BI Norwegian Business School - campus Oslo

GRA 19502

Master Thesis

Component of continuous assessment: Thesis Master of Science

Suboptimal producer behavior: Evidence from the Permian basin

Navn: Lein Mann, Viktor Myhre

Start: 02.03.2018 09.00

Finish: 03.09.2018 12.00

Viktor Myhre:
Lein Mann:

Hand-in date:

27.06.2018

Programme:

Master of Science in Business, Major in Economics

Acknowledgements

We would like to extend special thanks to our supervisor, Hilde C. Bjørnland, professor and director of Centre for Applied Macro and Petroleum economics[1] (CAMP) at the BI Norwegian Business School. Bjørnland introduced us to the literature around this subject, as well as giving us guidance during the project period. We are also grateful to CAMP for contributing with access to the extensive data and specialized knowledge provided by Rystad Energy that suited our research needs. For knowledgeable insights and suggestions, we would like to thank PhD Candidate Thomas S. Gundersen that ensured we are on track. We would also like to acknowledge PhD Candidate Arne F. Lyshol for helpful comments and advises, sometimes in short notice. Lastly, we would also like to recognise our lecturers and professors for challenging us and especially Tommy Sveen for encouraging us to keep being ambitious, but realistic.

Oslo, June 27th 2018

Lein Mann | Viktor Myhre

[1]Disclaimer: This master thesis is a part of a research project in CAMP and the access to the data provided by Rystad Energy was given as part of the collaboration with CAMP

Abstract

In this master thesis we examine to what extent shale well producers in the Permian basin respond flexibly in terms of allocating output intertemporally to price incentives. We use an extensive panel data based on micro data set provided by Rystad Energy dating back to 2000 until the end of 2017, which covers more than 13,000 shale wells. Our data indicate that producers are forward-looking and trade off production today for production in the future. More specifically, our main finding is that when the 3-month future spot spread increases by 10% well operators in Permian shift up production by 6.35%, which is significant at a 5%-level. This result also contradicts previous literature, which found other shale producers to shift production down or respond insignificantly to similar price incentives. According to our results, producers in Permian behave in a suboptimal manner, which opposes the Hotelling rule. We argue that these results are due to Permian's explosive growth compared to other U.S. shale regions in recent years, driven by easy access to investor funding and management incentives related to production growth.

Contents

1 Introduction

The cyclicality of the oil market and oil producer's behavior has always been of great interest for researchers. Shale[2] oil has experienced an impressive growth in recent years, which has transformed the U.S. energy industry and reshaped global oil markets. Shale oil production grew by more than 70% from 2012 to 2017 and were primarily led by the explosive growth in the Permian basin in Texas, often referred to as the "Permania". When the oil price (WTI) plunged from over $100/b in mid-2014 to below $27 in February 2016, Permian continued to increase production in contrast to all other major shale plays[3]. The producer's expansionary production behavior even in a plunging market have left analysts puzzled and has begged the question to what extent producers are flexible in terms of allocating output intertemporally.

The vast majority of Neoclassical economics assume firms to be maximizing profit (see for example Hirshleifer, 1980; Mas-Colell, Whinston & Green, 1995). In short, a firm will determine the price, input, and output levels that ensures the highest profit. However, in the Permian shale play, producers have been cash negative[4] for 7 consecutive years while continuing to receive capital injections by investors even though the oil prices are below the company's breakeven. This raises the question to what extent these producers are concerned by profit maximization.

This research paper sheds light on the production flexibility of the largest shale oil region in the United States, namely the Permian basin. Furthermore, the paper investigates to what extent Permian oil producers adjust production to changes in spot futures spreads with different maturities. Previous research has analyzed flexibility in shale regions mostly using data prior to 2016. Newell & Prest (2017) investigate production in five major U.S. states and Anderson, Kellogg & Salant (2018) analyze production Texas (primarily Permian and Eagle Ford), while Bjørnland, Nordvik & Rohrer (2017) analyze production in North Dakota (Bakken). The two first papers find production in short-run to be inelastic while

[2] The terms 'shale' and 'unconventional' are used interchangeably throughout this paper and refer to tight oil
[3] "Shale play" or "play" refers to geographically defined region of shale formations containing large amounts of natural oil or gas
[4] Cash negative meaning a negative cash flow per barrel produced

Bjørnland et al. (2017) finds production to be elastic in the short-run and with a negative coefficient for futures prices of 3-, 6- and 12-months. Meaning that firms reduce production when the change in the future spot spread price is increasing, effectively leaving oil in the ground awaiting a higher expected price.

By using data from Rystad Energy dating back to January 2000 until end of 2017, we have been able to analyze production from the very start of shale production. The data is mainly based on governmental databases and archives as well as company data. The data is excluded all conventional oil production and allows us to focus entirely on shale oil production. Having as recent observations as end of 2017 distinguish our research considerably from previous relevant research that typically have data prior to 2016; such as Anderson et al., (2018) (data from 1990-2007), Bjørnland et al. (2017) (data from 2000-2015) and Newell & Prest (2017) (data from 2000-2015). Having a more recent data set allows us to capture the effect of the mid-2014 downturn and its recent recovery.

What distinguishes this paper from similar research papers using time series data is the use of a micro panel data dating back to 2000 until the end of 2017 that covers more than 13,000 shale wells in Permian. The rich panel data set needed considerable structuring and adjustments in order to be applied appropriately. The data suggests that individuals are heterogeneous and the main benefit by using panel data is the ability to control for those fixed effects and obtain unbiased estimators. Additionally, we are studying a relative short time period which is appropriate to micro panel data, where working with a sizeable number of wells improve the accuracy of estimators.

Previous research of production elasticity in the U.S. has typically assumed that oil price is exogenous to the monthly output of oil produced from a particular shale play (see Anderson et al., 2018; Kellogg, 2014 and Bjørnland et al., 2017). According to Bjørnland et al. 2017, the fact that no single firm is able to exert market power and the fact that the growth from one shale play is relatively small compared to the global supply of oil, which determines the price of oil. Kilian (2016), Kilian (2017a), and Kilian (2017b) also found that the shale boom had a certain effect on oil prices from 2011-mid-2014, however the effect was negligible. We add to the model control variables that remove macro instability effects from production choices in order to mitigate a potential endogeneity problem. We use in addition futures prices as an indicator of the oil prices producers are expecting in the future, which is the most commonly used variable for predicting the oil price (See Bjørnland et al., 2017 and IMF, 2018). These assumptions are all discussed in section 5.1 and 5.2.

We contribute to the existing research literature in this field by focusing solely on the largest and fastest growing region in the U.S., Permian. We also have opposing findings to previous literature: 1) Permian has a flexible production profile in the short-run and 2) Permian produce *more* when the future spot spread increase and vice versa. Our main finding is when the 3-month future spot spread increases by 10% then well operators in Permian shift up production by 6.35%, significant at a 5%-level. This is in stark contradiction to what previous literature have found and also the results we found in Eagle Ford. We also find that producers do not respond to spot prices, which is in line with previous research.

We argue that these results are due to Permian's explosive growth opposed to other U.S. regions, driven by easy access to investor funding and management incentives contingent on production. This is reflected in the data where production in all other regions besides Permian reduced their production in the downturn in oil price from mid-2014 (see figure 5). In this period Permian accounted for almost 70% of the growth in the U.S. shale production and received more than 65% of the investor funding. The play experienced the increased funding even though the producers in the basin delivered continued negative cash flow. Management has also been heavily incentivized through bonus schemes contingent on production growth.

These two factors have resulted in producers in Permian being less concerned by cash flow and more concerned by investor funding and increasing production, which again has driven productivity. Hence, when futures increase relative to the spot price, producers are confident they will be able to receive increased funding on higher prices and decide to produce more today. This is an important finding as previous literature has failed to explain the relationship between production flexibility and investor funding.

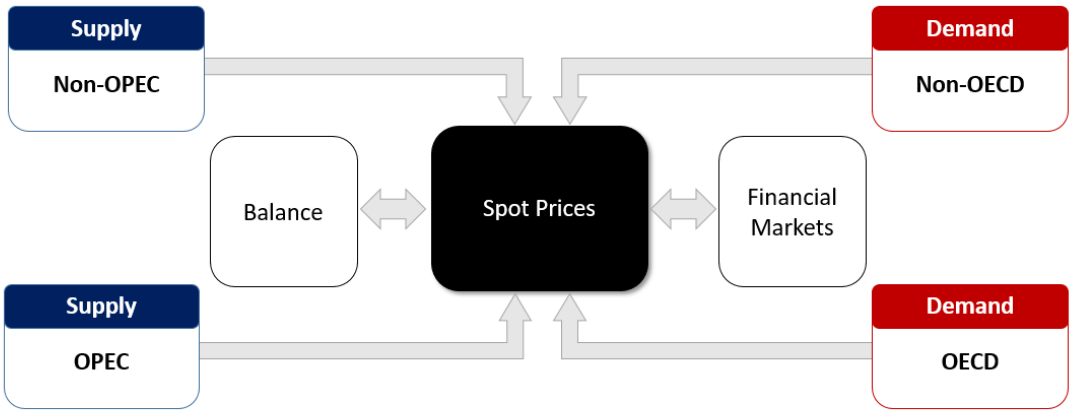
2 Overview of the oil supply side and its associated literature

1.1 Global supply of the oil market

1.1.1 The oil market and the price of oil

The oil market is composed of a wide range of consumers and producers, where investors play an important role in determining the price of oil. The underlying driver of the oil price is the balance between supply and demand, however the financial markets, driven by investors, has a substantial impact on the spot and futures price of oil. Figure 1 captures the key determinants of the spot oil price (EIA, 2018).

Figure 1: Key determinants of the spot price

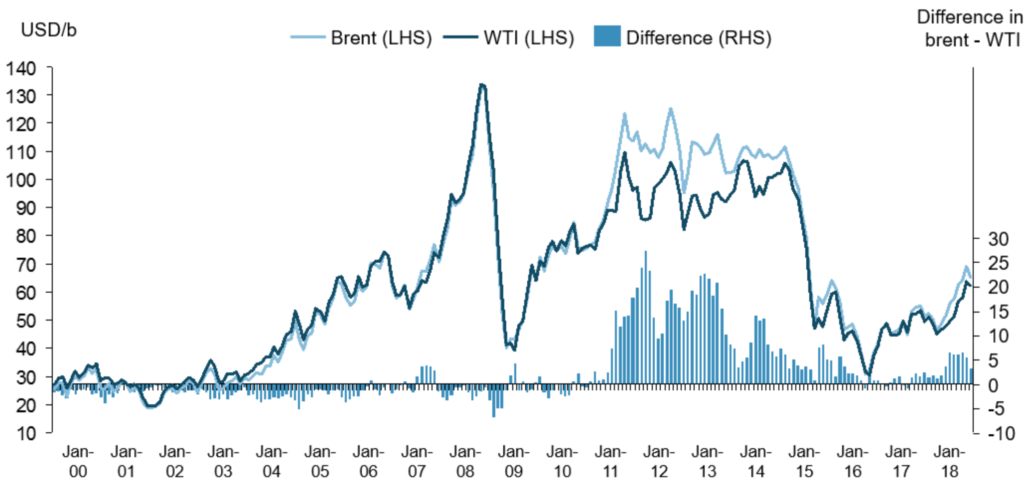


The U.S. Energy Information Administration (EIA) distinguishes between production from the Organization of the Petroleum Exporting Countries (OPEC), which have historically accounted for approximately 40% of world production and where the largest producers are Saudi Arabia, Iran and Iraq, and Non-OPEC countries. Non-OPEC accounted for approximately 60% of production where historically the largest producers have been U.S. and Russia. OECD has historically accounted for more than 50% of world demand side. However, Aastveit, Bjørnland & Thorsrud (2015) find that emerging economies have accounted for more than twice as much of the variance in the oil price as developed economies and point particularly at China as the main demand driver in the demand surge in the 2000s leading up to the financial crisis.

The two most commonly used prices of oil are mainly North Sea brent crude ("brent"), which is connected to oil from the North Sea and West Texas Intermediate (WTI), which is the price mostly referred to for production in North America. The spread between the price for brent oil and WTI has fluctuated considerably over the past 18 years, where the WTI has on average been trading at a discount of USD 2.4 to the brent price as illustrated in figure 2.

In mid-2008, the price of oil (WTI) declined from approximately 140$ to 40$ a barrel. It was preceded by the greatest decline in global economic activity since the 1920's, which was characterized as a demand shock (see Kilian, 2009). In mid-2014, the oil price started to decline from $115 and bottomed out in February 2016 below $27. The oil price decline was mainly attributed to OPEC signaling increased production along with an appreciation of the US dollar.

