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DIW Berlin
German Institute for Economic Research
Mohrenstr. 58
10117 Berlin

Tel. +49 (30) 897 89-0
Fax +49 (30) 897 89-200
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The Dynamics of Global Crude Oil Production

Aleksandar Zaklan[1], Georg Zachmann[2], Anne Neumann[3]

Abstract

We analyze the dynamic effect of prices and price volatility on current oil production, both on the level of country groups and the major individual producer countries. A comprehensive dataset at monthly frequency allows us to include a rich lag structure while controlling for key global and local determinants as well as seasonality. Our set of explanatory variables also includes real economic activity, investment, the strength of the U.S. dollar and institutional quality. We provide a naïve regression analysis using a broad model to show that lagged explanatory variables are important determinants of current oil production. We find that the reaction of oil production is heterogeneous across both country groups and the major individual producer countries.

JEL-Codes: D43, L13, Q43

Keywords: Crude oil, prices and production, dynamic time series

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[1] Corresponding author. Aleksandar Zaklan, DIW Berlin (German Institute for Economic Research), Mohrenstr. 58, D-10117 Berlin, azaklan@diw.de.

[2] BRUEGEL, Brussels, Belgium.

[3] University of Potsdam, Faculty of Economics and Social Sciences and DIW Berlin (German Institute for Economic Research), Germany.

1 Introduction

Oil is for apparent reasons one of the global commodities most studied by economists. Key areas of interest include price formation, i.e. the role of speculation versus fundamental drivers; the interaction of prices with other economic variables such as exchange rates and GDP; and the drivers of oil supply. While there has been much empirical work on the determinants of OPEC production, less effort has been devoted to a systematic investigation of *global* oil production. In this paper we take a naïve approach and estimate models to identify the relationship between country-specific oil production decision and world oil market prices as well as price volatility, while controlling for other important determinants of oil production decisions. By including lags of our explanatory variables that range from a decade ago to today we can analyze the response of oil production to specific influences over time.

In general, oil production has been analyzed from two perspectives. Since a major feature of fossil fuels is their nature, namely their exhaustibility and their geologic attributes, one stream of literature investigates whether oil production develops according to economic models of exhaustible resources based on Hotelling (1931), or whether oil production more closely relates to the question of worldwide oil depletion as suggested by Hubbart (1956). This stream of literature has produced mixed results given that the assumptions required in each model, such as the geographic scope of production, determine the predicted production pattern to some degree.

A second stream of literature examines the strategic behavior of the major oil producers. For example, the focus is on competition (i.e. MacAvoy, 1982) and revenue targets (i.e. Teece, 1982) in examining OPEC. Followers of the cartel hypothesis test if OPEC is a monopoly, an oligopoly, or if it acts as a dominant firm. Griffin's seminal paper (1985) is the starting point for numerous contributions to the cartel hypothesis and also analyzes the potential mechanisms used to steer production, mostly based on current price and production data. One conclusion is that production in non-OPEC and OPEC countries reacts differently to current price changes, yet there are also differing interpretations about the exact nature of the potentially strategic interactions. Some authors (Griffin, 1985, Jones 1990) claim that OPEC acts as a cartel or a bureaucratic syndicate (Smith, 2005), others (Alhajji and Huettner, 2000) find that market results can be explained by Saudi Arabia's dominant role, and a few researchers promote the "target revenue hypothesis" (Griffin, 1985, Ramcharran, 2002, Alhajji and Huettner, 2000), and the existence of a quota system (Kaufmann et al., 2008).

The empirical stream of literature disregards the importance of a range of prices prior to the current period for future oil production. However, oil production follows physical investment with a significant time lag of seven to ten years (Wurzel et al., 2009). Investments in R&D can take even longer to result in actual oil production. Therefore, short-run adjustments in oil supply due to price changes differ significantly from long-run adjustments determined by investment decisions. In addition, limited competition in oil production leads to a scenario in which investment decisions are a potentially strategic instrument just like actual production decisions.

Structurally, the global oil market has changed substantially since 1974. Whereas OPEC dominated the market until the early 1980s in terms of prices and quantities, several private companies have invested heavily in exploration and development. Recent figures suggest that non-OPEC production accounted for roughly 60% in 2009 (BP, 2010). Most remarkable is the increase of oil production from non-OECD/non-OPEC countries, which increased their share in global production from 29% in 1994 to 34% in 2009, at the same time the share of OECD producers decreased from 32% to 25%. We are interested in the major determinants of production in all countries, i.e. the high prices triggering exploration activities; financial crises implying economic downturns and hence negative growth in oil consumption; terrorist attacks delaying or even alienating investments, etc.

This paper analyzes in detail the effect of a range of current and past alterations in prices and price volatility on oil production in three groups of oil producing countries while controlling for the output effects of additional explanatory variables, such as investment, real economic activity, price volatility, strength of the U.S. dollar, etc. We base our analysis on an extensive sample of monthly data which allow for the inclusion of a rich lag structure. The remainder of the paper is organized as follows. Section II introduces the corresponding data and methodology. Section III presents and discusses our results. Section IV gives our conclusions and suggestions for future research.

2 Data and Model Specification

2.1 Data and basic intuition

The existing literature shows that a number of global and local factors may affect oil production in individual countries. Among the key global variables are the price of oil, price volatility, the state of the overall macroeconomic environment, and the strength of the U.S. dollar. Two significant local variables are the amount of investment in oil exploration and production and a country's own institutional quality. Table 1 provides summary statistics for the variables used in our analysis.

In order to capture the supply side of the global oil market as fully as possible we compile a comprehensive dataset at monthly frequency which encompasses the majority of countries and virtually all global crude oil production. We use monthly crude oil production data for the period 1994-2009 as provided by the U.S. Energy Information Agency (EIA). Our daily data on the key benchmark crude oil spot price, WTI, covering the period 1986-2009 from which we compute monthly averages also derives from the EIA. As a measure of oil price volatility we compute the monthly standard deviation of daily log returns based on the WTI price.

We control for the state of the macroeconomic environment by using a comprehensive global real economic activity index proposed by Kilian (2009) and used by He et al. (2010) which captures important developments while avoiding shortcomings of the obvious alternative measures, such as GDP or industrial production. These alternatives may either not be available on a global level or may

not be comparable across countries due to different methodologies and standards in the various national statistics offices. Exchange rate effects also may distort these measures.

