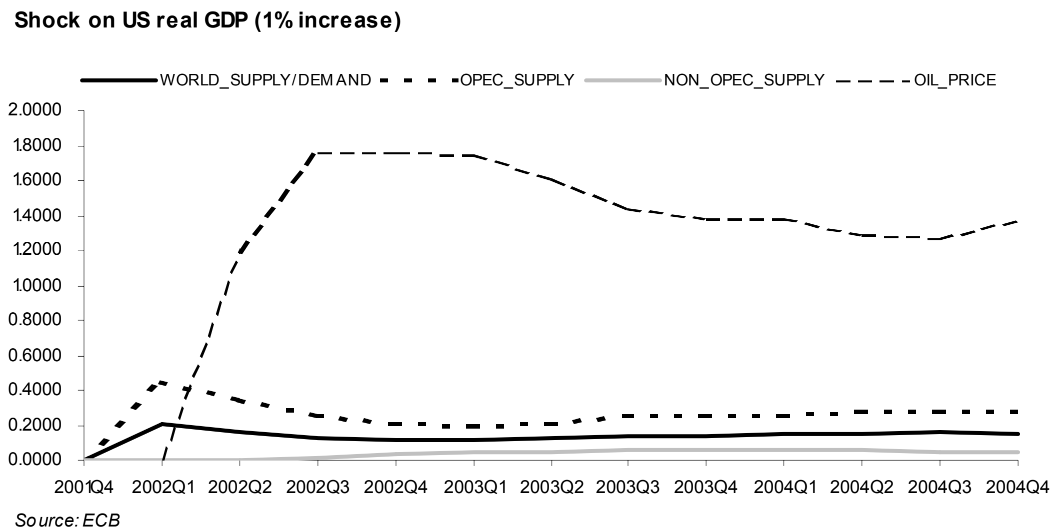
Figure 8



Demand shock: an increase in US GDP

A demand shock due to an increase in US real GDP by 1% leads to an immediate 0.2% rise in oil demand implying a 0.4% rise in OPEC production. Part of the excess demand is also eliminated by an increase in oil price by 1.2% after two quarters, which causes demand to decline slightly and non-OPEC supply to increase leading OPEC to satisfy only half of the initial need for the subsequent quarters (see Figure 9). However, the extent to which the model variables react to this shock is very small. Although the increase in US oil demand is in the long-term equivalent to the increase in real GDP (long-run elasticity equal to 0.96), there is in this model no second-round effect of US GDP increase on the rest of the world.

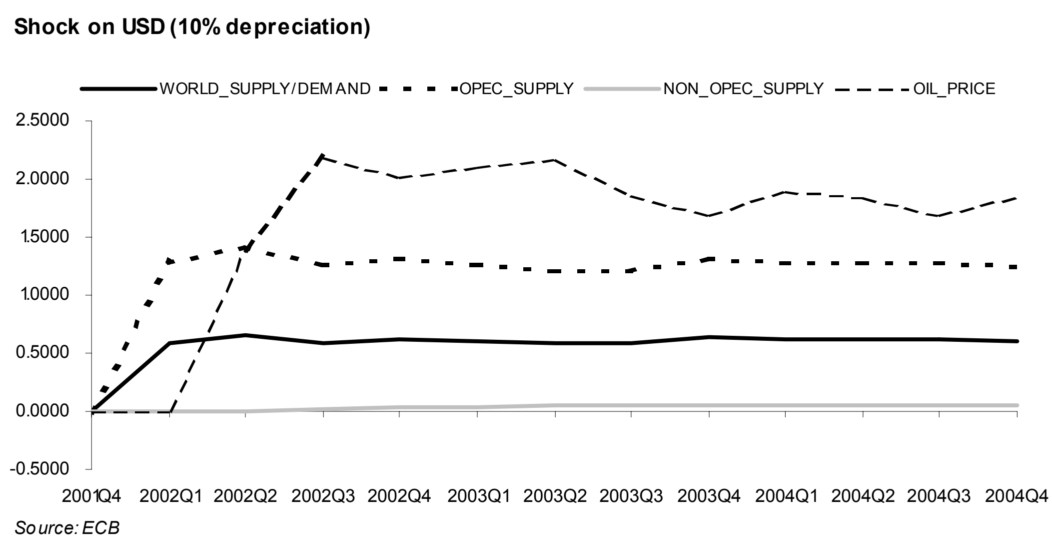
Figure 9



<u>*USD depreciation*</u>

A shock on the USD acts through the demand side of the model. Indeed, oil demand is modelled as dependent on the real price of oil in domestic currency. Hence, a US dollar depreciation tends to lower the price of oil in domestic currency for the countries other than the US. The shock simulated here is a 10% depreciation of the USD. This increases the demand for oil by around 0.7% in the short-run. Because demand rises, the price of oil increases (by 2%), reducing as a second-round effect the initial response of demand. In the long term, however, demand is permanently affected by the initial shock (by 0.5%), while oil price tends to converge towards a 1.5% permanent increase (see Figure 10).

