The relationship between oil prices, rig counts and tight oil production in the United States in the shale era

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Submitted to
Central European University
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In partial fulfillment of the requirements for the degree of
Master of Arts in Economic Policy in Global Markets

Budapest, Hungary
2018

Abstract

Since the beginning of an implementation of the hydraulic fracking and horizontal drilling techniques for extraction of a tight oil and shale gas from wells, the so called 'shale era' has started in the U.S. Its implication for the global energy market seems tremendous: some scholars indicate the surge of tight oil, as one of the major causes of the 2014-2015 plunge in oil prices. With rising importance of tight oil comes need for an assessment of the relationship between shale industry and global crude prices. Thus, this paper's aim was to evaluate the relationship between changes in oil prices, rigs counts and tight oil production in the U.S. in 2005-2018 while controlling for economic and financial variables. The VARX model was used to assess the relationship. The model was constructed based on Khalifa et al. (2017) with some adjustments. The results suggest that rig counts and tight oil output are responsive to the oil price shock. Though, the initial response is negative, the rig counts displayed statistically significant positive response with 2-month lag. This outcome is consistent with the literature and economic theory. Other key finding was that unlike common market believe the changes in rig counts and tight oil production do not have a direct and positive relationship. This outcome further strengthens the call to look beyond the rig counts when assessing the shale industry's 'health'. The changes in rig counts and oil output have only a minor impact on oil prices. But still the trend is negative, which is consistent with recent oil market developments.

Acknowledgements

First of all, I want to thank my mother for all her support and encouragement. Without her I would not be where I am right now.

I want to express my deepest gratitude for my supervisor Professor De Chiara for his guidance, patience and useful tips throughout the thesis writing process.

I also would like to thank Professor Bokros and Professor Horvath for their support, advices and interesting discussions held throughout these two years at CEU.

My genuine gratitude for Central European University, Open Society Foundation and George Soros for supporting young professionals to achieve their dreams and goals.

Thank you all so much!

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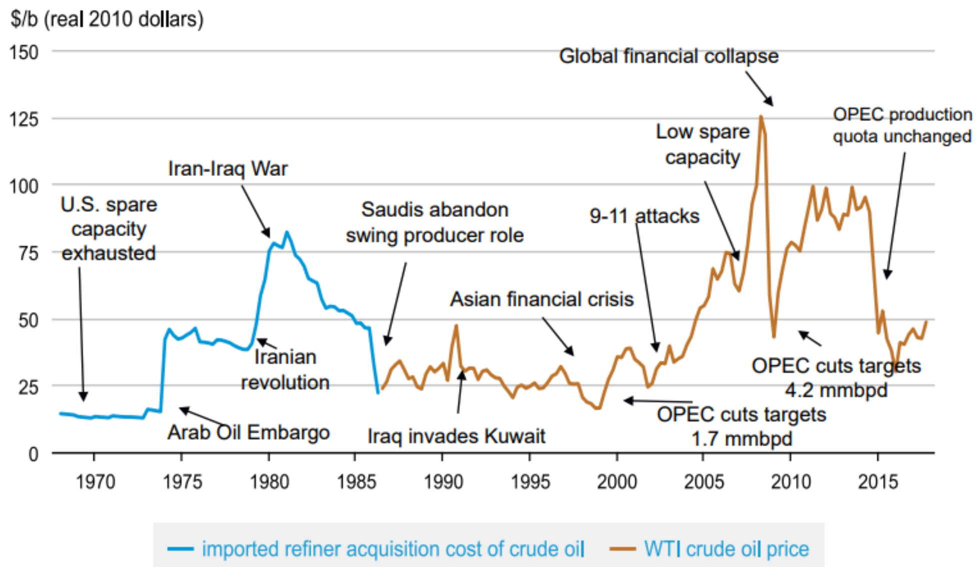
1. Introduction

If you follow the major business news outlets, like Bloomberg, Wall Street Journal and/or Forbes, you most certainly noticed that news from an oil industry (or, in this regard, an energy sector overall) are almost always on the front page. This is an understandable pattern: oil sector involves a tremendous amount of financial and human capital, it directly impacts global economic growth and development (Rentschler, 2013), and it shapes the countries' monetary and fiscal policies (Baffes et al., 2015). Other reason for close monitoring is the fact that the oil is one of the most volatile commodities in the world (Khalifa et al., 2017). Indeed, oil cost lower than $20 per barrel in late 1990s and reached $145 ten years later. These fluctuations seem to correspond with major geopolitical and economic events (see Figure 1). Though, the most recent oil plunge in oil prices has a particular pattern. Albeit there are still debates on the exact causes of this oil price drop in 2014-2015, the major consensus could be underscored on the following two supply related drivers: big top up of oil supply from the United States, which is mainly driven by an oil production from the unconventional sources (like a tight oil), and the Organization of Petroleum-Exporting Countries' decision to maintain the crude oil production level in late 2014.

The first cause, the rise of unconventional resources, has indeed gained momentum in recent years. Thus, according to the US Energy Information Administration (EIA), the US oil production increased by 1.2 million barrels per day (b/d) in 2014, which is the biggest increase in more than 100 years (EIA, 2015) and reached 9.42 million b/d in 2015 (EIA, 2016). The EIA's most recent Annual Energy Outlook (2018a) projects that the US will become the net energy exporter in 2022, which is a huge development, as the US has been the net importer of energy resources since 1953. The EIA attributes this transformation to the progress of the tight oil production.

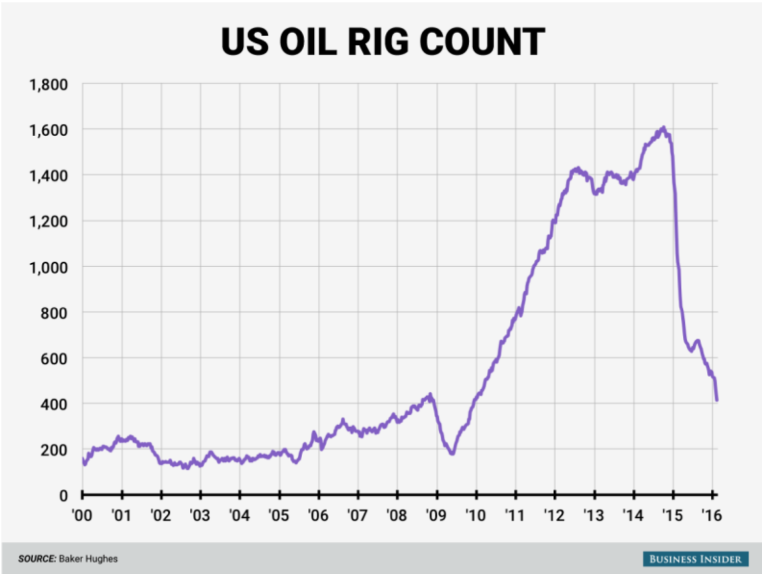
Figure 1. Crude oil prices and various geopolitical and economic events



Source: U.S. Energy Information Administration, Thomson Reuters. Retrieved from: *https://www.eia.gov/finance/markets/crudeoil/reports_presentations/crude.pdf*

The tight oil is one of the most prominent source of the unconventional oil. It is referred to as unconventional, as its extraction is more difficult and requires emergent technologies to produce the oil (Gordon, 2012). With discovery of the hydraulic fracturing and horizontal drilling the number of oil rigs has rapidly increased in the U.S. (for instance, there were 427 rigs in 2010, in September 2014 a peak of 1,601 rigs was reached. See Figure 2). Since then investors closely monitor the number of rigs (published by Baker Hughes), as it is considered to help to estimate the 'health' of the shale industry. The general economic perception is that with the increase of oil prices, the number of rigs would increase, which would lead in turn to increase of oil production levels and vice versa. However, the recent plunge in oil prices revealed that this pattern may not always be true: the rig counts sometimes may be in conflict with oil production levels – the former could be falling and the latter on contrary growing (see Figure 3). The technologic development is named as a primary cause of this trend: the tight oil producers learnt to boost production without adding additional rigs (Slav, 2018; Wethe, 2018). Thus, investors predisposed attention to the rig counts nowadays can be misleading (Terazono, 2015; Yager, 2017; Nibbelink, 2017). Hence, the EIA's reports on the tight oil production fluctuations could be a relevant addition to capture the developments in the shale industry.

