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Abstract

Hamilton identifies 1973 to 1996 as "the age of OPEC" and 1997 to the present as "a new industrial age." During 1974-1996 growth in non-OPEC oil production Granger causes growth in OPEC oil production. OPEC oil production decreases significantly with positive shocks to non-OPEC oil production in the earlier period, but does not do so in the "new industrial age". In the "new industrial age" OPEC oil production rises significantly with an increase in oil prices, unlike during "the age of OPEC" period. OPEC oil production responds significantly to positive innovations in global GDP throughout. Over 1997:Q1-2012:Q4 the negative effect on real oil price of positive shocks to non-OPEC oil production is larger in absolute value than that of positive shocks to OPEC oil production. The cumulative effects of structural shocks to non-OPEC oil production and to real oil price on OPEC oil production are large. The cumulative effects of structural shocks to OPEC production and real oil price on non-OPEC production are small. Results are robust to changes in model specification. An econometric technique to predict growth in OPEC oil production provides support for the results from the SVAR analysis. Results are consistent with important changes in the global oil market.

Keywords: OPEC production, non-OPEC, oil Price, global oil market,

JEL Codes: E31, E32, Q43

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OPEC and non-OPEC oil production and the global economy

1.Introduction

Hamilton (2013) identifies five main periods associated with significant changes in the price of oil; 1859-1899, 1900-1945, 1946-1972, 1973-1996 and 1997-present. Hamilton (2013) describes the latter two periods as “The age of OPEC” and “A new industrial age”, respectively. Hamilton associates the “The age of OPEC” with the move to a higher average real oil price, the change in the focus of the global oil market from North America to the Persian Gulf, and with assertive behaviour by OPEC. “A new industrial age” is connected with the tremendous economic growth in the major emerging economies, particularly China and India. Hamilton (2013) notes that the recently industrialized economies have absorbed over two-thirds of the increase in world oil consumption since 1998 and that this pattern of absorption of oil resources is likely to continue into the future. Kilian and Hicks (2013) show that rapid growth in emerging economies drove the rise in real oil price over 2003-2008.

In this paper we model the behaviour of real oil price and OPEC and non-OPEC production behaviour during the “The age of OPEC” from 1973 to 1996 and “A new industrial age” from 1997 to the present. The behaviour of the two types of producers has been differentiated in the literature and their behaviour has changed over time. Dées et al. (2007) report policy simulations indicating that non-OPEC production is inelastic to changes in price and that OPEC decisions about production impact oil prices. Barros et al. (2011) find that shocks affecting the structure of OPEC oil production are highly persistent. Kaufmann et al. (2008) finds that real prices generally have a positive effect on production by OPEC members.[1] Lin (2009) identifies 1990-2006 to be a time of a largely competitive oil market,

[1] Analysis of OPEC behaviour has focused on models of production for oil producers. Lin (2009) provides a review of work on the world oil market based on optimal non-renewable resource extraction models. Huntington (1994) shows that intertemporal optimization models did not function as well predicting the world oil market as recursive simulation models. Ramcharran (2002) estimates a negative and significant price elasticity of supply for OPEC. Kaufmann et al. (2004) find that OPEC influences real oil prices and that models not allowing for the endogeneity of oil price cannot provide tests of competing models of production behaviour. Gately (2007)

with the periods 1973-1981 and 1981-1990 having the market strongly influenced by OPEC. Huppmann and Holz (2012) argue that there has been a change in behaviour in the crude oil market since 2008 with OPEC having less market power, in contrast to before 2008 when Saudi Arabia acted as Stackelberg leader with a non-cooperative OPEC. Kolodzeij and Kaufmann (2014) argue that failure to model OPEC and non-OPEC oil production separately (and to just focus on aggregate global oil production) will lead to underestimation of the influence of supply shocks on real oil prices.

An increase in economic growth in developing countries may be associated with a higher expected growth for commodity demand than an increase in growth in developed countries. Radetzki (2006) finds that growth in emerging market countries is associated with a relatively greater usage of commodities than in expansion in developed economies.[2] Roberts and Rush (2010) report that commodity resources are used relatively intensively in traded goods and that growth in trade is a driving force in the growth of developing countries. Developing Asia grew at an average annual pace of 8.5% over the period between 2003 and 2013. The IMF expects developed economies to grow 2.2% in 2014 and developing economies to grow at almost 6% in 2014.[3]

In this paper we estimate the interrelationship between OPEC oil production, non-OPEC production, global aggregate demand and real oil price with a structural VAR model. Results are consistent with fundamental and related changes in the global oil market, based on strong global demand maintaining real oil price at high levels over most of 1997:Q1-2012:Q4, a steady upward trend in non-OPEC oil production over the last forty years, and a

observes that in discussing OPEC oil output relative to non-OPEC output in the composition of global oil production it is important to recognized that oil consumption in OPEC countries is rising rapidly. Gately et al. (2013) point out that OPEC′s domestic oil consumption has risen steeply since the 1970s and that collectively in recent years OPEC oil consumption approaches that of China.

[2] Radetzki (2006) finds that a dollar added to the GDP in developing Asian countries uses more than twice the quantity of commodities as does a dollar added to the GDP in OECD countries. Ratti and Vespignani (2013a) find that liquidity growth in China has a significant effect on crude oil price over 1997-2011.

[3] IMF Global Prospects and Polices can be found at http://www.imf.org/external/pubs/ft/weo/2013/01/

change in the behaviour of OPEC from reacting to non-OPEC oil production to responding to higher real oil price.

We find that growth in OPEC oil production moves to offset growth in non-OPEC production during 1974:Q1-1996:Q4, but not during 1997:Q1-2012:Q4. Growth in OPEC oil production is not influenced by oil price during 1974:Q1-1996:Q4, but is during 1997:Q1-2012:Q4. Growth in non-OPEC oil production responds significantly to positive innovations in real oil price over 1974:Q1-1996:Q4. Growth in Non-OPEC oil production does not respond significantly to positive innovations in real oil price over 1997:Q1-2012:Q4, possibly because real oil price during this period is above a threshold required for non-OPEC to maximize production[4]. Over 1997:Q1-2012:Q4 the negative effect on real oil price of positive shocks to growth in non-OPEC oil production is larger in absolute value than that to positive shocks to growth in OPEC oil production. Previously (over 1974:Q1-1996:Q4) growth in non-OPEC production didn't have a statistically significant effect on real oil price (due to offsetting OPEC adjustments).

Shocks to growth in OPEC oil production make large cumulative contribution to real oil price. Shocks to growth in non-OPEC oil production do not. The cumulative contribution to growth in OPEC oil production of real price shocks is large whereas that of growth in non-OPEC oil production is small. There is a large cumulative contribution to growth in OPEC oil production of shocks to growth in non-OPEC oil production, but that the reverse does not hold. The effect of shocks to growth in non-OPEC oil production on cumulative growth in OPEC oil production is larger over 1974-1996 than over 1997-2012.

Using an econometric technique to predict growth in OPEC oil production, developed by Lewellen (2004) and Westerlund and Narayan (2012), we find support for the results from the SVAR analysis. During the first period, growth in OPEC oil production can be predicted

[4] Ghalib (2004) estimates that among non-OPEC producers, the price ranges from a low of $12 for Norway to a high of more than $35 for Mexico that they require to balance the current account of their balance of payments.

by growth in non-OPEC oil production and global GDP growth, while during the second period growth in OPEC oil production can be predicted by growth in oil prices and global GDP growth. This evidence confirms Hamilton (2013)'s view of OPEC moving to a more market-orientated strategy from 1997.

The behaviour of OPEC oil production, non-OPEC oil production and real oil prices is discussed in Section 2. The econometric model, data and variables are presented in Section 3. Section 4 contains the empirical results. Section 5 considers robustness of results to changes in identification strategy, change in variables from real to nominal and variation in lag structure. In section 6 the predicted power of non-OPEC production, global aggregate demand and real oil price on OPEC oil production is examined. Section 7 concludes.

2. Oil prices, and OPEC and non-OPEC oil production

The behaviour of OPEC and Non-OPEC oil production over 1974 to 2012 is shown in Figure 1a and within OPEC oil production of Saudi Arabian oil production in Figure 1b. Nominal and real oil price is shown in Figure 2. The nominal and real oil price in U.S. dollars based on an index of 100 in 1974:Q4. Striking features in Figures 1a and 1b are the falls in OPEC oil production and Saudi oil production from the end of the 1970s through the first half of the 1980s. This is due to several factors, some more transitory than others. During the Iranian revolution, oil production fell between November 1978 and June 1979 by about 2.0-2.5 million barrels per day of oil. This reduction was mostly reversed shortly after the revolution. The onset of the Iran-Iraq War in September 1980 caused a further major fall in the output of both countries.

During the losses in oil production through the Iranian revolution and Iran-Iraq War, the nominal price of crude oil went from \$14 in 1978 to \$35 per barrel in 1981. The high oil prices in the 1970s lead to increased investment in production by non-OPEC countries, which resulted in ongoing increases in production well into the 1980s even after oil prices, subsided in real terms. OPEC reacted to lower real prices and increased production by non-OPEC countries by trying to restrict production with quotas over 1982 to 1985. Up until early 1986, Saudi Arabia cut production in an attempt to offset the fact that many OPEC countries exceeded agreed production restrictions, after which time Saudi production rose substantially.[5] This behaviour in Saudi oil production is illustrated in Figure 1b.

In 1990 oil price rose sharply with Iraqi's invasion of Kuwait and the Gulf War that followed. With the first Gulf War in 1990:8, oil production collapsed in Iraq and Kuwait. Oil production by Saudi Arabia increased sharply to partially (and substantially) offset this collapse. Oil production in Kuwait had recovered by early 1993. Oil production in Iraq remained relatively stable until the end of the 1990s.The price cycle then turned up. Growth in Asia over 1990 to 1997 contributed to world oil consumption and oil price increases. Non-OPEC oil production fell in the early 1990's attendant on a major decline in Russian production between 1990 and 1996.

The recovery from Asian financial crisis resulted in world petroleum consumption growth from 1999 onwards until the onset of recession in the U.S. beginning in March of 2001. In 2003 there was political unrest in Venezuelan and the second Persian Gulf War. The rapid increase in oil price leading to a peak in June 2008 is associated with rapid economic growth in major emerging economies, particularly China and India, and with low spare production capacity.[6] The fall in oil price from July 2008 to January 2009 is related to the global financial crisis during late 2008, recession in the U.S. over December 2007 to June

[5] Cairns and Calfucura (2012) argue that Saudi Arabia's objective is to set oil production to moderate oil prices so as to preserve a market for oil in the long run. Alkhathlan et al. (2014) also note that Saudi Arabia's intention is the stability of OPEC and the global oil market and that they will increase oil production to offset negative oil supply shocks.

[6] Hamilton (2013) notes that contributing factors to stagnation of oil production overall over 2002-2008 includes instability in Iraq and Nigeria, reduced production in the North Sea and by Mexico and Indonesia, and Saudi production being lower in 2007 than in 2005. Kaufmann (2011) attributes the sharp rise in oil price in 2007-2008 to flat non-OPEC oil production combined with exhaustion of OPEC spare capacity to increase oil production in the face of strong demand. Hamilton (2013) and WTRG Economics (2014) provide authoritative reviews of oil shocks and oil price behaviour for an extended period.