Figure 10

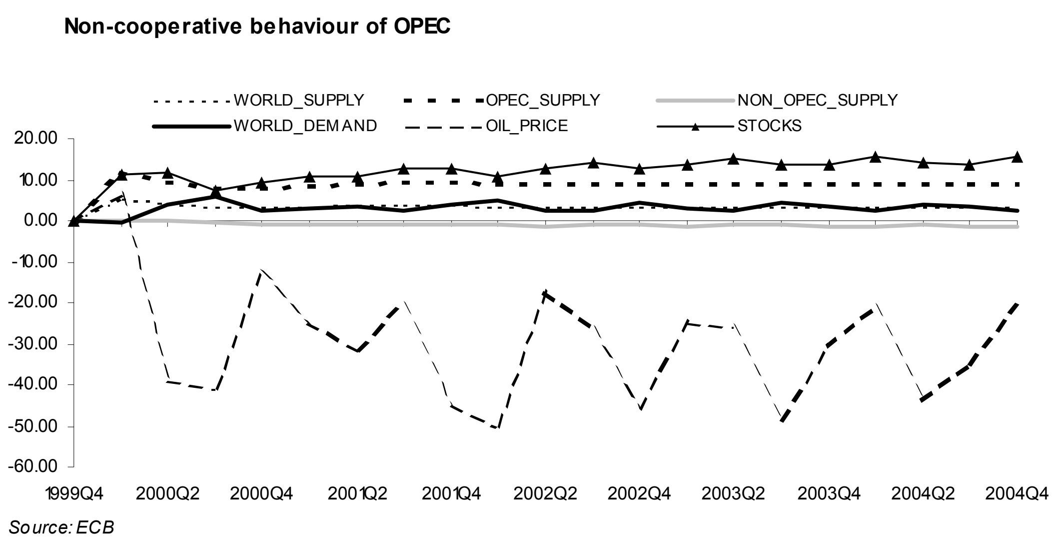


Alternative OPEC behaviour

In the previous simulations, we have assumed that OPEC adopted a co-operative behaviour. We have seen, however, that the current production levels of OPEC countries are less than their operable capacity (around 85%). In this last simulation, instead of considering OPEC as a swing producer, we assume that OPEC increases production to levels consistent with operable capacity (95% in this case, which represents a significant increase in OPEC supply). The closure of the model is in this case realised through the OECD stocks that absorb the excess of supply, putting downward pressures on oil prices. This price response acts negatively on non-OPEC supply but positively on oil demand. In the long run, the decrease in prices tend to let demand rise so that to absorb any remaining disequilibrium between demand and supply.

Part of the sharp increase in OPEC supply is absorbed by stocks, leading the price of oil to decline strongly – by 40% on average –, through the increase in the number of days of forward consumption (see Figure 11). However, another force plays in the other direction through the increase in OPEC capacity utilisation, which tends to make the price of oil more costly. This explains the very large oscillations exhibited in Figure 11. In the long-term, the effect of stock increase is larger, leading to a permanent decrease in oil price.

Figure 11



3 Concluding remarks

This paper describes a model of the world oil market used for oil price projections and to provide quantitative analyses to oil related risk assessments. In this model, oil demand is explained by behavioural equations that relate demand to domestic activity and the real price of oil. Oil supply for non-OPEC producers is derived from a competitive behaviour taking into account the effect of geological and economic variables. Oil prices are defined by a "price rule" based on changes in market conditions and OPEC behaviour. In particular, OPEC acts according to a co-operative behaviour and ensures the global equilibrium at the price determined by the price rule.

Econometric estimations show that the demand for oil is explained by economic activity, the real price of oil and a time trend representing technological developments related to energy efficiency. To estimate non-OPEC production, a complex interrelation between resource depletion, technical change, economic incentives and political considerations has been taken into account through a methodology that combines the curve fitting technique developed by Hubbert with econometric modeling methods. This so-called "hybrid method" has proved to be satisfactory to explain non-OPEC supply. The econometric estimation of the "price rule" indicates that the real oil prices are affected by OPEC capacity utilisation, OPEC production quotas, the degree to which OPEC members cheat on those quotas, and crude oil stocks in OECD nations. Underlying analysis indicates also that these variables 'Granger cause' real oil prices but real oil prices do not 'Granger case' OPEC capacity utilisation, OPEC production quotas, the degree to which they cheat on those quotas, and oil stocks in OECD nations. This result shows that OPEC can exert a powerful influence on real oil prices over the medium and long term and undermines claims about the decline in OPEC market power.

Simulation results show that the model satisfactorily reproduces past developments in oil markets and it performs according to expectations when exogenous shocks are introduced. The response of prices is significant and consistent in a historical perspective. As expected, the responses of demand and non-OPEC supply are rather inelastic to changes in price. 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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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 (16.17)
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 (-5.37)	-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				-0.03 (-1.45)	-0.08 (-2.01)
ΔROIL(-1)	-0.02 (-1.78)	-0.03 (-1.63)	-0.05 (-2.73)		
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	1984:1-2002:1	1984:1-2002:1	1985:2-2002:1	1984:1-2002:1	1984:1-2002:1
R2	0.58	0.96	0.61	0.79	0.66

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	1993:1-2002:1	1995:1-2002:1	1993:1-2002:1	1993:1-2002:1	1991:1-2002:1
R2	0.78	0.92	0.64	0.78	0.52

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)	-0.14 (-2.17)	-0.81 (-7.01)	-0.96 (-8.28)
Constant	-0.01 (-2.01)	0.06 (8.02)	0.00 (0.52)	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)	0.65 (1.21)		
ΔROIL				-0.17 (-2.71)	-0.30 (-2.65)
ΔROIL(-1)	-0.03 (-1.03)	-0.07 (-1.84)	-0.05 (-2.73)		
Q2	-0.01 (-2.94)	-0.25 (-23.9)	-0.05 (-5.40)	-0.06 (-7.13)	0.00 (0.16)
Q3	0.01 (2.24)	-0.05 (-3.53)	0.00 (0.14)	-0.03 (-2.56)	0.08 (4.21)
Q4	0.01 (2.56)	0.02 (1.52)	0.02 (2.18)	0.01 (1.37)	0.06 (3.28)
Sample	1984:1-2002:1	1984:1-2002:1	1985:2-2002:1	1984:1-2002:1	1984:1-2002:1
R2	0.57	0.96	0.61	0.81	0.68