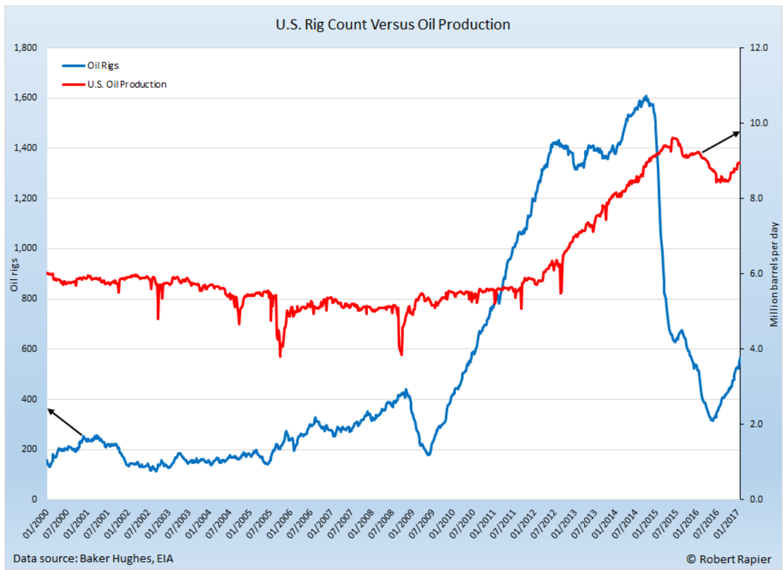
Figure 2. The rig count in the U.S.



Source: Baker Hughes, retrieved from: Business Insider, 2017.

This paper's aim is to study the relationship between the changes in the oil price, rig counts and tight oil production in the United States over the period of 2005 – 2018 while controlling for relevant economic and financial variables. Such exact period of the examination is set to capture relationship notably in the 'shale era', i.e. when hydraulic fracking and horizontal drilling techniques have been adopted in the tight oil production (and consequently the tight oil producers started to gain 'weight' in the global oil markets). The Vector Autoregressive with the exogenous variables (VARX) model has been used to assess the relationship. VARX model was constructed similar to one developed in Khalifa et al (2017). The key adjustments to the model was the inclusion of the tight oil production among endogenous variables. This was a necessary step, as the industry, due to technological development, demands to look beyond rig counts during the exploration of the relationship between the oil prices and the shale industry.

Figure 3. Rig count and Oil production in the United States



Source: Rapier, 2017. Retrieved from: http://www.energytrendsinsider.com/2017/02/06/can-u-s-shale-oil-offset-opec-production-cuts/

The understanding of the nature of the relationship should help to better estimate the oil price fluctuations and its impact on the shale industry and vice versa. The shale industry proved to be a resilient market player, thus it is crucial to capture the trends between the global crude oil prices and the shale industry's key indicators, like: rig counts and tight oil output. The findings should further contribute to the understanding of the developing relationship between rig counts, tight oil production levels and global oil prices. Outcomes will be beneficial for investors and analysts to adjust their forecasts and investment plans and for policymakers to adopt timely an appropriate tax and retraining policy agendas.

The paper has the following structure. Section 2 shares light to the shale industry's key aspects and features. Section 3 discusses the related literature. Section 4 describes the data used for the study: its source and initial descriptive analysis. Section 5 is dedicated for Methodology discussion. The estimated results and discussion are in Section 6. Section 7 contains the Conclusion.

2. Background

Aim of this section is to introduce readers with the US shale industry, its basic terms and features.

Shale Revolution and Hydraulic fracturing

The US sought independence from oil imports since World War II. Especially this vulnerability was highlighted during the oil embargo imposed by OPEC in 1970s against the countries allegedly supporting Israel. The oil price has hiked and negatively affected the US economy, which was one of the major oil importers at that time.

The oil and gas production boom in the US in 2000s helped to mend this weakness and strengthened the US position in the energy market. This boom is now referred to as a 'shale revolution'. The major facilitator of massive gains in oil production was an adoption of hydraulic fracturing and horizontal drilling technique in oil and gas extraction process (Brown and Yucel, 2013).

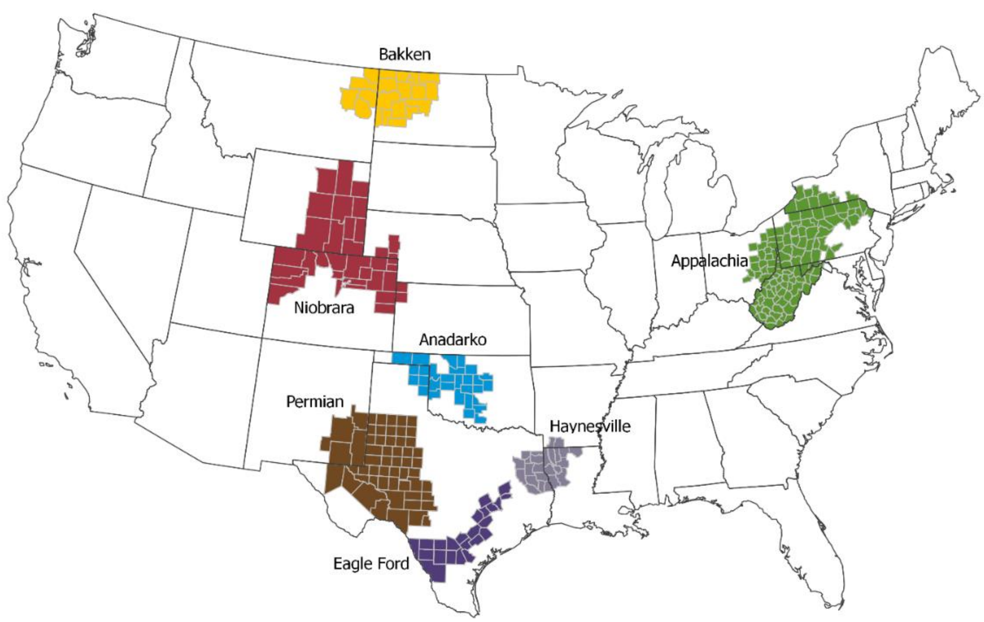
It is important to understand that hydraulic fracturing or 'fracking' is not a drilling technology. Its key function involves the boost of the hydrocarbons' flow from well, after it was drilled and the drilling rig has been removed from site (Larkin, 2016). Fracking is the process, which produces fractures in the shale rock formation by pumping a huge quantities of fluids (predominantly water mixed with sand and chemicals) at high pressure down a wellbore and into the shale formation. This technique stimulates the flow of hydrocarbons from these formations (for more information on fracking, please see Larkin[1], 2016).

[1] The current paper provides the basic information regarding the hydraulic fracturing (which is sufficient for goals of the study). If you are interested to learn more about fracking technology, I highly recommend to read "Hydraulic Fracturing" article written by Stephen Larkin (2016).

Major regions of tight oil production in the United States

Tight oil is predominantly produced in Bakken, Eagle Ford, Haynesville, Marcellus, Niobrara, Permian, and Utica basins, which spread across fifteen States (see Figure 4). The Permian basin, which is located in Texas, is one of the oldest oil fields and a modern center of the tight oil production. According to EIA (2018b), it accounted for 36% of U.S. tight oil production in 2017. It once was a major source of conventional crude oil production with a peak reached in 1973 (2.1 million barrels per day). Since then the crude oil production from conventional sources was gradually declining in the region. The new life was brought to the field, when the fracking and horizontal drilling techniques have been used to produce tight oil from old reservoirs. Notably due to "the developed existing oil infrastructure and the proximity of major pipelines and low breakeven prices" the production of unconventional oil from the Permian basin showed the most resilience to low oil prices in 2014-2015 among all other tight oil plays (Strpić et al. 2017, p.24).

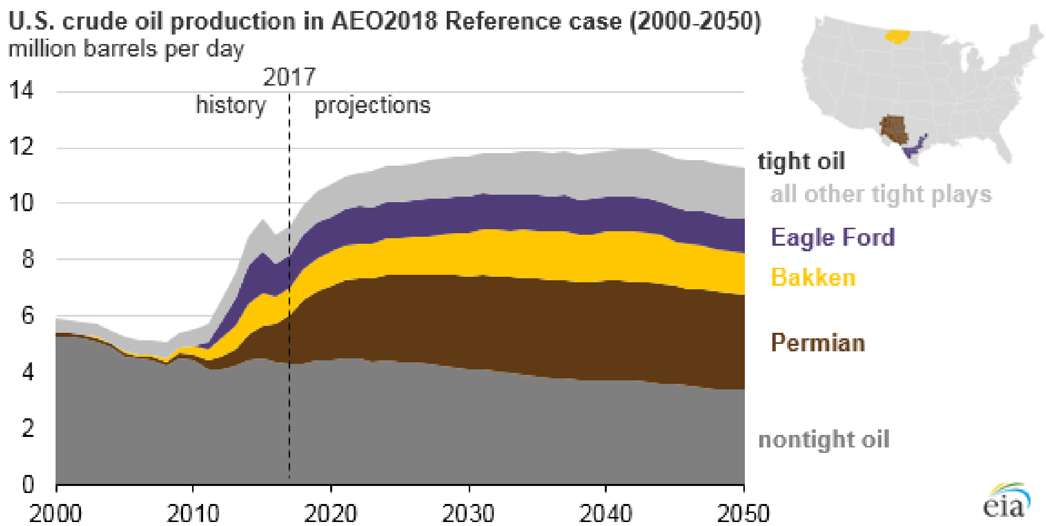
Figure 4. Seven major areas of tight oil production



Source: U.S. Energy Information Administration, 2018

Figure 5 displays the current share of the major plays in the total oil production in the country. Permian is projected to only increase its production volumes, while two other key tight oil fields, Bakken and Eagle Ford, should maintain current production levels up to 2050.

