A Micro-Based Model for World Oil Market*

Ramon Espinasa
IADB

Sergio Guerra Reyes
HKS

Osmel Manzano
IADB

Roberto Rigobon
MIT and NBER

July 1, 2011

Abstract

In this paper we decompose and analyze the drivers of the oil price and provide a detailed explanation of the reasons behind the price increase that took place during last decade. We address the problem of endogeneity using a novel data set that allowed us to incorporate technological restrictions that occur at the micro level in the production of crude oil. We find that when oil price peaked in mid-2008, reaching almost US$150, at least 2/3 of this price hike can be explained using only fundamentals of the oil market. Speculative shocks to the oil price have serial correlation with a persistence that last two years at most. They are also bounded in magnitude at their historical peak around US$ 40. Therefore, given that the oil prices that we observe today are responding to the same fundamentals than in previous years, we expect real oil prices fluctuating around US$ 100 in the short and medium-term.

1 Introduction

"What drives oil prices in the short run and the long run?" This is perhaps one of the most asked questions by market participants, policy makers, and academics at large. In fact, during the first decade of the 21st century, when oil prices increased tenfold, from about 14 dollars per barrel ($/b) in mid 1998 up to almost 150 $/b by mid 2008, the reasons behind the price rise were heatedly debated. Some argued that the price increases were the outcome of high world demand, especially driven by the growth in China and India. Others argued that the problem was the inability of the world to increase its supply of oil to attend the demand. Another group argued that the price was the result of speculation in financial markets. From the practical point of view it is possible

*Comments are welcome to: sergioguerra1@gmail.com. The views expressed are solely those of the authors and do not necessarily reflect those of the institutions to which they are affiliated.

to argue that all theories are relevant, and the answer to the question of what is driving the price of oil is ultimately an empirical one.

The problem is, however, that solving the problem of estimation, and in particular, the issue of identification is an extremely difficult one. Oil prices, oil production, world demand, world prices, etc. are all endogenous variables, with circular causality among them. Most of the empirical papers in the literature take an aggregate approach, and use reduced form regression analysis[1]. To solve the problem of estimation, they have use exclusion restrictions. Sometimes, those assumptions are questionable, and therefore their assessments about the process driving the price of oil are disputable. One aspect forgotten from this aggregate / reduced form approach is the technological, geological and institutional limitations that exist in the production of oil. In other words, the macro approach has not taken advantage of significant restrictions that occur at the micro level. This is the gap the present paper intends to take a first step to fill up.

The production of oil has several steps, from exploration, to drilling, to exploitation, and finally to commercialization. Therefore, for example, when the demand for oil increases, and the price rises, the supply chain increases production following a very precise set of steps: first it drills, then it produces. Of course the effort for exploration also increases. From the estimation point of view, the beauty of the drilling activity is that the oil industry has a very precise data recording where each drilling rig is located, whether it is active or not, and what it is being used for. This information is at the country level, and in the US it is even at the State level. In other words, we use the restriction that production cannot be expanded without some drilling activity. Hence, in this paper there is a natural exclusion restriction that arises from the technological limitations of oil production.

There are several microeconomic behaviors in the oil industry that have not been fully exploited in the estimation of aggregate oil models. The aspect of the drilling decision is one of them. Inventories, for instance is another one. Imagine that the price increase is the result of a bubble in the price level. In this environment, it is only natural to expect that inventories will react – i.e., it pays to hold on to oil. Inventories fluctuate incredibly in the data – at seven percent a month on average and with fluctuations as large as plus minus 15 percent – and this only in the US!

Using this information and additional restrictions we intend to disentangle the drivers of oil prices. How much it has been supply driven, how much it has been demand driven, and how much of the recent price increases could have been adjudicated to a bubble.

[1] See Kilian (2008), Kilian (2009)

In this paper, we take the first step toward this goal. We document the relationship that exists between drilling activity and the supply of oil or, put another way, the lag between the beginning of the drilling process and the actual output of oil. We also document how the change in the price level affects drilling activity. This is a very micro-supply side view of the petroleum market and it is an essential ingredient to understanding how the market works in general.

The first step is to collect data from Baker Hughes Inc.[2], an oil services company that provides the count of active oil rigs for the group of 65 most important oil producing countries (with the exception of Russia), on a monthly basis. We use the oil rigs classification that distinguishes between those used for crude oil and natural gas activities. This distinction is published starting on Jan-1995.

Baker Hughes Inc., register rotary rigs[3] which are not the only type of rigs available in the market but they are certainly the most used worldwide. The latter problem is not important methodologically but it reduces the number of countries to be used, because is possible to find countries with zero rotary rigs in some months with positive crude oil production. We then kept those countries with full data availability and eliminated those with positive oil production with no rotary drilling activity. This allows us to study the drilling-production relationship for a subgroup of 27 countries.

On the other hand we have the price of oil and take as reference the most widely used marker crude, the West Texas Intermediate, as settled in Cushing Oklahoma, on a daily basis. We expressed it in real terms using the US CPI provided by the Bureau of Labor Statistics. Finally we have average production per country provided on a monthly basis by the International Energy Agency (IEA), for the relevant period. The monthly crude supply is found in the IEA MODS database.

On the basis of this information we show that at the country level rig activity increase when prices increases permanently. And we show that it reacts with a significant lag. Half of this effect it reached with and interval of 1—11 months, depending on the country studied.

Similarly, we show that an increase in the use of rigs is associated with an increase in production. This stylized fact, however, is much harder to document/find. The main problem is that since 1999, the productivity per active rig has been falling worldwide and particularly in the OECD countries, due to exhaustion of their main reservoirs, particularly those in the US, North Sea and

[2] http://investor.shareholder.com/bhi/rig_counts/rc_index.cfm

[3] According to Baker Hughes Inc., a rotary rig rotates the drill pipe from surface to drill a new well (or sidetracking an existing one) to explore for, develop and produce oil or natural gas.

Mexico. This came after a sharp increase in production per active rig in the 1990s, due to both geological and technological reasons.

Because the productivity per active rig has fluctuated through time, and production among regions has also changed significantly, the relationship between rigs and production is unstable in the time series. Suppose for example that a country wants to keep its production constant while facing a decreasing productivity in their only reservoir. Under the assumption of a constant price and with the same technology of extraction, the only way to achieve their objective is to use more drills to obtain the same amount of crude oil. In this example the observed increase in the number of oil rigs is due to a declining trend in the productivity per active rig. The available data does not identify if those changes are due to long-term trends or to market behavior.

Using widely know filtering techniques, we isolate long term trends from short term market fluctuations in order to study the claimed relationship and to justify properly the exclusion restrictions that they implicate.

The message in the end is that several theories of oil price behavior can be tested using the technological restrictions that exist in the production of oil, and appealing to detailed micro data. This paper is of course a first step to tackle the issue – hence its title – but clearly a promising one. Future research should continue including the microeconomic and technical restrictions that exist in the production of oil, to simplify and offer more realistic identification assumptions for our global models.

The paper is organized as follows. Section 2 discusses the data sources in detail. Section 3 describes the challenges the macro data presents and the approaches taken in this paper. In particular, we highlight the seasonality of production and drilling activities, as well as the significant decline in rig efficiency that has taken place in the last decades. Section 4 discusses the empirical justification for our chain of causality. It is divided in two sub-sections; (i) the relationship between price and drilling activity as a proxy for investment in the oil industry and (ii) the relationship between rig activity and production of crude oil. In Section 5 we use this sequential approach to impose some exclusion restrictions in order to estimate a SVAR model. Section 6 presents the innovational accounting for the SVAR model, and section 7 concludes and offers avenues for further research

2 The Data

For this paper we use a set of four variables; the number of crude oil rigs and the production of crude oil at the country level, the crude oil price in real terms and an index of world real activity.

The number of active rigs measures drilling activity in each country. This is the best proxy for investment and constitutes the bulk of expenditure in the oil industry. Rigs are used for drilling new wells —or sidetracking existing ones— to explore for, develop and produce oil or natural gas.

Baker Hughes Inc.[4] publishes this variable on a monthly basis for a group of 65 countries and on a weekly basis for US and Canada. Two different classifications are available for the data; rigs used onshore and offshore and rigs used for crude oil and natural gas production. The former is available since Jan-1984 and the latter is available since Jan-1995. For this paper we just focus on the number of oil rigs that are used in crude oil production. This is because the relationship between the number of rigs used for crude oil and those used for natural gas is not direct. Markets for both products are not the same and follow different dynamics. An interesting fact that illustrates this distinction is that the correlation for the month-on-month variations between crude and natural gas production is -13%, and if we use a year-on-year variation this coefficient is only 14%.

Baker Hughes Inc., registers at the country level the number of rotary rigs[5], these are not the only type of rigs available in the market but they are certainly the most used worldwide. The latter problem is not important methodologically but it reduces the number of countries to be used. We then kept those countries with full data availability and eliminate those with positive oil production with no rotary drilling activity. This allows us to study a subgroup of 27 countries.

For the production series we use the MODS database, provided by the International Energy Agency (IEA). They track production on a monthly basis for the bulk of worldwide oil producing countries. Oil production in this database includes; crude oil, non-conventional oil and natural gas liquids (NGL). We decided exclude the NGL because they are captured using different methods other than crude oil rigs.

The price series that we use is the WTI provided on a monthly basis by the Energy Information Administration (EIA) and deflated using the US CPI with 2009 as base year.

[4] http://investor.shareholder.com/bhi/rig_counts/rc_index.cfm

[5] According to Baker Hughes Inc., a rotary rig rotates the drill pipe from surface to drill a new well (or sidetracking an existing one) to explore for, develop and produce oil or natural gas.

Finally we use a monthly index of global real economic activity provided by Kilian (2009). This index was designed to capture shift in the demand for industrial commodities in global business markets based on ocean transportation rates.

Thus, our whole time span for each country and each variable is 1995:01—2009:12.

3 Seasonality and Productivity

During the winter season it's impossible for some countries due to climatic conditions to increase or even to maintain the number of oil rigs constant. This is the case for example of Canada and Norway, two important countries outside the OPEC group. Figure 1 and 2 shows the evolution in the number of rigs in both countries, showing a clear seasonal pattern.

As can be easily seen, there is tremendous seasonality in both of these series. Furthermore, there exists seasonality in the price of oil as well. Because both seasonalities are yearly, if the seasonal component are not perfectly synchronized across countries, estimates of the delay are just capturing the des-synchronization of the seasonal components. For instance, assume that one series experiences a pick in December, while the other picks up in March. If the seasonal component is strong enough – so strong that it can be trivially detected by staring at the previous figures – then the estimation of the delay will actually only estimate the delay in the seasonal components – rather than estimating the true economic delay due to technical limitations.

To deal with this problem, all our series are stochastic seasonally adjusted using the Tramo/Seats methodology. We clean the data from all the yearly seasonality and estimate the relationship on those slower moving components of prices, production, and drilling.

[Insert Figure 1]

[Insert Figure 2]

Another important topic that arises in studies of the investment decision in the oil sector is the exhaustibility of the reservoirs. Production in a given field should ceteris paribus follow an inverse U shape production function, i.e., the flow per unit of time increases until peak production is reached then decline with the same level of investment. Thus, once peak production is reached, crude oil production at reservoir level yields decreasing returns. At that point, increasing investments are required to maintain production per unit of time assuming constant technologies. Productivity increases due to technology improvements could have an offsetting effect on the natural decline of a reservoir once it has reached peak production. Institutional changes could have potential impact as well.