Figure 2: Brent and WTI prices from Jan. 2000 – May 2018



There are several reasons for the difference between the two oil prices. The two most commonly mentioned are the chemical properties of unconventional oil and the transportation cost (bottlenecks in pipelines, rail and barges) (see Killian 2016; Wilkerson and Melek 2014; Gundersen 2018). The shale oil is characterized as heavy and sour, measured by API gravity and sulphur content respectively. Historically, U.S. has been dependent on oil consumption from their conventional oil production as well as some imports from the Middle East among others. Naturally, the U.S. refineries were established to accommodate the heavy and sour oil and were unable to process lighter oil without substantial capital expenditures.

Hence, most of the shale oil is transported to refineries outside the U.S. Due to this, bottlenecks emerged in the transport of oil through pipelines, railways and barges with limited capacity as shale production rose from 1.3mb/d to 6.9mb/d from 2007 to 2018 (Rystad Energy). These bottlenecks can put restrictions on producer behavior and are discussed in section 5.3.

1.1.2 Literature: Demand vs. supply

The interaction between the oil market and the world economy has been a subject of great interest for a long time for macroeconomists and researchers alike, and particularly the relationship between oil price shocks and its relation to supply and demand for oil. There are several researchers that have focused on theoretical explanations for oil price shocks (the unanticipated or surprise component of a change in the price of oil) and their origins. There are particular two dominant views that emerged in previous literature, namely the supply side and the demand side. One should also bear in mind that the prominent authors are analyzing data with different time horizons in a rapidly changing industry, i.e. results found in previous research might be true at the time, but no longer applicable in today's market.

According to Hamilton (1983; 1985), the supply side is the major determinant of explaining oil price shocks. Furthermore, he argues that oil price shocks are driven by exogenous disruption in world petroleum supply, which is associated with wars, or conflicts in post-war data. That being said, Hamilton only studies exogenous negative supply shocks. Hence, the author's findings may not be directly transferable to the recent positive supply shocks the oil and gas industry have experienced.

Lutz Kilian has made strong contributions to the literature; both on the demand and supply side. In his paper "Not All Oil Price Shocks Are Alike: Disentangling Demand and Supply Shocks in the Crude Oil Market" (2009) he used a structural vector autoregression (SVAR) method and identified demand as a more decisive driver than supply in explaining the oil price fluctuations after the 1970s. The author also went on to argue that there exists a two-way causality between the oil market and the macro economy, where demand and supply shocks in the oil market lead to different macroeconomic outcomes.

In a more recent paper Baumeister and Kilian (2016) argue that the supply side was the main driver for the downturn in 2014. Also, Caldara, Cavallo & Iacoviello (2016) finds, using a SVAR approach, that oil supply shocks and global demand shocks explain 50 and 35 percent of oil price fluctuations, respectively. Further, the authors emphasize the selection of oil market elasticities to be essential for understanding the source of oil price fluctuations. Thus, the debate between the demand and supply side is still highly relevant.

2.2 The U.S. shale oil boom

2.2.1 Key differences between conventional and shale oil production

In order to understand why it is likely that shale producers have a more flexible production curve than conventional oil, it is important to distinguish between shale and conventional production. Conventional producers extract belowground reserves of oil by drilling vertically to allow the oil that is trapped between rocks to spill out and be collected in the surface (Bjørnland et al., 2017). The hydrocarbon simply flows from high concentrated areas with high pressure to lower pressure areas.

Shale oil is found in tight geologic formations and have considerably lower permeability[5], making conventional extraction methods unsuitable. Shale producers use hydraulic fracturing (fracking) combined with drilling activity. Fracking involves stimulating the rock formations with fracking fluid; water, sand and chemicals in high pressure to fissure the rocks and create cracks from which the oil will come out and later be pumped, commonly referred to as *completion* of wells. To tap onto the shale oil, the producers first drill vertically and then turn approximately 90 degrees to continue to drill *horizontally*. At the completion phase, further drilling and fracturing is required to let the oil come out.

There are several reasons why one would also expect to find that shale production is more flexible in allocating output intertemporally than conventional. Three of the main reasons are 1) the extraction technology used in shale wells is more flexible, e.g. a shale well may be stimulated with water and chemicals many times during its lifetime, which improves the trade-off of extraction between period the producer is facing. Conventional well on the other hand is naturally flowing

[5] Permeability is the property of rocks that is an indication of the ability for oil and gas to flow through rocks

(Bjørnland et al., 2017) (Carpenter, 2014). 2) shale production has a far steeper decline rate[6] than conventional oil production, which makes the optimization of timing of well completion more desirable (see Bjørnland et al., 2017). 3) completion cost in shale accounts for more than 60% of production cost, which indicate that producers will be more sensitive to price when deciding *when* to produce (Kjus, 2017).

On the other hand, opposing views claim that shale oil producers are not significantly more flexible than conventional producers. Newel et al. (2017) explained that generally after a well started producing its flow is dependent on geological factors and thus the operator does not have that freedom to adjust production, but that it has been observed that operators preferred to choke production or artificially stimulate it. Anderson et al. (2017) support that view saying that it is economic theory together with physical constraints imply that price responsiveness of production from existing wells should be small or even zero.

2.2.2 Historical development of shale production

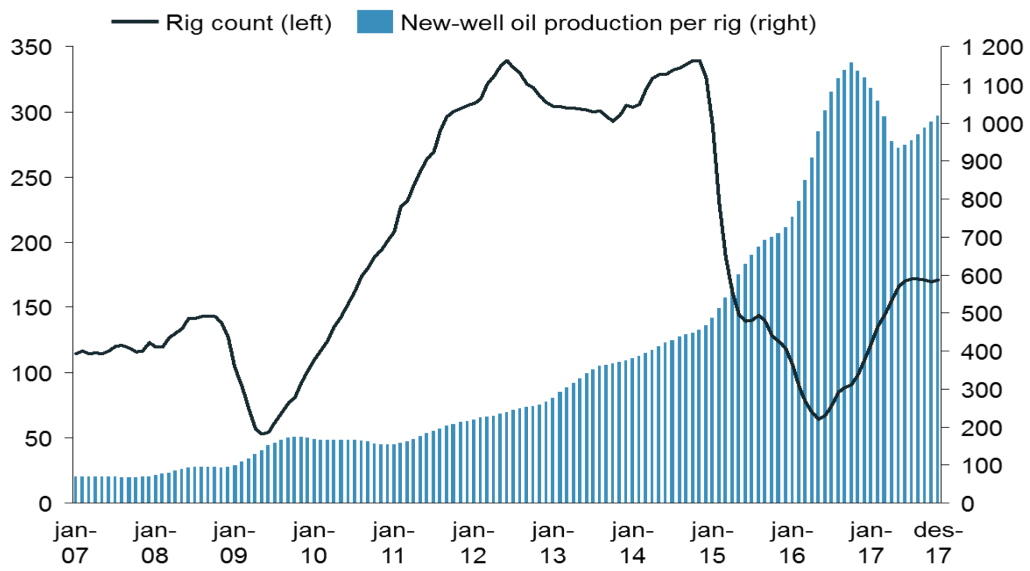
The U.S. shale oil industry has received considerable attention after the "shale boom", dating back to 2009 (Crooks, 2015), which changed the fundamental outlook of the oil and gas industry completely.

Typically, production in a region increase over time as the time the wells in operation goes up because the operator becomes more familiar with the characteristics of the specific well (optimizing completion design and land zone, drilling cost decline), leading to more optimized decision making. As the region matures, the output typically increases at a decreasing rate until it does not grow anymore due to the decline rate in the wells outgrows the production from new wells that are gradually drilled further and further out from the core acreage (Kimmeridge Energy, 2017). These shale specific decline rates imply that producers have to continuously complete and produce more in order to maintain the growth. Some refer to this as the "red queen effect", named after the red queen who tells Alice she needs to run faster and faster in order to stay in the same place in Carroll's (1871) "Through the Looking-Glass".

[6] Decline rate refers to the reduction in the rate of production from a single well or group of wells from peak production

Production per rig has been increasing significantly over the past 10 years and particularly in the last five years driven by productivity growth (Erlingsen, 2018). The rig count in the same period show signs of an industry characterized by high cyclicality and flexibility where number of active rigs fall rapidly in the two major oil price corrections in 2009 (post financial crisis) and 2014 (OPEC production surged). When the oil price plunged from over 100$/bd to 27$/bd between September 2014 and February 2016, the number of oil rigs declined from 1,600 to 400. This indicates that shale producers are able to flexibly reduce production and adjust the hiring of rigs when the oil price is not sufficiently high.

Figure 3: Rig count vs. production per rig for the 3 largest regions

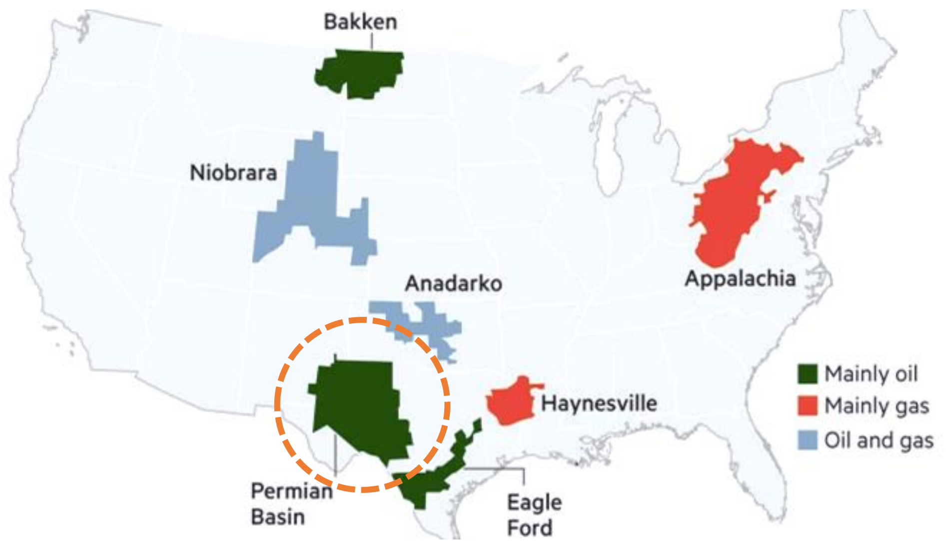


Data source: EIA

2.3 Presentation of the shale regions

US shale production is distributed across the country and is categorized by EIA into seven key tight oil and shale gas regions (EIA). In figure 4 Permian is highlighted by the orange dotted circle.

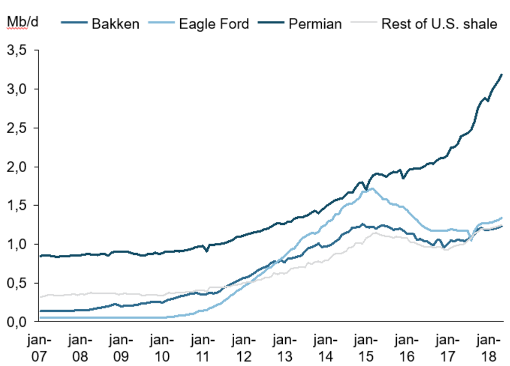
Figure 4: Geography of key tight oil and shale gas regions

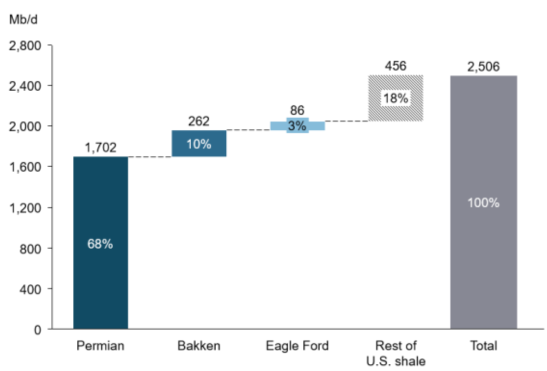


Source: EIA

Production in the three main shale oil regions, Permian, Bakken and Eagle Ford, have been rather stable, accounting for approximately 75-82% of U.S. shale production between 2007-2018 (see Figure 13A in appendix). However, the regions share of total U.S. production have varied significantly. Permian accounted for more than 50% of production from 2007-2010. While Eagle Ford experienced a massive growth between 2010 and 2014 where production rose from 4% to 28%. Since 2014 have production in Permian accounted for ~68% of growth in shale production (see figure 5).