2009, and weak growth in Europe. Also OPEC decreased production target from September 2008 to January 2009. Concurrent with the global financial crisis and the weak global economy the spot price for crude oil remains subdued before re-bounding by April 2011 while the global economic activity remains subdued.[7]

3. Literature Review on structural breaks in oil prices

The paper contributes to the structural break literature on oil prices by determining the characteristics of different periods such as "the age of OPEC" and "a new industrial age". Consideration of structural breaks in the behaviour of oil price goes back at least to Hamilton (1983) with recognition of a OPEC induced sharp rise in oil price in 1973.[8] The recognition of structural breaks in oil prices can influence conclusions concerning the time series properties of the oil price data. If the existence of structural breaks is not correctly taken into account, inaccurate conclusions may be arrived at concerning the times series properties of the data. This is an important issue in that if oil prices are stationary there is mean reversion, but if oil prices have a unit root then shocks have permanent effects. Pindyck (1999) and Ferreira et al. (2005) do not allow for structural breaks and conclude that oil prices are non-stationary. Maslyuk and Smyth (2008) with weekly data and Ghoshray and Johnson (2010) with monthly data permit up to two structural breaks and are unable to reject the null of unit root. Mishra and Smyth (2014) report that recognizing heteroskedasticity in addition to two structural breaks in daily energy data results in the finding that prices are mean reverting.[9]

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[7] Ratti and Vespignani (2013b) attribute the high crude oil prices despite weak global activity after 2009 to substantial increases in global liquidity.

[8] More recently it is recognized that oil price is endogenous and dependent on economic and financial conditions worldwide (Kilian; 2009).

[9] The literature on the time series properties of energy prices in the presence of structural breaks is extensive. Using weekly data between 1991 and 1996, and allowing one break in 1994, Gulen (1999) finds non-stationarity for several spot prices. Serletis (1992) allows for endogenously determined structural breaks in finding that daily energy futures price data are not stationary. In contrast, Lee et al. (2006) allow for two endogenously determined structural breaks and a quadratic trend and Lee and Lee (2009) allow for multiple breaks find evidence of supportive of stationary real resource price series. Noguera (2013) and Mishra and Smyth (2014) provide extensive reviews of the literature on investigations of the time series properties of energy prices.

In the oil price literature, different structural breaks have been found, at least in part because different time periods have been analysed and different frequency of data utilized. For example, using daily data Arouri et al. (2012) finds one structural break in 1997 and multiples breaks in 2008 in the gasoline market using data from January 2 1986 to October 20, 2009. Using monthly data from January 1961 and August 2011, Noguera (2013) found several structural breaks: when the data is used in levels a structural break is found for January 1978 and for both level and trend he found structural breaks for July 1979, February 1986, February 1991, July 1998 and November 2008 (during our sample period). The important issues of unit root, co-integration and structural breaks in the global oil price data are considered in the next section.

4. Methodology

The methodology of the paper is based on Killian (2009), but with the novelty that growth in global oil production is differentiated into growth in OPEC oil production and growth in non-OPEC oil production. Consider a SVAR constructed with quarterly data from 1974:Q1 to 2012:Q4, with the following variables: OPEC oil production(OOP_t), Non-OPEC oil production ($NOOP_t$), purchase power parity measure of global GDP in U.S dollars ($GGDP_t$) and oil prices (OP_t). Both, oil prices and global GDP (PPP) in U.S. dollars are deflated by the U.S. GDP deflator.

The SVAR model can expressed as:

$$B_0 X_t = \beta + \sum_{i=1}^{j} B_i X_{t-i} + \varepsilon_t \tag{1}$$

Where j is the optimal lag length determined by the Schwarz criterion (BC), one lag in this case, and ε_t denotes the vector of serially and mutually uncorrelated structural innovations. The vector X_t can be expressed as:

$$X_t = [\Delta \log(OOP_t), \Delta \log(NOOP_t), \Delta \log(GGDP_t), \Delta \log(OP_t)] \tag{2}$$

Contemporaneous restrictions are based on Killian (2009) and are summarised in the following equation:

$$B_o X_t = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ -b_{31} & -b_{32} & 1 & 0 \\ -b_{41} & -b_{42} & -b_{43} & 1 \end{bmatrix} \begin{bmatrix} \Delta\log(OOP_t) \\ \Delta\log(NOOP_t) \\ \Delta\log(GGDP_t) \\ \Delta\log(OP_t) \end{bmatrix} \quad (3)$$

Equation 4 implies that shocks to both growth in OPEC and growth in non-OPEC oil production are assumed to not respond to the other structural shocks within the same quarter. This assumption is based Kilian (2009) and supported by the LM ratio of over-identified restrictions test, which support zero restrictions for $-b_{12}$ or $-b_{21}$. In Kilian (2009) real oil price is in log-level, and aggregate demand and oil production are in percentage changes.

Growth in global GDP is assumed to respond contemporaneously to growth in both oil productions, but not to oil prices. This implies that global production could be affected by, for example, an oil production shortage. Nevertheless, growth in global output or growth in GDP is expected to respond with some delay to growth in oil prices given that production decisions cannot be made in response to short term price fluctuations. Finally, growth in oil prices respond contemporaneously to growth in oil productions and growth in global output.

4.1. Data and variables

The sample period is from 1974:Q1 to 2012:Q4. The study uses quarterly data so as to make use of a broad indicator of global economic activity provided by a proxy for global GDP which can be constructed at this frequency.[10] A proxy variable for global GDP $(GGDP)_t$ is provided by the aggregated purchase power parity GDP in US dollars for the United States, the European Union countries, Australia, Canada, China, Ireland, Japan,

[10] Finding a good scale variable for global real activity at a frequency greater than quarterly is difficult. In his influential contribution to analysis of the global determinants of real oil prices with monthly data, Kilian (2009) introduced the dry bulk shipping cost as an indicator of global demand for commodities. Kolodzeij and Kaufmann (2014) argue that the connection between dry bulk maritime freight costs and oil prices is due to the relationship between oil prices and the cost of transportation.

Korea, Mexico, New Zealand, Norway and Turkey.[11] Oil price (OP_t) is the spot price of Western Texas Intermediate (WTI) oil from the U.S. Department of Energy. These countries account for more than 80% of global GDP for most of the data period. The starting date is dictated by the availability of oil price data. The OPEC oil production (OOP_t) and non-OPEC oil production ($NOOP_t$) data in millions of barrels average pumped per day from U.S. Department of Energy. Real variables are nominal variables deflated by the US CPI from the Federal Reserve Bank of St. Louis.

4.2. Unit root, co-integration and structural breaks

4.2.1. Unit root and structural breaks

We start the analysis of the data by carrying out the Augmented Dickey Fuller (ADF), Dickey Fuller GLS (DF-GLS) and the Phillip-Perron (PP) unit root tests for all variables in the model without considering structural breaks. Results are reported in Table 1 and reveal that the logs of OPEC oil production, non-OPEC oil production, real global GDP and real oil price are first difference stationary. Those results are confirmed by the Kwiatkowski-Phillips-Schmidt-Shin (KPSS) test where the inverse null hypothesis is tested. The null hypothesis of unit root cannot be rejected even at 10% level for those series in levels but can be rejected at 1% level of significant for these series in first differences.

Perron (1989) shows that if there exists a one-time permanent change in the data, the ADF test for unit root could be biased towards reducing the ability to reject a false unit root null hypothesis. To deal with this issue we carry out Perron (1997)'s unit root test which allows identification of a structural break endogenously from the data (the details of this test are presented in Appendix A). Results of Perron (1997)'s unit root test are shown in Figure 3. This test suggests that the most significant structural break in the data occurs in Q4: 1996. In Table 2, results show that the null hypothesis that real oil price has a unit root with a

[11] The quarterly Chinese GDP data are interpolated from annual Chinese purchase power parity GDP in US dollars from OECD statistical tables.

structural break in both intercept and trend cannot be rejected at 1%. These results confirm both Hamilton (2013)'s claims of an important structural break in the oil market in 1997 and also that real oil price contain has a unit root even when a structural break is considered.

Consequently, we considered this result and Hamilton (2013)'s idea that during the period of analysis important change in the drivers of oil price occurs in the first quarter of 1997 as demand for oil by China and India intensifies. We also use the traditional Chow (1960) break point test for the points 1979:Q3, 1986:Q1, 1998:Q3 and 2008:Q4 following the findings by Noguera (2012) with monthly data, and the point 1997:Q1 indicated by Hamilton (2013) and identified out by Perron (1997)'s test.

We found that at quarterly frequency, the three different versions of the Chow test indicate structural change only from 1997:Q1. Specifically, the F-statistic for this test was 74.52, the Log likelihood ratio 61.52 and the Wald statistics 74.51. Thus the null hypothesis of no breaks at this specific breakpoint can be rejected at 1% level, confirming Hamilton's hypothesis.[12] On the contrary, the null hypothesis of no breaks at this specific breakpoint cannot be rejected at 10% level for the other points tested (results available upon request).

4.2.2 Cointegration

Saikkonen and Lütkepohl (2000) show that it is possible to account for structural breaks in testing for cointegration by developing a maximum likelihood approach allows for possible shifts in the mean of the data (see appendix B). Consequently, we test cointegration amongst the variables $\log(OOP_t)$, $\log(NOOP_t)$, $\log(GGDP_t)$ and $\log(OP_t)$ using Saikkonen and Lütkepohl (2000) in a VAR framework. Results are presented in Tables 3 and 4 for both trace statistics and maximum eigenvalue statistics. No evidence of cointegration vectors among the variables $\log(OOP_t)$, $\log(NOOP_t)$, $\log(GGDP_t)$ and $\log(OP_t)$ is found.

[12] For details about Chow test, please see Chow (1960) and Andrews and Fair (1988).

5. Empirical results

Results from estimating the SVAR model in equations (1)-(3) will now be reported. By way of introduction, preliminary causality results for growth in OPEC and non-OPEC oil production for both "the age of OPEC" and "a new industrial age" are reported. In Table 5 it is found that during "the age of OPEC", growth in non-OPEC oil production Granger causes growth in OPEC oil production while growth in OPEC oil production does not Grange cause growth in non-OPEC oil production. During the new industrial age, growth in OPEC oil production does not Granger cause growth in non-OPEC oil production and growth in non-OPEC oil production does not Granger cause growth in OPEC oil production.

5.1. Impulse response function results (full sample model)

Figure 4 shows the responses of the variables in the SVAR to one-standard deviation structural innovations. The SVAR is estimated with data over 1974:Q1-2012:Q4. The dashed lines represent a one standard error confidence band around the estimates of the coefficients of the impulse response functions.[13] In the first column are shown the responses of growth in OPEC oil production, non-OPEC oil production, global GDP, and real price of oil to a structural (positive) innovation in growth in OPEC oil production. The effect of an unanticipated supply increase on growth in OPEC oil production is very persistent and highly significant. An unanticipated innovation in growth in OPEC oil production does not cause a significant effect on growth in global real GDP. An unanticipated positive innovation in growth in OPEC oil production causes a significant negative effect on the growth in real price of oil that persists in magnitude from the second quarter onwards.