Ideally, we would want to develop an experiment at the micro level (probably at the field level) in which we can study questions such as the actual change in the number of active oil rigs due to exogenous changes in the oil price, holding everything else constant, or the change in the production of oil due to changes in the number of oil rigs. That will allow us to estimate the price elasticity of the investment in new rigs, the exact delay, and the productivity of each rig respectively. But these geological, technological, and institutional contemporaneous offsetting effects make an ideal experiment impossible.

There are no reasons to believe that country institutional and geological heterogeneity are negligible. Oil producing countries in Africa are relatively young in the oil industry while the OPEC countries and some producers outside OPEC, such as EE.UU or Mexico, have been producing for more than 100 years.

Figure 3 and 4 shows the quotient of the production of crude oil and the number of crude oil rigs in México and United States respectively. Both series were expressed in logs, seasonally adjusted and then filtered using the Hodrick-Prescott procedure.

[Insert Figure 3]

[Insert Figure 4]

This is a very simple statistic. We just divided the production in each region by the number of active drilling rigs. As can be seen there is a significant fluctuation in the "productivity" of each drill. It is important to remember that this is a stylized calculation of productivity. Because there is a delay between drilling and actual production, if a country desires to increase production, it needs to drill first, producing a drop in overall productivity before production actually occurs. However, the point we want to highlight is that productivity drops have trended for a long time in this industry, and these trends have important implications in the estimation of how drilling affects production.

Technically speaking, this is a regression with random coefficients, where the coefficients are trending, and such trend seems to be correlated with the price of oil we observe – not perfectly correlated but correlated enough to increase the possibility that a spurious relationship might be found. This shows that production per rig has shifted through time, and the timing and severity for this problem is not the same across countries and even regions.

In addition, declining in productivity across countries has not been constant through time, even for the time span available. This fact also has important implications in the estimation of the drilling–production relationship. Given that potential problem, we need to identify at the country level if the productivity per active rig has remained stable during the period studied or if it has changed over time.

To illustrate this fact, we construct the quotient of the production of crude oil (y_t) and the number of crude oil rigs (r_t) in every country , with the objective to test the null hypothesis that production per rig has been stable during the period using the following equation

$$\frac{y_t}{r_t} = \beta_0 + \beta_1 * t + u_t \tag{1}$$

And we will try to find evidence against that hypothesis by identifying significant changes in the time trend coefficient. The date for an potential change were selected minimizing the sum of square errors (SSE) for the following regression

$$\frac{y_t}{r_t} = \beta_0 + \beta_1 * t + \beta_2 * t * break + v_t \tag{2}$$

Results of estimating equation 2 using the time break that minimize the SSE are presented in Table 1.

[Insert Table 1]

All breaks were statistically significant, and for each country Eq.2 improves R2 statistics when compared with those obtained from Eq.1.

What this simple exercise tells us is that given all these changes in productivity which are not homogeneous across countries —in severity, magnitude and origin[6] — the problem of estimation should be addressed at the country level.

To address this problem, our identification strategy is based on two crucial but intuitive and broadly accepted assumptions. First, our production, investment and price variables can be decomposed into three different components;

[6]Reasons are diverse; from geological, technological or even institutional it is possible to observe breaks in productivity trends.

one that captures the seasonal pattern (S_t), a long-term trend (T_t), and short term market fluctuations (X_t). (See equation 3).

$$I_t = S_t * T_t * X_t \tag{3}$$

Our second assumption is that any institutional, technological or geological change will affect the second component in the number of rigs, i.e., the long-term trend.

The Tramo-Seats procedure allows us to capture the seasonal pattern of the series while the long-term trend will be captured using the Hodrick-Prescott filter. By extracting these two components from the log of the time series, we will be able to study market movements in the data and to identify the dynamic behavior of interest.

4 Preliminary look at the basic relationships in the data

As in the production of any other commodity, in the oil industry there is a circular causation prices-investment-supply. This relationship is not contemporaneous, however. The oil industry faces geographical, technical and political barriers that may delay the time lag between the decisions to invest and the time when physical investments actually begins. Furthermore, new investment does not yield crude oil (or natural gas) immediately, but with a lag while the adequate infrastructure is built. Finally, extracted crude takes time to reach the markets – although at monthly frequencies this might be imperceptible. As can be expected these lags vary significantly among countries, provinces, and fields.

Our goal in this section is to identify the direction of the causality in world crude oil production. This is the causality between changes in prices, investment in drilling, and production. This approach rests on the assumption of the lagged relationship between drilling and production, which is at the core of the technical limitations faced by the oil industry.

Our first step is then to study what forces drive changes in the number of oil rigs around the world. A decision to increase drilling activity should be based in the future profitability of those investments. Thus, higher prices should lead to larger investments if those increases are perceived as relatively permanent – or in other words, if the mean reversion is small enough such that a higher price of oil implies that oil prices will remain high for several months[7].

[7] Indeed, the evidence on the characteristics of the stochastic process for oil indicates that either oil prices follow a random walk – meaning that price movements are permanent – or that the oil price has a very slow mean reversion with half-lives larger than 3 years.

Then, our next step would be to study the response of crude oil production to changes in the number of active rigs at the country level. Under the assumption that there is no spare capacity, i.e. all productive capacity is used at full sustainable potential, we expect a positive relation between both variables. Furthermore, this relation should never being contemporaneous.

All our variables are in levels and expressed in logs, stochastically seasonally adjusted (with Tramo Seats) and de-trended (using the Hodrick-Prescott filter). Lets y_t denote the log level of crude oil production and r_t the log level in the number of oil rigs and p_t the oil price expressed in real terms.

4.1 Prices and Investment in Rigs

As we previously said, the decision to increase drilling activity should be based in the future profitability of those investments. Consequently, higher prices should lead to larger investments if those increases are perceived as relatively permanent.

To study this relation, we propose a dynamic equation for the number of crude oil rigs (See equation 4) and simulate a permanent 100% increase in the crude oil price to observe the response after 36 month in the number of oil rigs[8].

$$r_t = \mu + \sum_{i=1}^{6} \varphi_{i*} r_{t-i} + \sum_{i=0}^{12} \beta_{i*} p_{t-i} + \omega_t \tag{4}$$

An important subject to be aware is the reverse causality from global macroeconomic aggregates to the price of oil. Three arguments should be made at this point. First, there is a clear distinction between what is considered as a global macroeconomic aggregate and our variable of interest, i.e., the log number of rigs in a particular country, which in any case represents just one particular sector of the economy and thus its influence over a global equilibrium price, is limited.

Second, as pointed out by Kilian (2008), strict exogeneity is not required for estimating an equation such as Eq.4, but that innovations to the oil price series are predetermined with respect to the variable of interest. By working with monthly data feedback between variables could be treated as negligible.

Finally, changes in the number of oil rigs will affect directly the supply of crude oil, but this effect is not contemporaneous due to the proposed technological restriction, thus monthly feedback between the number of oil rigs and energy price is conceptually misleading.

[8] This response corresponds to the solution of the difference equation proposed and it should reflect a steady state.

Table 2 presents a summary of the results for each country. Point estimate reflects the long run response in the number of crude oil rigs. Usual statistics were calculated using bootstrapping methods[9].

[Insert Table 2]

Table 2 highlight that for almost all countries studied the response in the number of oil rig to a permanent increase in the price of oil would be positive. For those few countries with a negative point estimate results are very close to zero. Table also reflects that for Non-OPEC countries doubling the oil price (controlling for long term trends and seasonality) will increase permanently the number of oil rigs in 1.1%, for OPEC countries that figure is 0.6% while for OECD countries the increase is 1.3%. The fact that OPECs response is close to half to that of other groups is supporting evidence of collusive behavior.

For illustrative purposes Figure 5 displays the evolution of the claimed response for Canada.

[Insert Figure 5]

It is also important to highlight that the magnitude of these long-term effects are just one part of the story. The dynamics and timing of the response are also of clear importance in a complex market as the one of the crude oil. Literature have claimed that the market face short-run rigidities [Hamilton (2009), Smith (2009)] so that the "when" questions are also crucial.

Therefore, we try to answer the following question, how many periods are needed to achieve half of the long run effect estimated for oil investment? These estimates are called Half-lives and Table 3 shows the results for our group of countries.

[Insert Table 3]

Results range from 1—11 month needed to achieve half of the long-term effect estimated in Table 2. Averages across groups are more homogeneous than in the previous case, resulting for Non-Opec countries a period of 5.6 months, OPECs 5.3 months and for the OECD 4.5 months.

[9] Confidence Intervals for 10 and 90 percentile respectively, where calculated using bootstrapping methods.

What this table suggest is that we should not expect that the number of oil rigs i.e., the first phase for a country to expand its crude oil production, to respond immediately to changes in oil price even if those changes are considered permanent.

4.2 Investment in Rigs and Production

Another important —and crucial— relation is that between the number of rigs and the production of crude oil. Because the efficiency of oil rigs has shifted through time, and the production mix among regions has also changed significantly, the relationship between rigs and production is unstable and difficult to find. Furthermore, there is very diverse complexity in the drilling conditions from deep water deep drilling to shallow onshore drilling.

To increase the production of crude oil, the pace of drilling to bring new oil well on line should be increased first. Again, denote y_t as the log level of crude oil production and r_t the log level in the number of oil rigs. The claimed relation is that $\frac{\partial y_t}{\partial r_t} > 0$.

To study the speed and magnitude of this relation, we propose a dynamic equation for the production of crude oil (See equation 5). We then simulate a permanent 100% increase in the number of crude oil rigs to observe the response after 36 month in the oil production[10].

$$y_t = \alpha + \sum_{i=1}^{6} \delta_{i*} y_{t-i} + \sum_{i=0}^{12} \gamma_{i*} r_{t-i} + \varepsilon_t \tag{5}$$

Reverse causality is conceptually and empirically addresses using similar arguments than those in the previous case. Oil production will affect the number of oil rigs only through the effect on oil prices, but that relationship is not contemporaneous. Given that strict exogeneity is not required for estimating an equation such as Eq.5, we exploit the fact that there is a delayed time between each state to justify that innovations in the number of oil rigs are predetermined with respect to the variable of interest.

We then estimate Eq.5 for each country and compute the impulse response functions assuming a permanent increase (100%) in the number of crude oil rigs. Table 4 presents a summary of the results for each country. Point estimate reflects the long run response in the number of crude oil rigs.

[Insert Table 4]

[10] This response corresponds to the solution of the difference equation proposed and it should reflect a steady state.

Some negative signs are funds especially for OPEC countries and countries that marginally contribute to aggregate crude oil production. However, most of the countries present a clear positive response to an increase in the number of oil rigs.

An important point to highlight is that our variable of crude oil production, yt, is an observable variable that reflects the actual number of crude oil barrels delivered to markets. Most of OPEC countries, however, expand the number of rigs to increase potential capacity, which is not observable.

For the rest of cases, especially for Non-OPEC and OECD countries, the relationship between the number of rigs and crude oil production is strong and positive. Group comparison suggest that by doubling the number of oil rigs, the increase in crude oil production will be around 4.2% for the Non-OPEC group and 7.2% for the OECD.

For illustrative purposes Figure 6 displays the evolution of the claimed response for United States.