Future production possibilities are closely related to current and past investment activities. We use country-level rig count data obtained from Baker Hughes as a proxy for investment in oil exploration and production (Ringlund et al., 2008). A country's institutional set-up, while only changing very slowly, is a strong determinant of overall economic success in the long term (Acemoglu et al, 2001; Faria et al, 2010). Including institutional quality indicators is novel in the literature on energy economics and allows us to control for time-varying country individual effects.[4]

2.2 Descriptive statistics

We allocate the countries in our sample to three main groups: OPEC[5], OECD and non-OPEC/non-OECD. This division is in contrast to most of the related literature, e.g., Griffin (1985) and subsequent studies, which only distinguish between OPEC and non-OPEC. While the distinction of crude oil producing countries into OPEC and non-OPEC may have been appropriate in the past, we believe that a further subdivision of non-OPEC countries is warranted.

Table 1 indicates significant diversity between the local explanatory variables for the three country groups. Rig count activity differs substantially, particularly regarding its variation around mean activity. OPEC has both the lowest number of rigs and the smallest variation around the mean. The OECD region exhibits the most pronounced dynamics, driven by U.S. and Canadian rig activity, in terms of both the mean number of rigs and the extent of variation around the mean. The non-OECD/non-OPEC group exhibits intermediate variation in its investment activity. Since rig count is not a perfect proxy for investment, we need to assume a direct relationship between rig activity and investment in oil production and a stable relationship across countries. While this may be a strong assumption, we believe that including the rig count is preferable to not including it, given the lack of available data on investment.

Governance indicators also differ across country groups and are highest for the OECD group and lowest for OPEC. However, based on the institutional indicators, with values above zero indicating above-average performance relative to the other countries, both OPEC and non-OECD/non-OPEC countries are positioned lower than the median country.

[4] We include the mean of the World Bank's six country-level governance indicators: i) voice and accountability, ii) political stability and absence of violence/terrorism, iii) government effectiveness, iv) regulatory quality, v) rule of law and vi) control of corruption, which are available at annual frequency. The indicators are defined to range from -2.5 to 2.5, with higher values indicating higher quality in the respective category (Kaufmann et al., 2009). Values above zero indicate above-average performance on that particular indicator.

[5] We follow the IEA's definition of OPEC membership (IEA, 2009), so that we treat Algeria, Angola, Ecuador, Iran, Iraq, Kuwait, Libya, Nigeria, Qatar, Saudi Arabia, the UAE and Venezuela as OPEC members throughout the sample period. Thus, e.g., Indonesia is considered a non-OPEC country throughout.

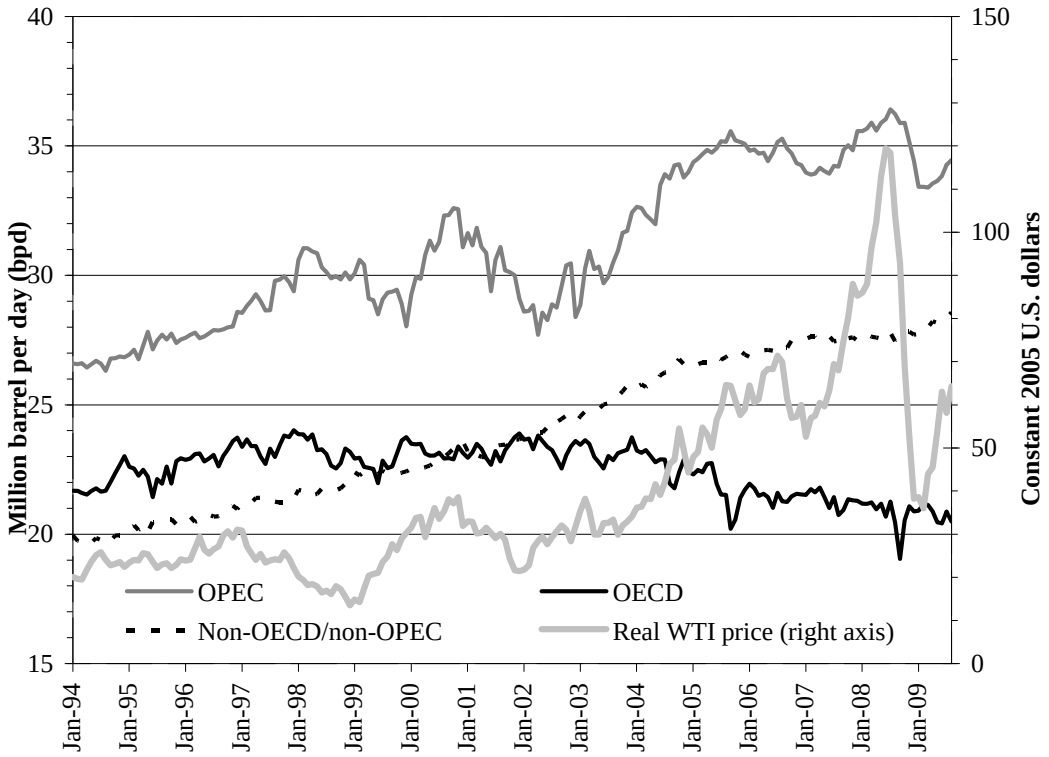
Table 1: Descriptive statistics

Global variables							
Variable	Obs.	From	To	Mean	SD	Min	Max
WTI spot price (real 2005 U.S. dollars)	284	Jan 86	Aug 09	36	18	14	119
WTI price volatility	284	Jan 86	Aug 09	0.023	0.013	0.007	0.110
Kilian real activity index	284	Jan 86	Aug 09	-3.5	23.6	-57.5	55.2
Exchange rate IMF Special Drawing Right (SDR) - U.S. dollar	332	Jan 82	Aug 09	0.75	0.10	0.61	1.04
Local variables by region							
OPEC							
Variable	Obs.	From	To	Mean	SD	Min	Max
Crude oil production (thousand barrels per day)	188	Jan 94	Aug 09	31,130	2,914	26,308	36,412
Rig count	332	Jan 82	Aug 09	192	43	105	303
Institutional quality	156	1996	2008	-0.49	0.04	-0.61	-0.45
OECD							
Variable	Obs.	From	To	Mean	SD	Min	Max
Crude oil production (thousand barrels per day)	188	Jan 94	Aug 09	22,457	978	19,043	24,012
Rig count	332	Jan 82	Aug 09	1739	738	698	5174
Institutional quality	156	1996	2008	1.19	0.03	1.14	1.23
non-OECD/non-OPEC							
Variable	Obs.	From	To	Mean	SD	Min	Max
Crude oil production (thousand barrels per day)	188	Jan 94	Aug 09	23,988	2,783	19,566	28,562
Rig count	332	Jan 82	Aug 09	431	88	247	591
Institutional quality	156	1996	2008	-0.43	0.03	-0.46	-0.38

Sources: Crude oil production and the WTI price are from the U.S. Energy Information Agency; the real activity index is from Kilian (2009); the U.S. dollar-SDR exchange rate is from Thompson Datastream; the rig count is from Baker Hughes; and the governance indicators are from the World Bank.
Prices are deflated by the 2005 U.S. CPI. Crude oil production is in thousand barrels per day. The institutional quality index ranges from -2.5 to 2.5, with higher numbers indicating better governance outcomes. The governance indices are available at annual frequency. Missing years 1997 and 1999 are completed through linear interpolation.