In the second column of Figure 4 a positive innovation in growth in non-OPEC oil production has a statistically significant negative effect on growth in OPEC oil production that is very persistent. The implication is that OPEC restricts growth in production when

[13] The confidence bands are obtained using Monte Carlo integration as described by Sims (1980), where 5000 draws were used from the asymptotic distribution of the VAR coefficient.

there is an unexpected increase in growth in non-OPEC oil production. A positive innovation in growth in non-OPEC oil production on growth in non-OPEC oil production is very persistent and highly significant. A positive shock to growth in non-OPEC oil production causes a negative effect on the growth in real price of oil that is only statistically significant in the first quarter, after which the absolute magnitude of the effect declines and becomes insignificant.

The effects of positive shocks to growth in global GDP are considered in the third column of Figure 4. A positive shock growth in global GDP has a positive effect on growth in OPEC oil production that is statistically significant and that grows over time. Eventually growth in OPEC oil production responds by a large amount to the growth in global GDP shock. A positive growth in global GDP shock has a negative effect on growth in OPEC oil production that is not statistically significant (except in the third quarter). An unanticipated expansion in growth in global GDP results in a significant increase in growth in real oil price that builds up over the first three years and then is sustained at a large value.[14]

The effects of an oil market–specific demand shock are shown in column 4 of Figure 4. In the last row of column 4 a positive shock in oil market-specific demand shock has a large and persistent positive effect on the growth in real price of oil. This effect is highly statistically significant and rises in magnitude over the first three quarters. A positive oil market-specific demand shock is not associated with significant effects on growth in OPEC oil production, but is linked with significant increases in growth in non-OPEC oil production. A positive oil market-specific demand shock has a negative effect on growth in global GDP. The effect is statistically significant in the third quarter.

5.2. Impulse response function results for 1974:Q1-1996:Q4 and 1997:Q1-2012:Q4

[14] This result is similar to the finding by Kilian (2009) for 1973:1-2007:12 with monthly data in that a positive shock to global real aggregate demand for all industrial commodities resulted in a significant oil price increase that builds up over the first year and then is sustained at a large value.

In Figures 5 and 6 the responses of the variables in the SVAR to one-standard deviation structural innovations are shown when the SVAR is estimated with data over 1974:Q1-1996:Q4 and 1997:Q1-2012:Q4, respectively. The objective is to determine whether there has been a change in the responses of growth in OPEC and in non-OPEC oil production to each other and to growth in global GDP and to change in real oil price over time.

5.2.1. "The age of OPEC"

In Figure 5 impulse response function results are presented for the SVAR estimated 1974:Q1-1996:Q4. Overall, the impulse response results for the "age of OPEC" period are very similar to those for the overall sample in Figure 4. The one noticeable difference is that an unanticipated increase global GDP growth does not result in a significant effect on the change in real oil price for the model estimated over 1974:Q1-1996:Q4. Conversely a negative shock to global GDP does not result in a significant change in real oil price over this period.

5.2.2. "A new industrial age"

In Figure 6 impulse response function results are presented for the SVAR estimated over 1997:Q1-2012:Q4. The impulse response results for the "A new industrial age" include several changes compared to the results for overall sample in Figure 4. First, OPEC oil production growth no longer declines with positive shocks to growth in non-OPEC oil production. Second, OPEC oil production growth responses to positive innovations in global GDP growth are still significant, but are now much smaller over 1997:Q1-2012:Q4 than for the full sample or for the 1974:Q1-1996:Q4 period. Third, OPEC oil production growth now rises significantly with an increase in the change in oil prices (this is consistent with Hamilton (2009)). Fourth, over 1997:Q1-2012:Q4, change in real oil price continues to respond negatively to positive shocks to OPEC oil production growth (the effect is smaller and less significant than previously), but change in real oil price now also responds negatively and significantly to positive shocks to non-OPEC oil production growth. Fifth, over 1997:Q1-2012:Q4 the negative effect on change in real oil price of positive shocks to non-OPEC oil production growth is larger in absolute value than that of positive shocks to OPEC oil production growth. Sixth, non-OPEC oil production growth does not respond significantly to positive innovations in change in real oil price over 1997:Q1-2012:Q4.

5.3. Historical decomposition of real oil price

The cumulative contribution to the change in real price of oil of the structural shocks to growth in OPEC oil production and growth in non-OPEC oil production are reported in Figure 7a, from estimating the SVAR model in equations (1)-(3). The cumulative contributions of structural shocks to real oil price in Figure 7a are three year annual averages to improve the readability of the plot. In Figure 7a the cumulative contribution to real oil price of shocks to growth in non-OPEC oil production are comparatively small compared to the cumulative contribution to real oil price of shocks to growth in OPEC oil production.

A striking observation in Figure 7a is that from 1981 to 1986 growth in OPEC oil production makes the greatest cumulative contribution to real oil price over the whole period. This is because OPEC oil production fell from levels over 25 million barrels a day in monthly data for several years leading up to August 1980, to levels barely above 13 million barrels a day in monthly data from February 1983 to June 1985.[15] This huge reduction in OPEC oil production in the early 1980s, due to revolution/wars and decisions on oil production by Saudi Arabia, means that even though real oil price fell over the period, the fall would have been even greater if the fall in OPEC production had not occurred. This is reflected in large positive cumulative contribution to real oil price by shocks to growth in OPEC oil production in the early 1980s.

[15] In monthly data, OPEC oil production peaked in December 1976 at 33.1 million barrels a day. Production then never fell below 25 million barrels a day in monthly data up August 1980. Production was 30.4 million barrels a day in July 1979.

During the late 1980s and early 1990s OPEC oil production increases and non-OPEC oil production falls.[16] This is reflected in Figure 7a by a positive cumulative contribution to real oil price of shocks by growth in non-OPEC oil production and negative cumulative contribution to real oil price of shocks by growth in OPEC oil production over 1987 to 1991. Thereafter, the largest cumulative contributions to real oil price of shocks from growth in oil production are by growth in OPEC oil production over 1999-2002 (positive), 2005 (negative) and 2009-2012 (negative). [17]

The cumulative contributions to growth in OPEC oil production and to growth in non-OPEC oil production of shocks to the real price are reported in Figure 7b. In Figure 7b the cumulative contribution to growth in non-OPEC oil production of shocks to the real price are small. The cumulative contribution to growth in OPEC oil production of real price shocks is large in Figure 7b. Increases real oil price are associated with positive cumulative contribution to growth in OPEC oil production over 1977-1981, 1989-1990, 1997, 2001-2002, 2005-2008 and 2012. Decreases real oil price are associated with negative cumulative contribution to growth in OPEC oil production over 1983-1988, 1994, 1998, 2003 and 2009. Despite dramatic increases in the real price of oil over the 2002 to 2008 period, growth in non-OPEC oil production didn't respond in the short-run.[18]

The cumulative contributions to growth in OPEC oil production of shocks to growth in non-OPEC oil production and the reverse are reported in Figure 7c. A conspicuous result in Figure 7c is that there is a large cumulative contribution to growth in OPEC oil production of shocks to growth in non-OPEC oil production, but that the reverse does not hold. It is also

[16] In monthly data, non-OPEC oil production peaked (up until that point) in May 1988 at 39.6 million barrels a day. Production then fell for several years, with a local minimum of 35.0 million barrels a day in September 1993. This fall in non-OPEC oil production is driven by the dramatic decline in Russian production oil production.

[17] Over 1998 to mid-2003 OPEC oil production goes up and down around the 28 million barrels a day mark. OPEC oil production has local maxima in September 2005, July 2008 and April 2012, and a local minimum in February 2007.

[18] From 1974 to 1978, the world crude oil price is in a period of moderate decline. During this period OPEC production was relatively flat near 30 million barrels per day. Production was 30.4 million barrels a day in July 1979.

apparent that the effect of shocks to growth in non-OPEC oil production on cumulative growth in OPEC oil production is larger in the first half of the sample than in the second half of the sample. Non-OPEC oil production is generally rising from 1974 to the mid-1980s, is largely flat running in the region of 38 million barrels a day from 1984 to 1988, after which point production falls until late-1993 (a local minimum of 35.0 million barrels a day in September 1993 monthly data). The 1984 to 1993 period of flat and falling non-OPEC oil production is associated with positive cumulative growth in OPEC oil production. From late 1993 non-OPEC production generally gradually rose to 42.6 million barrels a day in May 2005, after which point non-OPEC production flat lined with fluctuations usually above 40.0 above million barrels a day.

In summary, in terms of cumulative effects of structural shocks, growth in non-OPEC production influences growth in OPEC production, real oil price influences growth in OPEC production and growth in OPEC production influences real oil price. The cumulative effect of structural shocks to growth in OPEC production and real oil price on growth in non-OPEC production is relatively small.

5.4. Variance decomposition analysis

5.4.1. Decomposition of OPEC and non-OPEC production,

The forecast error variance decompositions (FEVDs) of OPEC and non-OPEC production are reported in Table 6 from the estimation of the structural VAR model in Equations (1), (2) and (3). Decompositions of the forecast error variance provide insight on the percent contribution of structural shocks in the global oil market on growth in OPEC and non-OPEC production. FEVDs are reported for 1974:Q1-1996:Q4 and 1997:Q1-2012:Q4.

At one year horizon, oil market-specific demand shock forecasts 2.08% of variation in growth in OPEC oil production during 1974:Q1-1996:Q4 and a statistically significant 21.18% during 1997:Q1-2012:Q4. Growth in global GDP shocks project 6.01% of variation in growth in OPEC oil production during 1974:Q1-1996:Q4 and only 5.72% during 1997:Q1-2012:Q4.

Growth in non-OPEC oil production forecasts a statistically significant 12.92% of variation in growth in OPEC oil production during 1974:Q1-1996:Q4 and only 0.22% during 1997:Q1-2012:Q4. The forecast error variance decompositions results confirm that growth in OPEC oil production is much more influenced by change in real oil price during 1997:Q1-2012:Q4 than during 1974:Q1-1996:Q4, and more responsive to growth in non-OPEC production during 1974:Q1-1996:Q4 than during 1997:Q1-2012:Q4.

5.4.2. Contributions to global GDP and oil prices: "The age of OPEC" and "A new industrial age"

Table 7 reports the forecast error variance decompositions of growth global GDP and change in oil prices in 1974:Q1-1996:Q4 and 1997:Q1-2012:Q4. During 1997:Q1-2012:Q4, growth OPEC oil production and in non-OPEC oil production forecast 6.02% and 6.54% of the variation in growth in oil price at the one year horizon, respectively. Over 1974:Q1-1996:Q4, the ability of growth in OPEC oil production and in non-OPEC oil production to forecast oil price captured by oil market-specific demand is much smaller. During 1997:Q1-2012:Q4 at the one year horizon growth in non-OPEC oil production forecasts 3.91% of the variation in growth in global GDP, and during 1974:Q1-1996:Q4 OPEC oil production forecast 2.56% of the variation in growth in global GDP.

6. Robustness analysis and alternative specifications

In this section, we examine the robustness of our model to: different identifications strategies, different measure of oil prices and lag structure in the VAR model.