Figure 5. Oil production share in the US since 2000 (with projections).



Source: U.S. Energy Information Administration, 2018

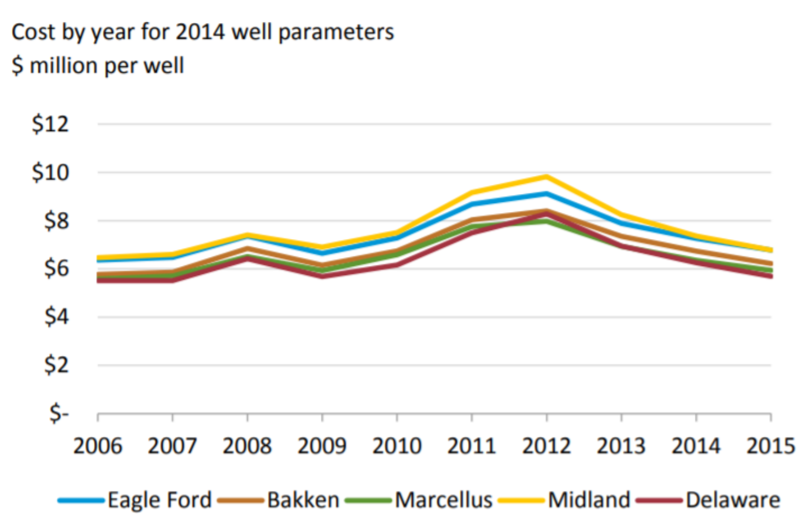
Prices, costs and productivity

As an unconventional oil is produced by independent oil companies in the United States, the oil price and cost of production are always of a key focus of these companies. The whole process of exploring, drilling and fracking wells demands large investments. The funds are usually borrowed from banks and/or market. Hence, most of these companies are highly indebted, and which in turn makes them a quite sensitive to the oil price fluctuations (Flores et al., 2011). On top of that the tight oil well's productivity period lasts only around 5 years (after that productivity falls by 90%), while conventional oil projects can produce the stable flow of oil for decades (Strpić et al. 2017).

But EIA's projections (2018b) are still optimistic on future tight oil production levels. There several reasons for that. First of all, the shale industry is evolving: it is adopting new technologies, improving well designs and developing best practices (EIA, 2016), which helps them to adjust and function even during low oil price environment. Thus, IHS (2015) in the study commissioned by EIA, reports that average well drilling and completion costs has decreased by 25% - 30% in 2015 in comparison with 2012 levels (see Figure 6).

Also, during downturns (like the 2014-2015 plunge in oil prices) the unconventional oil producers proved to be more flexible and their capital expenditures can be turned on and off relatively quickly (IHS, 2015). Additionally, the drilling costs in general, due to adoption of the hydraulic fracturing technique, has also decreased: "[a]verage horizontal well drilling costs range from $1.8 million to $2.6 million and account for 27% to 38% of a well's total cost. Before the expansion of horizontal drilling within unconventional plays, drilling costs ranged from 60% to as much as 80% of a well's cost" (IHS, 2015, p.7)

Figure 6. Average well drilling and completion costs for the 5 onshore plays



Source: U.S. Energy Information Administration, 2016

This all reflected in an apparent resurgence of the tight oil producers after the 2014-2015 drop of oil prices, which echoed by today's rig counts increase.

Overall, the US tight oil producers' adaptability and resilience to the oil price fluctuations only stresses the shale industry's role as an important factor in the energy market and thus, reinforces the significance of the current study.

3. Literature Review

This section discusses the relevant previous studies on the topic. Given the relatively recent rise of the shale industry, the relevant literature is proved to be scarce. Below are highlighted the key works, which are important for current study.

One of the most prominent studies on oil price/rig counts relationship are done by Ringlund et al (2008). Authors investigated the impact of the crude oil price change to the number of rigs in the non-OPEC countries using dynamic regression models. The study revealed the positive relationship between these variables in the long run. Thus, with increase of oil price, the oil rig activity enhances as well. But the extent of the impact varies across the regions. For example, the US and Canada showed faster and stronger reaction of the rig activity to the oil price change than their European counterparts in general. Authors explain such pattern with the fact that the oil production is carried out by private companies in these countries. Indeed, to be self-sustainable – the oil companies have to get more adaptive to the oil price fluctuations. Other possible cause mentioned is almost a full absence of government restrictions on oil companies' activities (at least in the US). To support this argument, even the 40-year-old ban on oil export in the US was lifted in December 2015. Meanwhile, other non-OPEC countries, except for some countries in Latin America (which also have a dominance of the private firms in the oil sector), have mostly the state oil companies running the oil production – hence there are a slower response to the price change. Ringlund et al. elaborate that with government control there are two stages in the decision–making process: first, company's management proposes action and only after government's approval, may this decision actually be implemented.

The more recent study on the rig counts and oil prices relationship is carried out by Khalifa et al. (2017). Authors used two models to test the relationship, notably: Vector autoregressive model with exogenous variables (which we replicate with adjustments in current study) and quantile regression methods to capture potential non-linearity. The sample covered the period of 1990 – 2015. The study revealed the positive lagged interaction between variables. Thus, the change in oil prices had a positive impact on rig counts, but with lag up to 1 quarter. The authors attribute such behavior to the importance of the size of the oil revenues on drilling activity. The central finding relevant for this paper was that the relationship showed signs of a linearity notably since 2005 and onwards. Before that, the relationship proved to be weaker and unstable. The authors explain such drastic difference with the development of a shale oil fracking in the industry in 2000s.

Furthermore, Toews and Naumov (2015) share light to the relationship between changes in oil prices, oil drilling activity (rig counts) and cost of drilling. They used the three-dimensional SVAR model to assess the impact of structural shocks on endogenous variables. The study reveals that the increase in oil prices positively affects drilling activity and cost of drilling with a lag of 1 year. However, drilling activity and cost of drilling shocks showed no significant impact on oil price.

Kellogg (2014) during his examination of the oil drilling activity in Texas has found out that during periods of high expected oil price volatility, the oil drilling activity decreases in accordance with the forecasts of real options theory. The notion of the real options theory is very fascinating. In essence it is about the firm's decision on investments, which involve sunk costs. Naturally, there are two possible options involved: to invest right away or delay investment. The theory dictates that:

> "[F]irms should delay irreversible investments until a significant gap develops between the investments' expected benefits and costs. Moreover, as uncertainty increases, real options theory tells us that the incentive to delay should grow

> stronger and the gap between the expected benefit and cost necessary to trigger investment should widen." (Kellogg, 2014, p. 1689)

Thus, Kellogg (2014) revealed that the oil producers' behavior in Texas (the major tight oil production region) is actually similar to the behavior prescribed by theory during the uncertain environment, i.e. oil price volatility.

Furthermore, Agerton et al. (2015) studied the relationship between changes in drilling activity and employment rate. Using time-series methods at the national level and dynamic panel methods at the state level they found that increase of rig counts has positive and statistically significant impact on employment rate. They report that addition of 1 new rig leads to initial 37 jobs creation and up to 224 new jobs in the long run.