Figure 1 plots the evolution of oil output against the development of WTI prices and indicates that oil production differs across the three country groups over the sample period. In particular, the development of oil output of the OECD and non-OECD/non-OPEC groups are dissimilar in terms of longer-term development and short-term dynamics. We observe that total OECD output has declined by about 14% since the turn of the century, with Norway and the U.K. accounting for most of the group's overall decline. Non-OECD/non-OPEC output has increased steadily over the entire sample period. Figure 1 also suggests that OECD oil output is more volatile in the short run compared to non-OECD/non-OPEC output, whose increase has been fairly smooth and almost monotonic over the sample period. In contrast, OPEC output roughly followed the evolution and steady increase of the WTI price, although with a certain delay, which suggests that OPEC output might be more closely related to the development of global crude oil prices than the output of the two other country groups.

Figure 1: Production by region and real WTI price



2.3 Intra-group dynamics in oil production – principal component analysis

Following our descriptive analysis we now evaluate the variation in our dependent variable, oil production, on a country level. Our intention is to better understand the rise of "new" producing countries, the decrease in OECD production and the role of OPEC. We use principal component analysis (PCA) to investigate the structure of the production data in a naïve manner. A graphical representation of the major principal components allows us to evaluate the degree of similarity among the production decisions of various countries over time. While we are not necessarily able to interpret principal components in a structural way, PCA is useful for achieving deeper insights about the set-up of our dependent variable without having to resort to parametric estimation techniques.

We conduct the PCA for all of OPEC, except for Iraq and Libya, and for the major producers from the other two groups.[6] For illustrative purposes we select three time periods to explore the relationship among key dimensions of oil production, given their varying behavior of the equilibrium price: the entire sample period; 1994-1998, a period of stagnating prices; and 2002-2006, a period of increasing prices.

[6] To be consistent with our quantitative analysis we conduct the PCA using differenced production data.

Table 2: PCA major producers, first differences - eigenvalues and proportion of total variation explained by sample period

Sample period	Principal component number	Eigenvalue	Proportion of total variation explained
1994-2009	1	2.7	8.6%
	2	1.9	6.2%
1994-1998	1	4.0	13.0%
	2	2.9	9.3%
2002-2006	1	3.2	10.4%
	2	2.5	8.2%

Table 2 shows that the first two principal components have eigenvalues clearly in excess of 1 in the three periods. The moderate proportion of variation explained differs by sample period. When there are more homogenous price developments eigenvalues are higher and a greater proportion of variation is explained compared to the entire period.

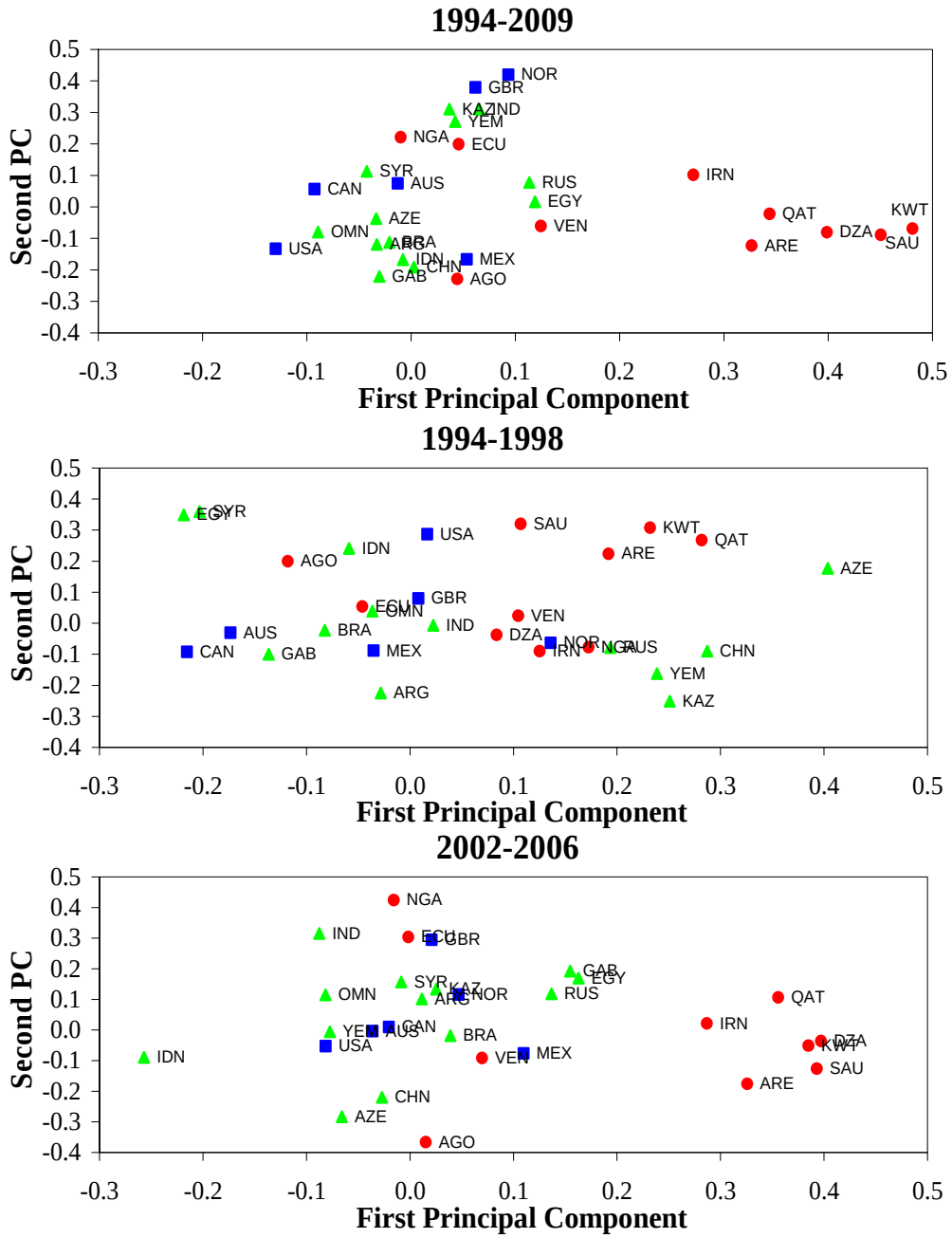
Figure 2 plots the distribution of the individual countries' production pattern over the two-dimensional space spanned by the first two principal components for the three periods.[7] When considering the pattern of oil production over the entire period (Figure 2, top panel), we notice a relatively high degree of similarity of output variation within the OPEC group, particularly among its Middle Eastern and North African members. However, Latin American and Sub-Saharan African OPEC members are significantly removed from this pattern. There is also a high degree of overlap between the OECD and non-OECD/non-OPEC groups

During the low-price period 1994-1998 (Figure 2, middle panel), cohesion within the three country groups diminishes and there is much more overlap. For OPEC, some countries from the so-called OPEC core (Smith, 2005) now also show signs of divergence.