[Insert Figure 6]

Half–Lives were also calculated for the Rigs to Crude Oil production relationship. The range across countries for this statistics is 2—25 month to observe half of the effect that will induce a permanent increase in the number of oil rigs. Although heterogeneity in the response is expected, there is a mean of 5 month in every group to observe have of the long run effect. Table 5 shows the results for the 28 countries with available data.

[Insert Table 5]

5 A Micro-Based Model for World Oil Market

In the previous section we have presented evidence of two relations that fully characterize the most important part of the petroleum industry. The first relation is that between oil prices and drilling activity, measured as the number of active crude oil rigs, and the second relation is that between drilling activity and final crude oil production. This evidence was presented at the country level.

In addition to both relations, we highlight the complications that could arise empirically due to problems of seasonality and exhaustion of the natural resource.

Our intention was to support a chain of causality frequently claimed by engineers (but so far not previously tested) in which the gold premise is that in order to expand the production of crude oil, first it is needed to expand the number of oil rigs, i.e., drill more.

This technological restriction creates a sequential approach that allows us to identify some exclusion restrictions (parameters with zero value) that occur at the micro level that should be translated into the structural macro behavior of the industry. Additionally, it helps us to avoid ad-hoc restrictions frequently found in the literature.

In the end, our objective is to be able to estimate what are the determinants of the price of oil. How much of the movement is due to supply disruptions, or world demand, or a speculative bubble. Indeed our objective is to use the previous relationships to be able to impose certain number of constraints on a VAR model to estimate all these variables together.

Let p_t, y_t, r_t, d_t denote the price of oil, production of crude oil, the investment in drilling rigs, and world real activity respectively.

The system of equation that we want to estimate has the general form[11]

$$A_0 X_t = k + A_1 X_{t-1} + ... + A_L X_{t-L} + \varepsilon_t \tag{6}$$

Where is X_t a 4x1 vector that includes endogenous variables, k is a 4x1 vector of constants, A_i is a matrix 4x4 matrix of coefficients, and ε_t is a 4x1 vector of structural innovations that are assumed to be white noise.

System of equation (6) can be rewritten in reduce form by pre-multiplying both sides by obtaining the following system

$$X_t = c + B_1 X_{t-1} + ... + B_L X_{t-L} + e_t \tag{7}$$

Where $c = A_0^{-1}k, B_i = A_0^{-1}A_i$, for $i = 1...L$, and $e_t = A_0^{-1}\varepsilon_t$

Additionally, we know that ε_t is a vector of disturbances assumed to be Gaussian white noise processes such that $E[\varepsilon_t] = 0$ and $Var[\varepsilon_t] = \Sigma$, where Σ is a diagonal matrix. Similarly, e_t is a vector where $E[e_t] = 0$ and $Var[e_t] = \Omega = A_0^{-1}\Sigma(A_0^{-1})'$, where Ω is a symmetric matrix.

[11] See appendix 1 for details.

Residuals represent the structural innovations. These shocks have a structural interpretation in the sense that they are orthogonal to each other, and have economic meaning. For instance, the shock to the fourth variable is assumed to be a demand shock keeping everything else the same – therefore this is exactly capturing the increase in the demand for oil from China (for example) given production and prices. Additionally, the shock to the price variable (first variable) is an increase in the price with everything else equal – production and demand included. Therefore, that shock might be capturing the so-called bubble component.

The reduced form approach to this problem assumes that all variables are endogenous, and in order to estimate or solve for the impulse responses, the literature has used a Choleski decomposition – which is simply implemented in estimation software by the ordering of the equations in the system. So, in general, it is assumed that variable 1 is totally exogenous, and it only affects variable 2, and both affect variable 3, and so on. This VAR approach is widely used in monetary policy, and also has been used to estimate the dynamics of the price of oil.

Our approach intends to be different. First, we will impose only those relationships that are supported by technical restrictions. Second, we will impose additional sign restrictions to further enhance the estimation. This is a much structural approach to the identification problem.

In both cases identification will be affected directly by the structure of matrix A_0. This matrix captures contemporaneous correlation between the endogenous variables.

The problem of estimation is that A_0 is a dense matrix. If the vector has N endogenous variables, then A_0 has $N(N-1)$ unknowns. The literature on identification has shown that from the time series data there only exists $N(N-1)/2$ possible moments to estimate A_0. Therefore, there are less moments than unknowns and it is impossible to solve for A_0.

To solve the problem of estimation we need to impose $N(N-1)/2$ additional equations. Usually, most VAR's assume some coefficients to take the value of zero (that is why most of those assumptions are called exclusion restrictions). The question is, which coefficients should be set to zero?

Assume that we take the standard Choleski decomposition approach and we order the variables p, y, r, and d. The contemporaneous relationship implied by this ordering implies that the matrix A_0 is lower triangular. This assumption set $N(N-1)/2$ zeros for all the elements on one side of the matrix that depend entirely on how the variables are ordered.

For some applications this method has proven to be useful, but for the case of oil we prefer to take a different approach, one where the zeros come from the technological restrictions in the data, and that are closely related to the way oil companies make those decisions.

Our matrix A_0 mimics the following system;

$$\begin{aligned} p_t &= k_1 - \beta^0_{12} y_t + \beta^0_{14} d_t + \varepsilon^p_t \\ y_t &= k_2 + \beta^0_{23} r_t + \varepsilon^y_t \\ r_t &= k_3 + \beta^0_{31} p_t + \varepsilon^r_t \\ d_t &= k_4 \pm \beta^0_{41} p_t \pm \beta^0_{42} y_t + \varepsilon^d_t \end{aligned} \tag{8}$$

This system captures our technological restrictions because; (a) it neglect any direct contemporaneous correlation between real oil prices and the number of crude oil rigs in a given country —any effect will be channeled through changes in crude oil production—, (b) the level of crude oil production is assumed to be affected only by changes in the number of crude oil rigs, (c) the number of crude oil rigs, i.e., investments in the oil sector, could only be affect by changes in the real oil price and (d), the number of crude oil rigs in a given country have no effect on any measure of aggregate activity. In addition, this system is capturing our expected sign relations.

We avoid the dynamic structure just to highlight the signs restrictions that we are imposing to our estimation. Sign restrictions assume a downward sloping demand curve for crude oil, a positive relation between crude oil rigs and crude oil production and positive relation between oil prices and the number of crude oil rigs. The previous section shows that some of the coefficients that we reference here are indeed significant and have correct signs.

Thus, our matrix A_0 (without any sign assumption) looks as follows[12]:

$$A_0 : \begin{bmatrix} 1 & -\beta^0_{12} & 0 & -\beta^0_{14} \\ 0 & 1 & -\beta^0_{23} & 0 \\ -\beta^0_{31} & 0 & 1 & 0 \\ -\beta^0_{41} & -\beta^0_{42} & 0 & 1 \end{bmatrix}$$

[12] Negative signs appear because matrix A is initially on the left side of the equality

5.1 Our dataset revisited

Our dataset contains time series for the time period jan-1995 to dec-2009 for the following variables;

- Crude oil price (p_t): for this variable we use the West Texas Intermediate provided by the EIA, expressed in real terms using the US-CPI with base year 2009=100. It is expected that the seasonality found in the production of crude oil affect the oil price. Also the problem of exhaustion of the natural resource should be correlated with the observed price. For that reason, our variable is seasonally adjusted[13] and detrended[14] using traditional methods. Additionally, we use a logarithmic transformation for this variable.
- Crude oil production (y_t): we use all kind of crude oil[15] produced in each country, it was provided by the IEA in monthly basis. It was also seasonally adjusted, detrended and expressed in logs.
- Crude oil rigs (r_t): this variable measure the number of active rigs used for the drilling activity of crude oil. It was provided by Baker Hughes Inc. who publishes it in a monthly basis for a group of 68 countries. It was seasonally adjusted, detrended and expressed in logs.
- World Activity Index (d_t): This is a monthly index that tries to capture real economic activity based on dry cargo single voyage ocean freight rates[16]. It has two main advantages; first, "it's not a proxy of real value added but rather a measure of the component of worldwide real economic activity that drives demand for industrial commodities", second it was constructed in a monthly periodicity, which help us to support the technological constraints faced at the micro level in the short run.

---

[13] Using Tramo-Seats
[14] Hodrick-Prescott filter
[15] All kinds of viscosity
[16] See Lutz (2009) for details.

6 Results

We then proceed to estimate our system of equation. Two important caveats should be made at this point

First, as we pointed out earlier, the complexity/diversity of drilling conditions challenges any estimation between the number of crude oil rigs and crude oil production. Thus, the more countries we try to aggregate, the more imprecise results.

Second, although heterogeneity in drilling conditions plays a minor role for most of the OPEC countries, the rig-production relation is still challenged because some of its members expand the number of crude rigs to increase potential capacity in production, which is not observable. Thus the more OPEC countries that we try to aggregate, the more imprecise results we obtain.

Given that we have data at the country level, we decided to present two country level results and then aggregate countries forming bigger and more representative groups. In particular, we will estimate six different models corresponding to the US (world's important consumer), Saudi Arabia (world's important producer), OECD, Non-OPEC, OPEC and the World respectively[17].

For all matrices $B_i = A_0^{-1} A_i$ that captures the dynamic structure of the reduce form model, OLS technique provides a consistent estimation for the parameters of interest. However, the estimation of matrix A_0, and the diagonal variance matrix Σ require non-linear techniques.

Given the assumption of Gaussian white noise process for the vector ε_t of structural residuals, all remaining ten parameters presented in system of equation (8), were estimated by Maximum Likelihood. Table 6 presents results of the estimation for our five different models without imposing any sign restriction.

6.1 Contemporaneous correlations

[Insert Table 6]

Results are clearly consistent with our sign intuition for Non-OPEC countries. In particular, there is a negative correlation between oil prices and the production of crude oil in the short run and oil prices react in the same direction as real activity does.

For the crude oil production equation, there is a positive correlation with the number of crude oil rigs. This is also consistent with our previous findings.

[17] See appendix B

Differences in magnitudes between models can be simply representing heterogeneity between production mix among regions and / or diversity in the drilling conditions.

In the equation for the number of crude oil rigs there is also a positive correlation with oil price. This result is also consistent with our previous results. However, it is important to highlight that our identification scheme appears to be failing with those countries that form the OPEC group. We were in fact expecting this result, because our observable variable for crude oil production, reflects the actual number of crude oil barrels delivered to market, and for most of the OPEC countries there is also an interest in expanding their potential capacity of production, which is not observable.

6.2 Impulse-Response functions

Given the estimation of these contemporaneous matrices and the structural implications behind them, it is possible to trace out the time path of the effects of orthogonal shocks (innovations) given by vector ε_t in our system. Figures 7 and 8 present the impulse response functions for one standard deviation of the vector of structural innovations for the US and Saudi Arabia model[18]. It is important to highlight that they are orthogonal to each other and have economic meaning. Bootstrapped confidence intervals are also presented.

All figures can be read as follows; columns represent a structural shock (innovation) in the variable of interest (keeping everything else constant) while rows capture the affected variable, for example, cell$_{(1,1)}$ in Figure 7 represents the crude oil price response to unanticipated events that cannot be capture by the dynamic structure of the price equation, this is what is called a shock. In other words, the shock to the price variable (first variable) is an increase in the price with everything else equal – production and demand included. Therefore, that shock might be capturing the bubble component.