6.1. Identification

The decomposition of oil production in OPEC and non-OPEC production has been studied in a macroeconomic model in equation (3) that follows Kilian's (2009) VAR analysis of the determinants of real oil price, but with growth in oil production differentiated into growth in OPEC oil production and growth in non-OPEC oil production. In equation (3) growth in OPEC oil production and growth non-OPEC oil production do not depend contemporaneously on each other. We now explore two of alternative contemporaneous restrictions for these variables. The alternative contemporaneous restrictions (analysed in turn in conjunction with equations (1) and (2)) are presented in equations (4) and (5):

$$B_o X_t = \begin{bmatrix} 1 & -b_{12} & 0 & 0 \\ 0 & 1 & 0 & 0 \\ -b_{31} & -b_{32} & 1 & 0 \\ -b_{41} & -b_{42} & -b_{43} & 1 \end{bmatrix} \begin{bmatrix} \Delta\log(OOP_t) \\ \Delta\log(NOOP_t) \\ \Delta\log(GGDP_t) \\ \Delta\log(OP_t) \end{bmatrix} \tag{4}$$

$$B_o X_t = \begin{bmatrix} 1 & 0 & 0 & 0 \\ -b_{21} & 1 & 0 & 0 \\ -b_{31} & -b_{32} & 1 & 0 \\ -b_{41} & -b_{42} & -b_{43} & 1 \end{bmatrix} \begin{bmatrix} \Delta\log(OOP_t) \\ \Delta\log(NOOP_t) \\ \Delta\log(GGDP_t) \\ \Delta\log(OP_t) \end{bmatrix} \tag{5}$$

In equation (4) we allow growth in OPEC oil production to depend contemporaneously on growth in non-OPEC oil production, and in equation (5) growth in non-OPEC oil production depends contemporaneously on growth in OPEC oil production. Both new specifications yield similar results to those results obtained in Figures 4, 5 and 6.

6.2. Nominal global GDP and nominal oil prices

We also specified the model using nominal global GDP and nominal oil prices. We observe that general results hold in terms of sign and statistical significance, while responses are somewhat larger. We also note some difference in the variance decomposition results for the nominal model. These results are reported in Tables 8 and 9. The main differences between the real and nominal can be seen by comparing Table 6 with Table 8 and Table 9 with 6.

The forecast error variance decompositions of growth in OPEC and non-OPEC production with nominal variables are reported in Table 9. A main difference in results is that greater fractions of growth in OPEC oil production are predicted by growth in nominal GDP than by growth in real GDP in both periods (and especially during 1997:Q1-2012:Q4 when the fraction predicted by growth in nominal GDP is 19.94%). However, the finding earlier that growth in non-OPEC production forecasts growth in OPEC production during 1974:Q1-1996:Q4 is robust to this change in model specification.

6.3. Lags structures in the SVAR model

We check the sensitivity of our results to the lag selection strategy. The Akaike Information Criterion (AIC) is also widely used in time series analysis when a longer structure is preferred; in our model this criterion selected two lags (or six months). We re-estimated the model with two lags and we find that results are very similar to those already estimated, although the error bands in the impulse response function slightly increase.

6.4. The Global and Asian Financial Crises

The Global Financial Crisis was associated with dramatic changes in commodity prices and the behaviour of key macroeconomic variables. Perri and Quadrini (2011), for example document unprecedented business cycle synchronization among the developed countries during the last two quarters of 2008. The authors argue that this is due to the fact that in the last two quarters of 2008, GDP declined by a substantial amount in all G7 countries. To correspond to this analysis, we introduce a dummy variable that takes the value 1 in Q3 and Q4 2008 and 0 otherwise into equations (1) to (3). Results are essentially unchanged from those in Figures 5 and 6 from following this strategy for dealing with the global financial crisis (and are available from the authors).

Some authors have attributed a structural break in the oil market to the Asian Financial Crisis. Arouri et al. (2012) argue that as consequence of the Asian economic and financial crisis a possible structural break occurred in 1997 in the oil market. Maslyuk and Smyth (2008) also claim that the most significant events around the period 1997-1998 that could disrupt the oil market have been the Asian financial crisis and Russian default. These factors may indeed reinforce the finding of a break between the two periods identified by Hamilton (2013) as "The age of OPEC", 1973-1996, and "A new industrial age", 1997-present. Radelet and Sachs (1998) identify recognition of the start of the Asian Financial Crisis with the sharp devaluation of the Thai Baht on 2 July 1997, but note that underlying problems predate this event. As observed earlier, we identify the structural break in the oil market as occurring in 1996Q4 in line with the Perron (1997) test result.

7. Predicting growth in OPEC and non-OPEC oil production and real oil prices

In this section we use we use recent developed econometric techniques to estimate whether or not it is possible to infer the predictability of growth in OPEC oil production, non-OPEC oil production and real oil prices using the variables in the previous sections for the periods of interest 1974:Q1-1996:Q4 and 1997:Q1-2012:Q4. This will provide a further test of the robustness of the results obtained from SVAR analysis. A potential problem with prediction of OPEC or of non-OPEC oil production is that innovations in the prediction variables are correlated with the variables being predicted. An additional potential problem is that growth in oil production is heteroskedastic, making it challenging to assess the value of information coming from the predictors. For these reasons we employ an OLS bias-adjusted heteroskedasticity consistent standard errors and covariance technique due to Lewellen (2004), Westerlund and Narayan (2012) and Narayan et al. (2014) to predict OPEC and non-OPEC oil production. Fan and Yao (2003) provide a detailed discussion of techniques for forecasting when innovations in the prediction variables are correlated with the variables being predicted and there is heteroskedasticity.

7.1. Econometric framework

Consider the following extension of Lewellen (2004) applied to OPEC oil production:[19]

$$\Delta\log(OOP_{t+h}) = \alpha + \beta\Delta\log(NOOP)_t + \gamma\Delta\log(GGDP_t) + \tau\Delta\log(OP_t) + \epsilon_{t+h}\ . \quad (6)$$

Equation (6) states that growth in OPEC oil production h periods ahead can be predicted by contemporaneous growth in non-OPEC oil production, growth in global GDP and growth in oil prices. In this model we are testing the null hypothesis that either $\beta = 0, \gamma = 0$ or $\tau = 0$, to test whatever or not growth in non-OPEC oil production, growth in global GDP and or growth in oil prices, respectively, have any significant predictive power for growth in OOP_{t+h}. A possible shortcoming of this predicting regression is that if growth in $NOOP_t$, in $GGDP_t$ or in OP_t are endogenous then their coefficients will be biased. Now, consider the following version of autoregressive processes for growth in $NOOP_t$, growth in $GGDP_t$, and growth in OP_t:

$$\Delta\log(NOOP_{t+h}) = \mu_{noop}(1-\rho) + \rho\Delta\log(NOOP_t) + \varepsilon_{noop,t+h}, \quad (7)$$

$$\Delta\log(GGDP_{t+h}) = \mu_{ggdp}(1-\rho) + \rho\Delta\log(GGDP)_t + \varepsilon_{ggdp,t+h}, \quad (8)$$

$$\Delta\log(OP_{t+h}) = \mu_{op}(1-\rho) + \rho\Delta\log(OP_t) + \varepsilon_{op,t+h}, \quad (9)$$

where: $|\rho| \leq 1$. To avoid the endogeneity problem that biases estimates of the coefficients β, γ and τ, Lewellen (2004) proposes a regression to capture the possible endogenous effect by assuming the following relationship:

$$\epsilon_t = \beta_1\varepsilon_{noop,t} + \gamma_1\varepsilon_{ggdp,t} + \tau_1\varepsilon_{op,t} + \sigma_{noop,t} + \sigma_{ggdp,t} + \sigma_{op,t}\ , \quad (10)$$

where ϵ_t and $\varepsilon_{noop,t}, \varepsilon_{ggdp,t}, \varepsilon_{op,t}$ have a mean of zero and ϵ_t is not correlated with either $\varepsilon_{noop,t}, \varepsilon_{ggdp,t}$ or $\varepsilon_{op,t}$. An extended version of Lewellen's (2004) methodology can be inferred by making equation (6) conditional to equation (10). The equation can be writing as:

[19] Note that all variables are only first difference stationary and therefore changes in logs transformation have been applied.

$$\Delta\log(OOP_{t+h}) = \alpha + \beta\Delta\log(NOOP_t) + \beta_1\Delta log(NOOP_{t+h} - \rho NOOP_{t+h-1}) + \gamma\Delta\log(GGDP_t) + \gamma_1\Delta log(GGDP_{t+h} - \rho GGDP_{t+h-1}) + \tau\Delta\log(OP_t) + \tau_1\Delta log(OP_{t+h} - \rho OP_{t+h-1}) + \sigma_{t+h} \quad (11)$$

Because ρ is unknown, equation (11) cannot be estimated. To solve this issue Lewellen (2004) assumes that the unknown ρ=0.999.[20] Given that the value of ρ can be taken as a given (by assumption) equation (11) can be estimated as:

$$\Delta\log(OOP_{t+h}) = \alpha + \beta_0\Delta\log(NOOP_t) + \beta_1\Delta log(NOOP_{t+h} - \rho_0 NOOP_{t+h-1}) + \gamma_0\Delta\log(GGDP_t) + \gamma_1\Delta log(GGDP_{t+h} - \rho_0 GGDP_{t+h-1}) + \tau_0\Delta\log(OP_t) + \tau_1\Delta log(OP_{t+h} - \rho_0 OP_{t+h-1}) + \sigma_{t+h} \quad (12)$$

In equation (12) we have $\beta_0 = \beta - \beta_1(\rho - \rho_0), \gamma_0 = \gamma - \gamma_1(\rho - \rho_0), \tau_0 = \tau - \tau_1(\rho - \rho_0)$ and α is a constant. Accordingly, $\beta_0, \gamma_0\ and\ \tau_0$ are the bias-adjusted predictor coefficients of growth in $NOOP_t, GGDP_t\ or\ OP_t$, respectively. Making equation (6) conditional to equation (10) the correlations among ϵ_t and $\varepsilon_{noop,t,}$ $\varepsilon_{ggdp,t}$ and $\varepsilon_{op,t}$ can be accounted for.

Analogues to equation (12), equations (13) and (14) can be used to estimate the predictability power of growth OPEC oil production, growth in global GDP and growth in real oil price on growth in non-OPEC oil production, and the predictability power of growth in OPEC oil production, growth non-OPEC oil production and growth in global GDP on growth in real oil prices. The prediction equations for growth in non-OPEC oil production and growth in real oil price are given by

$$\Delta\log(NOOP_{t+h}) = \upsilon + \delta_0\Delta\log(OOP_t) + \delta_1\Delta log(OOP_{t+h} - \rho_0 OOP_{t+h-1}) + \vartheta_0\Delta\log(GGDP_t) + \vartheta_1\Delta log(GGDP_{t+h} - \rho_0 GGDP_{t+h-1}) + \varphi_0\Delta\log(OP_t) + \varphi_1\Delta log(OP_{t+h} - \rho_0 OP_{t+h-1}) + \sigma_{t+h} \quad (13)$$

[20] Note that Westerlund and Narayan (2012) and Narayan et al. (2014) provide an alternative assumption for ρ, that $\rho = 1 + \frac{c}{T}$, where $c \leq 0$ is a drift parameter that measures the degree of persistency in the predictor variable and T is the number of observations.

and

$$\Delta\log(OP_{t+h}) = \zeta + \lambda_0\Delta\log(NOOP_t) + \lambda_1\Delta log(NOOP_{t+h} - \rho_0 NOOP_{t+h-1}) + \eta_0\Delta\log(GGDP_t) + \eta_1\Delta log(GGDP_{t+h} - \rho_0 GGDP_{t+h-1}) + \kappa_0\Delta\log(OOP_t) + \kappa_1\Delta log(OOP_{t+h} - \rho_0 OOP_{t+h-1}) + \sigma_{t+h} \quad (14)$$

7.2. Results

In Tables 10, 11 and 12, the bias-adjusted OLS heteroskedasticity consistent standard error results are reported from estimating equations (12) ,(13) and (14), respectively. In the Tables results are presented for 1974:Q1 to 1996:Q4 in columns 1, 3 and 5 with different setting values of ρ. In columns 2, 4 and 6 the same estimation is presented, but for the period 1997:Q1 to 2012:Q4. In columns 1 and 2 we follow Lewellen (2004) in setting $\rho = 0.999$. We also report results following Westerlund and Narayan (2012) and Narayan et al. (2014) in setting $= 1 + \frac{c}{T}$. In columns 3 and 4, $c = 0$, and in columns 5 and 7, $c = -2$.