Figure 5: Shale oil production Jan. 2007 – Mar. 2018 (graph left) and share of production growth 2014-2017 (graph right) for key shale regions





Source: EIA

Permian is located in the Western part of the U.S. State of Texas and the southeastern part of the U.S. State of New Mexico. The area was named Permian due to it being one of the world's thickest deposits of rocks from the Permian geologic period. Permian is the largest shale play in the U.S., producing ~46% of the total shale oil production in the U.S. in May 2018. It has been estimated by the EIA that the recoverable oil[7] was 43 bn. barrels of oil in 2017. However, CEO of DrillingInfo, Allen Glimer, estimates that the remaining content is somewhere around half a trillion barrels to 2 trillion barrels (Blackmon, 2017). Given the thickness of the rocks, the Permian producers have arguably benefited to a larger extent than other shale regions from the development extraction and completion technology.

In 2017, 90% of the oil and gas wells in the Permian region were drilled horizontally, up from just 10% in 2014 (Rystad Energy). In 2016, there were about 300 rigs total working in the U.S. onshore while at the beginning of 2018 there were about 400 horizontal rigs working in the Permian alone. Indicating the massive growth in the basin has experienced. Production in Bakken and Eagle Ford was reduced considerably from mid-2014 and did not recover to previous levels until May 2018.

The main reasons why one has seen such a massive growth in the Permian play is the fact that the play has witnessed a tremendous productivity increase which has allowed producers to drill in acreage previously thought of as untouchable. This, combined with superior oil reserves opposed to Eagle Ford and Bakken has driven investments into Permian. IEA (2017) expects production from Permian to double by 2023.

2.4 Literature: Oil production flexibility

Questions concerning how the shale producers might respond differently to production, drilling and completion of wells for a certain oil price has recently gained significant attention. Researchers tend to focus on two main areas that can be categorized as optimal resource extraction, and supply elasticity in the short- and long-run.

[7] These are estimates of oil reserves that has yet to be found, but if found, could be produced using currently available technology and industry practices.

The resource extraction literature typically seeks to characterize firms' optimal extraction choice. A theory that is commonly applied in the extraction literature is the Hotelling rule (see for example Bjørnland et al. 2017; Anderson et al. 2018). The classic model of exhaustible resource extraction, or simply the Hotelling's rule (1931), refers to forward-looking non-renewable resource owners that maximize wealth by trading off extraction today versus extraction in the future. The rule defines oil reserves as an inventory, and the choice and timing of production as an intertemporal decision of when to decrease or increase the underground inventory.

The majority of previous studies have found the Hotelling rule not to hold. Newell & Prest (2017) looked at conventional and unconventional oil producers from 2000-2015 in the largest shale regions and finds that the production is inelastic while the drilling response is of a more flexible nature. Anderson et al. (2018), which investigated conventional and unconventional oil producers in Texas also finds that the quantity produced from already producing wells not to be elastic. It is important to note that the papers mentioned above do not include data from 2016-2017, where the biggest increase in productivity took place and presumably bottlenecks started to influence production adversely (Rapier, 2018) (see section 5.3).

Bjørnland et al. (2017) investigated the flexibility of shale producers in terms of production as well as completion of wells, relative to the flexibility of conventional producers, in North Dakota (covering the Bakken region). Contrary to previous studies, they find that unconventional extraction technology is considerably more flexible in allocating output between periods using forward-looking prices, given by the future spot spread as an indicator of expected prices in future periods. These results indicate that unconventional oil producers behave more consistently with the Hotelling rule than previous research has found.

Previous literature has also paid considerable attention to the demand and supply elasticity where short and long-run elasticities are compared. These findings have largely been that gas and oil supply elasticities are inelastic once a well has been drilled and moreover that supply tend to be less responsive in the short run than in the long-run (Griffin (1985); Hogan (1989); Pesaran (1990); Dahl and Yücel

(1991); Ramcharran (2002); Smith (2009) and Griffin and Teece (2016). Bjørnland et al. (2017) considerably question these results on short-term elasticity.

3 Methodology

3.1 Data environment

3.1.1 Data set

Most of our analysis is conducted on data collected from Rystad Energy. Rystad Energy is an independent oil and gas consulting services and business intelligence data firm that offers global databases, strategy consulting and research products. Their expertise in well-data and shale production makes their database well suited for our modelling and research purposes, using panel data. The data in its raw form is generally of good quality, however the major benefit is the availability of very rich and detailed cross-section of wells separated by distinct names.

More specifically, we take use of Rystad's ShaleWellCube module that covers well-level shale oil data for North-American operators with monthly frequency starting from early 2000 until the end of 2007. The sampled data contains monthly production from 13,177 wells from the Permian basin and 14,534 wells from Eagle Ford (for the extension part). We focus on the period beginning from when shale oil became relevant and technology and infrastructure was in place to enable effective extraction of shale oil and therefore the sample period used in the analysis is limited to January 2005-December 2017 (see analysis of alternative time periods in section 4.1). Retrieving the desired data from the module was conducted in the following way; shale well data could be filtered as the well data was divided into horizontal, vertical and diagonal drilling used in production. After horizontal drilling was selected, the correct play could be chosen, which made it easier to make a distinction between Permian and Eagle Ford even though both lie in the same state (Texas).

After the desired raw data was obtained we had to restructure the data in order to focus on active wells (as explained below), fit the data into such a form that Stata would recognize it as a panel data and add price vectors and control variables. This was a rather demanding task given that at this point we had over 4 mill.

observations and that Microsoft Excel and Stata have their size limitations and worked quite sluggishly. The raw data was first treated in the following way; Similar to Bjørnland et al. (2017), we restricted the sample by removing any shut-in periods in production which are longer than one month. Hence, wells with production that is ceased for 1 month and is followed by positive production remained in the sample.

One month of inactivity can occur due to that well operators hold back production because of low oil prices and expect to bring up production again when oil prices pick up. Longer periods of inactivity can in addition result from oil reserves simply not being profitable enough to extract with the current technology or resources. A third explanation could be the refracking[8] of wells, which requires wells to be shut down before being stimulated. Hence, we believe it makes sense to allow for one month of zero production. Including the wells that have had zero production for more than one month may distort the estimators and give us a false supply elasticity and are therefore excluded from the sample. Additionally, wells that had non-zero production in January 2000 were excluded from the sample due to that we could not observe the total number of months the well is operative. In total as little as 2 wells were excluded as a result.

3.1.2 Production profile

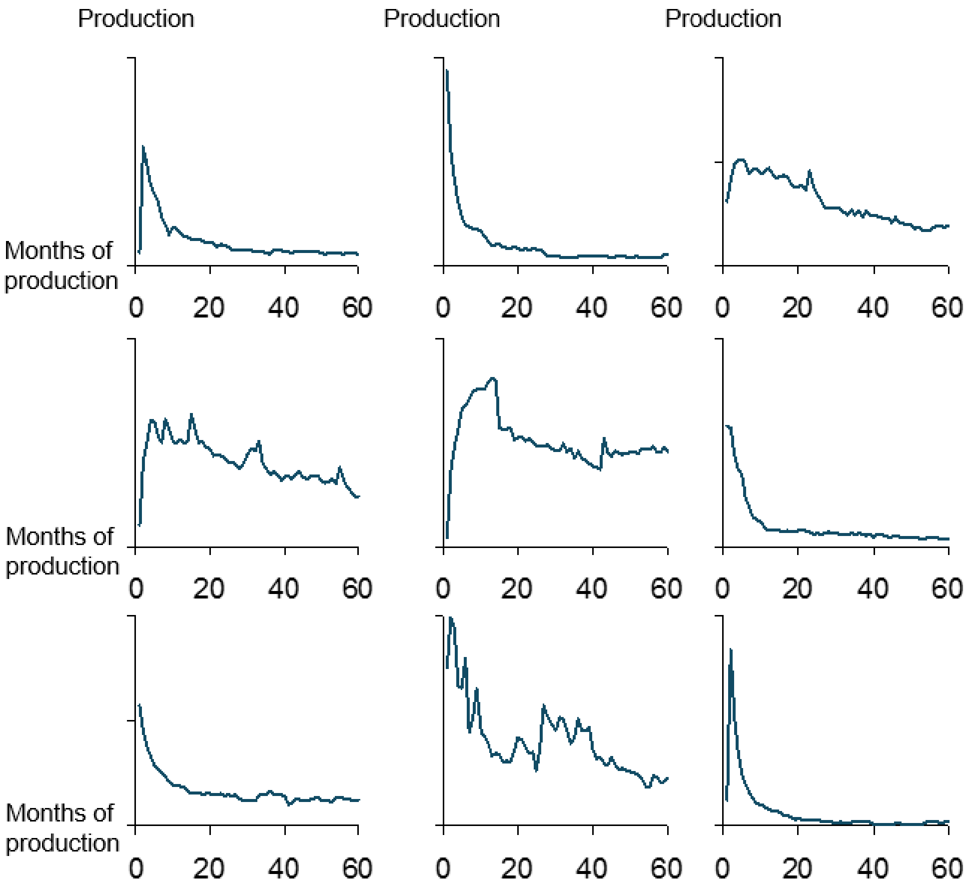
The shale fracturing process results in a heavily front-loaded production profile. After a well is fracked, it tends to reach its peak level production after one to two months and then it falls, giving the production profile a downward-sloping appearance. The production profile would indicate that shale producers need to be aware of the timing of completing drilling the well and start of production. Data from Permian indicate that shale production falls with approximately 41%, 75% and 87% after 3, 12 and 24 months, respectively, as illustrated in illustration 3.1 for 9 randomly selected wells. Similar decline rates are observed for wells in Eagle Ford (see table A.1 summary statistics in appendix for more details).

From figure 6 we see that the production profile for different wells vary substantially. Most wells reach their peak production level on the first or second month. However, exceptions occur as is illustrated by the well that lies in the

[8] Re-fracking is the process of fracking wells that has already been fracked, often to capitalize on more effective extraction technologies

center, which reaches its peak production after about 12 months. Interestingly, we see signs that producers are able to adjust production along the lifetime of a well which suggests that the well operator is able to flexibly adjust the output to his favor.

Figure 6: Production profile from 9 randomly selected wells in Permian[9]



Source: Rystad Energy

3.1.3 Panel data

To accomplish the purpose of this paper, the use of a panel together with microeconomic data was found most suitable. The main advantage of using panel data is being able to maintain the micro relations and study them. If one was to conduct a similar analysis using time series it would require aggregating production over the wells, making it impossible to extract for example the production profile, the age of a single well or its location (see Bjørnland et al.

[9] Wells include: Yarbrough & Allen 4H, XBC Giddings Estate 1019H, Wright, J.M. Unit 92H, Wright, J.M. Unit 90, Wright, J.M. Unit 22X, Willard 48 Unit 1, Wellman SW. San Andres Unit 40H, Weatherby "H" 2TM and Wallin, H. C. 5H

2017). Apart from that, well fixed-effects will also not be able to be obtained and be controlled for and thus this operation is problematic as it is similar to imposing identical parameter values for all wells regardless of inherent differences across wells, essentially leading to biased estimates. In that sense the precision in estimation is increased by using panel data as it incorporates more information and larger variability within each well, provided that they are heterogeneous. Furthermore, since we work with micro panels, i.e. large number of individual observations collected for a relatively short time period, the estimators are likely to be more accurately measured than in macro panel, that often involve data aggregated over countries that is observed over time, because biases stemming from aggregation effects (see for example Cameron & Trivedi, 2005 for further details).

3.1.4 Prices and spreads

The oil prices used in the analysis are the West Texas Intermediate (WTI) (see section 2.1.1 for further details). The time series of spot prices are provided by the U.S. Energy Information Administration (EIA) and the futures prices (financial contracts obligating the buyer to purchase oil at a predetermined future date and price) with different maturities, *j*-months, are traded on the NYMEX and retrieved from Bloomberg. Futures prices are commonly used as the main predictor for future oil price by central banks and the International Monetary Fund (IMF), among others (IMF 2018). Hence, it will serve as the proxy for expected future price in this paper. Futures contracts can be bought at various delivery dates, whereas 1, 3, 6 and 12 months being the most common as liquidity falls drastically after 12 months (Kjus 2017) (see section 5.2 for limitations).