During the high-price period 2002-2006 the WTI price tripled in real terms and we see greater similarity among OPEC members' output compared to the entire period (Figure 2, bottom panel). Output decisions appear to be well coordinated among the Middle Eastern and North African OPEC members, whereas Nigeria, Angola, Venezuela and Ecuador clearly diverge. Variations in the output of the main OECD producers also become more similar than in 1994-1998 and in the entire period. Only the non-OECD/non-OPEC group is less coherent than during the entire period.

[7] OPEC countries are depicted as circles, OECD as squares and non-OECD/non-OPEC countries as triangles. Country labels correspond to the World Bank's country coding system.

Figure 2: Principal component analysis, major producers, first differences: various sample periods



While we cannot readily interpret the results of the PCA in economic terms, they support our findings from the previous descriptive analysis, strongly suggesting that a substantial amount of heterogeneity exists in the dynamics of oil output by country group, on the level of individual countries, and over time. Thus, we can derive two hypotheses which we discuss in the following sections:

> ***Hypothesis 1:*** Crude oil production responds to prices and price volatility. A significant response is expected to come for both the current and previous periods along a lag-structure from the very short to the longer term.

Hypothesis 2: The reaction of crude oil production to changes in prices and price volatility is heterogeneous among country groups as well as among members within the groups.

2.4 Methodology

Much of the existing literature based on Griffin (1985) uses logarithms of prices and quantities, however, the price and quantity variables especially are clearly non-stationary over the sample period under consideration, thus providing spurious results in unadjusted OLS regressions.[8] Therefore, Kaufmann et al. (2008) adapt their estimation to the presence of non-stationarity by using an error correction approach. Their VEC estimation finds more than one cointegration relationship in each case, which leads to multiple sets of estimation results and unclear interpretations.

Therefore, we decide to trade off information content in favor of analytical clarity. We leave the real activity index and the standard deviation of log returns on oil unchanged, since both are stationary. We also leave the governance index in levels. We take first differences of the remaining variables to ensure covariance stationarity of our data.

We aim to identify the effects of prices and price volatility on crude oil production based on the estimation of the following model:

$$\Delta Q_{t,i} = \alpha_i + \sum_{k=0}^{K} \beta_{k,i} \Delta P_{t-k} + \sum_{n=0}^{N} \varphi_{k,i} SD(\Delta P_t)_{t-k} + \sum_{l=0}^{L} \gamma_{m,i} REAL_{t-m}$$
$$+ \sum_{m=1}^{M} \delta_{l,i} \Delta RIG_{t-l,i} + \sum_{p=0}^{P} \theta_{k,i} \Delta EX(USD)_{t-k} + \lambda_i INST_{t,i} + \sum_{j=1}^{11} \rho_j D_{t,j} + \varepsilon_{t,i}$$

where $Q_{t,i}$ is crude oil output by group or country and P_t is the CPI-deflated WTI oil price[9], while $SD(\Delta P_t)_t$ is the monthly standard deviation of daily log returns of the WTI, our measure of volatility. $REAL_t$ is the real activity index constructed by Kilian (2009), $RIG_{t,i}$ is the rig count, our proxy for investment in oil exploration and production, and $EX(USD)_t$ is the exchange rate between the Special Drawing Right (SDR) and the U.S. dollar issued by the International Monetary Fund and represents a basket of major global currencies. Thus, this exchange rate measures the value of the U.S. dollar in a global context. $INST_{t,i}$ is the mean of the six WGI governance indicators and D_t is a full set of monthly dummy variables to control for seasonality, such as potentially decreased oil production or rig activity due to adverse weather conditions.

Heteroskedasticity and autocorrelation are accounted for by using Newey-West corrected standard errors in the main regression model, with a generous autocorrelation specification of a lag up

[8] Unit root tests reveal non-stationarity for a number of variables under consideration, while first differences are I(1).
[9] We also perform our analysis using key regional crude oil prices. The results are essentially unchanged, which provides additional evidence in favor of the oil market's global integration (Bachmeier and Griffin, 2006).

to 80 months. Since we do not include lagged output as an explanatory variable, residual autocorrelation will not affect the consistency of our estimations.

We include nine years of lags for oil price, price volatility, real activity, rig count, and U.S. dollar exchange rate to explore the full dynamics of the spectrum of lags. For prices we include monthly lags for the first quarter, then lags at quarterly frequency for the remainder of the first year and yearly averages beyond the first year, to analyze short-term, medium-term and longer term responses of crude oil production to price changes. To maintain relative parsimony for our model we include quarterly averages for the first year for the remaining explanatory variables and yearly averages thereafter.

3 Results and discussion

We present our analysis by major country group. We first describe the results for the aggregated group-level regressions and then focus on some major individual countries in each group to evaluate our hypotheses at the country level.

Note that while having included CIS member countries and China when presenting descriptive statistics, we do not consider them in the group-wise analysis due to either missing or incomplete data on rig count.[10] We do present results for China and Russia for a specification of our model that excludes rig count, given that they represent a large proportion of non-OECD/non-OPEC oil output. Additionally, we omit Iraq and Libya from OPEC for the group-wise analysis.[11]

While including a number of control variables in our regressions, we are mainly interested in the results for prices and price volatility.[12]

[10] However, running the group-wise regression based on the entire sample while excluding the rig count variable does not significantly change our results for most variables.

[11] In Iraq, political factors strongly impacted the oil industry over the entire sample period. For Libya data on the rig count was only available after 2002. For Iran data on the rig count ceased in 2006; given that Iran represents a significant share of OPEC production and that its rig count is available for the greatest part of the sample period, we included it in the OPEC group.

[12] The full results are available upon request.