Cell$_{(2,1)}$ is the crude oil production response variable (second variable) to a shock in the price with everything else equal – including the number of crude oil rigs. Given that our assumption is that crude oil price affects crude oil production only through the number of rigs, it is expected that the graph corresponding to cell$_{(2,1)}$ fluctuate around zero. Cell$_{(3,1)}$ is the response in the number of rigs (third variable) to a shock in the price variable with everything else equal – including crude oil production. We should expect cell$_{(3,1)}$ to have a positive response but we should keep in mind that; (a) all shocks are transitory, (b) all shocks have a standard deviation of magnitude. Cell$_{(4,1)}$ is the world real activity response (fourth variable) to a shock in the price variable with everything else equal – including crude oil production and number of rigs. Row 2 captures

[18] Remember that the reduce form residuals can be expressed as $e_t = A_0^{-1}\varepsilon_t$, so that pre-multiplying both sides by A_0 we obtain ε_t.

the response to each variable of interest to a shock in the crude oil production keeping everything equal, including prices and the number of crude oil rigs, and so on.

Figures 7 and 8 presents Impulse-Response functions for US and Saudi Arabia respectively. See Appendix C to obtain the rest of them.

[Insert Figure 7]

[Insert Figure 8]

All our impulse response functions can be interpreted as % of increase/decrease in the variable of interest (Y-axis). Horizontal axis represents time horizon in months.

With only small differences, all models have a similar behavior in their response to different shocks that may happen in the world oil markets. Some of them that deserve to be highlighted are the following;

- Crude oil production appears to be very inelastic in the sense that, it response to different shocks (or innovations) in all models fluctuates around zero.
- Similarly, the response to oil prices to unanticipated shocks in oil production is small and differs across models.
- Both findings are consistent with previous literature and they could be the result of; (a) the magnitude of the shock that is assumed (it's never similar to an oil embargo from Arabic countries), (b) The response of crude oil inventories.
- Finally, it is of our interest that the shock to the price variable (first variable) with everything else equal – production and demand included, in all five models is positive but transitory in the short term. Therefore, this is evidence any bubble component in the oil price disappear in around 8 months

6.3 Variance Decomposition

Previous subsection allowed us to trace out the time path of the effects of structural shocks in our system. Variance decomposition on the other hand, allow us to calculate the contribution of each orthogonalized innovation to the mean square error of the n-step ahead forecast for each equation. This kind of analysis complements impulse-response functions in the sense that it helps us to evaluate if any sequence evolves independently of structural shocks.

Tables 7 and 8 presents the variance decomposition for the US and Saudi Arabia model respectively. See Appendix D to obtain the rest of them.

[Insert Table 7]

[Insert Table 8]

Variance decompositions can be interpreted as the variance percentage in the n-step forecast attributable to each orthogonal shock (structural errors). Some observation deserves to be highlighted about them;

- The variance (not point estimate) of real oil price is gradually explained by other than its “own” shocks in the long term. In sum, the rest of the structural innovations explain around 25—50 % (depending on the model that we choose). This result is particularly important because of the observed volatility that is observed in this commodity. Previously, we have claimed that the shock to the price variable —everything else equal— gives a positive but transitory response in the real oil price in the short term. Second, the same shock seems to explain, at most, 75% of long-term volatility. It’s also relevant to consider that our model do not include inventory movements.
- Real crude oil price seems to explain around 17—34 % of the rigs volatility in the long run, while 32—60 % seems to be explained by it’s “own” shocks.
- Previously we claimed that crude oil production appears to be very inelastic in the sense that it response to different shocks (or innovations) in all models fluctuate around zero. In addition to that result, its volatility in the long run is explained around 18—53 % by structural shocks other than those of the production equation. Differences in volatility in the production forecast might be the result of the heterogeneity in the production mix among regions and/or diversity in drilling

6.4 The anatomy of the oil price bubble

So far we have presented two important results concerning the short run behavior of the oil price. The first one is that when controlling for the structural dynamic of the oil market, a pure innovation in the oil price (i.e. a shock to the price variable *ceteris paribus*) translates into a positive but transitory effect in the real oil price. This kind of shock not explained by the fundamentals of the market is what we called the "bubble component".

The second result is that the volatility of the oil price is heavily dependent on its own behavior in the short run, i.e., independent of the structure of the market, but in the medium and long run, they are tied together.

Our next step is then to investigate what kinds of shocks have occurred in the past so that we can formulate a consistent story to support (or reject) the "bubble hypothesis" in oil price.

If the speculation in the financial markets is responsible (or partly responsible) for the oil price increase during the 1998-2008 period (when they increased tenfold), we should be able to seen a continuum of price shocks that support that story.

Figure 9 present the monthly evolution of the structural shocks implied by our model. Panel A shows the structural residuals for the price equation of our model, Panel B the 3-month cumulative sum of that series and Panel C the 12-month cumulative sum.

[Insert Figure 9]

They might look different, but all three panels show us a very consistent story. Structural price shocks have fluctuated around zero within months of difference. They are very volatile. Much more important, however, is that these shocks are serially correlated in the short term. As it is observed in panels B and C of Figure 9, in some periods is possible to observe a continuum of positive/negative oil shocks that have affected the observed oil price, but phenomena is only observed in time periods that last two years at most.

Consistency for a story that claims that speculation in the financial markets drove the 1998-2008 oil price increase requires a much stronger evidence, which we do not found.

Furthermore, what would happen if we were able to set all this structural price shocks to zero? Will the observed oil price differ too much from this hypothetical scenario? This is also an exercise that we can simulate by setting the first column of the matrix of structural residuals ε_t to zero and then rebuild a different series for the real oil price. Figure 10 shows us the result of that exercise using data on production and investment in EE.UU, the world most important oil consumer, and Saudi Arabia, the world most important oil producer. The vertical axe represents the percentage deviation of the structural "no bubble" price from the observed real price of oil (seasonally adjusted and de-trended).

[Insert Figure 10]

Both series share a correlation coefficient of 0.87, which suggest that conclusions should be very similar using either country, as in fact they do. 98% of the deviations of the structural "no bubble" price from the observed oil price range between (+40%; -40%) using data from the US and 96% using data from Saudi Arabia. If we reduce the interval to (+30%; -30%) we still observe that 94% of the variations between both series lies on that range for the US model and 92% in the Saudi Arabia Model. The max and min variation that we observe are found on Jun-2008 (49.41%) and Abr-2009 (46.44%), both for the model of Saudi Arabia.

These results suggest that, if there is in fact a speculative bubble in the oil price, its effect is bounded both in magnitude and in time-horizon. This is so because we are assuming that all structural errors in the price equation are due to speculative movements.

Furthermore, we divided this 15-year period into three equal sub-periods corresponding the years 1996-2000, 2001-2005 and 2006-2010, and calculate the mean deviation and variance for each sub-period for each model. Using US data, the mean variation for each period were: 3.5%, -4.4% and -0.8%, while for Saudi Arabia the mean differences were 4.2%, -2.8% and -4.2%.

On the other hand, the variance of the difference between both series has experienced a significant increase. For the 2001-2005 period the variance was 1.16 times the one observed during 1996-2000, while the variance observed during 2006-2010 was 2.37 times the observed in the first sub-period. These estimates are slightly higher if we use data from Saudi Arabia.

To conclude, Figure 11 presents the real oil price in constant US$ (2010) seasonally adjusted and the structural "no bubble" series constructed using data from the US, including their long-run trend.We then divided this 15-year period into three equal sub-periods corresponding the years 1996-2000, 2001-2005 and 2006-2010. The differences of both series during these sub-periods show us two important facts. First, the mean difference between the series has remained stable. For the 1996-2006 the mean difference was 3.5%, for the 2001-2005 it was -4.4% while for the 2006-2010 it was only -0.8%. Second, the variance of the difference has increased twofold. The variance of the 2001-2005 periods was 1.16 times the one observed during 1996-2000 while the variance for 2006-2010 was 2.37 times the observed in the first sub-period.

[Insert Figure 11]

The real oil price (S.A.) reached a maximum value of US$ 131.2 on jun-2008. US$ 96.7 of that price can be explained using only the fundamentals of the oil markets (more than 2/3) while US$ 34.6 can be attributed —at most— to speculative behavior.

7 Conclusions

The final goal of this paper was to decompose and analyze the drivers of the oil price. Our intention was to provide a detailed understanding of the reasons behind the price increase that took place during last decade. Three hypothesis have been heatedly debated on this topic, some have argued that the increase was demand driven, others argued that it was supply driven and another group argued that the price was the result of speculation in the financial market. These competing hypotheses can be grouped into two different conceptual lines of argument: fundamental or real movements of the oil price, and speculative (bubble type) non-fundamental movements.

The first empirical problem that we faced when dealing with our objective was to properly address the problem of endogeneity. We proposed a solution using a novel micro-data set at the country level that allowed us to incorporate technological restrictions that occur at the micro level in the production of crude oil.

We find that when oil price peaked in mid-2008, reaching almost US$150, at least 2/3 of this price hike can be explained using only fundamentals of the oil market. In other words, at most US$ 40 can be attributed to speculative behavior of the market. We were able to disentangle both reasons because we solved the identification problem using a semi-structural approach of the crude oil production process at the country level.

These speculative shocks to the oil price are very volatile. Its variance has doubled in one decade. They also have serial correlation, with a persistence that last two years at most.

They are also bounded in magnitude at their historical peak of US$ 40. This is so because we are assuming that all structural shocks in the oil price equation of our system are due to speculative movements.

Therefore, given that the oil prices that we observe today are responding to the same fundamentals than in previous years, and given that our structural analysis of the residual suggest that there's no enough evidence to support a long-term disequilibria driven by pure speculation in the world oil markets, we expect real oil prices fluctuating around US$ 100 in the short and medium-term.

References

[1] Barsky, Robert B., and Lutz Kilian. 2004. "Oil and the Macroeconomy Since the 1970s." *Journal of Economic Perspectives*, 18(4): 115–134.

[2] Hamilton, James 2009. "Understanding Crude Oil Prices." *Energy Journal*, 30(2): 179-206.

[3] Hamilton, James 2009. "Causes and Consequences of the Oil Shock of 2007-08." *Brookings Papers on Economic Activity*, Spring 2009: 215-259.

[4] Hvozdyk, L. and Valerie Mercer-Blackman. 2009. "What Determines Investment in the Oil Sector?". Working Paper. IMF

[5] Kilian, Lutz 2008. "The Economic Effects of Energy Price Shocks." *Journal of Economic Literature*, 46(4): 871–909.

[6] Kilian, Lutz 2008. "Exogenous Oil Supply Shocks: How Big Are They and How Much Do They Matter for the U.S. Economy?." *Review of Economics and Statistics*, 90(2): 216-240.

[7] Kilian, Lutz 2008. "A Comparison of the Effects of Exogenous Oil Supply Shocks on Output and Inflation in the G7 Countries." *Journal of the European Economic Association*, 6(1): 78-121.

[8] Kilian, Lutz 2009. "Not All Oil Price Shocks Are Alike: Disentangling Demand and Supply Shocks in the Crude Oil Market." *American Economic Review*, 99(3): 1053–69.

[9] Ringlund, G., Rosendahl, K. and Terje Skjerpen. 2004. "Does oilrig activity react to oil price changes? An empirical investigation". Discussion Papers No. 372, Statistics Norway, Research Department.

[10] Smith, James L. 2009. "World Oil: Market or Mayhem?" *Journal of Economic Perspectives*, 23(3): 145–64.