7.2.1. Predicting growth in OPEC oil production

In Table 10, we report results for the estimation of growth in OPEC oil production in equation (12). During the period 1974:Q1 to 1996:Q4, estimates of the coefficient β_0 are statistically significant from zero at the 5% level for all three assumptions for ρ. The point estimates suggest that a 1% point increase in growth in non-OPEC oil production is associated with a reduction of about 1.6% points in growth in OPEC oil production. Given that during 1974:Q1 to 1996:Q4 non-OPEC oil production is about 50% greater than OPEC oil production, the point estimate of β_0 suggests a fall in production by OPEC (compared to where it would have been) that is approximately equal to the increase in production by non-OPEC (compared to where it would have been). For the period 1996:Q1 to 2012:Q4, growth in OPEC oil production does not significantly respond to growth in non-OPEC oil production.

During the period 1974:Q1 to 1996:Q4, an increase in growth in global real GDP has a statistically significant effect at 1% level on growth in OPEC oil production. From 1996:Q1 to 2012:Q4, growth in OPEC oil production responds significantly to increase in growth in global real GDP at the 5% or 10% levels, depending on the assumption made about ρ. However, there is a substantial reduction in magnitude of the estimated effect of growth in global real GDP on growth in OPEC oil production for the period 1996:Q1 to 2012:Q4 compared to the period 1974:Q1 to 1996:Q4.

For the period 1996:Q1 to 2012:Q4, growth in OPEC oil production responds significantly to growth in real oil prices, but does not do so during 1974:Q1 to 1996:Q4. Estimates of τ_0 indicate that a 1% point rise in growth real oil price leads to an increase in growth in OPEC oil production of around 0.05% points during 1996:Q1 to 2012:Q4. These forecast results confirm that the findings for the early period, 1974:Q1 to 1996:Q4, that growth in OPEC oil production responds to growth in non-OPEC oil production but not to growth in real oil price, are reversed for the later period 1996:Q1 to 2012:Q4.

7.2.2. Predicting growth in non-OPEC oil production

We now turn to the estimation of equation (13), where growth in non-OPEC oil production is the dependant variable. In Table 11, the only adjusted-bias predictor coefficient which is statistically significant is φ_0, indicating that a 1% point increase in real oil prices is associated with about a 0.02% point rise in growth in non-OPEC oil production. For the period 1996:Q1 to 2012:Q4, no predictor coefficients are statistically significant at conventional levels. Dées et al. (2007) note that non-OPEC oil production is limited by geological and institutional conditions, with the implication that growth in non-OPEC oil production is not responsive in the short-run to the variables growth in global real GDP, growth in OPEC oil production and growth in real oil price.

7.2.3. Predicting growth in real oil price

In Table 12, we report results for the estimation on equation (14), where growth in real oil price is predicted. Consistent, with Hamilton (2011)'s view, there are remarkable changes between the two periods in terms of the variables that have predictive power for growth in real oil price. During the period 1974:Q1 to 1996:Q4 only growth in OPEC oil production is statistically significant in explaining growth in real oil prices (indicated by statistical significance of the coefficient κ_0). For the period 1996:Q1 to 2012:Q4 only growth in real global GDP is statistically significant in explaining real oil prices (reflected by statistical significance of η_0).

8. Discussion and Conclusion

Hamilton identifies 1973 to 1996 as "the age of OPEC" and 1997 to the present as "a new industrial age." The impulse response results for the "A new industrial age" suggest a number of changes compared to the results for "the age of OPEC". First, growth in OPEC oil production decreases significantly with positive shocks to growth in non-OPEC oil production in the earlier period, but does not do so in the "new industrial age". In the "new industrial age" growth in OPEC oil production rises significantly with an increase in oil prices, unlike during "the age of OPEC" period. Growth in OPEC oil production response to positive innovation in growth in global GDP is statistically significant but much smaller over 1997:Q1-2012:Q4 than over the 1974:Q1-1996:Q4 period. During 1997:Q1-2012:Q4 the negative effect on change in real oil price of positive shocks to growth in non-OPEC oil production is larger in absolute value than that of positive shocks to growth in OPEC oil production.

Structural shocks to growth in non-OPEC oil production make a large cumulative contribution to growth in OPEC oil production. The reverse does not hold. The effect of shocks to growth in non-OPEC oil production on cumulative growth in OPEC oil production is larger over 1974-1996 than over 1997-2012. Shocks to growth in OPEC oil production make large cumulative contribution to change in real oil price and vice versa. Shocks to growth in non-OPEC oil production do not make a large cumulative contribution to change in real oil price and vice versa.

Results are consistent with important changes in the global oil market. Strong global demand has maintained real oil price at high levels over most of 1997:Q1-2012:Q4. There has been a major change in the behaviour of OPEC from reacting to non-OPEC oil production from 1974 to 1996 and to responding to higher real oil price from 1997 to 2012. Consistent with results from the SVAR analysis, use of a new econometric prediction technique suggests that during the "the age of OPEC", growth in OPEC oil production can be predicted by growth in non-OPEC oil production and growth in global economic growth, and that during the "new industrial age" period, growth in OPEC oil production can be predicted by change in real oil prices and growth in global GDP. These finding suggest a more market-oriented oil production strategy by OPEC since 1997.

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Appendix A

Perron (1997) extends the dickey-fuller's unit root test by using the following set of regression equations:

$$y_t = \mu + \beta t + \theta DU_t + \delta D(T_b)_t + \alpha y_{t-1} + \sum_{t=1}^{k} c_i \Delta y_{t-1} + \varepsilon_t \qquad \text{(A.1)}$$

$$y_t = \mu + \beta t + \theta DU_t + \gamma DT_t + \delta D(T_b)_t + \alpha y_{t-1} + \sum_{t=1}^{k} c_i \Delta y_{t-1} + \varepsilon_t \qquad \text{(A.2)}$$

Where $DU_t = (t > T_b)$ and $DT_b = 1(t = T_b + 1)$ being the indicator function, $DT_t = 1(t > T_b)t$. In equation (A.2), both a change in the intercept and slope are allowed at time T_b. The test is performed using the t-statistics for the null hypothesis that $\alpha = 1$ in (A.2).

$$DT_t^* = 1(t > T_b)(t - T_b) \qquad \text{(A.3)}$$

$$y_t = \mu + \beta t + \gamma DT_t^* + \hat{y}_t \qquad \text{(A.4)}$$

$$\hat{y}_t = \alpha \hat{y}_{t-1} + \sum_{t=1}^{k} c_i \Delta \hat{y}_{t-1} + \varepsilon_t \qquad \text{(A.5)}$$

Where $t_{\hat{\alpha}}(i, T_b, k)(i = 1,2,3)$, the t-statistics for testing $\alpha = 1$ under model I with break date T_b and truncation lag parameter k (using regression (A.1), (A.2) and (A.4) for $= 1,2,3$, respectively, where T_b and k are treated as unknown).

Under (A.4), a change in the slope is allowed but both segments of the trend function are joined at the time break. Following two-step procedure, the series is detrended using the regression (A.3). The test is then carried out using the t-statistics for $\alpha = 1$ in regression (A.5). Finally, T_b is selected endogenously by choosing the statistics as $t_\alpha^*(i) = Min_{T_b \epsilon (k+1,T)} t_{\hat{\alpha}}(i, T_{b,} k)(i = 1,2,3)$.

Appendix B

Following Saikkonen and Lütkepohl (2000) assume that an observed n-dimensional time series $y_t = (y_{1t}, \ldots, y_{nt})$ where $t = 1, \ldots, T)$ is generating by:

$$y_t = \beta_0 + \beta_1 t + \alpha_0 Dt_{0t} + \alpha_1 D_{1t} + x_t \qquad \text{(B.1)}$$

$$d_{0t} = \begin{cases} 1, & t = T_0 \\ 0, & t \neq T_0 \end{cases} \quad \text{(B.2)}$$

$$d_{1t} = \begin{cases} 0, & t < T_1 \\ 1, & t \geq T_1 \end{cases} \quad \text{(B.3)}$$

In (B.1) β_i and α_i $(i = 0, 1)$ are unknown $(n\, x\, 1)$ parameter vectors, D_{0t} is an impulse dummy variable and D_{1t} is a shift dummy that account for the presence of structural breaks. Following this procedure, Saikkonen and Lütkepohl (2000) shown that the VAR Johansen system of cointegration vector can be used to test for cointegration in presence of a structural break (for more detail see for example Saikkonen and Lütkepohl (2000)). For this test we use 4 lags (1 year) which coincides with lags selection of the Schwartz Bayesian information criterion and intercept and trend following Saikkonen and Lütkepohl (2000).

Table 1: Test for unit roots 1974:Q1-2012:Q4

Level	ADF	KPSS	First difference	ADF	KPSS
log (OOP_t)	-1.35	0.64**	Δlog (OOP_t)	-10.73***	0.24
log ($NOOP_t$)	-2.52	1.14***	Δlog ($NOOP_t$)	3.13**	0.43
log ($GGDP_t$)	-1.47	1.54***	Δlog ($GGDP_t$)	-6.53***	0.34
log (OP_t)	-0.78	0.80***	Δlog (OP_t)	-10.14	0.11

Notes: The null hypothesis for the ADF test is the variable has a unit root and the null hypothesis for the KPSS test is the variable is stationary. The first difference of the series is indicated by Δ.The lag selection criteria for the ADF is based on Schwarz information Criteria (SIC) and for the KPSS is the Newey-West Bandwidth. ***, **, * indicates rejection of the null hypothesis at 1%, 5% and 10%, levels of significance.

Table 2: Perron (1997)'s unit root test with structural break

Null Hypothesis: log of real oil prices has a unit root with a structural break in intercept and trend	
Perron 1997 unit root test	-3.58
1% critical value	-6.32
5% critical value	-5.59
10% critical value	-5.29

Table 3 Saikkonen and Lütkepohl cointegration tests (with breaks) 1974:Q1-2012:Q4

Cointegration Rank Test (Trace)

Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob.**
None	0.150	46.525	47.856	0.066
At most 1	0.096	21.877	29.797	0.305
At most 2	0.030	6.627	15.497	0.621
At most 3	0.012	1.931	3.841	0.164

Table 4 Saikkonen and Lütkepohl cointegration tests (with breaks) 1974:Q1-2012:Q4

Cointegration Rank Test (Maximum Eigenvalue))

Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob.**
None	0.150	24.647	27.584	0.113
At most 1	0.096	15.250	21.131	0.271
At most 2	0.030	4.695	14.264	0.779
At most 3	0.012	1.931	3.841	0.164

Trace test indicates no cointegration at the 0.05 level
* denotes rejection of the hypothesis at the 0.05 level
**MacKinnon-Haug-Michelis (1999) p-values

Table 5: Causality test of growth in OPEC and non-OPEC oil production

Null Hypothesis: x does not Granger cause y

	The Age of OPEC (1974-1996)		The new industrial age (1997-2012)	
Granger test/Lags	1	4	1	4
Δlog (OOP_t) does not granger cause Δlog ($NOOP_t$)	0.01	0.52	0.031	2.05
Δlog ($NOOP_t$) does not granger cause Δlog (OOP_t)	15.22***	2.76**	0.001	1.30

Notes: Variables are in logs. *** Indicates rejection of the null hypothesis at 1% level of significance.