Table 3: Determinants of crude oil production, group-wise analysis

	(1) OPEC	(2) OECD	(3) Non-OECD/ non-OPEC
Real WTI price, monthly average	0.717	4.850	4.021
	(0.967)	(0.590)	(0.174)
Real WTI price, monthly average (-1)	43.93**	-11.31*	3.136
	(0.014)	(0.094)	(0.121)
Real WTI price, monthly average (-2)	37.34***	-22.10*	-0.503
	(0.001)	(0.070)	(0.921)
Real WTI price, quarterly average (-1)	55.29	-107.8**	3.588
	(0.416)	(0.018)	(0.834)
Real WTI price, quarterly average (-2)	42.46	-47.73	9.095
	(0.377)	(0.318)	(0.534)
Real WTI price, quarterly average (-3)	6.723	-22.28	27.82*
	(0.921)	(0.631)	(0.074)
Real WTI price, yearly average (-1)	-227.6	-18.76	152.5**
	(0.466)	(0.954)	(0.034)
Real WTI price, yearly average (-2)	-281.7	-69.29	136.5**
	(0.150)	(0.885)	(0.012)
Real WTI price, yearly average (-3)	-283.5	-317.9	85.02
	(0.378)	(0.496)	(0.360)
Real WTI price, yearly average (-4)	-342.0	181.3	-25.65
	(0.302)	(0.441)	(0.699)
Real WTI price, yearly average (-5)	-667.0***	111.6	28.06
	(0.004)	(0.692)	(0.488)
Real WTI price, yearly average (-6)	-801.0***	164.5	60.31
	(0.000)	(0.694)	(0.205)
Real WTI price, yearly average (-7)	-593.1***	-148.8	66.75**
	(0.010)	(0.552)	(0.043)
Real WTI price, yearly average (-8)	-537.9***	-108.0	33.23
	(0.005)	(0.644)	(0.284)
Real WTI price, yearly average (-9)	-128.2	-169.3	96.08***
	(0.467)	(0.292)	(0.000)
Std. dev. (log price returns), quarterly average	-2280.5	-31416.4*	3571.9
	(0.892)	(0.091)	(0.179)
Std. dev. (log price returns), quarterly average (-1)	-28300.0*	-19445.4	3814.2**
	(0.053)	(0.200)	(0.012)
Std. dev. (log price returns), quarterly average (-2)	-4256.9	-45361.2	5832.1**
	(0.812)	(0.190)	(0.035)
Std. dev. (log price returns), quarterly average (-3)	-12222.5	-51857.0***	7602.3**
	(0.645)	(0.009)	(0.047)
Std. dev. (log price returns), yearly average (-1)	-68432.4	-112561.3*	35889.9***
	(0.446)	(0.068)	(0.007)
Std. dev. (log price returns), yearly average (-2)	-42727.4	-12441.7	22982.0***
	(0.640)	(0.850)	(0.004)
Std. dev. (log price returns), yearly average (-3)	5948.3	-77540.3	38218.6**
	(0.941)	(0.243)	(0.010)
Std. dev. (log price returns), yearly average (-4)	-31194.9	-5763.1	46136.3***
	(0.535)	(0.928)	(0.000)
Std. dev. (log price returns), yearly average (-5)	-85231.9**	-73120.4	24259.2*
	(0.041)	(0.357)	(0.076)
Std. dev. (log price returns), yearly average (-6)	-94699.2*	-28556.9	24664.7**
	(0.070)	(0.588)	(0.016)
Std. dev. (log price returns), yearly average (-7)	-73456.5*	-58790.9	34260.1*
	(0.087)	(0.148)	(0.055)
Std. dev. (log price returns), yearly average (-8)	-136500.9***	-16146.6	17953.7
	(0.008)	(0.576)	(0.104)
Std. dev. (log price returns), yearly average (-9)	-60660.6**	-42324.9*	4168.7
	(0.035)	(0.085)	(0.362)
Constant	13692.3	11141.8	-3740.0**
	(0.283)	(0.270)	(0.028)
Observations	156	156	156

*, **, *** indicate significance at the 10%, 5% and 1% level, respectively; robust p-values in parentheses.

3.1 OPEC

Column 1 in Table 3 shows that an increase in prices leads to an increase in production at the group level. This output reaction is consistent with the pursuit of OPEC's stated price stabilization objective. However, in the medium to long term, the relationship reverses, which suggests significant revenue smoothing over a longer time horizon. The country level in Table 4 shows a more mixed picture, although it broadly confirms the impression from the group level regression. A notable exception is Nigeria, which exhibits revenue smoothing from the short to medium term. For some countries, particularly Iran and the UAE, we also observe that while oil output positively relates to price changes in the short term, there is no significant reaction in the medium to longer term. The country-level regressions also reveal that oil output appears to respond more strongly to prices for certain countries, especially for Saudi Arabia and Venezuela, which appears to drive the result on the group level.

OPEC as a group exhibits significant aversion to price risk, as evidenced by the negative reaction of production changes to increases in price volatility. This observation is borne out on the country level, where a majority of OPEC countries exhibit a negative relationship between changes in output and increases in price volatility across the lag spectrum. Past increases in volatility have strong negative effects on future output although with significantly differing time lags. While Saudi Arabia's output decline takes place immediately, Angola's output decreases in the medium term, and the UAE's output only reacts in the longer term.

Overall, our results regarding OPEC suggest a significant amount of coordination among OPEC members regarding their output reaction to changes in prices and price volatility. However, the coordination is imperfect, confirming the literature, e.g., Smith (2005), that OPEC seems to act like a bureaucratic cartel.

3.2 OECD

The group level regression for the OECD (Table 3, column 2) reveals a substantial amount of revenue smoothing for prices in the short term, while on the country level significant heterogeneity becomes apparent (Table 5, columns 1-4). We find revenue smoothing behavior especially for Norway and the U.S., and a positive relationship between changes in output and price in Canada and the U.K. The country level results suggest that aggregate results should be treated with caution, since the group level results may be driven by a subset of producer countries, in this case by the U.S.

OECD also shows signs of aversion to price risk on the group level, although to a lesser degree than OPEC. On the country level it becomes clear that the majority of the major OECD producers seem to be risk averse with respect to price volatility, the clear exception being Norway, which exhibits a strong positive relationship between the level of price volatility and changes in the growth of output across most of the lag spectrum.

Overall our results on the country level show that OECD producers constitute a heterogeneous group with respect to both prices and price volatility.