8 Appendix A

The system of equation that we want to estimate has the general form

$$\begin{bmatrix} 1 & -\beta_{12}^{(0)} & -\beta_{13}^{(0)} & -\beta_{14}^{(0)} \\ -\beta_{21}^{(0)} & 1 & -\beta_{23}^{(0)} & -\beta_{24}^{(0)} \\ -\beta_{31}^{(0)} & -\beta_{32}^{(0)} & 1 & -\beta_{34}^{(0)} \\ -\beta_{41}^{(0)} & -\beta_{42}^{(0)} & -\beta_{43}^{(0)} & 1 \end{bmatrix} \begin{bmatrix} p_t \\ y_t \\ r_t \\ d_t \end{bmatrix} = \begin{bmatrix} k_1 \\ k_2 \\ k_3 \\ k_4 \end{bmatrix} + \sum_{i=1}^{L} \begin{bmatrix} \beta_{11}^{(i)} & \beta_{12}^{(i)} & \beta_{13}^{(i)} & \beta_{14}^{(i)} \\ \beta_{21}^{(i)} & \beta_{22}^{(i)} & \beta_{23}^{(i)} & \beta_{24}^{(i)} \\ \beta_{31}^{(i)} & \beta_{32}^{(i)} & \beta_{33}^{(i)} & \beta_{34}^{(i)} \\ \beta_{41}^{(i)} & \beta_{42}^{(i)} & \beta_{43}^{(i)} & \beta_{44}^{(i)} \end{bmatrix} \begin{bmatrix} p_{t-1} \\ y_{t-1} \\ r_{t-1} \\ d_{t-1} \end{bmatrix} + \begin{bmatrix} \varepsilon_t^p \\ \varepsilon_t^y \\ \varepsilon_t^r \\ \varepsilon_t^d \end{bmatrix}$$

Or more compactly as

$$A_0 X_t = k + A_1 X_{t-1} + ... + A_L X_{t-L} + \varepsilon_t$$

Where X_t is a 4x1 vector that includes endogenous variables, k is a 4x1 vector of constants, A_i is a matrix 4x4 matrix of coefficients, and ε_t is a 4x1 vector of structural innovations that are assumed to be white noise.

The previous system of equation can be rewritten in reduce form by pre-multiplying both sides by A_0^{-1} obtaining the following system

$$X_t = c + B_1 X_{t-1} + ... + B_L X_{t-L} + e_t$$

Where $c = A_0^{-1}k$, $B_i = A_0^{-1}A_i$ for $i = 1 \ldots L$, and $e_t = A_0^{-1}\varepsilon_t$

Additionally, we know that ε_t is a vector of disturbances assumed to be Gaussian white noise processes such that $E[\varepsilon_t] = 0$ and $Var[\varepsilon_t] = \Sigma$, where Σ is a diagonal matrix. Similarly, e_t is a vector where $E[e_t] = 0$ and $Var[e_t] = \Omega = A_0^{-1}\Sigma A_0^{-1\prime}$, where Ω is a symmetric matrix.

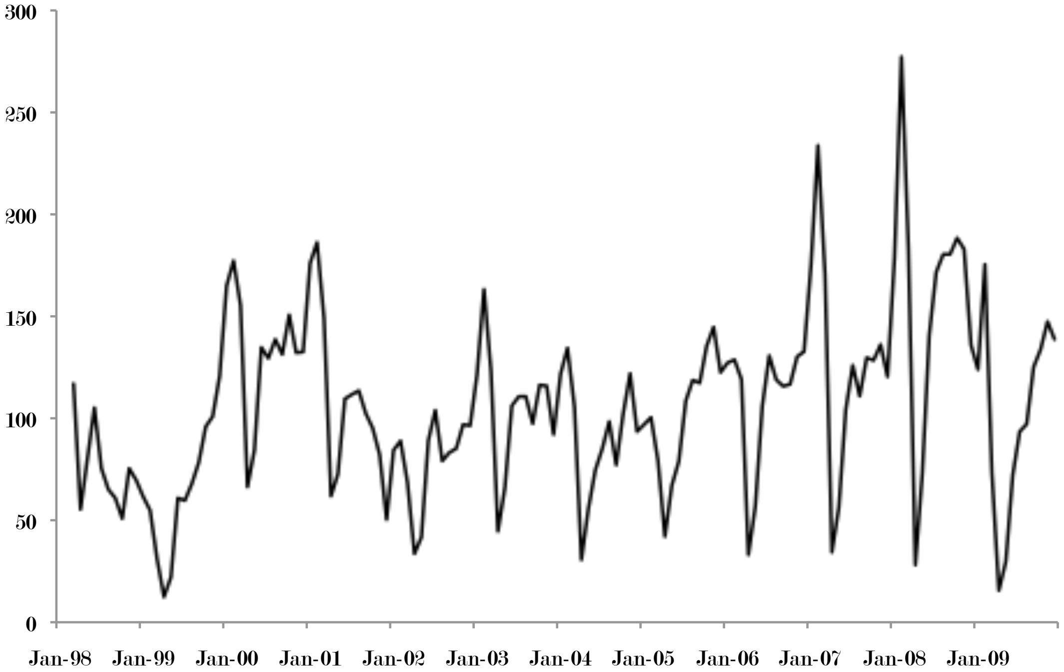
9 Appendix B

In this section we describe groups constructions that corresponds to our 5 different VAR models that characterize world oil markets.

- Group 1: United States
- Group 2: OECD countries; (AUS), Canada (CAN), Great Britain (GBR), Mexico (MEX), Norway (NOR), United States (US).
- Group 3: Non-OPEC countries; Argentina (ARG) AUS, Brazil (BRA), Canada (CAN), China (CHN), Colombia (COL), Egypt (EGY), Great Britain (GBR), IND, Mexico (MEX), MMR MYS, Norway (NOR), Oman (OMN), Syria (SYR), United States (USA), VNM, Yemen (YEM).
- Group 4: OPEC countries; Angola (AGO), Algeria, Indonesia, Kuwait (KWT), Nigeria (NIG), Qatar (QAT), Saudi Arabia (SAU), United Arabs Emirates (UAE), Venezuela (VEN).
- Group 5: Non-OPEC + OPEC countries.

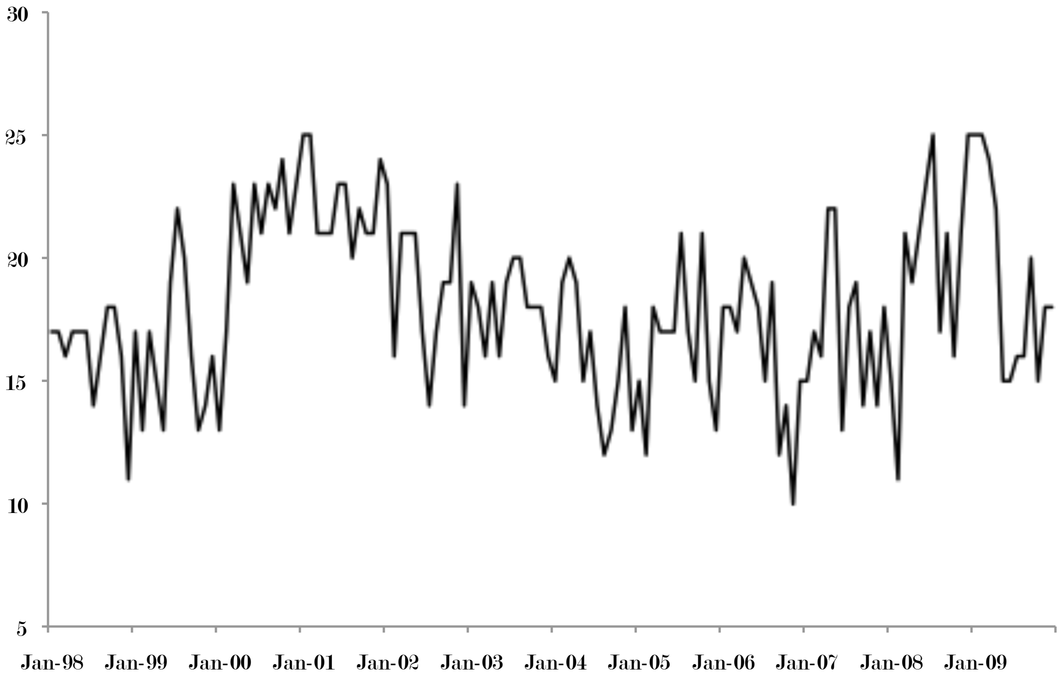
Figures

Figure 1: Canada number of crude oil rigs



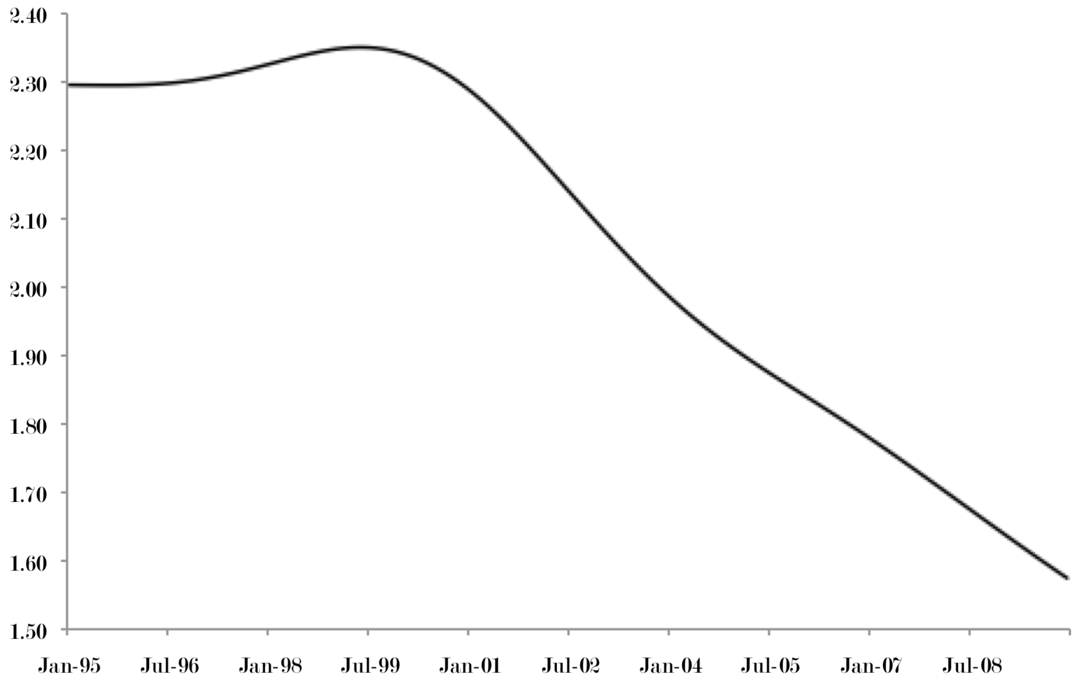
Source: Backer Hughes Inc.