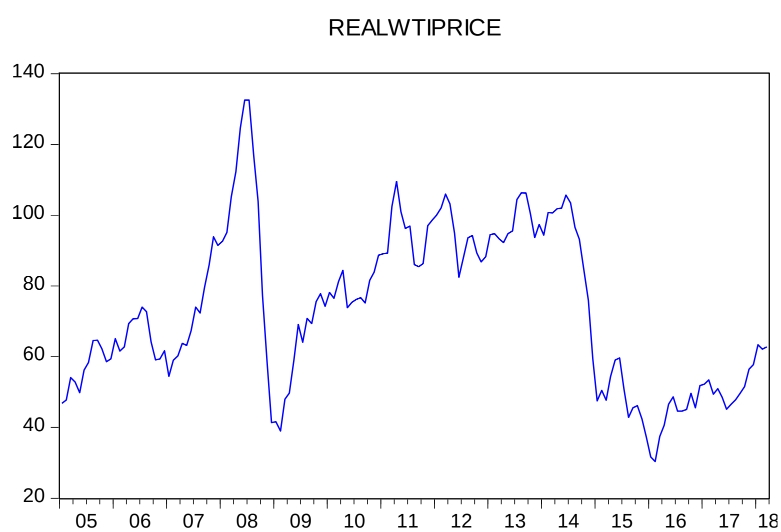
4. Data

The primary source of data was the Federal Reserve Bank of St. Louis. All datasets were downloaded in an Excel file and imported into EViews. Timeframe was purposefully narrowed to January 2015 - March 2018, as the goal of the thesis is to capture the relationship namely during the 'rise' of the shale industry.

The study included the following variables:

Real Oil price (WTI). West Texas Intermediate is a grade of the crude oil, which together with Brent Crude, is one of the world's leading benchmark in oil pricing. The nominal spot price of WTI crude oil was derived from Federal Reserve Bank of St. Louis. The period was taken between January 2005 and March 2018. The data later was transformed to the real values by dividing the nominal numbers to consumer price index (also derived from the Federal Reserve Bank of St. Louis database). Figure 7 depicts the fluctuations of the oil prices throughout the last 13 years.

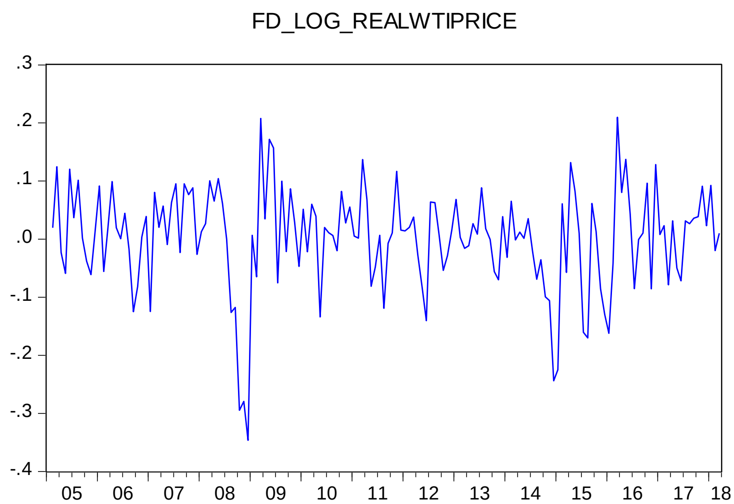
Figure 7. The Real oil price (WTI grade) 2005-2018



It is clearly visible, that the biggest swings in oil prices involve the global financial crisis in 2008-2009 and the oil price plunge of 2014.

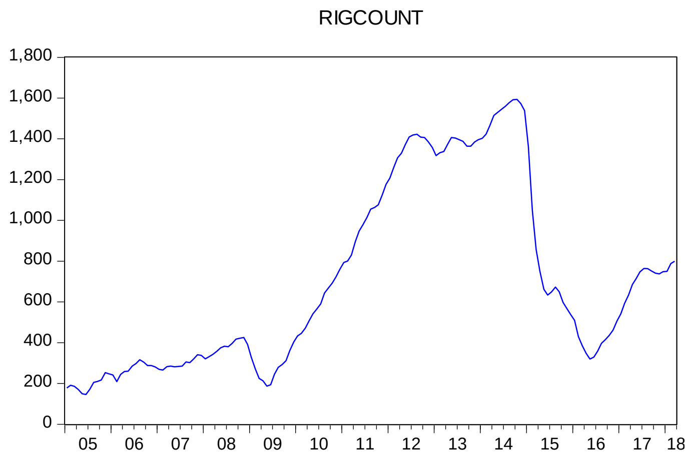
The standard tests for a presence of unit roots showed that the time series are not stationary. Taking the log and first differences helped to resolve the issue and the series became stationary (see Figure 8).

Figure 8. The Real oil price (WTI grade) in natural logarithmic terms and first differences



Rig counts. The dataset was downloaded from Baker Hughes, which started to estimate the rotary rig counts from 1944. The rotary rigs are the installations, which rotate "the drill pipe from surface to drill a new well (or sidetracking an existing one) to explore for, develop and produce oil or natural gas" (Baker Hughes, Rig Count FAQ, n.d.). What is important is that the Baker Hughes Rotary Rig count includes only those rigs that are "significant consumers of oilfield services and supplies and does not include cable tool rigs, very small truck mounted rigs or rigs that can operate without a permit" (Baker Hughes, Rig Count FAQ, n.d.). Thus, the data contains only legally set and well established rigs. Figure 9 shows the change of the number of the rotary rigs in the U.S. between the period of 2005-2018.

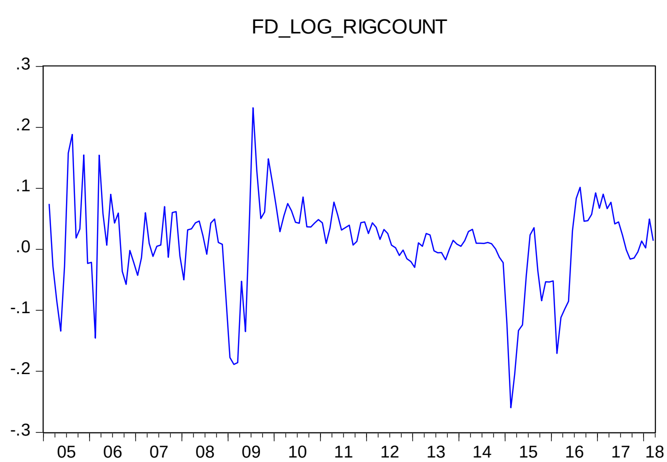
Figure 9. The number of oil rigs in the U.S. in 2005 – 2018



Since 2005 the number of rigs were gradually increasing up until the global financial crisis, which cause the relatively small plunge in numbers. However, after the downturn the oil rig counts has recovered quickly and reached the maximum number of 1,601 rigs in October, 2014. This period was followed with a harsh drop in numbers in 2014 and 2015. The numbers started to gradually recover and now are at 700-800 levels.

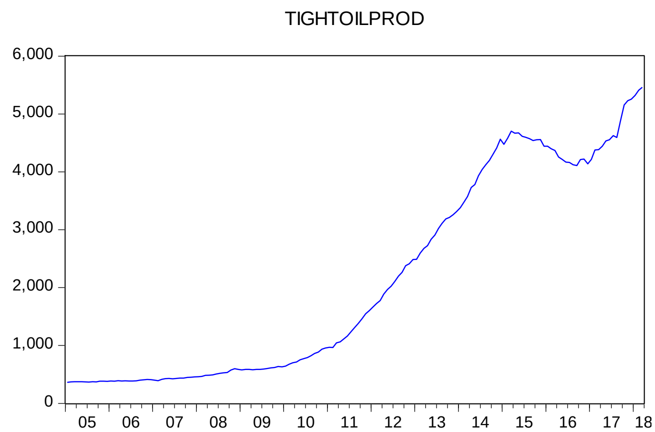
The data required taking the natural logarithm and first differences in order for series to become stationary (see Figure 10).

Figure 10. Rig counts in natural logarithmic terms and first differences



Tight oil production in the U.S. The source of data is the U.S. Energy Information Agency (EIA). As per EIA's definition the tight oil is a "[o]il produced from petroleum-bearing formations with low permeability such as the Eagle Ford, the Bakken, and other formations that must be hydraulically fractured to produce oil at commercial rates" (EIA, Glossary, n.d.). The EIA has begun to publish the monthly production data since 2000. The numbers are derived and aggregated from state administrative data. The tight oil production levels throughout 2005 – 2018 period are shown in Figure 11.