Table 4: Determinants of crude oil production, OPEC producers

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Algeria	Angola	Iran	Kuwait	Nigeria	Saudi Arabia	UAE	Venezuela
Real WTI price, monthly average	-0.752	2.554	-2.276	1.945	-1.399	2.689	0.0340	2.735
	(0.216)	(0.158)	(0.799)	(0.294)	(0.757)	(0.573)	(0.992)	(0.522)
Real WTI price, monthly average (-1)	-0.555	2.719*	5.716	4.540**	-6.719***	22.39**	10.39*	23.10
	(0.271)	(0.058)	(0.153)	(0.018)	(0.000)	(0.017)	(0.078)	(0.126)
Real WTI price, monthly average (-2)	1.124	0.519	11.69*	3.461	-9.811***	29.24***	6.468***	31.44
	(0.193)	(0.787)	(0.073)	(0.115)	(0.001)	(0.000)	(0.008)	(0.104)
Real WTI price, quarterly average (-1)	-0.351	4.075	22.69	1.649	-34.14***	84.54***	26.71	44.77
	(0.846)	(0.355)	(0.438)	(0.678)	(0.006)	(0.001)	(0.162)	(0.264)
Real WTI price, quarterly average (-2)	-2.364	9.330	32.24	0.232	-44.40***	83.91***	27.90	51.27
	(0.265)	(0.127)	(0.355)	(0.970)	(0.000)	(0.000)	(0.409)	(0.449)
Real WTI price, quarterly average (-3)	-4.701**	8.590	46.00*	-0.771	-36.19***	51.67*	26.95	48.04
	(0.035)	(0.402)	(0.060)	(0.931)	(0.006)	(0.100)	(0.391)	(0.471)
Real WTI price, yearly average (-1)	-23.70***	32.61	107.6	13.03	-95.97*	65.65	146.7	-17.37
	(0.006)	(0.262)	(0.252)	(0.639)	(0.064)	(0.588)	(0.235)	(0.929)
Real WTI price, yearly average (-2)	-33.02***	-19.06	350.5	-4.970	-120.9**	14.72	161.1	-133.1
	(0.001)	(0.311)	(0.107)	(0.844)	(0.037)	(0.900)	(0.273)	(0.336)
Real WTI price, yearly average (-3)	-41.62**	-24.77	182.1	-46.63	-87.95*	-122.8	101.7	-167.7
	(0.038)	(0.306)	(0.459)	(0.371)	(0.069)	(0.123)	(0.202)	(0.385)
Real WTI price, yearly average (-4)	-8.455	-28.50**	145.5	-36.23	48.87	-158.1	74.71	-260.7*
	(0.543)	(0.049)	(0.359)	(0.378)	(0.578)	(0.180)	(0.156)	(0.080)
Real WTI price, yearly average (-5)	-25.67**	-23.66*	112.8	-28.98	36.52	-460.1**	102.2	-279.5*
	(0.028)	(0.099)	(0.313)	(0.493)	(0.585)	(0.029)	(0.216)	(0.094)
Real WTI price, yearly average (-6)	-32.68***	-35.63*	107.6	-40.01	106.5	-512.7***	55.37	-454.9***
	(0.005)	(0.053)	(0.190)	(0.203)	(0.175)	(0.002)	(0.594)	(0.001)
Real WTI price, yearly average (-7)	-14.53	-27.20**	43.50	10.82	5.056	-297.8***	23.03	-244.8**
	(0.201)	(0.024)	(0.407)	(0.645)	(0.868)	(0.000)	(0.704)	(0.023)
Real WTI price, yearly average (-8)	-18.73	15.91	-41.30	-3.776	54.87*	-232.5***	-32.06	-78.99
	(0.102)	(0.504)	(0.187)	(0.735)	(0.067)	(0.002)	(0.505)	(0.546)
Real WTI price, yearly average (-9)	-11.53***	13.65	-93.43	29.51**	14.46	-44.53	-11.81	-3.567
	(0.007)	(0.309)	(0.161)	(0.026)	(0.408)	(0.430)	(0.651)	(0.965)
Std. dev. (log price returns), quarterly average	-293.3	1639.9	-4957.9	161.1	-1575.5	-6724.1	-2646.5	10271.7**
	(0.611)	(0.291)	(0.334)	(0.925)	(0.658)	(0.456)	(0.534)	(0.048)
Std. dev. (log price returns), quarterly average (-1)	-1089.1***	-1435.4	793.2	-1087.7	-6629.2***	-13393.5***	-1825.0	3932.9
	(0.003)	(0.265)	(0.848)	(0.528)	(0.005)	(0.000)	(0.394)	(0.615)
Std. dev. (log price returns), quarterly average (-2)	1473.0*	-2162.4	1560.0	4103.7	-8441.8***	1365.7	847.1	3912.7
	(0.091)	(0.154)	(0.854)	(0.210)	(0.006)	(0.897)	(0.777)	(0.695)
Std. dev. (log price returns), quarterly average (-3)	-706.9	-172.9	-6347.2	2271.0	-5428.9***	-8890.4	148.8	892.9
	(0.509)	(0.913)	(0.611)	(0.570)	(0.010)	(0.458)	(0.970)	(0.932)
Std. dev. (log price returns), yearly average (-1)	1998.5	-3460.0	-87263.5	5565.4	-13538.0	-47047.2	-14209.2	1817.3
	(0.489)	(0.241)	(0.220)	(0.722)	(0.255)	(0.199)	(0.185)	(0.972)
Std. dev. (log price returns), yearly average (-2)	3016.5**	-1045.6	-67133.2*	-6821.2	-9931.9**	14037.5	-12562.6	-36828.3
	(0.039)	(0.659)	(0.070)	(0.304)	(0.041)	(0.587)	(0.157)	(0.444)
Std. dev. (log price returns), yearly average (-3)	-439.1	2815.3	-50087.4**	899.7	-19575.1**	38247.1	-1330.9	20717.3
	(0.692)	(0.510)	(0.050)	(0.882)	(0.034)	(0.111)	(0.840)	(0.470)
Std. dev. (log price returns), yearly average (-4)	3004.9*	-10036.5**	2283.0	12837.3*	-21909.5	24133.3	729.9	-23904.2
	(0.074)	(0.049)	(0.945)	(0.084)	(0.103)	(0.235)	(0.896)	(0.456)
Std. dev. (log price returns), yearly average (-5)	820.9	-9938.5	17811.6	-3407.3	-15008.1	-4076.9	-2336.7	22027.0
	(0.623)	(0.159)	(0.489)	(0.664)	(0.290)	(0.699)	(0.823)	(0.461)
Std. dev. (log price returns), yearly average (-6)	-423.3	-9860.9*	5607.3	-4973.3	-7555.9	5651.9	-355.2	-10853.1
	(0.852)	(0.057)	(0.681)	(0.113)	(0.644)	(0.763)	(0.957)	(0.280)
Std. dev. (log price returns), yearly average (-7)	1671.0	-5423.4*	-5272.7	-4128.0	-7958.3	1233.0	2617.6	-8418.5
	(0.568)	(0.097)	(0.770)	(0.182)	(0.654)	(0.954)	(0.864)	(0.608)
Std. dev. (log price returns), yearly average (-8)	1865.9	-4390.5**	28219.3***	-7769.5***	-755.8	-13014.7	-16457.5**	-67611.6**
	(0.511)	(0.015)	(0.003)	(0.002)	(0.944)	(0.380)	(0.025)	(0.043)
Std. dev. (log price returns), yearly average (-9)	874.9	-110.5	14092.5	1268.7	-11045.6**	18205.8	-3153.6	-60934.3*
	(0.447)	(0.952)	(0.124)	(0.793)	(0.020)	(0.237)	(0.716)	(0.056)
Constant	52.26	1119.9**	2873.1	199.2	3308.7	-281.2	944.8	-1052.8
	(0.880)	(0.046)	(0.472)	(0.788)	(0.114)	(0.943)	(0.485)	(0.772)
Observations	156	156	125	156	156	156	156	156
Mean share in group production	5.5%	3.3%	12.4%	7.4%	7.1%	31.3%	8.4%	9.6%