We measure how well operators respond to price incentives given by the percentage change in the spot price, but most importantly to a growth in the spread, as done by Bjørnland et al. (2017). The spread is given by the futures price contracted at time t with delivery at time $t+j$ over the spot price at time t and is used as a proxy for the expected change in oil prices over j months ahead. We study the marginal change in output to changes in the spread, thus the change in the spread can be defined as:

$$\Delta\left[F_{t+j,t} - P_t\right] = \log\left(\frac{F_{t+j,t}}{P_t}\right) - \log\left(\frac{F_{t+j,t-1}}{P_{t-1}}\right) \tag{1.0}$$

Which can be rewritten in the following way:

$$\Delta\left[F_{t+j,t} - P_t\right] = \log\left(F_{t+j,t}\right) - \log\left(F_{t+j,t-1}\right) - \left(\log[P_t] - \log[P_{t-1}]\right) \quad (1.1)$$

Hence, a positive (negative) spread indicates that oil price is expected to grow (fall) going forward. Another way to think of it by observing at equation 1.1: If the spread shifts upwards, then futures prices grow faster compared with the growth in spot prices from previous period. We deflated the futures prices with delivery at time $t+j$ to time t period by using the time series Consumer Price Index for All Urban Consumers from Fred St. Louise. This is in order to avoid distortions in the elasticity parameter that are may be caused by inflation, as done by Newell & Prest (2017), Anderson et al. (2018) and Bjørnland et al. (2017).

3.2 Empirical model

In order to estimate the short-term supply elasticity, we regress the monthly percentage change of barrels produced in well *i* on (I) percentage change in spot prices and (II) on percentage change in futures spot spread, i.e. spread between futures contract that can be purchased at time *t* with *j* months maturity and spot prices. This is a first difference equation and all the above-mentioned variables are in log differences. As researchers traditionally use spot prices to measure supply elasticity, the spread will be used as an indicator of how the market believes the prices will develop in the near future (see section 1.0, 5.1 and 5.2.).

The baseline model specification follows the intuition of Bjørnland et al. (2017) and can be written formally with a 3-months spread[10] as:

$$\begin{aligned}\Delta Q_{it} = \alpha\Delta Q_{it-1} + \beta_1\Delta P_t + \beta_2\Delta\left[F_{t+3,t} - P_t\right] + \delta_1 Age_{it} \\ + \delta_2\Delta MSCIWorld_t + \delta_3\Delta VIX_t + \mu_i + \lambda_t + \upsilon_{it}\end{aligned} \quad (1.2)$$

The dependent variable ΔQ_{it} is the log difference in monthly output for well *i* at time *t*. The first lag of the dependent variable, ΔQ_{it-1}, is added to allow production to be autocorrelated. ΔP_t is log difference of WTI crude spot prices. $\Delta[F_{t+3,t} - P_t]$ is the change in the spread between futures contract maturing in 3 months and the spot price.

[10] We substantiate the reasons why in section 3.3.1

Additional control variables that are associated with both the predictors of interest and the outcome are added to the baseline model in order to mitigate the effect of confounding variables. In other words, we exclude alternative explanations to the effect of prices on adjustment of output while doing statistical inference on the variables of interest. First comes the Age_{it} variable, that captures any linear relationship between the number of months the well is in operation and the change in output in period *t*. The variable is constructed as a cumulative vector that counts the number of months the well is in production. It takes a value of zero for all months of inactivity before the first month of non-zero production, which then takes a value of 1 and with any month with positive output grows by 1. A month with zero production preceded and not followed by non-zero production gets a value of zero for that particular month and all next periods as in that case the well ceased production permanently. As the well becomes more mature (Age_{it} goes up) the well operator is likely to be more familiar with the well characteristics and adjust the production more optimally. Additionally, the data shows that the younger the well is, the higher the natural decline rate.

Furthermore, $\Delta MSCIWorld_t$ and ΔVIX_t are log changes of MSCI World index[11] and VIX index[12], respectively, which are macro instability indicators. These indicators are expected to influence both oil price, future spot spreads and production decisions. Production decisions in turn influence current and future developments in oil prices and by adding those terms we expect to mitigate a potential endogeneity problem. More on this is discussed in section 5.1.

Moreover, both well μ_i and time (year) λ_t fixed effects are estimated to isolate any aggregate yearly changes in well production and well-specific linear trends (see more details on fixed effects in panel data in Cameron & Trivedi, 2005). As oil price is a variable that is common to all firms and has a monthly frequency, adding year fixed effects were preferred over monthly fixed effects because otherwise monthly fixed effects would wash away the price changes and it would be impossible to identify the effect of a monthly price change on output. Furthermore, well fixed effects remove well-specific linear trends, such as trends in production or in technological learning. The model is in first differences, which

[11] MSCI World index is a broad global equity index that represents large and mid-cap equity performance across 23 developed markets countries

[12] VIX Index a popular measure of the stock market's expectation of volatility implied by S&P 500 index options

means that inherent well characteristics such as geological properties of the well, acreage and so on are removed by differencing.

Lastly, we use two-way clustering in the residuals υ_{it}, both on wells and months. This was made possible given the Reghdfe package that implements the estimator described in Correia (2017), which is compatible with Stata and is used to estimate numerous levels of fixed effects and additional robust standard errors as multi-way clustering and Heterogeneity and Autocorrelation (HAC) standard errors. In our framework it is natural that the error terms will correlated over time when we measure growth in production. Additionally, we allow the standard errors across wells at time *t* to be correlated as all wells can be affected by common price shocks in the same period. Following Bjørnland, Nordvik and Rohrer (2017), we specify HAC standard errors[13] using one lag as we here add two way clustering. This allows us to get heteroscedasticity- and autocorrelation-consistent estimators.

3.3 Results and interpretation

3.3.1 Results

In table 1 we run three different regressions: a regression without fixed effects or controls in column (1), a regression with year and well fixed effects but without controls in column (2), and a regression with fixed effects and controls in column (3) that is also our baseline model. The choice of using 3-month spread is based on the results in table 2 later in this section and the time horizon of beginning of 2005 and end of 2017 is based on the results in Table 3 (see section 4.1).

The focus is on the parameters of interest, β_1 and β_2, which measure the average change in monthly well production in the Permian basin at time t for a change in current oil prices from previous period and a growth in the spread, respectively.

[13] The Newey West standard errors are specified with a Bartlett kernel and a bandwidth of 2, which implies that the contemporaneous variance the autocovariance of the first order is included in the estimation of the covariance matrix. See Hayashi (year 2001, pages 417) for details.

Table 1: Supply elasticity for Permian

Variables	(1) Response to prices	(2) Response to prices	(3) Response to prices
Dep. Var: ΔQ_{it}			
ΔQ_{it-1}	-0.079***	-0.089***	-0.089***
	(-3.440)	(-3.277)	(-3.284)
ΔP_t	0.079	0.032	-0.004
	(1.379)	(0.495)	(-0.051)
$\Delta[F_{t+3,t} - P_t]$	0.784*	0.703*	0.635**
	(1.923)	(1.796)	(2.052)
$Well\ age_{it}$			-0.003
			(-1.346)
$\Delta MSCI_t$			0.323
			(1.025)
ΔVIX_t			0.040
			(0.905)
Observations	482,757	482,629	482,629
R-squared	0.007	0.022	0.022
Year fe	No	Yes	Yes
Well fe	No	Yes	Yes
Controls	No	No	Yes
Time period	2005-2017	2005-2017	2005-2017

Notes: t-statistics are in parentheses. * Significantly different from zero at the 90% level, ** at the 95% level and *** at the 99% level

Starting from the first column, the t-test on the response to the spot price shows that it is insignificant to any levels, meaning that we cannot reject the null hypothesis that the response to spot prices is zero and keep the null hypothesis. It essentially means that an increase or decrease in the spot prices from previous period do not have an effect on the output produced today, on average. Additionally, the average well exhibits a strong and positive response to a change in the spread of 0.784. This implies that an increase (decrease) of 10% in the spot future spread is correspondent with a shift up (down) of 7.84% in oil production. In this case we manage to reject to null hypothesis and favor the alternative hypothesis that the parameter is different from zero. This is consistent with 90% confidence, a relative low explanation power, however these results are obtained when neither fixed effects are considered or controls are added.

As observed in the data, shale wells are best described as heterogeneous and as discussed in section 3.2 it is crucial to be aware of aggregate yearly changes in well production and well-specific linear trends. In column 2 we account for well and year fixed effects and all estimators shift downwards as a result, which makes us conclude that these variables are important in our framework and therefore control for these effects in our baseline (1.0) by adding well and year fixed effects. Figure 12A in the appendix illustrates why one should be aware of, and control for, aggregate yearly changes in production that is common to all wells at time *t.* It shows a typical production profile of Permian wells over months in operation, for three different time points: 2013, 2015 and 2017, and implies that Permian well producers managed, on average, to increase the volumes of oil they extract. This can be due to for example innovations in technology that affect all wells or the cyclicality of oil prices, common to all wells, that cause producers to shift production to wells that yield more output when prices are low. Well operators still not found to respond significantly to changes in spot prices (however the estimator goes down to 0.032 from 0.079) but do respond contemporaneously to current developments in the spread by increasing production with 7.03% to an increase of 10% in the spot future spread, which it significant at 10% level.

In column 3 we add control variables on top of fixed effects from column 2 and by adding them, we remove the effect of well-specific age and macroeconomic instability. In turn, the t-values for the spot price and the spread goes down and up, respectively, making it harder to reject the null for the spot and easier to reject the null for the future spot spread. The coefficient for the spread falls by 0.068 percentage point to 0.635, which implies that if 3 months spread goes up with 10%, well producers increase output with 6.35%. It is consistent with 95% confidence. This positive forward-looking supply elasticity may be puzzling at first stance given what was found in earlier research (discussed in section 2.4 and 3.3.3 and can be interpreted as in section 3.3.2). On the other hand, spot proved to be statistically insignificant at any of the levels, meaning that Permian producers are forward looking in their production decisions and are not able to adjust production instantly.

As evidenced by Bjørnland et al. (2017), a similar regression found that the spot prices are significant at the 5% level for shale oil producers in the Bakken region. This research is made for a longer time horizon that did not include the recent years (1986-2015) (see section 4 for different time horizons) or additional macro instability control variables, that are added to dampen the potential endogeneity in the model. The spread that was added was a 1-month future spot spread gave a coefficient value of 0.195 and found to be significant at the highest level, 1%. Even though our coefficient is larger, the change in production seems to grow in the same direction as the change in the spread with a shorter time horizon.

Table 2: Supply elasticity for different futures maturities

Variables	(1) 1-month horizon	(2) 3-month horizon	(3) 6-month horizon	(4) 12-month horizon
Dep. Var: ΔQ_{it}				
ΔQ_{it-1}	-0.089***	-0.089***	-0.086***	-0.081***
	(-3.273)	(-3.284)	(-3.254)	(-3.167)
ΔP_t	-0.058	-0.004	0.031	0.083
	(-0.634)	(-0.051)	(0.429)	(0.679)
$\Delta[F_{t+1,t} - P_t]$	0.516			
	(1.199)			
$\Delta[F_{t+3,t} - P_t]$		0.635**		
		(2.052)		
$\Delta[F_{t+6,t} - P_t]$			0.516	
			(1.492)	
$\Delta[F_{t+12,t} - P_t]$				0.563
				(1.276)
Well age_{it}	-0.003	-0.003	-0.004	-0.005
	(-1.242)	(-1.346)	(-1.394)	(-1.485)
$\Delta MSCI_t$	0.339	0.323	0.282	0.243
	(1.049)	(1.025)	(0.909)	(0.800)
ΔVIX_t	0.038	0.040	0.034	0.037
	(0.919)	(0.905)	(0.781)	(0.844)
Observations	482,629	482,629	458,290	385,880
R-squared	0.022	0.022	0.022	0.020
Year fe	Yes	Yes	Yes	Yes
Well fe	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes
Time period	2005-2017	2005-2017	2005-2017	2005-2017
Spread	1 month	3 months	6 months	12 months

Notes: t-statistics are in parentheses. * Significantly different from zero at the 90% level, ** at the 95% level and *** at the 99% level

We use our baseline model in column 3 and regress the change in production on spreads with different maturities, one at a time, to explore what time horizons Permian well operators are more responsive to. In table 2 we still find that producers do not respond significantly to spot prices for none of the specified horizons and that the only important time horizon for the spread Permian producers consider is three-month horizon. One-month spread is highly correlated with the spot price and its value is very close to zero and thus the coefficient is smaller in magnitude than for the 3-month horizon, but we cannot reject that it is different from zero. Consequently, table 2 substantiate the choice of focusing on 3 months spread as it proves to be significant at 5% level and the only significant response of adjusting current production.