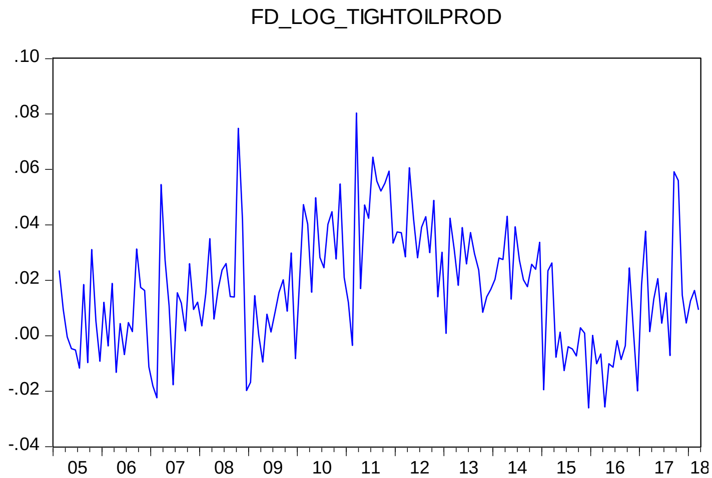
Figure 11. The tight oil production estimates 2005-2018



It is interesting that the tight oil production did not show noticeable reaction to the global financial crisis. The most probable reason, in my opinion, is that production levels were quite small and insignificant, thus the reaction was limited. The situation has changed after 2010. The tight oil output began to increase significantly. At this point the tight oil production mimics the rig counts surge, but there is a stark difference. While the rig counts have slumped sharply after the oil prices collapsed in 2014, the tight oil production was still showing upward trend in the same year and only started to decrease in 2015. Such behavior only reinforces the importance of understanding the relationship between these variables.

The unit root tests showed that we cannot reject the Null hypothesis of non-stationarity. Taking the natural log and first differences helped to resolve the issue. The stationary time series is displayed in Figure 12.

Figure 12. Tight oil production in natural log terms and first differences

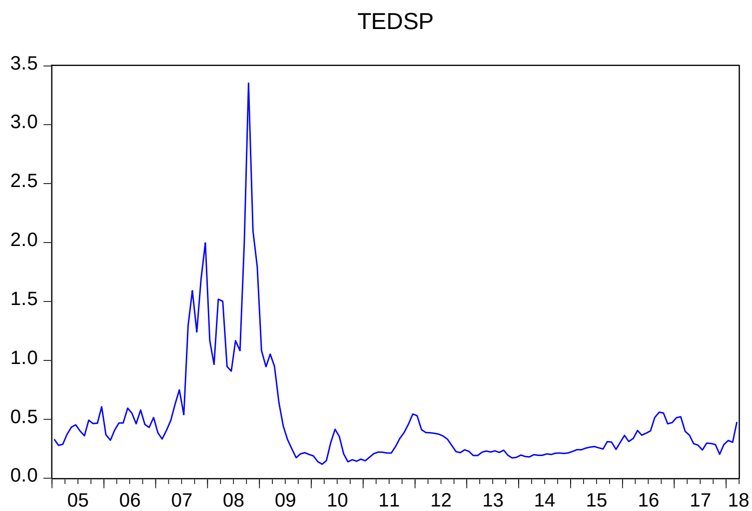


FED funds rate. The data was derived from the Federal Reserve Bank of St. Louis. The federal funds rate is the interest rate at which banks trade federal funds (balances held at Federal Reserve Banks) with each other overnight. This is the arm of conventional monetary policy (Khalifa et al., 2017), as the U.S. Fed increases the interest rates during the economic expansion to cool off the inflation rate and decreases rates during the economic slump. The unit root tests showed that the time series are not stationary. Taking the first differences made the series stationary. The same procedure was done with the next variables.

The National financial condition index. The data was retrieved from the Federal Reserve Bank of St. Louis. The National Financial Conditions Index (NFCI) is prepared by the Federal Reserve Bank of Chicago (Chicago Fed) and reflects the U.S. financial conditions in money markets, debt and equity markets and the banking system. This index encompasses overall 105 measures of the financial activity and published weekly by Chicago Fed.

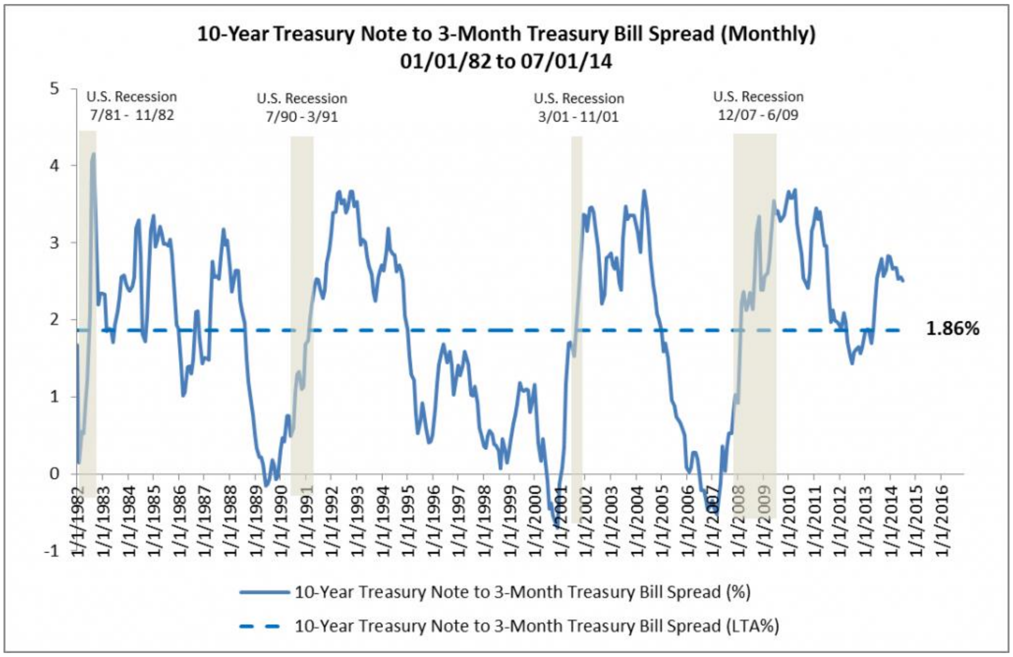
TED Spread. The source of data is the Federal Reserve Bank of St. Louis. This variable reflects the difference between 3-month London Inter-bank Offered Rate (LIBOR) and Treasury bills based on US dollars. In basic terms, this is the measure of the world financial and economic health (Rudra, 2010), as the increasing spread indicates the uncertainties within the financial market. Thus, the U.S. Treasury bills are considered as risk-free investments, meanwhile an investment in banks typically involve a higher risk, hence the yield is also higher. The TED spread usually is within 10-50 basis points boundaries. When it is higher, it may point to fact that banks are reluctant to lend to one another. This happened during the global financial crisis in 2008-2009 (see Figure 13), when the spread hiked to almost 350 basis points.

Figure 13. TED Spread. 2005-2018



Term Spread. The data source is the Federal Reserve Bank of St. Louis. The Term Spread is difference between 10-Year Treasury Constant Maturity and 3-Month Treasury Constant Maturity. Usually the long-term interest rates are higher than short-term interest rates, therefore the term spread is typically positive. However, if the term spread becomes negative, it tends to point to an upcoming recession and macroeconomic upheaval (see Figure 14). Indeed, the negative term spread has preceded all three latest financial recessions. Thus, the investors and economists are closely following the interest rate spreads.

Figure 14. Historic Term Spread from 1982 – 2016



Source: Peshut, 2014. Retrieved from: *http://realforecasts.com/why-do-yield-curves-of-treasury-securities-forecast-business-cycles-so-well/*

5. Methodology

5.1. Model

The relationship between the changes in oil prices, rig counts and tight oil production will be tested using the Vector Autoregressive with eXogenous variables (VARX) model. As mentioned previously, we adopt the model developed by Khalifa et al. (2017) and extend it by including the tight oil production among the endogenous variables, hence making it more relevant to current oil market developments. Additionally, as the examination period covers the 2008-2009 global financial crisis, a dummy controlling for it was added as well.

Thus, the following model will be estimated:

$$\begin{bmatrix} \Delta Rig_t \\ \Delta TProd_t \\ \Delta OilPr_t \end{bmatrix} = \alpha + \sum_{i=1}^{3} h_i + \begin{bmatrix} \Delta Rig_{t-i} \\ \Delta TProd_{t-i} \\ \Delta OilPr_{t-i} \end{bmatrix} + \beta[\Delta FedR_{t-1}\ \Delta FinInd_{t-1}\ \Delta TedSp_{t-1}\ \Delta TermSp_{t-1}] + \varepsilon_t$$

where α is three-components vector of means, and each h_i is a 3x3 matrix of autoregressive coefficients, while β is a 3x4 matrix of coefficients controlling the covariates' impacts.