*, **, *** indicate significance at the 10%, 5% and 1% level, respectively; robust p-values in parentheses.

Table 5: Determinants of crude oil production, OECD and non-OECD/non-OPEC producers

	OECD				Non-OECD/non-OPEC			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Canada	Norway	United Kingdom	United States	Brazil	Indonesia	Russia	China
Real WTI price, monthly average	0.274	3.667	2.638	-11.97*	4.433*	-0.774	-2.512	-1.885
	(0.951)	(0.586)	(0.505)	(0.068)	(0.059)	(0.184)	(0.242)	(0.289)
Real WTI price, monthly average (-1)	1.206	5.800	-4.471	-13.11*	5.409***	-2.656***	-3.401***	2.593
	(0.501)	(0.405)	(0.474)	(0.058)	(0.002)	(0.001)	(0.000)	(0.285)
Real WTI price, monthly average (-2)	-2.409	2.162	-1.676	-34.09***	1.177	-1.898*	-3.719	3.381*
	(0.500)	(0.809)	(0.859)	(0.003)	(0.589)	(0.068)	(0.311)	(0.074)
Real WTI price, quarterly average (-1)	20.80	-42.04	-26.20	-143.5***	2.086	-7.645**	-18.82*	10.39
	(0.108)	(0.236)	(0.422)	(0.006)	(0.736)	(0.012)	(0.050)	(0.271)
Real WTI price, quarterly average (-2)	24.17**	-83.84*	20.78	-120.1**	6.631	-4.029	-27.91*	19.72**
	(0.045)	(0.059)	(0.495)	(0.011)	(0.242)	(0.395)	(0.058)	(0.028)
Real WTI price, quarterly average (-3)	26.61*	-145.0***	51.35*	-104.9***	11.58*	-5.384	-35.60*	27.28**
	(0.071)	(0.000)	(0.078)	(0.007)	(0.066)	(0.295)	(0.086)	(0.018)
Real WTI price, yearly average (-1)	166.4*	-684.9***	172.0*	-150.2	46.34*	-8.912	-135.4*	123.4***
	(0.066)	(0.000)	(0.071)	(0.392)	(0.078)	(0.641)	(0.082)	(0.003)
Real WTI price, yearly average (-2)	102.1	-445.7***	2.979	-141.1	30.46*	-7.797	-85.35	100.3**
	(0.379)	(0.004)	(0.984)	(0.606)	(0.077)	(0.620)	(0.253)	(0.029)
Real WTI price, yearly average (-3)	132.2	-436.5***	-78.05	-347.6	-5.502	-12.05	-43.17	94.15**
	(0.225)	(0.002)	(0.638)	(0.401)	(0.830)	(0.540)	(0.192)	(0.049)
Real WTI price, yearly average (-4)	81.46	-132.7	25.43	-45.85	-31.83	-3.263	41.19	58.88
	(0.311)	(0.164)	(0.757)	(0.819)	(0.304)	(0.869)	(0.327)	(0.133)
Real WTI price, yearly average (-5)	67.33	-286.0***	84.34	313.2	-25.45	26.73*	-13.44	11.59
	(0.432)	(0.007)	(0.234)	(0.324)	(0.195)	(0.080)	(0.872)	(0.683)
Real WTI price, yearly average (-6)	50.10	-90.21	108.6**	71.21	-7.361	30.94***	13.01	3.501
	(0.568)	(0.312)	(0.023)	(0.822)	(0.723)	(0.002)	(0.818)	(0.867)
Real WTI price, yearly average (-7)	-12.70	-233.7**	51.86	-12.62	-0.607	29.56**	-17.20	12.93
	(0.859)	(0.022)	(0.423)	(0.950)	(0.972)	(0.011)	(0.611)	(0.629)
Real WTI price, yearly average (-8)	-23.84	34.37	72.92**	-168.2	1.964	10.27	-1.023	30.73***
	(0.604)	(0.598)	(0.032)	(0.280)	(0.890)	(0.203)	(0.976)	(0.005)
Real WTI price, yearly average (-9)	-20.21	12.24	4.559	-89.63	39.74**	-5.945	-42.45**	12.54
	(0.471)	(0.886)	(0.917)	(0.274)	(0.039)	(0.313)	(0.017)	(0.175)
Std. dev. (log price returns), quarterly average	783.0	12707.9***	1870.5	-29338.3**	1955.5	-403.5	-1468.6	339.8
	(0.679)	(0.007)	(0.637)	(0.035)	(0.118)	(0.629)	(0.604)	(0.842)
Std. dev. (log price returns), quarterly average (-1)	-1089.0	9212.3**	-3565.7	-30572.8**	-68.47	-529.7	-2018.4	1383.6
	(0.713)	(0.012)	(0.311)	(0.017)	(0.942)	(0.731)	(0.142)	(0.370)
Std. dev. (log price returns), quarterly average (-2)	-2555.5	5762.6	-1769.0	-20783.8	595.5	281.9	-1669.4	2340.7
	(0.682)	(0.386)	(0.512)	(0.380)	(0.777)	(0.839)	(0.330)	(0.257)
Std. dev. (log price returns), quarterly average (-3)	944.8	1955.5	-5636.8	-39457.5*	1361.4	-1271.6	-3172.5	-64.29
	(0.857)	(0.748)	(0.456)	(0.096)	(0.510)	(0.467)	(0.269)	(0.980)
Std. dev. (log price returns), yearly average (-1)	-5371.3	-4061.8	8283.8	-54445.3	5094.9	-64.49	-6210.9	1939.9
	(0.826)	(0.843)	(0.807)	(0.415)	(0.559)	(0.987)	(0.625)	(0.717)
Std. dev. (log price returns), yearly average (-2)	-4339.0	15954.4	7381.0	-21645.9	-1923.3	-3678.4**	1991.4	2594.7
	(0.858)	(0.462)	(0.577)	(0.358)	(0.831)	(0.044)	(0.693)	(0.519)
Std. dev. (log price returns), yearly average (-3)	-1369.2	22639.5	-32129.7***	-125878.2***	6637.0	-7656.3***	-2976.4	-2510.1
	(0.940)	(0.472)	(0.000)	(0.000)	(0.578)	(0.002)	(0.497)	(0.665)
Std. dev. (log price returns), yearly average (-4)	-6587.4	56011.4***	-4073.1	-105285.9***	12025.6*	437.0	-493.8	6338.3
	(0.716)	(0.000)	(0.701)	(0.006)	(0.055)	(0.924)	(0.947)	(0.185)
Std. dev. (log price returns), yearly average (-5)	-10943.8	45704.6***	-1921.7	-79307.2***	4586.2	2756.6	870.2	-1099.7
	(0.574)	(0.000)	(0.925)	(0.003)	(0.644)	(0.561)	(0.877)	(0.862)
Std. dev. (log price returns), yearly average (-6)	-5005.0	40151.9***	16694.8	-80911.3***	6351.8	1765.2	7888.9**	7989.3*
	(0.706)	(0.000)	(0.441)	(0.000)	(0.510)	(0.560)	(0.018)	(0.081)
Std. dev. (log price returns), yearly average (-7)	-4445.1	29229.8*	33174.1**	-101743.1***	9322.9	-207.6	2087.5	11842.0***
	(0.668)	(0.087)	(0.017)	(0.002)	(0.321)	(0.913)	(0.507)	(0.003)
Std. dev. (log price returns), yearly average (-8)	-16241.9**	35996.2***	26486.5*	-24464.9	3348.1	2752.8	5075.2**	4194.6
	(0.017)	(0.005)	(0.086)	(0.489)	(0.604)	(0.366)	(0.030)	(0.222)
Std. dev. (log price returns), yearly average (-9)	-2444.7	4469.4	-3550.4	2176.3	5549.3	2046.0**	-749.3	-4890.8
	(0.777)	(0.676)	(0.664)	(0.925)	(0.326)	(0.038)	(0.798)	(0.182)
Constant	1248.6	1725.9	-2125.4*	18149.5***	-1191.1	249.3	219.7	-850.0
	(0.549)	(0.531)	(0.090)	(0.000)	(0.371)	(0.652)	(0.698)	(0.305)
Observations	156	156	156	156	156	156	156	156
Mean share in group production	12.9%	13.5%	10.5%	39.8%	6.9%	5.7%	32.4%	14.6%