A similar exercise was conducted by Bjørnland et al. (2017), however they added spot future spread at different time horizons, i.e. 3-, 6- and 12-month spreads on top of 1-month time horizon, one at a time, due to high correlation between them. The authors have found the spot price not to be significant in any of the cases. Additionally, they have found large significant negative response for longer (3-, 6- and 12-month) spot future spreads. The macro instability control variables we apply were not included in their model.

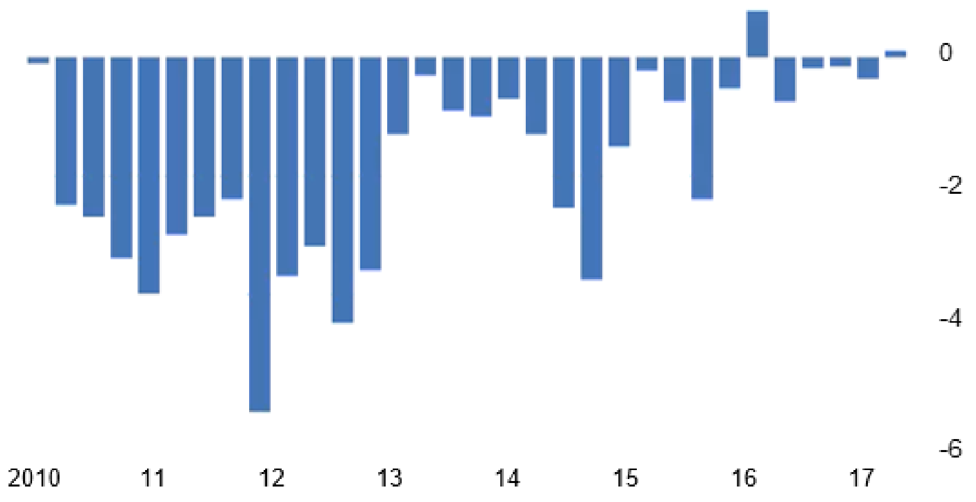
3.3.2 Key drivers of producer behavior

Buddy Clarck, co-chairman of the energy practice group at Haynes Boone, stated it rather straightforward: "*If you've got the rocks, you can get the money*". The funding of the cash negative operations of Permian's shale producers has been a key driver for maintaining their explosive growth. The Permian basin is clearly different from the other shale regions in terms of production growth where the play seemingly has continued to receive high levels of funding even through the downturn in oil prices from mid-2014 to end of 2016 (see figure 5).

Executive incentives are a crucial part of production behavior (Landsburg 1993). Historically, the two most important factors for management bonuses are growth in production and shareholder return relative to comparable peers in the shale industry (Crooks 2017). The latter is not much of a constraint if the entire industry prioritize the first objective. Hence, Permian producers have been heavily incentivized to increase production with limited emphasize on cash flow (see figure 7). Thus, their main restriction for further production growth is the availability of capital infusion. When the expected futures oil price rise, so does future revenue and the value of the shale companies, which makes it easier to attract funding (Reuters Staff 2018)

As seen in figure 7 the shale producers have operated with negative free cash flow per barrel meanwhile the Permian producers have still managed to increase production. Recent breakeven costs in the Permian region has been considerably higher than Bakken and slightly lower than Eagle Ford (see figure 16A). This further strengthen our argument that Permian producers pay limited attention to cash flow also compared to other fields. While Bakken and Eagle Ford reduce production at lower prices, Permian is doing the opposite even at similar or higher breakeven prices. This is why we find a positive coefficient in the Permian spread and a negative coefficient for Eagle Ford as in the extension according to previous literature (see section 3.2).

Figure 7: Free cash flow per barrel produced for a sample of leading shale companies in in the Permian region (2010-2017)[14]

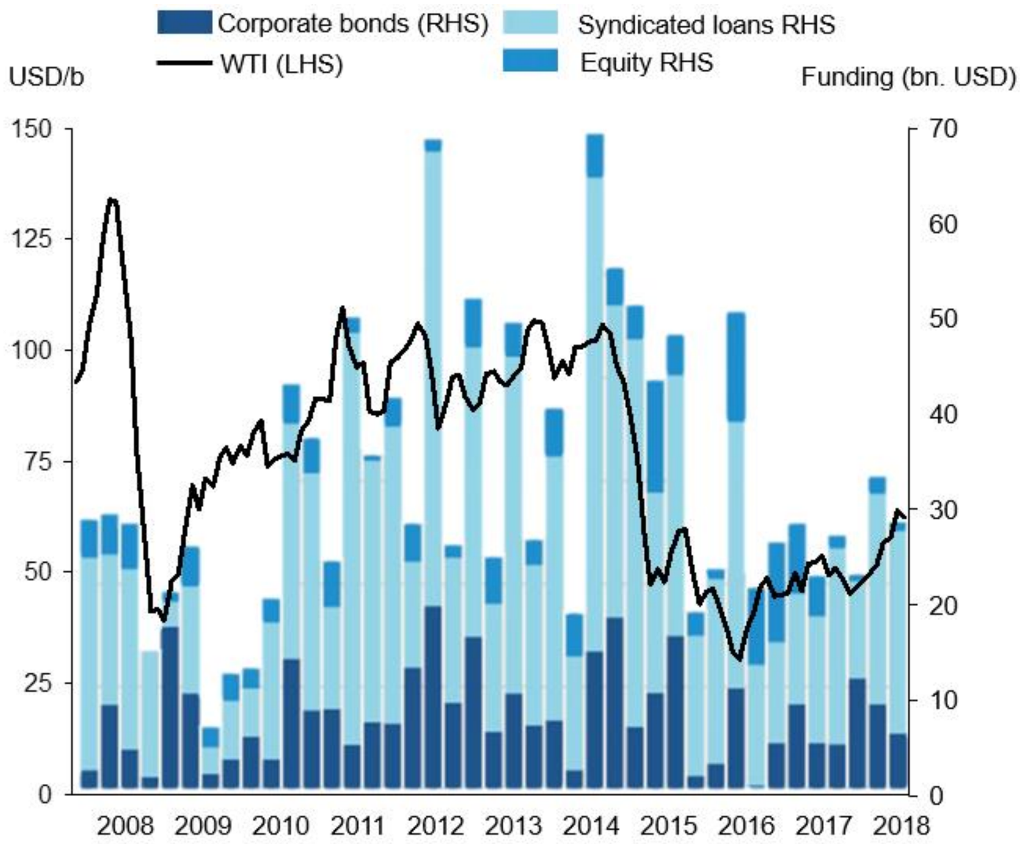


Source: Wood Mackenzie

While free cash flow per barrel gradually has become more positive, producers have still been in need for continuous funding, from equity and bonds issues as well as bank loans (see figure 8). Naturally, when the price of oil plunged during the financial crisis investors had limited dry powder for shale company investments. However, in the years preceding the recession considerable amounts of funding was driven into the industry – particularly when prices were high as before the downturn in 2014.

[14] Companies include EOG Resources, Pioneer Natural Resources, Devon Energy, Continental Resources and Newfield Exploration

Figure 8: Quarterly capital raising by U.S. E&P companies



Source: Dealogic

We find two main takeaways from the graph above; 1) companies receive considerable amounts of funding independent of the oil price, but 2) investors are increasing funding when the oil price is higher. This is in line with our assumption that companies can tolerate negative cash flow, since there will always be investors willing to fund operations. Furthermore, when future oil prices increase (the spread increases) it will be easier to receive funding and companies would want to increase production as quickly as possible.

3.3.3 Extensions

We would like to investigate whether producers in Eagle Ford, another shale play located in Texas and in relatively close proximity to Permian, behave in the same suboptimal manner to forward-looking prices and whether they respond to spot and spread similarly. After restructering the data, as was done for Permian, the sample was reduced to 14,534 active wells.

We constructed an interaction term with the price vectors and a dummy variable "Eagle Ford" that gives 0 if the well *i* is located in Permian and 1 if the well is in Eagle Ford. As before, Permian wells do not react significantly to recent changes in spot prices and the same is observed for Eagle Ford as the coefficient, -0.08, becomes negative, however insignificant[15]. When we perform this regression the supply elasticity of Permian with the forward-looking term (the spread) becomes

Table 3: Supply elasticity for Permian and Eagle Ford

VARIABLES	(1) Response to prices
Dep. Var: ΔQ_{it}	
ΔQ_{it-1}	-0.125***
	(-4.103)
ΔP_t	0.028
	(0.464)
ΔP_t * Eagle Ford	-0.108
	(-1.514)
$\Delta[F_{t+3,t} - P_t]$	0.732**
	(1.974)
$\Delta[F_{t+3,t} - P_t]$ * Eagle Ford	-1.270***
	(-2.800)
Well age_{it}	-0.000
	(-0.049)
$\Delta MSCI_t$	0.229
	(1.444)
ΔVIX_t	0.013
	(0.644)
Observations	1,116,734
R-squared	0.031
Year fe	Yes
Well fe	Yes
Controls	Yes
Time period	2005-2017

Notes: t-statistics are in parentheses. * Significantly different from zero at the 90% level, ** at the 95% level and *** at the 99% level

slightly more positive and shifts up to 0.732, remaining significant at the 5% level. Interestingly enough, Eagle Ford with a coefficient of -0.538 exhibit an "optimal" behaviour by holding back production if prices reach alower level than

[15] By performing a partial F-test on the response of Eagle Ford to spot prices (0.028 + (-0.108)) with a null hypothesis that the absolute elasticity is zero we cannot reject the null (Prob > F = 0.1187)

what they expected to be in 3 months' time, as was evidenced for Bakken. This result is significant at the 5% level[16].

Our findings from Eagle Ford are in line with Bjørnland et al. (2017) estimator's of the Bakken play, which have similar production patterns. We notice from the table that producers in Permian and Eagle Ford have entirely different production behavior. This further strengthens our argument shale wells are heterogeneous (here: across plays) and that Permian well producers are distinct by having a suboptimal production behavior.

4 Robustness

From table 4, we see that our results remain robust when looking at different time periods; the entire length of the data available (2000-2017) and the period after the financial crisis with its major oil downturn (2009-2017). The forward-looking supply elasticity (spread) seems to grow (become more positive) as we approach more recent times, however, only marginally. It should be noted that 98% of all oil that was produced in our sample was produced between 2009-2017. Since this coefficient measures the average monthly growth across the entire time period, a stronger supply elasticity stems from the fact that production boomed in Permian in the last years that followed the large capital stimulus and management incentives contingent on production. There is an advantage by constraining the sample to more recent periods as the supply elasticity will be more relevant to the current time. Nevertheless, restricting the sample to too few data points may be insufficient and make it more difficult to argue that the estimators are asymptotically close to their true value. Hence, the period of when the shale boom approximately started 2005-2017 was chosen.

[16] We can reject the null at the 5% level for (0.732 + (-1.270)) (Prob > F = 0.0262)

Table 4: Supply elasticity with different time periods

VARIABLES	(1) 2000-2017	(2) 2005-2017	(3) 2009-2017
Dep. Var: ΔQ_{it}			
ΔQ_{it-1}	-0.092***	-0.089***	-0.086***
	(-3.261)	(-3.284)	(-3.259)
ΔP_t	-0.006	-0.004	0.005
	(-0.080)	(-0.051)	(0.062)
$\Delta[F_{t+3,t} - P_t]$	0.626**	0. 635**	0.666**
	(2.056)	(2.052)	(2.116)
Well age_{it}	-0.003	-0.003	-0.003
	(-1.339)	(-1.346)	(-1.380)
$\Delta MSCI_t$	0.315	0.323	0.374
	(1.035)	(1.025)	(1.099)
ΔVIX_t	0.039	0.040	0.044
	(0.905)	(0.905)	(0.943)
Observations	486,988	482,629	470,811
R-squared	0.023	0.022	0.022
Year fe	Yes	Yes	Yes
Well fe	Yes	Yes	Yes
Controls	Yes	Yes	Yes
Time period	2000-2017	2005-2017	2009-2017

Notes: t-statistics are in parentheses. * Significantly different from zero at the 90% level, ** at the 95% level and *** at the 99% level

5 Limitations and further research

5.1 Assumption about oil price exogeneity

Even though there exists a large literature assuming that the oil price is exogenous to production in a certain play, some of the recent literature have criticized this assumption. Kilian and Davis (2011), Coglianese, Davis, Kilian & Stock (2017) argue that given the explosive growth in shale production it is natural to assume that production in U.S. plays have to a certain extent affected global oil prices.