Horvath (2003) provides a quite comprehensive assessment of the VARX models:

> "Ideally all considered variables are treated as endogenous and exogeneity should be tested during the model-building process. However, this requires a start from the most general VAR setting, which is often not feasible. The common practice… is to allow the most relevant variables to be endogenous and to control for the effects of other variables by considering them exogenously… This, i.e. the imposition of exogeneity, can imply a reduction of the number of parameters and also an improved precision of forecasting." (Horvath, 2003, p. 57)

The endogenous variables of current model, aside the changes (first difference) in tight oil production ($\Delta TProd_t$), are changes in rig counts (ΔRig_t) and changes in real oil prices ($\Delta OilPr_t$). The exogenous variables include the changes in Fed funds rate ($\Delta FedR_{t-1}$), in National Financial Condition Index ($\Delta FinInd_{t-1}$), in TED Spread ($\Delta TedSp_{t-1}$) and in Term

Spread ($\Delta TermSp_{t-1}$). According to Khalifa et al. (2017), these covariates "reflect the relevant variables in the oil industry, the conventional monetary policy and financial risk and stress variables" (Khakifa et al., 2017), which theoretically should have an impact on all three endogenous variables of the model. Indeed, investors and traders are cautious and follow almost every relevant financial and economic indicator, which impacts their investment decisions (whether, for example, to short or long the shares of oil companies), which in turn cause substantial moves in the futures markets and hence, affects the oil prices.

5.2. Impulse Response Analysis

The coefficients of estimated VAR models are usually considered as of little use by themselves (Horvath, 2003). Instead, the Impulse Response Functions (IRF) are used to assess the relationship. Pioneered this approach Christopher Sims (1980). In basic terms, IRF describes "the evolution of the variable of interest along a specified time horizon after a shock in a given moment" (Alloza, 2017). According to Horvath (2003), IRF seeks the answer for the following question: "What is the effect of a shock of size δ in the system at time t on the state of the system at time t + τ , in the absence of other shocks?" (Horvath, 2003).

In this study we will estimate the impulse responses of endogenous variables to Cholesky one standard deviation innovations of variables increase with +/- 2 standard error bands controlling for exogenous variables.

5.3. Residuals Tests

The standard VAR model checks will be conducted in this paper.

First, I will run Langrage Multiplier (LM) test to check for autocorrelation in errors. The null hypothesis of the test is that there is no serial correlation up to specified order. If test proves no autocorrelation in residuals, then the produced coefficient can be considered efficient.

Further, I will run the Jarque-Bera test to check whether residuals are normally distributed or not. It is important to note though that a non-normal distribution will not necessarily mean inconsistency of the model, however it may impact the p-values.

6. Estimated Results and Discussion

Based on the Akaike information criterion, sequential modified LR test statistic and Final prediction error (see Table 1), 7 lags have been selected as an optimal number for the model. The results of the VARX model are shown in the Table 2. As the estimates of the VAR models do not describe much by itself, we go straight to interpretation of the Impulse Response Functions.

Table 1. VARX Lag selection criteria

VAR Lag Order Selection Criteria
Endogenous variables: FD_LOG_REALWTIPRICE FD_LOG_RIGCOUNT FD_LOG_TIGHTOILPROD
Exogenous variables: FD_FEDRATE FD_NFINCONIN FD_TEDSP FD_TERMSPREAD FINCRISDUM C
Sample: 2005M01 2018M03
Included observations: 148

Lag	LogL	LR	FPE	AIC	SC	HQ
0	736.0932	NA	1.23e-08	-9.703962	-9.339437	-9.555856
1	806.3405	131.9509	5.36e-09	-10.53163	-9.984839*	-10.30947
2	828.5318	40.78401	4.49e-09	-10.70989	-9.980837	-10.41368*
3	842.5940	25.27395	4.19e-09	-10.77830	-9.866982	-10.40803
4	856.8961	25.12536	3.91e-09	-10.84995	-9.756370	-10.40563
5	863.5879	11.48460	4.04e-09	-10.81876	-9.542915	-10.30038
6	878.3975	24.81613	3.75e-09	-10.89726	-9.439160	-10.30484
7	893.6222	24.89446*	3.46e-09*	-10.98138*	-9.341015	-10.31490
8	899.8004	9.851682	3.61e-09	-10.94325	-9.120620	-10.20272
9	904.3069	7.003340	3.86e-09	-10.88253	-8.877634	-10.06794
10	908.2338	5.943434	4.16e-09	-10.81397	-8.626815	-9.925334

* indicates lag order selected by the criterion
LR: sequential modified LR test statistic (each test at 5% level)
FPE: Final prediction error
AIC: Akaike information criterion
SC: Schwarz information criterion
HQ: Hannan-Quinn information criterion

Table 2. VARX model estimated results

Vector Autoregression Estimates
Sample (adjusted): 2005M09 2018M03
Included observations: 151 after adjustments
Standard errors in ( ) & t-statistics in [ ]

	FD_LOG_REALWTIPRICE	FD_LOG_RIGCOUNT	FD_LOG_TIGHTOILPROD
FD_LOG_REALWTIPRICE(-1)	0.172760	0.132306	0.049884
	(0.08138)	(0.04402)	(0.01739)
	[2.12295]	[3.00537]	[2.86929]
FD_LOG_REALWTIPRICE(-2)	0.161874	0.159589	0.003040
	(0.08444)	(0.04568)	(0.01804)
	[1.91705]	[3.49368]	[0.16850]
FD_LOG_REALWTIPRICE(-3)	-0.126062	0.167534	-0.017141
	(0.09023)	(0.04881)	(0.01928)
	[-1.39705]	[3.43206]	[-0.88913]
FD_LOG_REALWTIPRICE(-4)	0.135596	0.139647	0.009274
	(0.09505)	(0.05142)	(0.02031)
	[1.42655]	[2.71578]	[0.45670]
FD_LOG_REALWTIPRICE(-5)	0.124848	0.032028	0.008577
	(0.09711)	(0.05254)	(0.02075)
	[1.28558]	[0.60963]	[0.41341]
FD_LOG_REALWTIPRICE(-6)	-0.049498	-0.068482	-0.047391
	(0.09498)	(0.05138)	(0.02029)
	[-0.52112]	[-1.33274]	[-2.33536]
FD_LOG_REALWTIPRICE(-7)	0.158356	0.049129	-0.017993
	(0.09628)	(0.05209)	(0.02057)
	[1.64467]	[0.94320]	[-0.87469]
FD_LOG_RIGCOUNT(-1)	-0.141178	0.339030	-0.007689
	(0.15519)	(0.08395)	(0.03316)
	[-0.90970]	[4.03824]	[-0.23191]
FD_LOG_RIGCOUNT(-2)	0.064969	-0.002553	0.091084
	(0.16046)	(0.08680)	(0.03428)
	[0.40489]	[-0.02941]	[2.65701]
FD_LOG_RIGCOUNT(-3)	-0.247664	0.049113	0.034702
	(0.15431)	(0.08348)	(0.03297)
	[-1.60497]	[0.58833]	[1.05262]
FD_LOG_RIGCOUNT(-4)	0.070346	0.176488	0.070097
	(0.14682)	(0.07943)	(0.03137)
	[0.47912]	[2.22197]	[2.23466]
FD_LOG_RIGCOUNT(-5)	0.033469	0.017056	-0.013338
	(0.14504)	(0.07846)	(0.03099)
	[0.23076]	[0.21737]	[-0.43045]
FD_LOG_RIGCOUNT(-6)	-0.035115	-0.275686	-0.034564
	(0.14323)	(0.07749)	(0.03060)
	[-0.24516]	[-3.55791]	[-1.12953]
FD_LOG_RIGCOUNT(-7)	0.155901	0.184354	0.034560
	(0.12120)	(0.06557)	(0.02589)