Table 6: Variance decomposition of growth in OPEC and non-OPEC oil production

OPEC oil production									
Age of OPEC (1974-1996)					New industrial age (1997-2012)				
Quarters	OPEC	Non-OPEC	Global GDP	Oil prices	Quarters	OPEC	Non-OPEC	Global GDP	Oil prices
2	81.60	13.40	4.11	0.90	2	81.21	0.07	1.17	17.53
4	78.94	12.96	6.01	2.08	4	72.86	0.22	5.72	21.18
8	78.72	12.92	6.26	2.08	8	72.71	0.23	5.93	21.13

Non-OPEC oil production									
Age of OPEC (1973-1996)					New industrial age (1997-2012)				
Quarters	OPEC	Non-OPEC	Global GDP	Oil prices	Quarters	OPEC	Non-OPEC	Global GDP	Oil prices
2	7.10	86.81	0.10	5.97	2	0.39	97.09	2.23	0.27
4	7.04	85.44	1.42	6.08	4	0.42	93.92	2.26	0.40
8	7.03	85.12	1.76	6.07	8	0.42	96.90	2.27	0.40

Table 7: Contribution of growth in OPEC and non-OPEC oil production after 4 lags (1 year) to growth in global GDP and oil prices

Global GDP					Oil Prices				
	Age of OPEC (1973-1996)		New industrial age (1997-2012)			Age of OPEC (1973-1996)		New industrial age (1997-2012)	
Quarters	OPEC	Non-OPEC	OPEC	Non-OPEC	Quarters	OPEC	Non-OPEC	OPEC	Non-OPEC
2	2.20	0.19	0.00	3.95	2	2.65	0.08	4.83	6.71
4	2.54	0.19	0.11	3.91	4	2.65	0.18	6.02	6.54
8	2.56	0.19	0.11	3.91	8	2.65	0.18	6.02	6.53

Table 8: Variance decomposition of growth in OPEC and non-OPEC oil production (nominal model)

OPEC oil production									
Age of OPEC (1974-1996)					New industrial age (1997-2012)				
Quarters	OPEC	Non-OPEC	Global GDP	Oil prices	Quarters	OPEC	Non-OPEC	Global GDP	Oil prices
2	77.44	13.19	9.36	0.00	2	81.45	0.00	11.14	7.40
4	76.15	13.13	9.82	0.90	4	74.48	0.11	17.50	7.88
8	76.15	13.13	9.82	0.90	8	74.10	0.10	17.94	7.83

Non-OPEC oil production									
Age of OPEC (1973-1996)					New industrial age (1997-2012)				
Quarters	OPEC	Non-OPEC	Global GDP	Oil prices	Quarters	OPEC	Non-OPEC	Global GDP	Oil prices
2	8.54	86.97	0.69	3.80	2	0.25	98.73	0.00	1.01
4	8.50	85.98	1.61	3.90	4	0.30	98.38	0.23	1.04
8	8.49	85.95	1.64	3.90	8	0.31	98.36	0.28	1.04

*Note that in this Table global GDP and oil prices are in nominal terms

Table 9: Contribution of growth in OPEC and non-OPEC oil production after 4 lags (1 year) to growth in global GDP and oil prices (nominal model)

Global nominal GDP					Oil Prices (nominal)				
	Age of OPEC (1973-1996)		New industrial age (1997-2012)			Age of OPEC (1973-1996)		New industrial age (1997-2012)	
Quarters	OPEC	Non-OPEC	OPEC	Non-OPEC	Quarters	OPEC	Non-OPEC	OPEC	Non-OPEC
2	4.63	1.64	1.75	0.46	2	4.47	0.10	4.79	5.68
4	4.83	1.61	3.20	0.40	4	4.46	0.35	5.74	5.60
8	4.84	1.61	3.35	0.39	8	4.45	0.35	5.74	5.61

Table 10: Forecasts of growth in OPEC oil production. Results of OLS bias-adjusted heteroskedasticity consistent standard errors and covariance under different ρ values and $h = 1$.

Dependant variable: growth in OPEC oil production						
	$\rho = 0.999$		$\rho = 1$		$\rho = 1 + \frac{-2}{T}$	
	1974-1996	1997-2012	1974-1996	1997-2012	1974-1996	1997-2012
	Coefficient (SE)	Coefficient (SE)	Coefficient (SE)	Coefficient (SE)	Coefficient (SE)	Coefficient (SE)
α	-0.031*** (0.011)	-0.003 (0.003)	-0.031*** (0.009)	-0.003 (0.003)	-0.031*** (0.009)	-0.003 (0.003)
β_0	-1.652** (0.715)	0.237 (0.377)	-1.651** (0.655)	0.238 (0.426)	-1.678** (0.648)	0.236 (0.421)
β_1	1.372** (0.556)	0.051 (0.250)	1.372*** (0.517)	0.051 (0.280)	1.372*** (0.517)	0.051 (0.282)
γ_0	5.051*** (1.368)	1.023* (0.525)	5.060*** (1.337)	1.023** (0.486)	5.026*** (1.327)	1.018** (0.488)
γ_1	1.697 (1.305)	0.234 (0.654)	1.697 (1.175)	0.234 (0.701)	1.697 (1.175)	0.234 (0.701)
τ_0	-0.074 (0.062)	0.047** (0.023)	-0.075 (0.047)	0.047** (0.021)	-0.073 (0.046)	0.047** (0.021)
τ_1	-0.068 (0.049)	0.003 (0.018)	-0.068 (0.046)	0.003 (0.022)	-0.068 (0.046)	0.003 (0.023)
R^2	0.35	0.28	0.35	0.28	0.35	0.28
$adj. R^2$	0.30	0.21	0.30	0.21	0.30	0.21
F-stat.	7.45	3.77	7.45	3.77	7.45	3.77
n	90	64	90	64	90	64

***, **, *, indicates coefficients are statistically significant at 1%, 5%, and 10%, respectively. Lag order was selected by Schwarz Bayesian Criterion (SBC). Standard errors are given in parenthesis. Results are robust when a dummy variable accounting for the global financial crisis (GFC) is introduced for the third and fourth quarters of 2008, in line with Perri and Quadrini (2011) identification of this crisis.

Table 11: Forecasts of growth in non-OPEC oil production. Results of OLS bias-adjusted heteroskedasticity consistent standard errors and covariance under different ρ values and *h*=1.

Dependant variable: growth in non-OPEC oil production						
	$\rho = 0.999$		$\rho = 1$		$\rho = 1 + \frac{-2}{T}$	
	1974-1996	1997-2012	1974-1996	1997-2012	1974-1996	1997-2012
	Coefficient (SE)	Coefficient (SE)	Coefficient (SE)	Coefficient (SE)	Coefficient (SE)	Coefficient (SE)
υ	0.002 (0.002)	-0.001 (0.001)	0.002 (0.002)	-0.001 (0.001)	0.002 (0.002)	-0.003 (0.003)
δ_0	0.036 (0.025)	0.007 (0.089)	0.036 (0.024)	0.007 (0.089)	0.035 (0.024)	0.236 (0.421)
δ_1	0.027* (0.015)	0.011 (0.079)	0.026* (0.015)	0.011 (0.079)	0.026* (0.015)	0.051 (0.282)
ϑ_0	0.329 (0.280)	0.198 (0.224)	0.329 (0.281)	0.198 (0.229)	0.329 (0.281)	0.197 (0.225)
ϑ_1	0.329 (0.269)	0.074 (0.313)	0.328 (0.268)	0.075 (0.314)	0.328 (0.269)	0.075 (0.315)
φ_0	0.020* (0.012)	0.001 (0.001)	0.021* (0.013)	0.001* (0.000)	0.021* (0.012)	0.001* (0.000)
φ_1	0.000 (0.000)	0.016* (0.008)	0.000 (0.009)	0.017* (0.008)	0.000 (0.000)	0.016* (0.007)
R^2	0.10	0.07	0.10	0.07	0.10	0.07
$adj. R^2$	0.04	0.03	0.04	0.03	0.04	0.03
F-stat.	1.64	0.7	1.64	0.7	1.64	0.7
n	90	64	90	64	90	64

***, **, *, indicates coefficients are statistically significant at 1%, 5%, and 10%, respectively. Lag order was selected by Schwarz Bayesian Criterion (SBC). Standard errors are given in parenthesis. Results are robust when a dummy variable accounting for the global financial crisis (GFC) is introduced for the third and fourth quarters of 2008, in line with Perri and Quadrini (2011) identification of this crisis.

Table 12: Forecasts of real oil price. Results of OLS bias-adjusted heteroskedasticity consistent standard errors and covariance under different ρ values and h = 1.

Dependant variable: growth in real oil price						
	$\rho = 0.999$		$\rho = 1$		$\rho = 1 + \frac{-2}{T}$	
	1974-1996	1997-2012	1974-1996	1997-2012	1974-1996	1997-2012
	Coefficient (SE)	Coefficient (SE)	Coefficient (SE)	Coefficient (SE)	Coefficient (SE)	Coefficient (SE)
ζ	-0.020 (0.028)	-0.020 (0.020)	-0.021 (0.028)	-0.020 (0.030)	-0.020 (0.028)	-0.020 (0.027)
λ_0	-0.528 (1.894)	-2.410 (2.414)	-0.527 (1.894)	-2.413 (2.416)	-0.546 (1.880)	-2.352 (2.390)
λ_1	0.929 (1.181)	-3.074* (1.769)	0.929 (1.180)	-3.074* (1.769)	0.930 (1.181)	-3.074* (1.769)
η_0	3.904 (3.682)	10.342*** (3.970)	3.902 (3.683)	10.357*** (3.950)	3.933 (3.659)	10.008*** (3.890)
η_1	-1.522 (2.340)	17.442*** (6.208)	-1.522 (2.340)	17.442*** (6.208)	-1.521 (2.340)	17.442*** (6.208)
κ_0	-0.688* (0.376)	-0.358 (1.191)	-0.689* (0.377)	-0.358 (1.192)	-0.681* (0.373)	-0.372 (1.175)
κ_1	-0.387 (0.271)	0.748 (1.144)	-0.387 (0.271)	0.747 (1.144)	-0.387 (0.271)	0.748 (1.144)
R^2	0.07	0.36	0.07	0.36	0.07	0.36
F-stat.	1.00	5.44	1.00	5.44	1.00	5.44
n	90	64	90	64	90	64

***, **, *, indicates coefficients are statistically significant at 1%, 5%, and 10%, respectively. Lag order was selected by Schwarz Bayesian Criterion (SBC). Standard errors are given in parenthesis. Results are robust when a dummy variable accounting for the global financial crisis (GFC) is introduced for the third and fourth quarters of 2008, in line with Perri and Quadrini (2011) identification of this crisis.