Our control variables are likely to mitigate some of the potential endogeneity. Even so, further research should apply an instrumental variable (IV) approach where one can use instruments that capture global macro factors that represent the strength in global demand that affects oil prices, as Hamilton showed in 2014, or other variables with mechanisms that effect oil prices, but are not likely to be affected by it to a large degree. (see for example Newel et al. (2017) and Kilian (2016)).

5.2 Assumption about futures price

Even though the futures price of oil is the most commonly used for expected future spot price, it is far from perfect. The futures oil market is influenced by numerous factors, but arguably the most prominent factors are convenience yield and hedging. Convenience yield is associated with the advantage of holding an underlying product, rather than the contract or derivative product (Alquist, Bauer & Diez de los Rios 2014). When storage levels of a commodity are scarce, the commodity's price have a habit of increasing, and vice versa. The purpose of hedging is to avoid losses from unexpected unfavorable price changes and lock in an acceptable market price. Whenever there is a gain from the futures contract, there is a loss from the spot market, or vice versa. In 2018, 2/5 of the largest shale producers had hedged output (Rystad Energy 2018). This is in order to de-risk the company’s business profile and often a requirement from banks to have a certain share of production hedged. Consequently, the futures price is highly influenced by the storage costs and hedging of producers and may not reflect the producer’s actual expectations of the price.

Further research should experiment with alternatives to the futures price. One alternative is to add costs variables (breakeven costs, capital expenditures, etc.) or income/earnings variables (expected revenue, cash flow, etc.). In accordance with our arguments, one would expect to find that producers put less emphasize on costs and the bottom line. According to our results, if expected revenue increases then production should increase shortly after. Thus, expected revenue would be an interesting variable to examine.

5.3 Bottlenecks effect on production

Analysts have pointed to scarcity in fracking teams, availability of water and sand and infrastructure constraints as the main bottlenecks in production (Kjus, 2017). These constraints are often said to be reflected in the drilled but uncompleted wells (DUCs), which are wells that are drilled but not completed. In 2017, the backlog of DUCs increased drastically as shale E&Ps drilled far more wells than they either could complete or wanted to complete (See Bjørnland et al. 2017 for more). According to Rystad (2018), the drilled-to-completion ratio and fracking teams are causing a persistent bottleneck for the producers (see figure 14A). Fracking teams is the labor forced used to complete the DUCs, generally a fracking team requires ca. 30 people per well. These fracking teams have been a limited resource in U.S., which constrained producers that want to complete wells and produce that are now unable to do so.

The Permian's pipeline network has been filling up during the last couple of years, forcing significant discounts for oil. According to intelligence firm Genscape (2017), pipeline utilization in the Permian has during the last years jumped to 96% at several times. This has resulted in spot crude at Midland, Texas, trading at almost $16 a barrel below the price of oil in Houston. Also, fracking sand and water is an integral part of the completion stage of a well. The completion stage has required gradually more sand and water over time and the availability and transportation of it has emerged as a clear constraint for the producers. Demand for fracking sand surged from 34 million tons in 2012 to and expected amount of over 100 million tons in 2018 (Rystad Energy). Fracking sand costed $120 per short ton on the Texas wellhead in 2017, triple of the costs in the Bakken because of the cost of transportation. Hence, the transportation of oil and availability of fracking teams, sand and water can also constrain producers from producing according to the producer’s optimal profile.

Further research should try to incorporate the bottlenecks mentioned into their model. Bjørnland et al. (2017) look at the timing of completion as an alternative manner for producer’s to adjust production, while Newell & Prest (2017) finds that drilling is the most elastic part of the producer’s decision making. Both of these producer decisions should be tested on Permian data. Furthermore, it could be interesting to add the potential bottlenecks to the model, for example distance to refineries, utilization of fracking teams and demand for water and sand related to the amount transported or available. In such a way we could isolate this effect from our estimators.

6 Conclusion

In this thesis we have examined the producer responsiveness to different price incentives in the Permian play. Furthermore, we conducted analysis on Eagle Ford to benchmark our findings in Permian and previous literature. By having access to Rystad Energy's Shale Well Cube we were able to conduct an extensive analysis on recent data. Our data suggested that wells are heterogeneous and a major advantage of the use of panel data in our analysis that allowed us to obtain well fixed effects and estimate them. Additionally, we managed to mitigate aggregation bias by using a rich panel data.

In this paper we have found that when the 3-month future spot spread increases by 10% then well operators in Permian shift up production by 6.35%, which is significant at a 5%-level. We have argued that this intriguing finding comes about due to the producer's opportunistic behavior of receiving more funding at higher future prices and increased bonus. Furthermore, we find that Permian producer's also behave differently to producers in Eagle Ford, which shifts production down to similar price incentives. We interpret such output pattern of the Permian producers to be inconsistent with the Hotelling theory of optimal extraction as the maximization of wealth is not likely to be achieved by this producer behavior. Hence, we find that the production pattern of the Permian producers has been of a suboptimal nature.

Our results suggest that policy makers should be aware of the shale producer's incentives when implementing policies. For example, monetary policy could affect the oil and gas industry in Permian differently compared with what general producer theory would imply (i.e. profit maximizing producers). An implication of our findings is that if the producer incentives do not result in improved cash flow or sufficient increase in productivity, investors should alter the current incentives. For further research, we suggest that one look into applying IV, as well as experimenting with hedging constraints and bottlenecks to remove those restrictions and obtain a more realistic representation of producer's behavior.

References

Aastveit, Knut Are, Hilde C. Bjørnland and Leif Anders Thorsrud (2015). ‘What drives oil prices? Emerging versus developed economies’. *Journal of Applied Econometrics 30.7*, pp. 1013–1028.

Alquist, R., G. Bauer & A. Diez de los Rios. (2014). "What Does the Convenience Yield Curve Tell Us about the Crude Oil Market?". *Staff Working Papers*, Bank of Canada, pp. 14-42.

Anderson, S.T., R. Kellogg, and Stephen W. Salant, "Hotelling under Pressure". *Journal of Political Economy 126*, no. 3, pp. 984-1026.

Baumeister, C. and J. D. Hamilton. (2015). Structural interpretation of vector autoregressions with incomplete identification: Revisiting the role of oil supply and demand shocks. *Manuscript, University of Notre Dame and UCSD.*

Baumeister, C. and L. Kilian. (2016). Understanding the Decline in the Price of Oil since June 2014. *CESifo Working Paper Series 5755*.

Bjørnland, C. H. & Frode Martin Nordvik & Maximilian Rohrer. (2017). Supply Flexibility in the Shale Patch: Evidence from North Dakota. *Centre for Applied Macro- and Petroleum economics (CAMP), BI Norwegian Business School, Working Papers No 2/2017.*

Blackmon, D. (2017). *Gilmer: We Should View The Permian Basin As A Permanent Resource*. Forbes. URL: https://www.forbes.com/sites/davidblackmon/2017/08/17/gilmer-we-should-view-the-permian-basin-as-a-permanent-resource/#3ea674fa56ff (visited on 25/06/2018)

Caldara, D., M. Cavallo & M. Iacoviello. (2016). Oil Price Elasticities and Oil Price Fluctuations. *International Finance Discussion Papers 1173.*

Cameron, A. C., & Trivedi, P. K. (2005). Microeconometrics: methods and applications. *Cambridge university press.*

Carpenter, C. (2014). Design optimization of horizontal wells with multiple hydraulic fractures in the bakken shale. *Journal of Petroleum Technology 66(11), 118–123.*

Carroll, L. (1871). Through the Looking-Glass. *Macmillan Publishers Ltd.*

Coglianese, J., L. W. Davis, Lutz Kilian & J. H. Stock. (2017). "Anticipation, Tax Avoidance, and the Price Elasticity of Gasoline Demand". *Journal of Applied Econometrics, vol 32(1),* pp. 1-15.

Correia, A. (2017). Reghdfe: Stata module for linear and instrumental-variable/GMM regression absorbing multiple levels of fixed effects. *Statistical Software Components S457874, Boston College Department of Economics.*

Crooks, E. (2015). The US shale revolution. Financial Times. URL:

https://www.ft.com/content/2ded7416-e930-11e4-a71a-00144feab7de (visited on 25/06/2018)

Dahl, C. and M. Yücel (1991). Testing alternative hypotheses of oil producer behavior. *The Energy Journal 12 (4), 117–138.*

Erlingsen, E. (2018). U.S. tight oil production on growth path as cost falls. U.S. URL: https://www.rystadenergy.com/newsevents/news/press-releases/us-tight-oil-production/ (visited on 25/06/2018)

Genscape. (2017). Growth in Permian Production to Stress Outbound Infrastructure in Late 2017. URL: https://www.genscape.com/blog/growth-permian-production-stress-outbound-infrastructure-late-2017 (visited on 25/06/2018)

Griffin, J. M. (1985). OPEC Behavior: A Test of Alternative Hypotheses. *American Economic Review, 75 (5)*, pp. 954-63.

Griffin, J. M. and D. J. Teece. (2016). *OPEC behaviour and world oil prices*. Routledge.

Hamilton, J. D. (1983). 'Oil and the macroeconomy since World War II'.In: *The Journal of Political Economy 91.2*, pp. 228–248.

— (1985). Historical causes of postwar oil shocks and recessions. *The Energy Journal 6.1*, pp. 97–116.

— (2014). Oil prices as an indicator of global economic conditions. *Econbrowser: Analysis of current economic conditions and policy*, http://econbrowser.com/archives/2014/12/oil-prices-as-an-indicator-of-globaleconomic-conditions.

Hayashi, F. (2001). Econometrics. *Princeton University Press*

Hogan, W. W. (1989). World oil price projections: a sensitivity analysis. *Harvard University, Energy and Environmental Policy Center, John F. Kennedy School of Government.*

Hotelling, H. (1931). The economics of exhaustible resources. *Journal of Political Economy 39 (2)*, pp. 137–175.

International Energy Agency. (2017). World Energy Outlook 2018. URL: https://webstore.iea.org/world-energy-outlook-2018 (visited on 25/06/2018)

Kilian, Lutz (2009). Not All Oil Price Shocks Are Alike: Disentangling Demand and Supply Shocks in the Crude Oil Market. *American Economic Review 99.3*, pp. 1053–69.

— (2016). The Impact of the Shale Oil Revolution on US Oil and Gasoline Prices. *CESifo Working Paper series 5723*.

— (2017a). How the Tight Oil Boom Has Changed Oil and Gasoline Markets. *CESifo Working Paper Series 6380*, CESifo Group Munich.

— (2017b) Baumeister, Christiane & Kilian, Lutz, 2017. Lower Oil Prices and the U.S. Economy: Is This Time Different?. *CEPR Discussion Papers 11792, C.E.P.R. Discussion Papers*.

Kilian, L and L. W. Davis. (2011). *Journal of Applied Econometrics, 2011, 26(7)*, pp. 1187-1214.

Kimmeridge Energy Management Company. (2017). The Impact of the Permian Production Tsunami: Lessons From Natural Gas. URL:

http://www.kimmeridgeenergy.com/wp-content/uploads/2017/03/Research-Note-Permian-Slug.pdf (visited on 25/06/2018)

Kjus, Thorbjørn (2017). *Oil Market Outlook 2017*, DNB Markets.

Mas-Colell, A., Michael D. Whinston and Jerry R. Green. (1995*). Microeconomic Theory*. Oxford University Press.

Meyer, G. (2017). US shale oil output remains resilient despite rig count fall. URL: https://www.ft.com/content/73c5297e-d813-11e6-944b-e7eb37a6aa8e (visited on 25/06/2018)

Newell, R. G. & B. C. Prest. (2017). The Unconventional Oil Supply Boom: Aggregate Price Response from Microdata. *NBER Working Papers 23973, National Bureau of Economic Research, Inc*.

Pesaran, M. H. (1990). An econometric analysis of exploration and extraction of oil in the UK continental shelf. *The Economic Journal 100 (401), 367–390*.