	[1.28631]	[2.81172]	[1.33471]
FD_LOG_TIGHTOILPROD(-1)	-0.080976	0.112499	-0.010863
	(0.40407)	(0.21859)	(0.08633)
	[-0.20040]	[0.51465]	[-0.12584]
FD_LOG_TIGHTOILPROD(-2)	-0.104027	0.059466	0.023878
	(0.37991)	(0.20552)	(0.08116)
	[-0.27382]	[0.28935]	[0.29419]
FD_LOG_TIGHTOILPROD(-3)	-0.019654	-0.001814	0.023942
	(0.37130)	(0.20086)	(0.07933)
	[-0.05293]	[-0.00903]	[0.30181]
FD_LOG_TIGHTOILPROD(-4)	0.093440	-0.000376	0.168761
	(0.35768)	(0.19350)	(0.07642)
	[0.26124]	[-0.00194]	[2.20846]
FD_LOG_TIGHTOILPROD(-5)	-0.045393	0.428478	0.069303
	(0.36458)	(0.19723)	(0.07789)
	[-0.12451]	[2.17251]	[0.88977]
FD_LOG_TIGHTOILPROD(-6)	-0.012477	-0.335452	0.235805
	(0.36930)	(0.19978)	(0.07890)
	[-0.03379]	[-1.67907]	[2.98869]
FD_LOG_TIGHTOILPROD(-7)	-0.148016	-0.320054	0.150910
	(0.40444)	(0.21879)	(0.08641)
	[-0.36597]	[-1.46281]	[1.74651]
FD_FEDRATE	0.105816	-0.095414	-0.037717
	(0.06942)	(0.03756)	(0.01483)
	[1.52426]	[-2.54064]	[-2.54309]
FD_NFINCONIN	-0.303735	-0.034715	0.040876
	(0.07101)	(0.03841)	(0.01517)
	[-4.27737]	[-0.90370]	[2.69437]
FD_TEDSP	0.056734	0.005383	-0.005516
	(0.04035)	(0.02183)	(0.00862)
	[1.40620]	[0.24663]	[-0.63990]
FD_TERMSPREAD	0.139247	-0.007168	-0.006307
	(0.03448)	(0.01865)	(0.00737)
	[4.03849]	[-0.38430]	[-0.85614]
FINCRISDUM	0.027793	-0.031572	-0.013213
	(0.02402)	(0.01299)	(0.00513)
	[1.15728]	[-2.43009]	[-2.57528]
C	0.003298	0.007291	0.005942
	(0.01049)	(0.00568)	(0.00224)
	[0.31423]	[1.28424]	[2.65043]
R-squared	0.426670	0.725779	0.563064
Adj. R-squared	0.306455	0.668281	0.471449
Sum sq. resids	0.681303	0.199387	0.031097
S.E. equation	0.074124	0.040099	0.015836
F-statistic	3.549237	12.62267	6.145946
Log likelihood	193.5179	286.2894	426.5787
Akaike AIC	-2.205535	-3.434296	-5.292433
Schwarz SC	-1.666021	-2.894783	-4.752920
Mean dependent	-0.000188	0.008988	0.017751
S.D. dependent	0.089007	0.069623	0.021782

6.1. Impulse Response Functions

Figure 15 depicts the Impulse responses of endogenous variables to one standard deviation innovations of real oil price increase with +/- 2 standard error band. The rig counts' response to oil price increase indicates an interesting trend. The first reaction is that the rig counts decreases, though the result is small and insignificant. However, after first month the relationship becomes positive and significant, which is consistent with literature and economic theory. The possible explanation for lagged positive response is that the private oil companies in the US want to be certain that oil price increase is not episodic and a long stable trend (Khalifa et al., 2017). This is also consistent with the real options theory: during the uncertain environment (like after oil price shock), firms put on hold the investments until the gap between expected benefits from investment and its costs is sufficiently wide enough (Kellogg, 2014). We should not forget also that it takes time to set up a new rig (Osmundsen et al., 2008).

Moving on, the tight oil production responds positively to the oil price shock, though response has its peculiarity. Thus, the first reaction is positive, then by 4th month the tight oil output returns to pre-shock equilibrium. After this, the tight oil output starts to increase again and the response is statistically significant. The peak is reached by 2 quarter after this the effect remains positive. Such uneven response is also reasonable. First of all, we learnt that oil companies adopted the technology that allows them to increase the production without actual increase in number of rigs (Slav, 2018; Wethe, 2018). Hence, the initial increase is most probably caused by this prop-up of production from the existing rigs (which require less investment than establishment of the actual new rig). The statistically significant increase of tight oil production after 4th month should be the outcome of addition of new rigs (when the oil companies became certain that increase is a forming trend).

Figure 15. Impulse Responses to one standard deviation innovations of real oil price increase

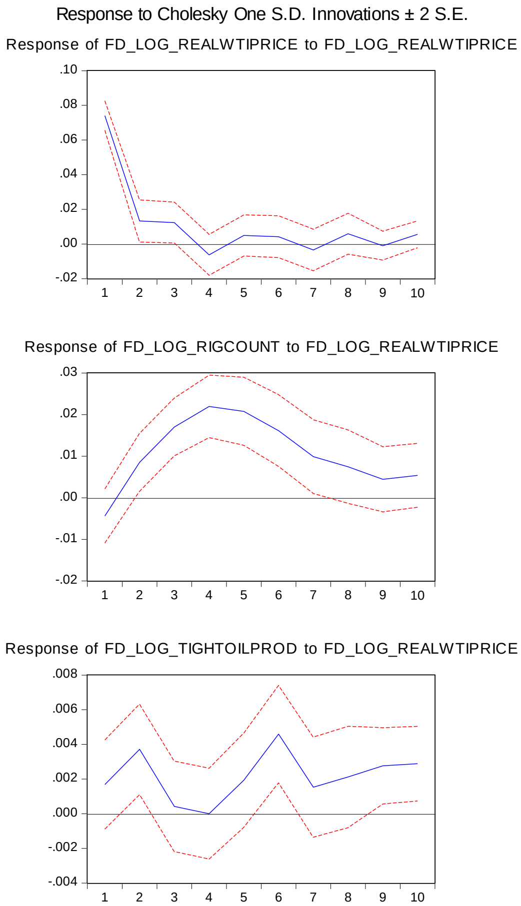


Figure 16. Impulse Responses to one standard deviation innovations of rig counts increase

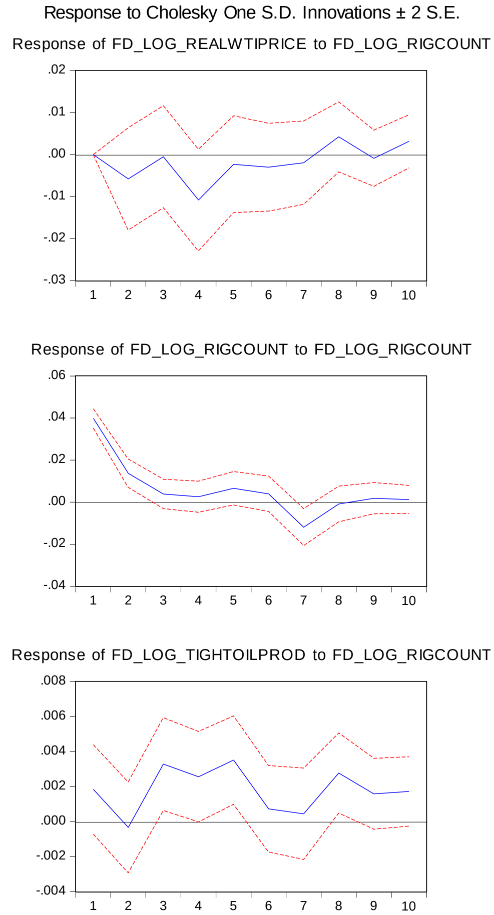
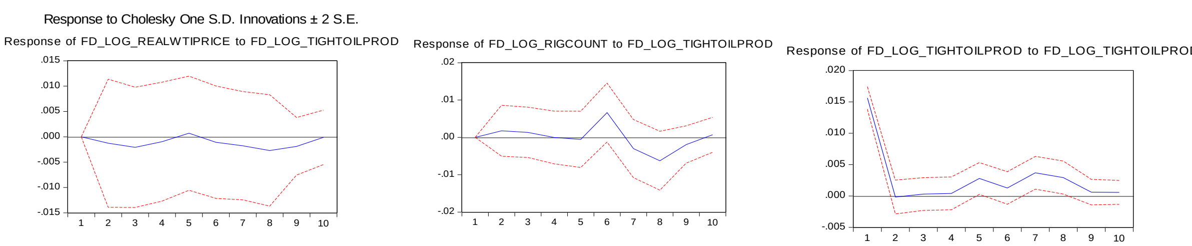


Figure 16 illustrates impulse responses of the endogenous variables to the shock in rig counts. The oil prices do not demonstrate an immediate reaction. However, by 2nd month the relationship becomes negative, though the result is small and insignificant. Still, such behavior depicts well the market interconnection between variables. Thus, during recent oil supply glut, news regarding increase of rig counts was met negatively by market and had a downward pressure on oil prices.

The tight oil production's response may be characterized as positive in general. But there is the episode at month 2, when the movement drifts below the equilibrium level and becomes negative for a short period of time. Though, such response is statistically insignificant, this uneven impulse response of the tight oil output to one standard deviation innovation in the rig counts proves the complicated evolving relationship between variables and further stresses the rising chorus of energy market experts that the rig counts increase (decrease) does not necessary mean the oil production increase (decrease).