Figure 1a: Oil production for OPEC and non-OPEC countries (quarterly data):1974:Q1 to 2012:Q4

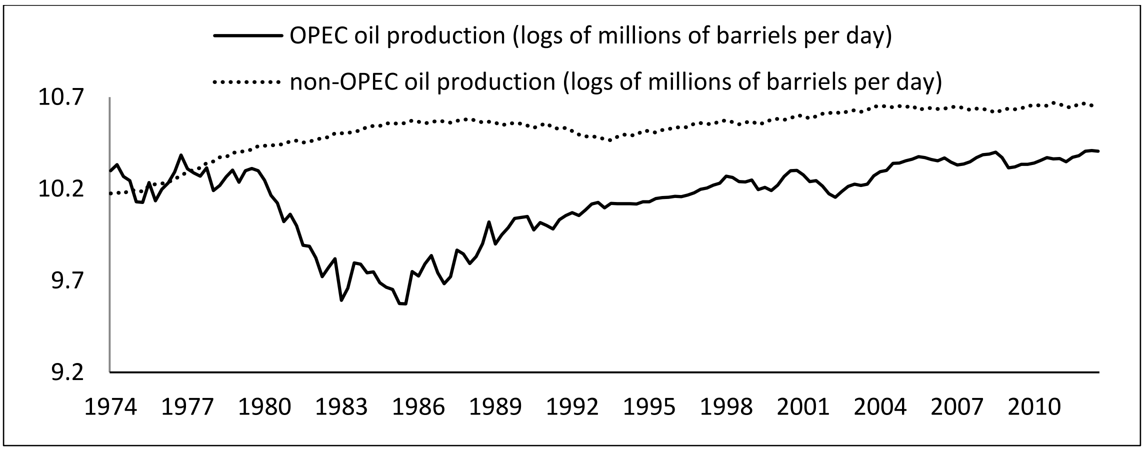
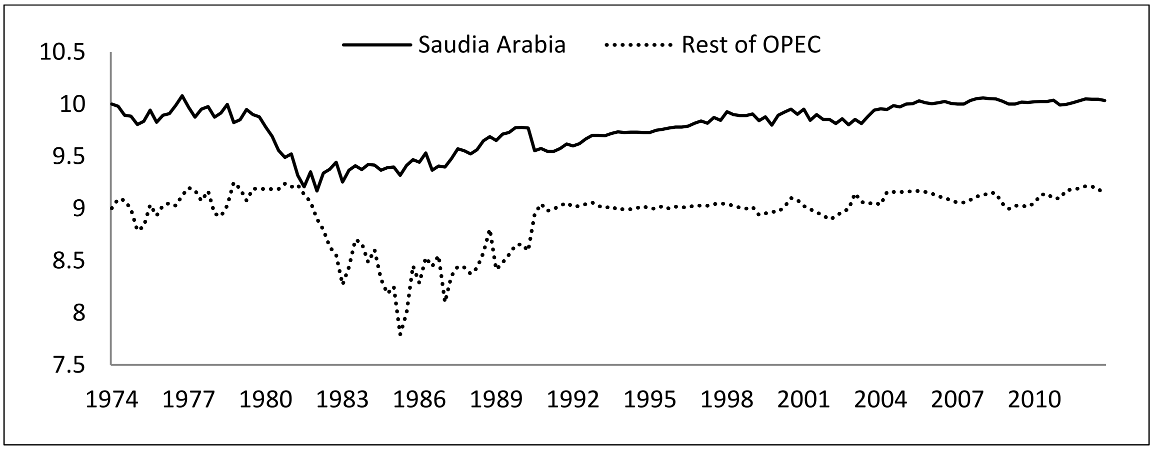
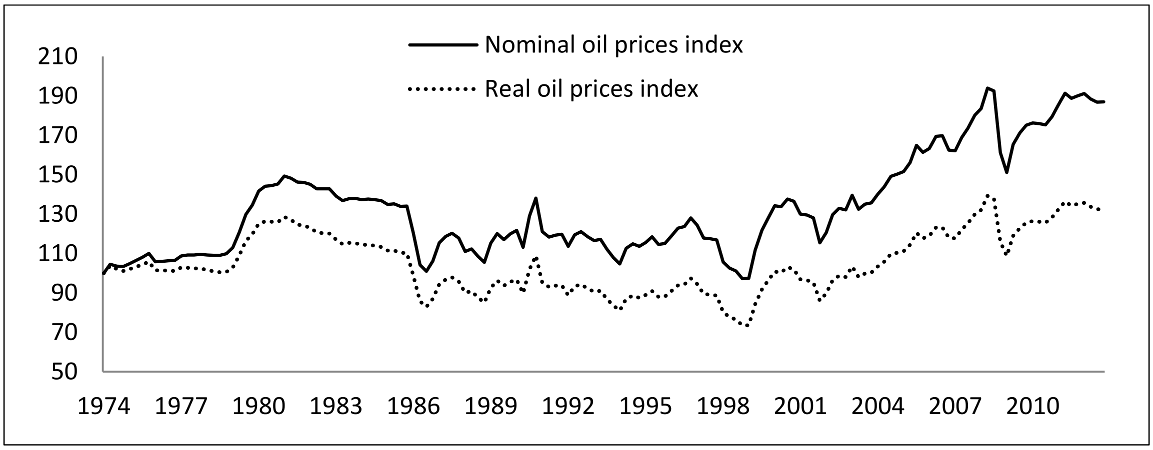


Figure 1b: Oil production for Saudi Arabia and for OPEC minus Saudi Arabia (quarterly data):1974:Q1 to 2012:Q4.



Notes: Oil production in log of millions of barrels

Figure 2 Nominal and real oil prices index 1974 Q1=100



Notes: Nominal oil price is US dollar index. Real oil price is nominal oil price divided by US CPI index.

Figure 3 Perron 1997 Break point and unit root test

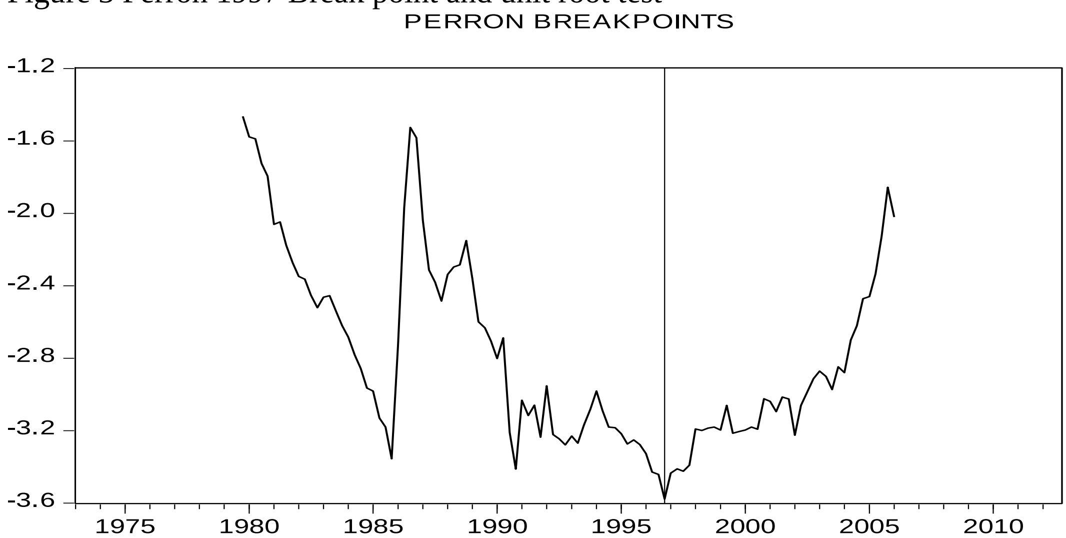


Figure 4. The impulse response effects of the structural shocks: 1974:Q1-2012:Q4

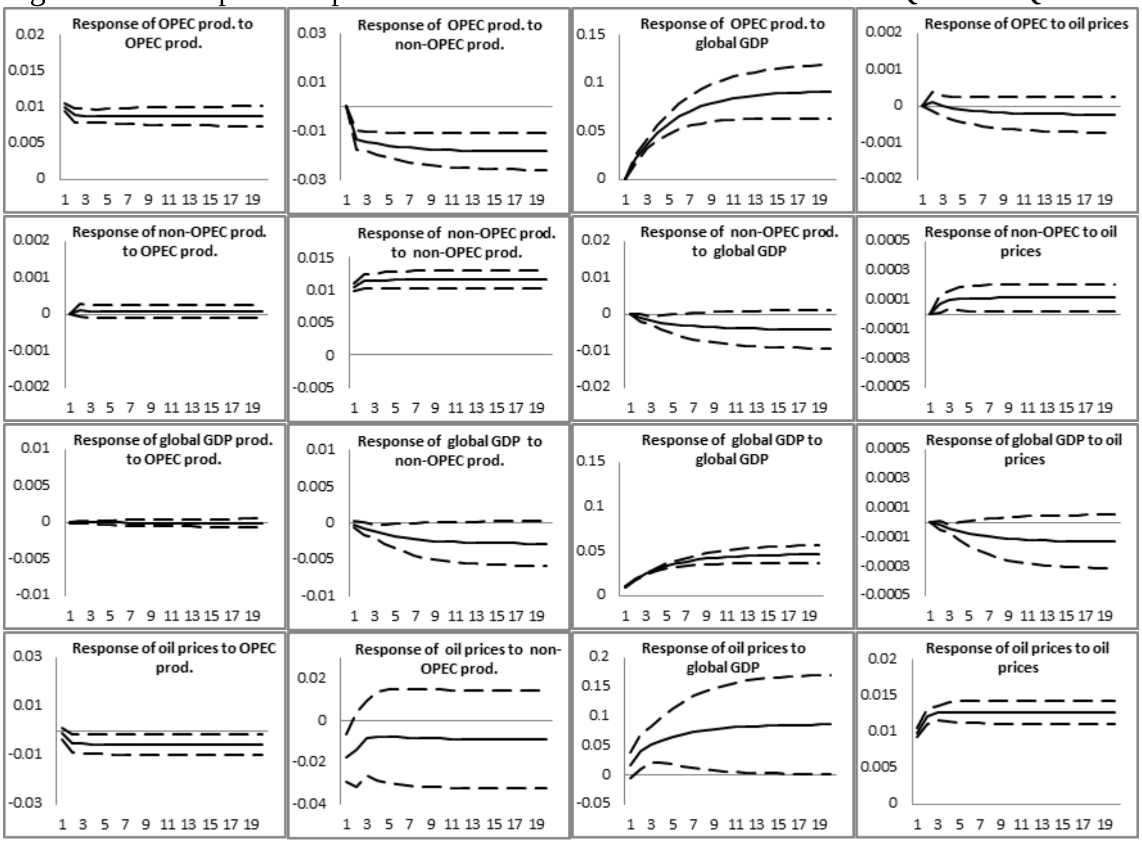


Figure 5. The impulse response effects of the structural shocks during the age of OPEC 1974:Q1-1996:Q4