Figure 2: Norway number of crude oil rigs



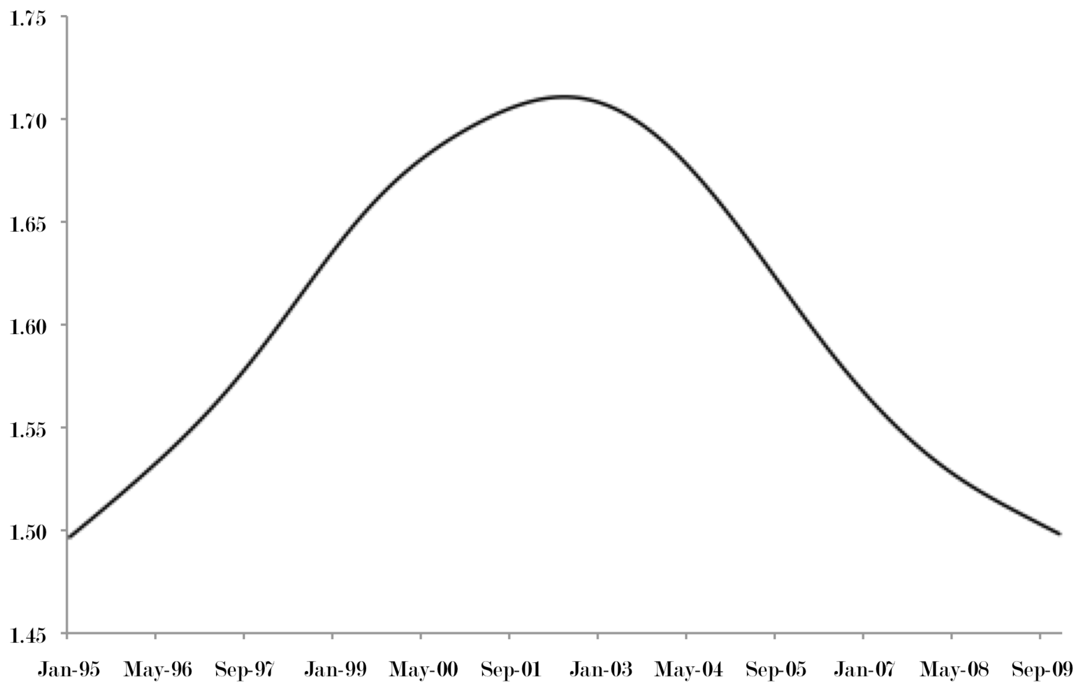
Source: Backer Hughes Inc.

Figure 3: Mexico Production per Rig, in logs (Hodrick-Prescott Trend)



Source: Backer Hughes Inc., IEA and own calculations

Figure 4: USA Production per Rig, in logs (Hodrick-Prescott Trend)



Source: Backer Hughes Inc., IEA and own calculations

Figure 5: Canada crude oil rigs response to a permanent increase in the oil price

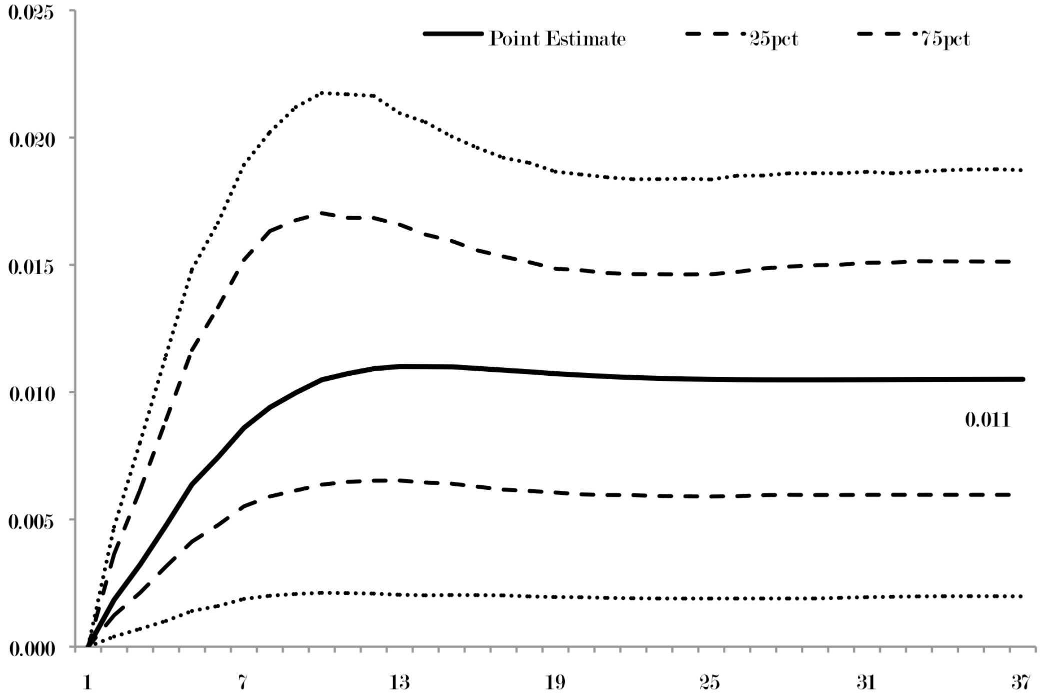


Figure 6: United States crude oil production response to a permanent increase in the crude oil rigs