The impulse responses to the tight oil production shock is illustrated in Figure 17. Both the oil prices and the rig counts do not react instantly. After that reactions are close to pre-shock mean value. However, the trends are important, though statistically insignificant and small the oil price's response is predominantly negative, while rig counts show positive reaction at first to the tight oil output increase, but slowly drops below equilibrium line after 2nd quarter. This again highlights the fact that the rig count and tight oil production do not have a direct and positive relationship and this further reinforces the call to look beyond the rig counts when assessing the shale industry's 'health'.

Figure 17. Impulse Responses to one standard deviation innovations of tight oil production



6.2. <u>Forecast Error Variance Decomposition:</u>

The Forecast Error Variance Decomposition of the model is depicted in Table 3. This estimate shows how relevant each shock is in explaining the deviation in each of the variables in the model (Sims, 2011).

Thus, the changes in rig counts explain around 3.2% of the oil price variation. Though, the initial contribution of the rig counts to the oil price fluctuation is small, it gradually increases through time and by 10th month it reaches maximum (3.2%). Hence, the changes in rig counts are the biggest source of the oil price variation, aside the oil prices' own shock (more than 96%), as the changes in tight oil production showed a limited contribution to the oil price fluctuation.

The tight oil production shock accounts for 2.6% of variation of the rig counts by 10th month. However, this contribution is dwarfed by the oil prices' impact. Thus, the oil price shock accounts for 17.5% of the rig counts fluctuation at quarter 1, after that the impact only increases and reaches a substantial 45.1% by the end of the 3rd quarter. Without a doubt, the oil price is the largest contributor of the rig counts variation together with the rig counts' own shock (around 52% by 10th month).

Meanwhile, the oil price and the rig counts shocks have almost equal impact on the tight oil production variation. At first, the effect is limited, but it increases through time. The oil price shock explains 16.6% of the tight oil output fluctuation by 10th month. The effect of the rig counts reaches 12.1% at the same period.

Table 3. The Forecast Error Variance Decomposition

		Variance Decomposition of FD_LOG_REALWTIPRICE:		
Period	S.E.	FD_LOG_REALWTIPRICE	FD_LOG_RIGCOUNT	FD_LOG_TIGHTOILPROD
1	0.074124	100.0000	0.000000	0.000000
2	0.075538	99.38713	0.584763	0.028104
3	0.076568	99.32525	0.573582	0.101164
4	0.077588	97.38437	2.502025	0.113610
5	0.077781	97.30126	2.577253	0.121486
6	0.077959	97.14507	2.715008	0.139922
7	0.078080	97.04170	2.767836	0.190469
8	0.078464	96.66324	3.029975	0.306782
9	0.078497	96.59539	3.040254	0.364355
10	0.078760	96.45890	3.179031	0.362072

Variance Decomposition of FD_LOG_RIGCOUNT:

Period	S.E.	FD_LOG_REALWTIPRICE	FD_LOG_RIGCOUNT	FD_LOG_TIGHTOILPROD
1	0.040099	1.196968	98.80303	0.000000
2	0.043263	4.896460	94.93817	0.165367
3	0.046663	17.48342	82.29199	0.224583
4	0.051638	32.36670	67.44987	0.183432
5	0.056052	41.21265	58.62239	0.164960
6	0.058836	44.92221	53.65106	1.426725
7	0.060915	44.53098	53.89394	1.575073
8	0.061694	44.87225	52.56127	2.566473
9	0.061911	45.07041	52.28444	2.645150
10	0.062160	45.45834	51.90524	2.636424

Variance Decomposition of FD_LOG_TIGHTOILPROD:

Period	S.E.	FD_LOG_REALWTIPRICE	FD_LOG_RIGCOUNT	FD_LOG_TIGHTOILPROD
1	0.015836	1.127245	1.353502	97.51925
2	0.016270	6.276484	1.322584	92.40093
3	0.016606	6.089747	5.181370	88.72888
4	0.016807	5.944760	7.379507	86.67573
5	0.017503	6.702878	10.83377	82.46335
6	0.018154	12.62770	10.23223	77.14007
7	0.018594	12.71286	9.811147	77.47599
8	0.019143	13.21851	11.35170	75.42979
9	0.019416	14.87314	11.70277	73.42409
10	0.019713	16.57085	12.11702	71.31213

Cholesky Ordering: FD_LOG_REALWTIPRICE FD_LOG_RIGCOUNT FD_LOG_TIGHTOILPROD

6.3. Model check

The standard diagnostic tests of the VARX model are illustrated in Table 4 and Table 5. Hence, the LM test for the residual correlation shows no serial correlation up to 7 lags (see Table 4).

Table 4. LM test for serial correlation among residuals

VAR Residual Serial Correlation LM Tests
Null Hypothesis: no serial correlation at lag order h
Sample: 2005M01 2018M03
Included observations: 151

Lags	LM-Stat	Prob
1	7.598393	0.5751
2	6.568518	0.6819
3	6.449110	0.6943
4	14.13920	0.1175
5	10.55129	0.3077
6	7.140927	0.6224
7	10.77356	0.2915

Probs from chi-square with 9 df.

The Normality test of Jarque-Bera revealed that two out of three variables are normally distributed. The one, which is not though has kurtosis around five.

Table 5. The Jarque-Bera Normality test

VAR Residual Normality Tests
Orthogonalization: Cholesky (Lutkepohl)
Null Hypothesis: residuals are multivariate normal
Date: 06/03/18 Time: 11:00
Sample: 2005M01 2018M03
Included observations: 151

Component	Skewness	Chi-sq	df	Prob.
1	-0.015860	0.006330	1	0.9366
2	-0.071088	0.127181	1	0.7214
3	0.063239	0.100646	1	0.7511
Joint		0.234157	3	0.9719

Component	Kurtosis	Chi-sq	df	Prob.
1	3.032794	0.006766	1	0.9344
2	4.604398	16.19534	1	0.0001
3	3.094147	0.055767	1	0.8133
Joint		16.25787	3	0.0010

Component	Jarque-Bera	df	Prob.
1	0.013097	2	0.9935
2	16.32252	2	0.0003
3	0.156413	2	0.9248
Joint	16.49203	6	0.0113

Based on the test results, it is safe to state that the model coefficients could be considered as consistent and unbiased.

7. Conclusion

The US tight oil became an important factor in the world energy markets with influence even the OPEC seems to reckoning with. Hence, some scholars name notably the surge of the tight oil output as one of the key cause of the 2014-2015 plunge in oil prices. With rising importance of tight oil appears a need for an assessment of the relationship between shale industry and global crude prices. Thus, the aim of the study was to analyze the relationship between changes in oil prices, rig counts and tight oil production in the U.S. in the shale era (since 2005 and onwards) while controlling for economic and financial variables. For these purposes, we used VARX model constructed by Khalifa et al (2017) and updated it with the inclusion of the tight oil production among endogenous variables to make it more relevant to current industry's developments.

The key outcomes of the study revealed a negative initial response of rig counts to oil price shock, but from 2nd month and onwards the relationship becomes positive and statistically significant. This lagged positive response could be attributed to the oil companies' desire to make sure first that the oil price increase is a stable trend till they decide to greenlight a new drilling of well. Also, it takes time to set-up a new rig. Other relevant outcome that the study revealed is the uneven relationship between changes in the rig counts and tight oil production. The increase of rig counts has initial positive impact on tight oil output, but the response is short-lived and reaches equilibrium by 2nd month and rises again between 3rd and 5th months. While, the rig counts are in general irresponsive to tight oil production shock. Such complex relationship could be explained by technological innovations in the shale industry: now oil producers can increase output without setting up additional oilrigs (Slav, 2018; Wethe, 2018). Hence, this further reinforces the call for investors and market analysts to look beyond the rig counts and take in consideration other indicators of the US shale industry to assess its wellbeing. Finally, the study revealed a weak impact of rig counts and tight oil shocks on oil prices fluctuation. Forecast Error Variance test reinforced this finding by revealing that changes both in rig counts and tight oil output explain just limited share of oil price variation.

The current results of the study should be beneficial for investors and market analysts to improve their forecasting models and investment strategies in the energy sector. The revealed outcomes could be useful for policymakers as well. The positive relationship between changes in oil prices and rig counts with two-month lag should help to better forecast the changes in tax returns and employment rate fluctuations in the oil rich states.

Without doubt the topic will require further research. Being relatively a new phenomenon with fast evolving technological innovations, the shale industry will need a continuous adjustment of the models estimating the impact of the changes in oil returns on shale industry variables and vice versa. Naturally, the inclusion of additional parameters and covariates within the model to align it with industry developments will be necessary as well.

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