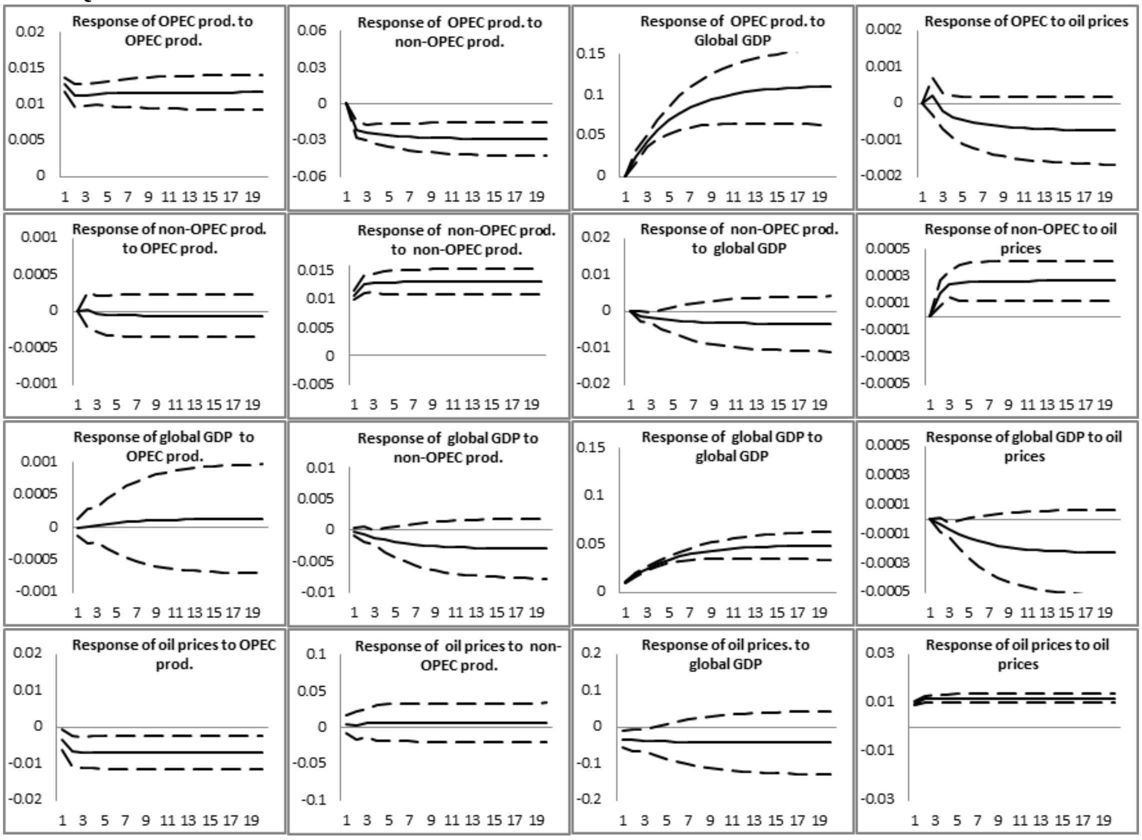


Figure 6. The impulse response effects of the structural shocks during the new industrial age 1997:Q1-2012:Q4

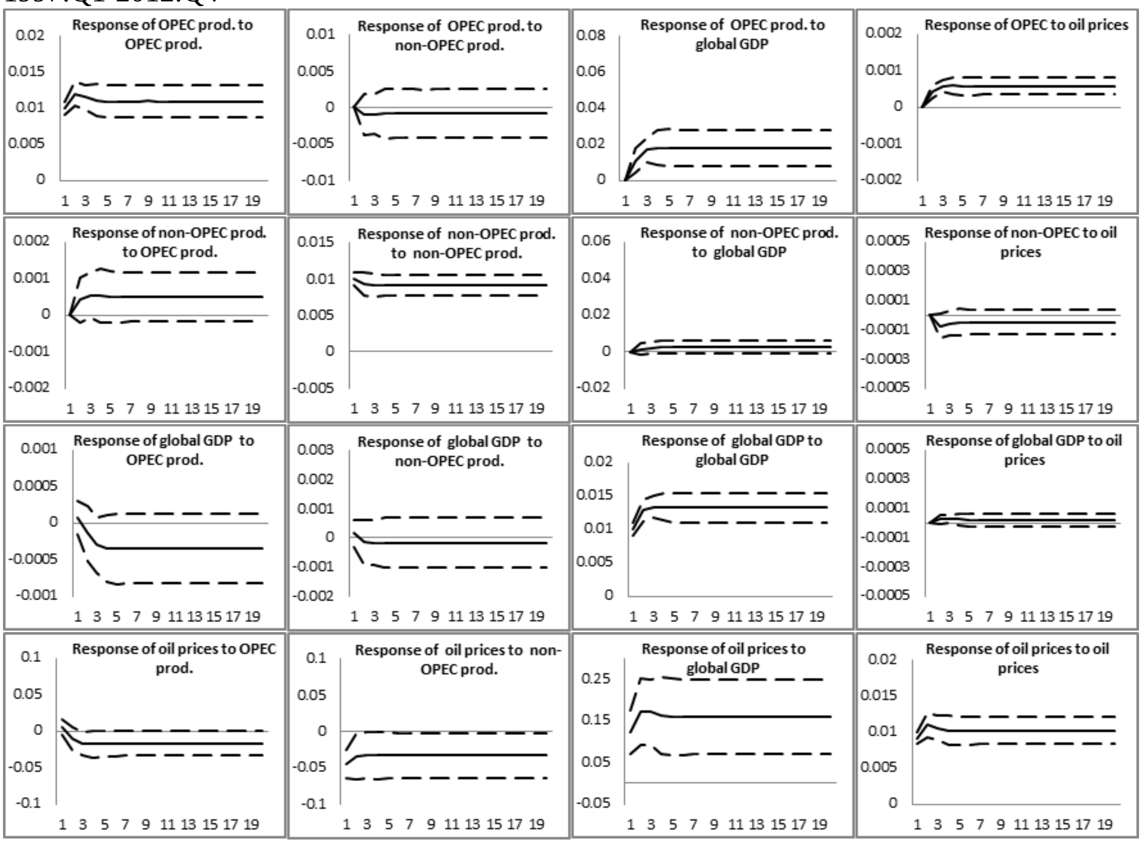


Figure 7a: Cumulative effect of structural shocks on real price of oil

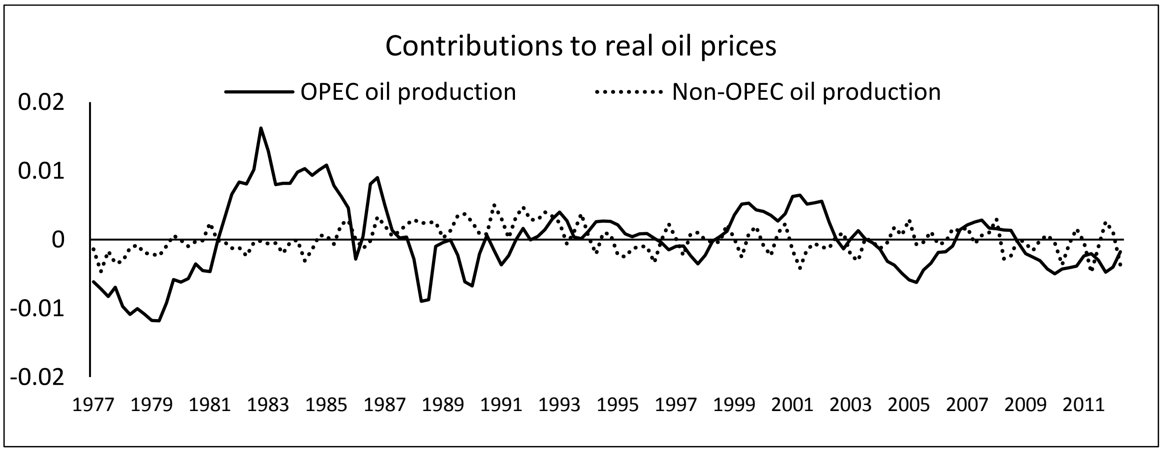


Figure 7b: Cumulative effect of structural shocks to real oil price on growth in OPEC oil production and non-OPEC oil production.

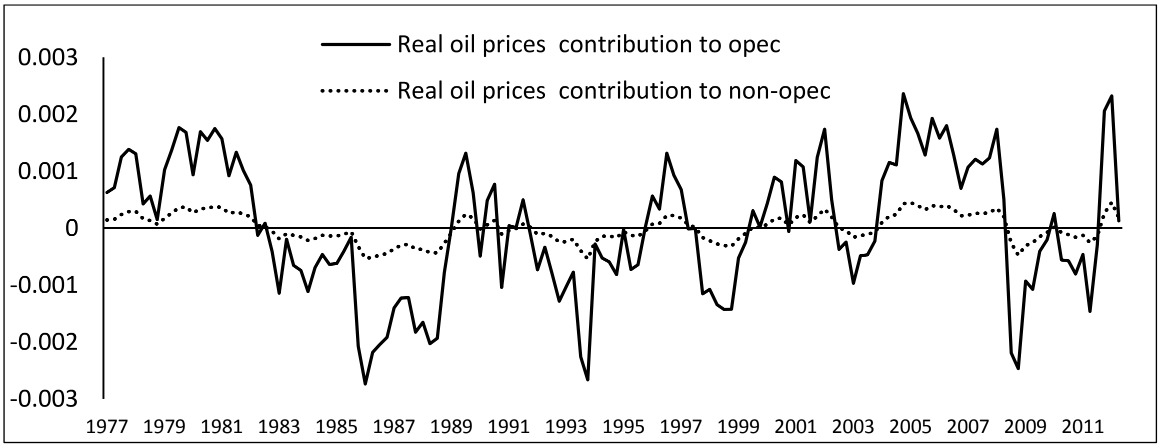
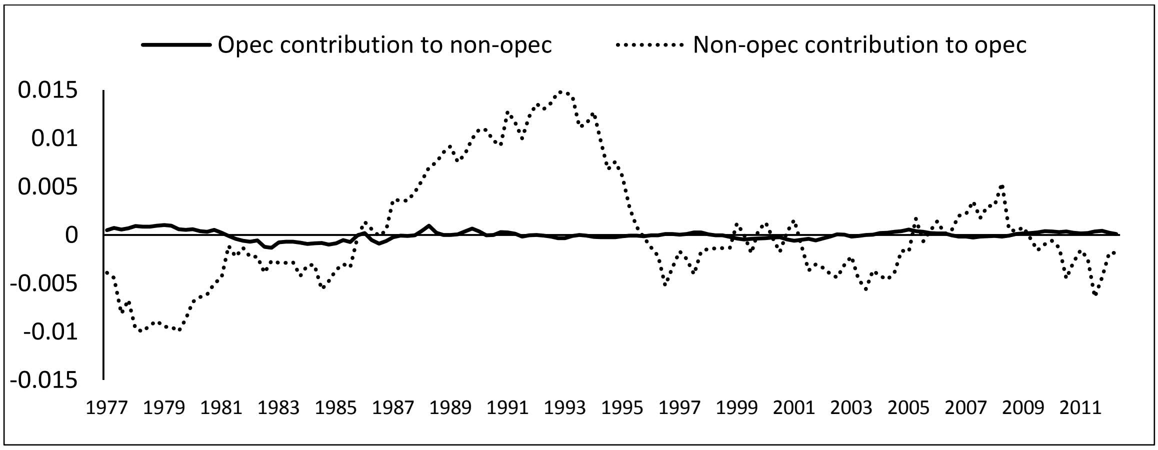


Figure 7c: Cumulative effect of structural shocks on growth in OPEC oil production by growth in non-OPEC oil production and the reverse.



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