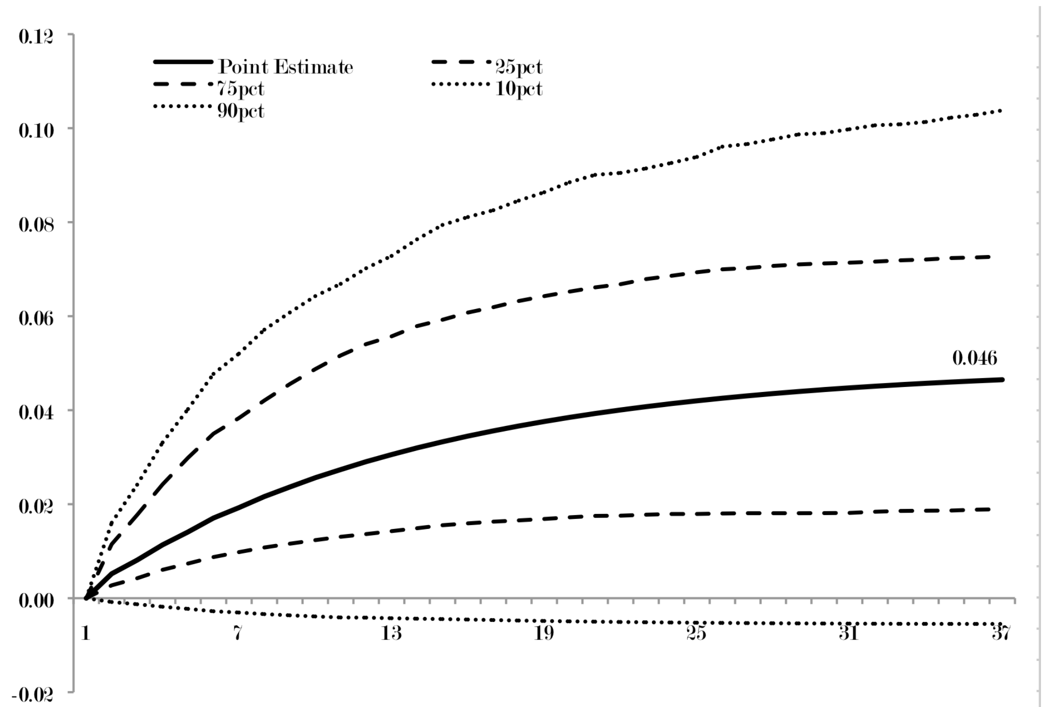


Figure 7. Impulse Response Functions, US Model

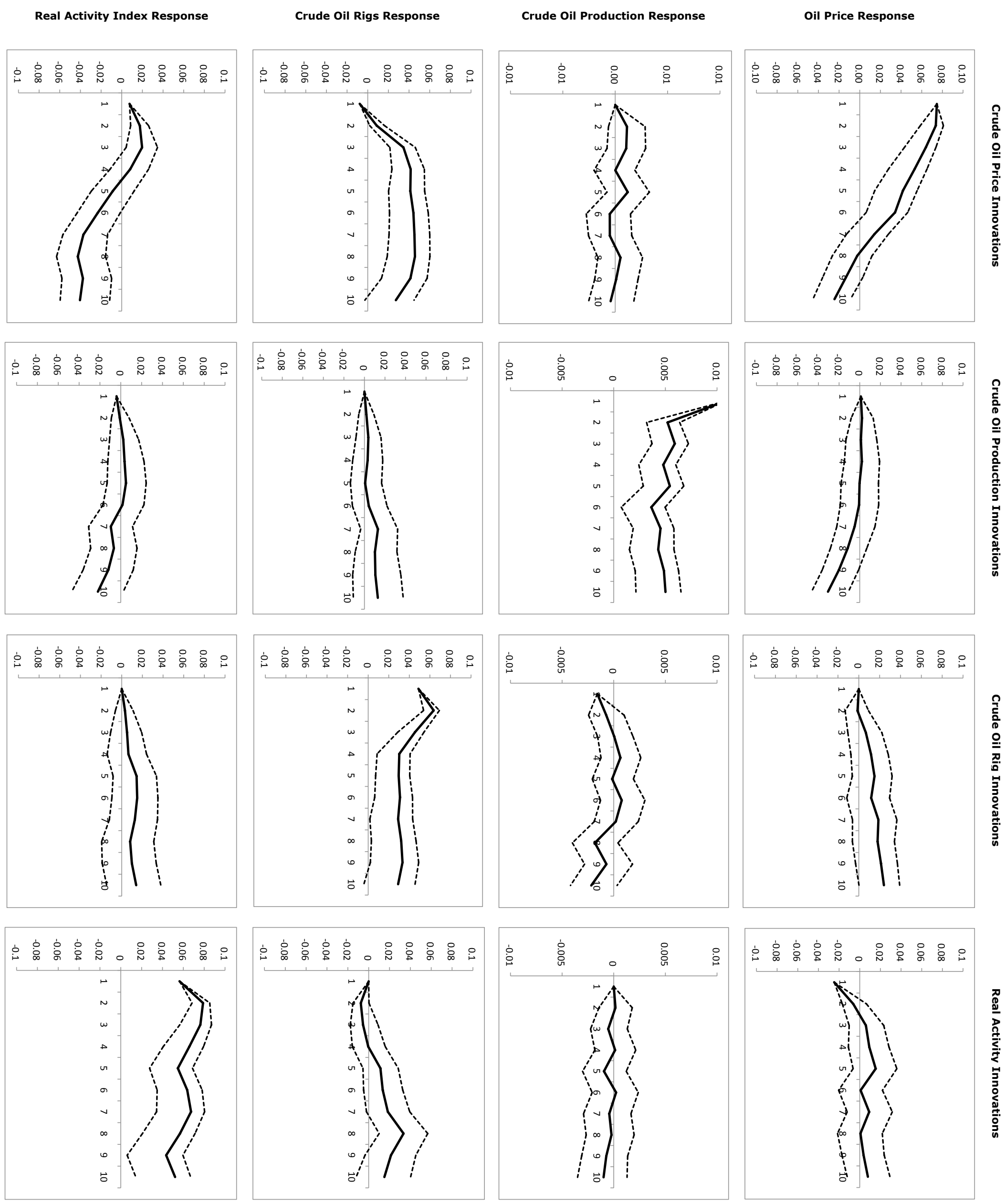


Figure 8. Impulse Response Functions, Saudi Arabia Model

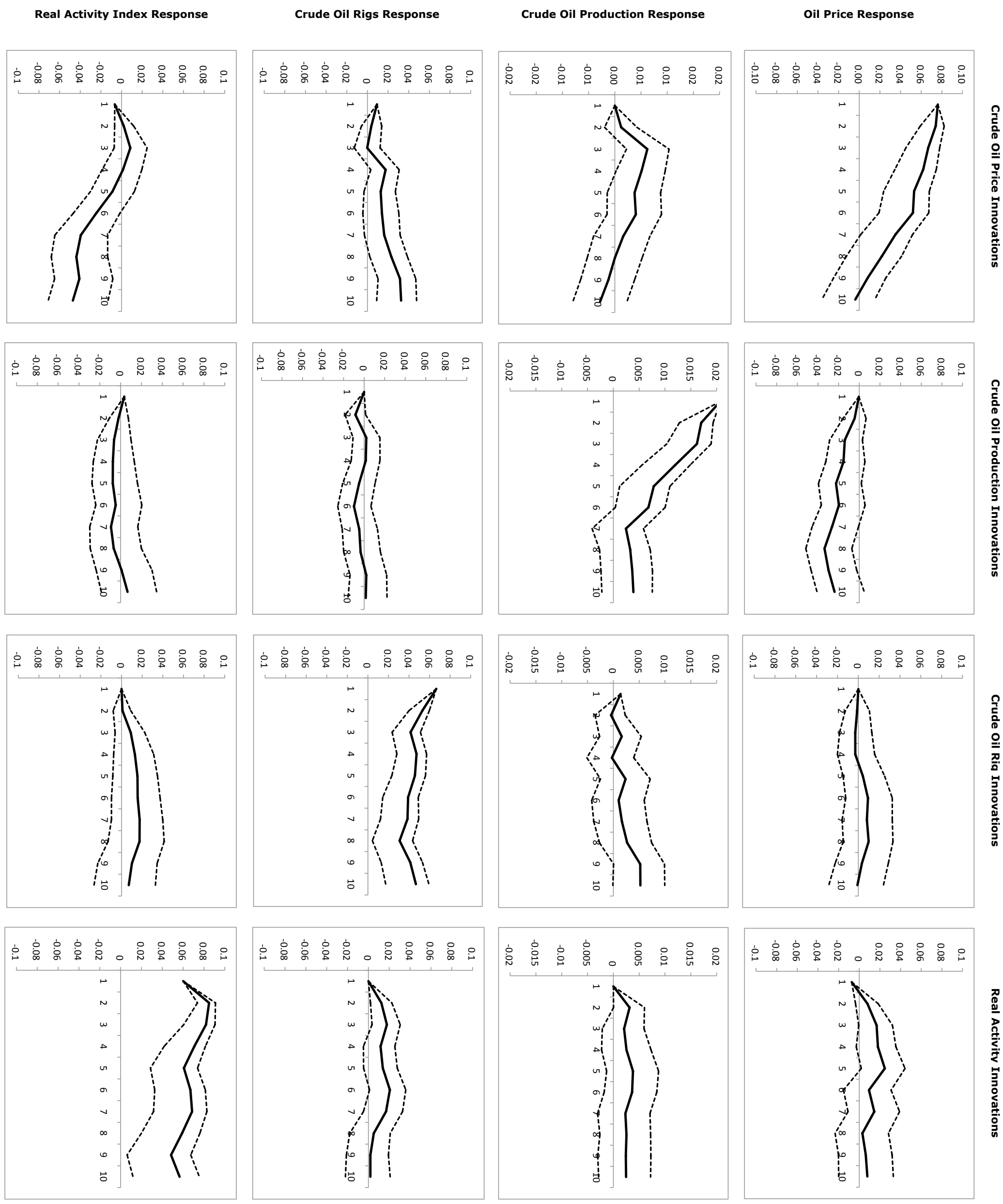


Figure 9. Price Equation Structural Residuals (in logs), US Model

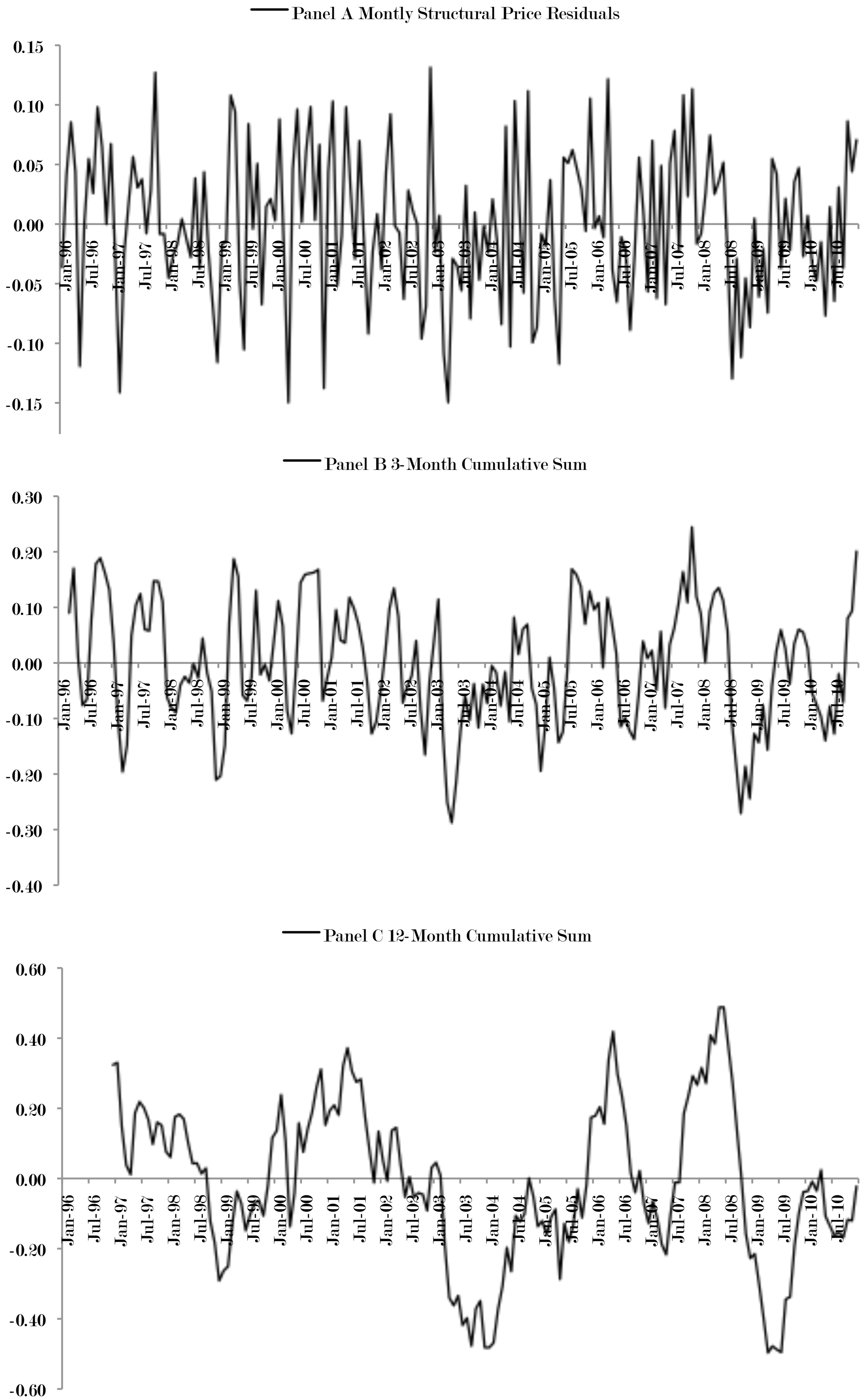
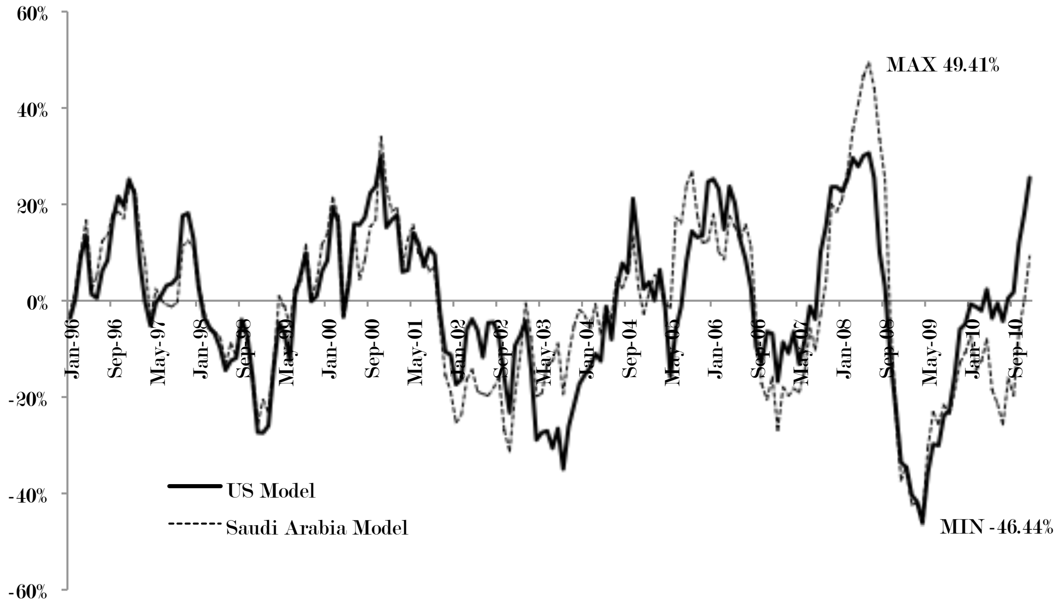


Figure 10. "No bubble" oil price deviations from observed oil price (S.A. and detrended). US and Saudi Arabia Models



Source: IEA and own calculations

Figure 11. Observed WTI (SA) and No-Bubble WTI, Constant 2010 US$. US Model

Source: IEA, BLS and own calculations

Tables

Table 1: Break test in the trend of production per rig relation

Country	Constant	Slope	Break date	lope after brea	R^2
NOR	3.043	-0.004	Oct-01	0.002	0.938
GBR	2.563	0.002	Jan-04	-0.002	0.728
Egy	2.570	-0.007	Apr-03	0.002	0.986
KWT	4.384	-0.012	Jan-00	0.005	0.981
OMN	2.507	-0.003	Mar-04	-0.001	0.992
QAT	3.635	-0.007	May-01	0.006	0.459
SAU	3.433	-0.003	Oct-03	-0.003	0.973
SYR	2.604	0.000	Aug-99	-0.001	0.887
YEM	5.200	-0.031	Apr-04	0.009	0.930
DZA	5.399	-0.036	Jan-03	0.014	0.825
AGO	2.829	0.018	Aug-06	-0.004	0.982
NGA	2.936	0.058	Feb-08	0.012	0.988
ARG	1.648	0.003	Jan-01	-0.004	0.726
BRA	2.312	0.000	Nov-11	-0.002	0.857
COL	2.403	0.002	Jun-04	-0.005	0.847
ECU	2.999	-0.010	Jan-05	0.003	0.953
MEX	2.376	-0.002	Nov-01	-0.002	0.964
VEN	1.706	0.004	Feb-05	-0.001	0.940
AUS	3.105	0.012	Apr-02	-0.015	0.826
IND	1.655	0.002	Jan-03	-0.003	0.772
IDN	2.136	-0.004	Aug-01	0.001	0.960
MYS	2.726	-0.014	Jul-03	0.005	0.875
MMR	0.692	0.001	Nov-98	0.001	0.991
CHN	4.756	-0.008	Feb-03	-0.004	0.983
VNM	2.895	0.003	Apr-07	0.002	0.878
USA	1.539	0.002	Apr-04	-0.002	0.729
CAN	0.096	0.020	May-04	-0.008	
UAE	2.660	0.003	Sep-01	0.001	0.982