Ramcharran, H. (2002). Oil production responses to price changes: an empirical application of the competitive model to OPEC and non-OPEC countries. *Energy Economics 24 (2), 97–106.*

Rapier, R. (2018). The Permian Basin's Looming Bottleneck. Forbes. URL: https://www.forbes.com/sites/rrapier/2018/04/05/the-permian-basins-looming-bottleneck/#3474c84750a8 (visited on 25/06/2018)

Reuters Staff. (2018). *Refi wave lurks for energy borrowers on back of higher oil prices.*URL: https://www.reuters.com/article/energy-refi/corrected-refi-wave-lurks-for-energy-borrowers-on-back-of-higher-oil-prices-idUSL2N1T20NG

Rystad Energy. (2018). Top 33 shale oil producers need extra 8.3 BUSD to balance 2018 cash flows at 60 USD WTI. URL: https://www.rystadenergy.com/newsevents/news/newsletters/UsArchive/shale-newsletter-january-2018/ (visited on 25/06/2018)

Sims, C. A. (1980). Macroeconomics and Reality. *Econometrica 48.1*, pp. 1–48.

Smith, J. L. (2009). World oil: market or mayhem?. *The Journal of Economic Perspectives 23 (3)*,pp. 145–164.

U.S. Energy Information Administration. (2017). Oil: Crude and Petroleum Products Explained, Oil and the Environment. Retrieved 14th of January 2018 from https://www.eia.gov/energyexplained/index.cfm?page=oil_environment (visited on 25/06/2018) (visited on 25/06/2018)

Wilkerson, Chad R and Nida Cakir Melek (2014). Getting crude to market:central US oil transportation challenges. *Main Street Economist 1*, pp. 1–7.

A Appendix

Table 5A: Summary Statistics

Authors's calculations are based on data that has been being restructured (i.e. sampled data). The table is based on the time series with monthly frequency and the cross-section of wells that lie in Permian and Eagle Ford

Time series		**Mean**	**St.dev**	**Min**	**Max**
Start date	2005:M01				
End date	2017:M12				
No. of months	156				
Well production		0.0290	0.0968	0	5.4431
Change in production		-0.0332	0.8114	-91.8138	90.3171
Spot price		74.3603	22.4823	32.74	139.96
Change in spot price		0.0021	0.0927	-0.3912	0.2753
Change in three months spread		-0.00002	0.0177	-0.0654	0.0793
Change in MSCI world		0.0040	0.0387	-0.1798	0.0955
Change in VIX index		-0.0012	0.2050	-0.4860	0.8526

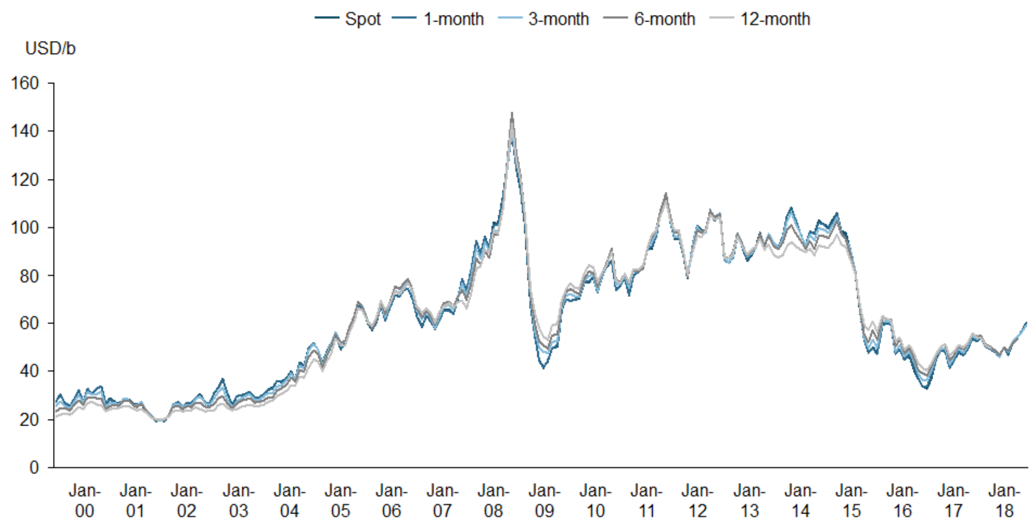
Total cross-section					
No. of wells	27,711				
Observations	4,322,916				

Permian		**Mean**	**St.dev**	**Min**	**Max**
No. of wells	13,177				
Well production (kb/d)		0.0266	0.0949	0	3.6792
Change in well prod.		-0.0288	0.9617	-91.8138	90.3171
Well age (month)		7.8024	20.1230	0	214
3-month decline rate	41 %				
12-month decline rate	75 %				
24-month decline rate	87 %				

Eagle Ford		**Mean**	**St.dev**	**Min**	**Max**
No. of wells	14,534				
Well production (kb/d)		0.0312	0.0984	0	5.4431
Change in well prod.		-0.0365	0.6733	-29.6909	89.3667
Well age (month)		8.1097	16.1250	0	115
3-month decline rate	40 %				
12-month decline rate	75 %				
24-month decline rate	87 %				

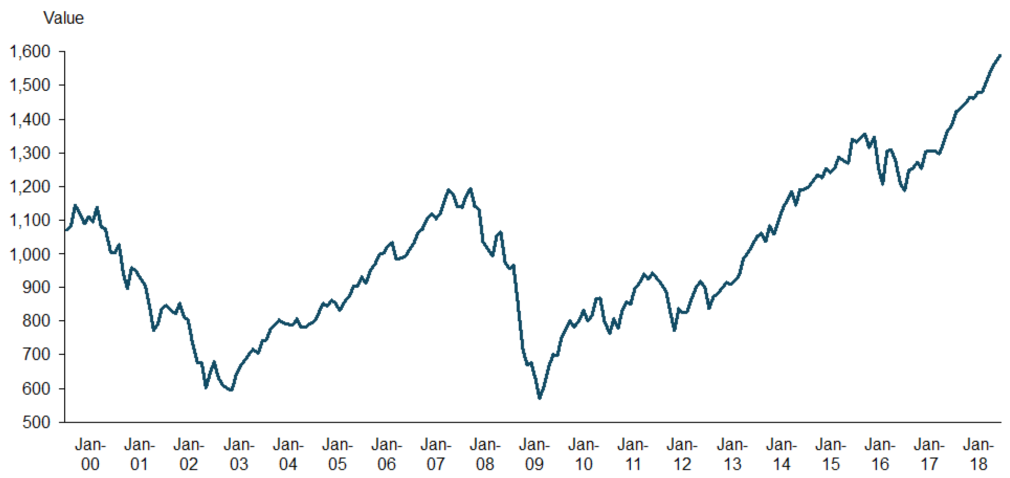
Source: Well data from Rystad Energy. Spot prices from EIA. Futures prices, MSCI world index and VIX from Bloomberg.

Figure 9A: Deflated futures prices and spot price 2000-end of 2017



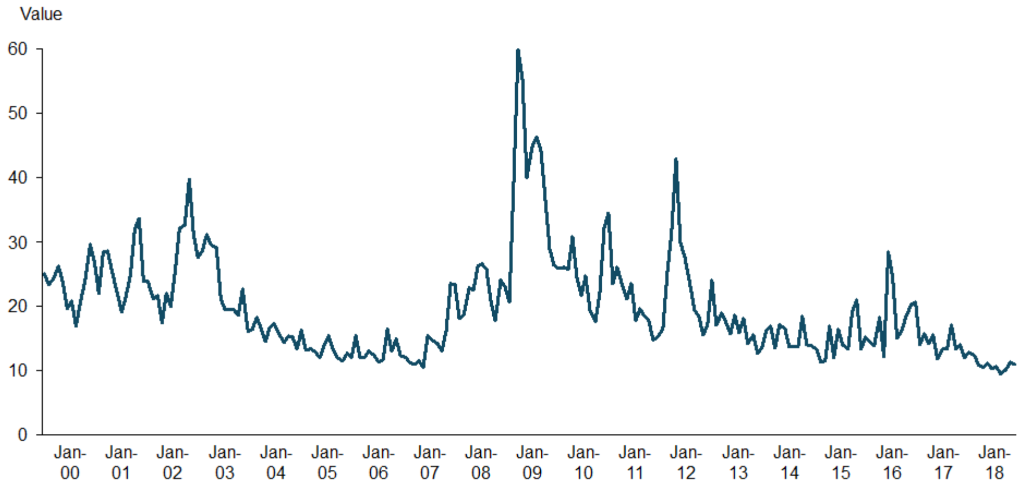
Source: EIA and Bloomberg

Figure 10A: MSCI world index 2000-end of 2017



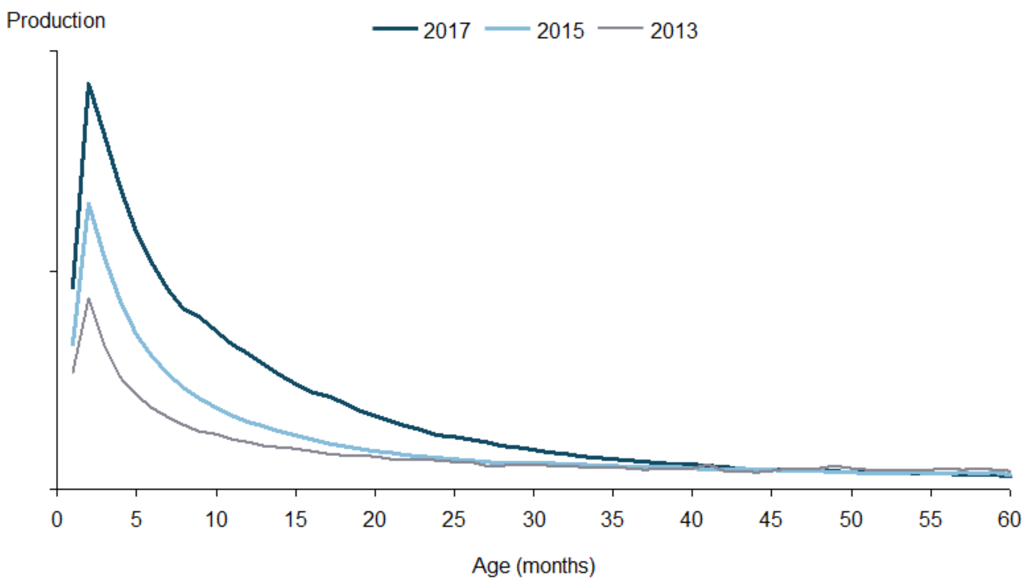
Source: Bloomberg

Figure 11A: VIX index 2000-end of 2017



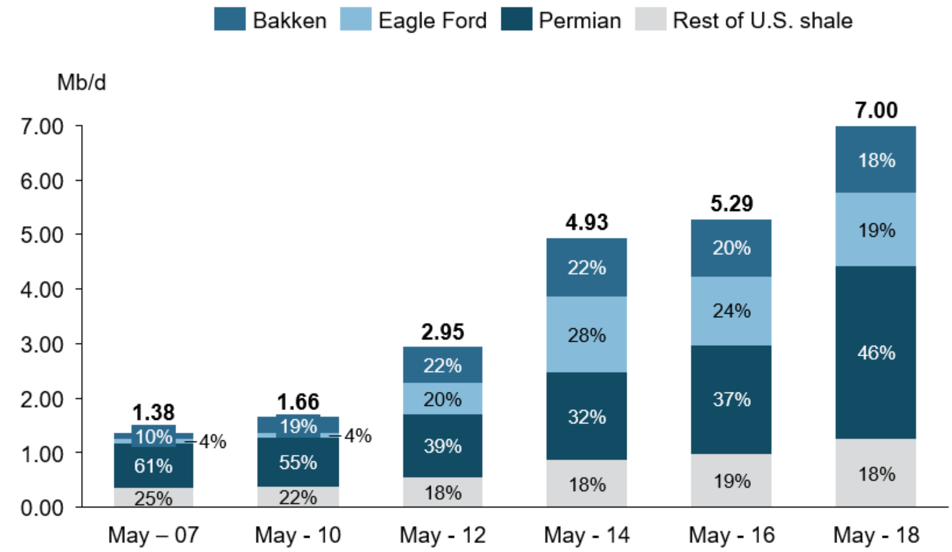
Source: Bloomberg

Figure 12A: Productivity improvement over time in Permian



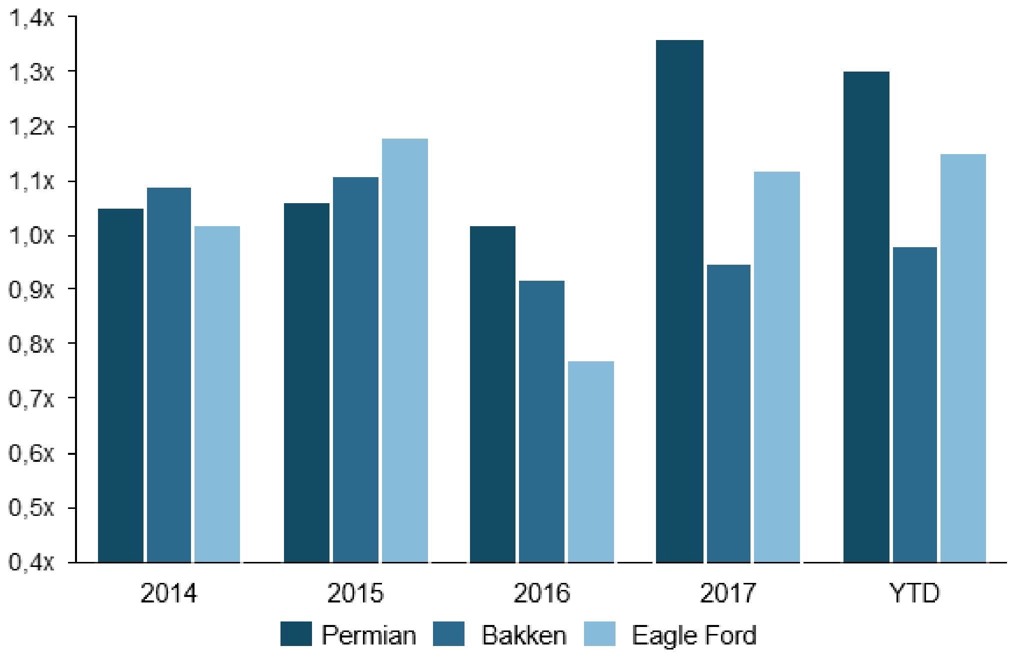
Source: Rystad Energy

Figure 13A: Key shale oil plays share of total shale oil production in the U.S. 2000-end of 2017