*, **, *** indicate significance at the 10%, 5% and 1% level, respectively; robust p-values in parentheses.

3.3 Non-OECD/non-OPEC

The non-OECD/non-OPEC group exhibits a positive relationship between changes in output and changes in price growth in the medium term. Again, this relationship is less clear when considering the country level (Table 5, columns 5-8). While oil output in China and Brazil shows a positive reaction to price changes, Russia exhibits significant revenue smoothing with respect to prices, and Indonesia is an intermediate case.

Only the non-OECD/non-OPEC group shows a positive relationship between price volatility and changes in output on the group level, possibly because the group represents producers which are less risk averse and may therefore increase production when price volatility rises. The results are less clear when considering the country level, especially for Indonesia. However, overall positive and significant coefficients dominate.

Thus, while exhibiting substantial heterogeneity in the reaction of output to price changes, the non-OECD/non-OPEC group seems to be more homogenous than OECD in responding to price volatility. The lower degree of risk aversion sets it apart from the others, further validating our division of the non-OPEC countries into OECD and non-OECD/non-OPEC groups.

4 Conclusions

In this paper we contribute to the empirical literature on the global crude oil market by providing a substantive empirical analysis of the dynamics of global production. We analyze the response of oil production to key global and local determinants of oil producers' output decisions, such as prices, price volatility, investment, real economic activity, the strength of the U.S. dollar and indicators of institutional quality, based on a rich dataset covering global crude oil production at monthly frequency. However, while controlling for important explanatory factors, we focus our analysis on oil prices and price volatility. We conduct the analysis for the three country groups, OPEC, OECD and non-OECD/non-OPEC, and for selected countries representing the majority of each group's oil production.

Based on a descriptive analysis we motivate the division of the countries in our sample into the three groups and then derive two hypotheses. To the best of our knowledge this is the first contribution that separates non-OPEC producers and provides individual analyses for all three groups. Our first hypothesis states that the proper modeling requires a dynamic model specification, since crude oil production responds to crude oil prices and price volatility not only in the current period, but over a range of lags, varying from the short term to the longer term. The second hypothesis states that the output response varies among the three groups of countries, as well as within each country group. Having specified a generous lag structure ranging from the current period to a lag of nine years, we find that oil output reacts to the entire lag spectrum of current and past prices and volatilities, which confirms the first hypothesis. Furthermore, substantial heterogeneity exists in the response of oil output in most cases, which confirms the second hypothesis.

Specifically, we find that OPEC production is consistent with price stabilization in the short term and with revenue smoothing in the medium to longer term. We also find strong evidence for price risk aversion in the oil output decisions of OPEC countries. The group of OECD countries exhibits a significantly higher degree of heterogeneity among its major oil producers. We find substantial evidence of revenue smoothing with respect to the oil price in the short to medium term. We also find a significant amount of aversion to price risk, with the exception of Norway. We find a largely positive

reaction of output to price changes across the major producers in the non-OECD/non-OPEC group. Furthermore, third group exhibits the least amount of aversion to price risk of our three groups.

In conclusion, OPEC output decisions appear to be better coordinated than those of either OECD or non-OECD/non-OPEC, although we note the coordination is imperfect. Also, substantial differences in the response of oil output, particularly its reaction to price volatility, validate separating the non-OPEC countries into two groups.

The implication for further research is straightforward. Oil production differs across countries, regardless of OPEC membership and thus, findings should not be generalized. We suggest that researchers should closely examine the rise of developing and non-industrialized countries for lessons learned. Finally, from a technical perspective, a simultaneous equation approach may be a useful step forward.

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