Table 2: Long Run effect in the number of rigs in response to a permanent increase in the oil price (Point Estimate can be interpreted as %)

Country	Point Estimate	SD	10pct	90pct	Affiliation
AGO	0.011	0.008	0.000	0.021	OPEC
ARG	0.015	0.010	0.003	0.028	Non-OPEC
AUS	0.014	0.012	0.000	0.029	OECD, Non-OPEC
BRA	0.013	0.006	0.006	0.020	Non-OPEC
CAN	0.011	0.007	0.002	0.019	OECD, Non-OPEC
CHN	0.006	0.009	-0.006	0.017	Non-OPEC
COL	0.020	0.009	0.007	0.029	Non-OPEC
DZA	-0.001	0.007	-0.010	0.007	OPEC
ECU	0.011	0.007	0.000	0.020	OPEC*
EGY	0.017	0.007	0.007	0.026	Non-OPEC
GBR	0.027	0.013	0.011	0.043	OECD, Non-OPEC
IDN	0.008	0.008	-0.002	0.017	OPEC**
IND	-0.003	0.007	-0.011	0.006	Non-OPEC
KWT	-0.020	0.017	-0.040	0.001	OPEC
MEX	-0.007	0.012	-0.020	0.007	OECD, Non-OPEC
MMR	0.003	0.009	-0.006	0.015	
MYS	0.003	0.006	-0.005	0.010	
NGA	0.007	0.012	-0.008	0.023	OPEC
NOR	0.011	0.003	0.007	0.014	OECD, Non-OPEC
OMN	0.001	0.004	-0.004	0.007	Non-OPEC
QAT	0.021	0.017	0.001	0.040	OPEC
SAU	0.008	0.010	-0.003	0.021	OPEC
SYR	0.000	0.003	-0.003	0.003	Non-OPEC
UAE	0.004	0.003	0.000	0.007	OPEC
USA	0.023	0.009	0.012	0.033	OECD, Non-OPEC
VEN	0.016	0.006	0.009	0.024	OPEC
VNM	0.003	0.006	-0.003	0.011	
YEM	0.003	0.006	-0.005	0.011	

*From December 1992 until October 2007, Ecuador suspended its men

**Indonesia suspended its membership effective January 2009.

Table 3: Months needed to achieve half of the long-term response

Country	Point Estimate	SD	25pct	75pct	10pct	90pct	Affiliation
AGO	3	1.176	2	3	1	4	OPEC
ARG	5	1.411	4	5	3	6	Non-OPEC
AUS	2	0.623	2	3	2	3	OECD, Non-OPEC
BRA	8	2.921	4	9	3	11	Non-OPEC
CAN	4	0.753	3	4	2	4	OECD, Non-OPEC
CHN	4	1.263	3	4	2	5	Non-OPEC
COL	5	1.969	3	5	2	7	Non-OPEC
DZA	5	1.795	3	6	3	7	OPEC
ECU	3	0.798	2	3	2	4	OPEC*
EGY	9	3.047	5	9	4	11	Non-OPEC
GBR	6	2.044	4	6	3	8	OECD, Non-OPEC
IDN	5	1.450	4	5	3	6	OPEC**
IND	7	2.253	5	8	4	10	Non-OPEC
KWT	11	2.993	8	12	6	14	OPEC
MEX	9	2.795	5	9	4	11	OECD, Non-OPEC
MMR	10	2.721	6	10	5	12	
MYS	3	1.220	2	3	1	4	
NGA	5	1.829	4	6	3	7	OPEC
NOR	1	0.144	1	1	1	1	OECD, Non-OPEC
OMN	6	1.812	4	6	3	7	Non-OPEC
QAT	6	2.131	4	7	3	8	OPEC
SAU	8	2.674	5	9	4	11	OPEC
SYR	7	2.196	4	7	3	9	Non-OPEC
UAE	3	1.069	2	3	2	4	OPEC
USA	5	1.466	4	6	3	7	OECD, Non-OPEC
VEN	4	1.274	3	5	3	6	OPEC
VNM	3	0.781	2	3	2	3	
YEM	4	0.773	3	4	2	4	

Table 4: Long Run effect in the crude oil production in response to a permanent increase in the number of oil rigs (Point Estimate can be interpreted as %)

Country	Point Estimate	SD	10pct	90pct	Affiliation
AGO	0.017	0.080	-0.070	0.130	OPEC
ARG	0.156	0.056	0.082	0.218	Non-OPEC
AUS	-0.055	0.068	-0.143	0.029	OECD, Non-OPEC
BRA	0.239	0.076	0.123	0.312	Non-OPEC
CAN	0.161	0.099	0.028	0.269	OECD, Non-OPEC
CHN	0.002	0.017	-0.024	0.021	Non-OPEC
COL	0.041	0.083	-0.069	0.140	Non-OPEC
DZA	-0.053	0.120	-0.255	0.041	OPEC
ECU	-0.187	0.122	-0.329	-0.041	OPEC*
EGY	-0.051	0.088	-0.149	0.054	Non-OPEC
GBR	0.096	0.062	0.020	0.180	OECD, Non-OPEC
IDN	0.001	0.047	-0.072	0.044	OPEC**
IND	-0.016	0.048	-0.078	0.046	Non-OPEC
KWT	0.063	0.055	-0.013	0.127	OPEC
MEX	0.039	0.044	-0.019	0.093	OECD, Non-OPEC
MMR	-0.234	0.323	-0.676	0.141	
MYS	-0.067	0.063	-0.139	0.015	
NGA	-0.195	0.094	-0.303	-0.070	OPEC
NOR	0.143	0.109	0.003	0.277	OECD, Non-OPEC
OMN	0.130	0.148	-0.045	0.309	Non-OPEC
QAT	0.049	0.066	-0.023	0.136	OPEC
SAU	-0.014	0.067	-0.092	0.078	OPEC
SYR	-0.346	0.283	-0.737	-0.054	Non-OPEC
UAE	0.152	0.230	-0.148	0.419	OPEC
USA	0.046	0.048	-0.005	0.104	OECD, Non-OPEC
VEN	-0.042	0.112	-0.185	0.091	OPEC
VNM	-0.104	0.267	-0.494	0.185	
YEM	-0.042	0.046	-0.099	0.016	

*From December 1992 until October 2007, Ecuador suspended its membership.

**Indonesia suspended its membership effective January 2009.

Table 5. Month needed to achieve half of the long-term response

Country	Point Estimate	SD	25pct	75pct	10pct	90pct	Affiliation
AGO	5	1.550	4	5	3	7	OPEC
ARG	9	2.516	5	9	4	11	Non-OPEC
AUS	3	1.489	2	3	1	5	OECD, Non-OPEC
BRA	4	1.514	3	5	2	6	Non-OPEC
CAN	6	2.663	2	6	2	8	OECD, Non-OPEC
CHN	2	0.787	2	2	1	3	Non-OPEC
COL	5	1.628	3	5	2	6	Non-OPEC
DZA	7	2.276	5	8	4	10	OPEC
ECU	7	2.531	4	8	3	10	OPEC*
EGY	8	2.416	5	9	4	11	Non-OPEC
GBR	5	1.720	3	5	2	6	OECD, Non-OPEC
IDN	6	2.444	4	8	3	9	OPEC**
IND	2	0.532	2	2	2	3	Non-OPEC
KWT	4	0.888	4	5	3	5	OPEC
MEX	5	1.619	3	5	2	6	OECD, Non-OPEC
MMR	25	1.031	25	25	24	26	
MYS	6	1.850	4	6	3	8	
NGA	7	2.551	3	7	2	9	OPEC
NOR	4	1.468	2	4	2	5	OECD, Non-OPEC
OMN	9	2.909	4	9	3	11	Non-OPEC
QAT	4	1.071	3	4	3	5	OPEC
SAU	3	0.740	3	3	2	4	OPEC
SYR	17	3.261	12	17	10	18	Non-OPEC
UAE	5	1.439	4	5	3	6	OPEC
USA	8	2.727	5	8	3	11	OECD, Non-OPEC
VEN	5	1.430	4	6	4	7	OPEC
VNM	6	2.166	4	7	4	9	
YEM	5	1.413	4	5	3	7	

Table 6. Maximum Likelihood Estimation of contemporaneous relations

	US	SAU	OECD	Non-OPEC	OPEC	World
			Oil price equation			
$\ln(y_t)$	-0.103	0.020	-0.518	-2.465	0.400	-2.211
d_t	0.439	0.122	0.045	0.016	0.130	0.060
			Crude oil production equation			
$\ln(r_t)$	0.033	-0.021	0.013	0.004	0.023	0.014
			Crude oil rigs equation			
$\ln(p_t)$	0.104	-0.121	0.049	0.052	-0.052	0.008
			World Activity Index equation			
$\ln(p_t)$	-0.101	0.087	0.114	0.097	0.162	0.091
$\ln(y_t)$	0.379	-0.170	-0.414	-1.725	0.564	-1.556

Table 7. Variance Decomposition Percentage. US Model

	Crude oil price equation			
Month	P_t	Y_t	R_t	D_t
1	95.62	0.01	0.00	4.38
6	74.48	0.31	2.30	22.91
12	62.98	12.52	4.99	19.51
24	50.48	24.80	11.82	12.89
	Crude oil production equation			
Month	P_t	Y_t	R_t	D_t
1	0.05	97.81	2.14	0.00
6	2.40	91.26	6.05	0.29
12	2.32	87.88	6.74	3.06
24	3.85	82.20	7.07	6.87
	Crude oil rigs equation			
Month	P_t	Y_t	R_t	D_t
1	2.42	0.00	97.47	0.11
6	39.64	0.52	45.09	14.75
12	36.42	3.37	34.75	25.46
24	33.04	11.97	32.67	22.32
	World real activity			
Month	P_t	Y_t	R_t	D_t
1	0.00	0.50	0.01	99.49
6	3.20	2.55	2.76	91.49
12	23.89	2.54	2.43	71.14
24	35.00	11.09	6.05	47.85

Table 8. Variance Decomposition Percentage. SAU Model

	Crude oil price equation			
Month	P_t	Y_t	R_t	D_t
1	99.09	0.00	0.00	0.91
6	82.31	5.17	0.61	11.91
12	71.75	15.28	1.52	11.45
24	66.58	20.77	3.61	9.04

	Crude oil production equation			
Month	P_t	Y_t	R_t	D_t
1	0.01	99.54	0.45	0.00
6	9.33	84.20	1.04	5.43
12	9.96	76.50	6.40	7.14
24	12.79	74.00	7.39	5.82

	Crude oil rigs equation			
Month	P_t	Y_t	R_t	D_t
1	1.90	0.00	98.08	0.02
6	2.02	1.76	88.66	7.56
12	9.51	2.37	81.80	6.31
24	17.18	7.17	70.48	5.17

	World real activity			
Month	P_t	Y_t	R_t	D_t
1	1.18	0.34	0.00	98.48
6	4.18	3.02	2.66	90.13
12	14.66	2.78	3.06	79.50
24	23.60	3.21	2.33	70.86