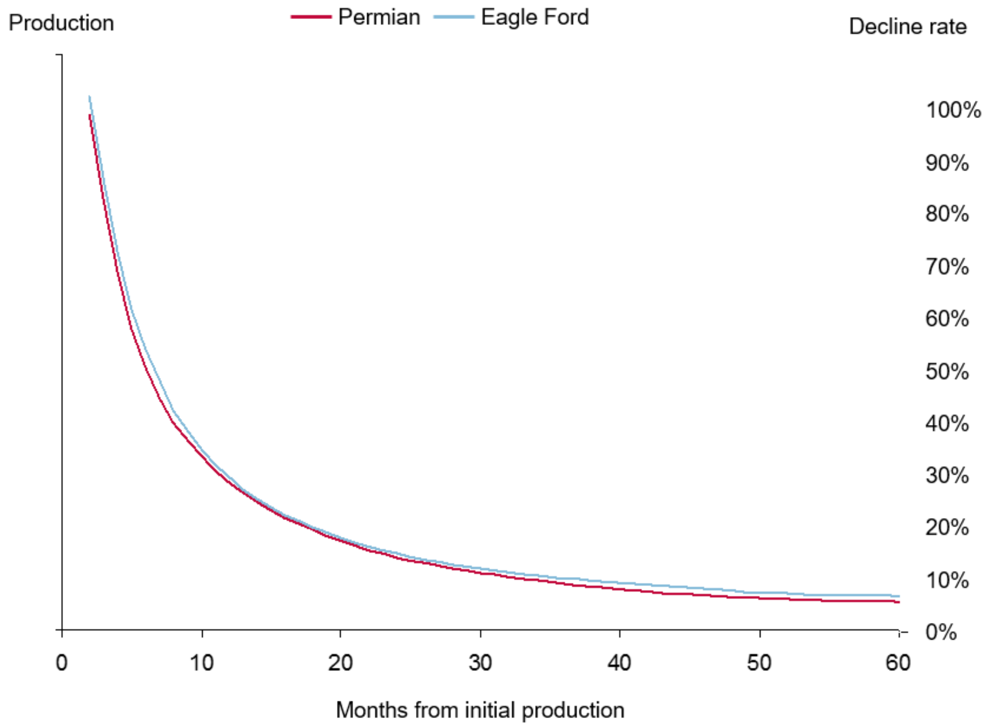
Source: EIA

Figure 14A: Average drilling/completion ratio from 2014 - May 2018



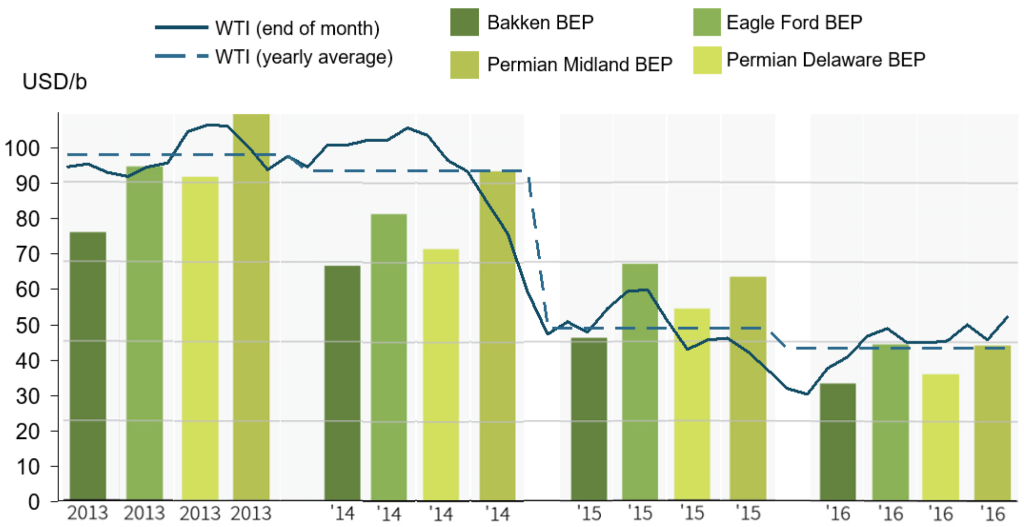
Source: EIA

Figure 15A: Decline rates over the first 60 months of production from 2000 - 2017



Source: Rystad Energy

Figure 16A: Breakeven prices for the three largest shale oil plays and WTI price



Source: Rystad Energy

List of figures

List of tables

BI Norwegian Business School - campus Oslo

GRA 19502

Master Thesis

Component of continuous assessment: Forprosjekt, Thesis MSc

Preliminary Thesis

Navn: Lein Mann, Viktor Myhre

Start: 01.01.2018 09.00

Finish: 15.01.2018 12.00

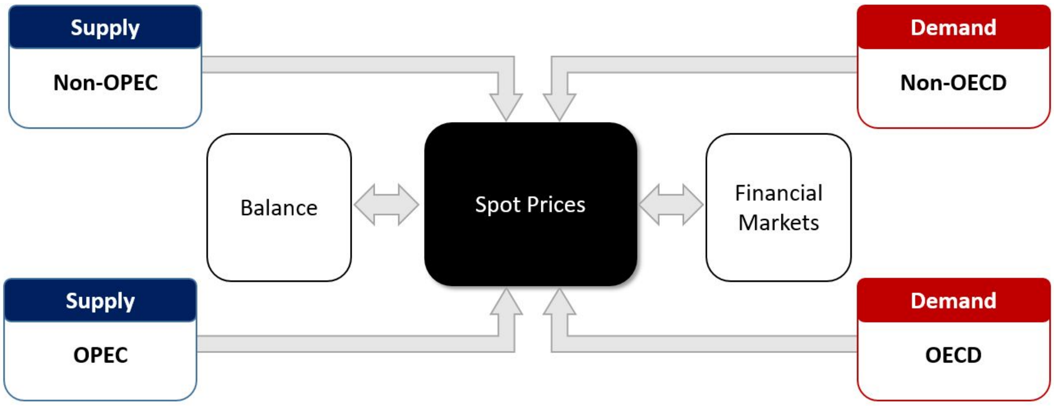
Table of contents

1.0 Motivation

1.1 Global demand and supply of oil

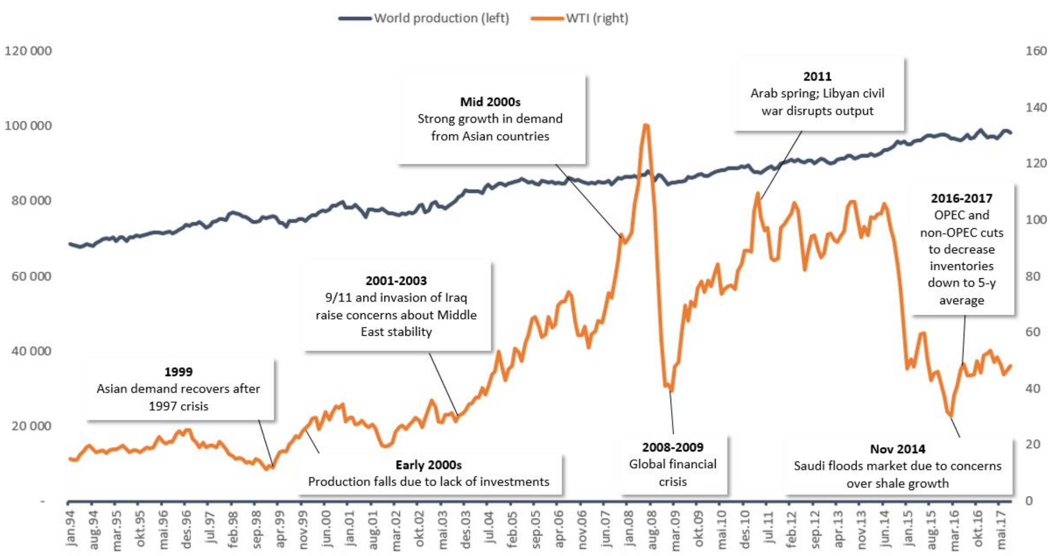
The oil market is composed of a wide range of consumers and producers, where investors play an important role in determining the price of oil. The "paper-market", driven my investors such as commodity futures market is a key determinant of the price, however the underlying driver of the oil price is the balance between supply and demand.

Figure 1: Key determinants of the spot price



The two most commonly used prices of oil are mainly brent crude, which is connected to oil from the North Sea and West Texas Intermediate (WTI), which is the benchmark for production in North America.

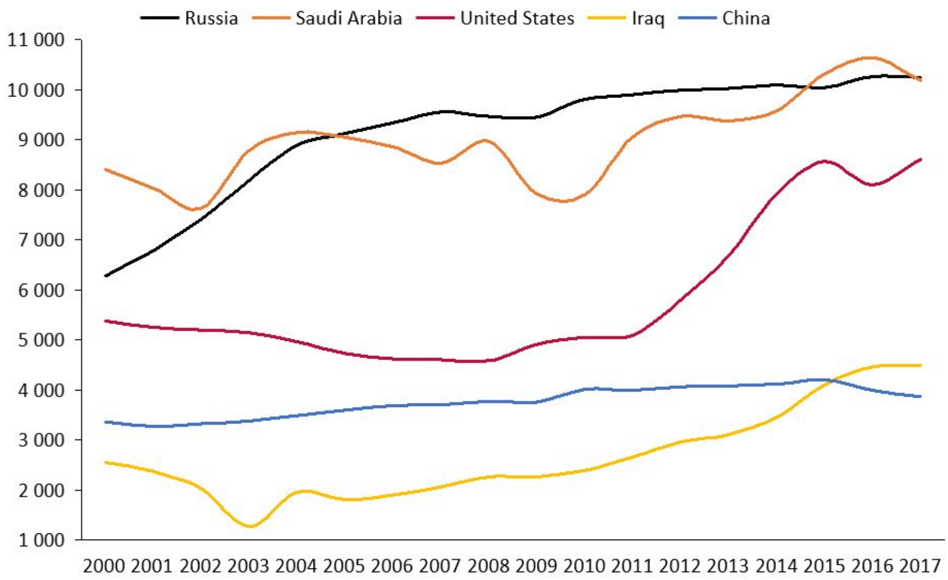
Figure 2: The recent history of oil price and supply growth



From Figure 2 one can see that while production has increased steadily the last twenty years the oil price has fluctuated considerably. The WTI price has historically been far more volatile than other commodities, with historical annualized price volatility reaching 50% not an uncommon phenomena.

The 5 largest oil producers have increased their supply of oil to the market during 2000-2017. Russia is currently the largest producer of crude oil, surpassing slightly Saudi Arabia which in turn produce more output than the US, Iraq, China and the rest of the world (in this order) (Rystad Energy 2018).

Figure 3: Global crude oil production by 5 largest oil producers 2000-2017 (kkbl/d)



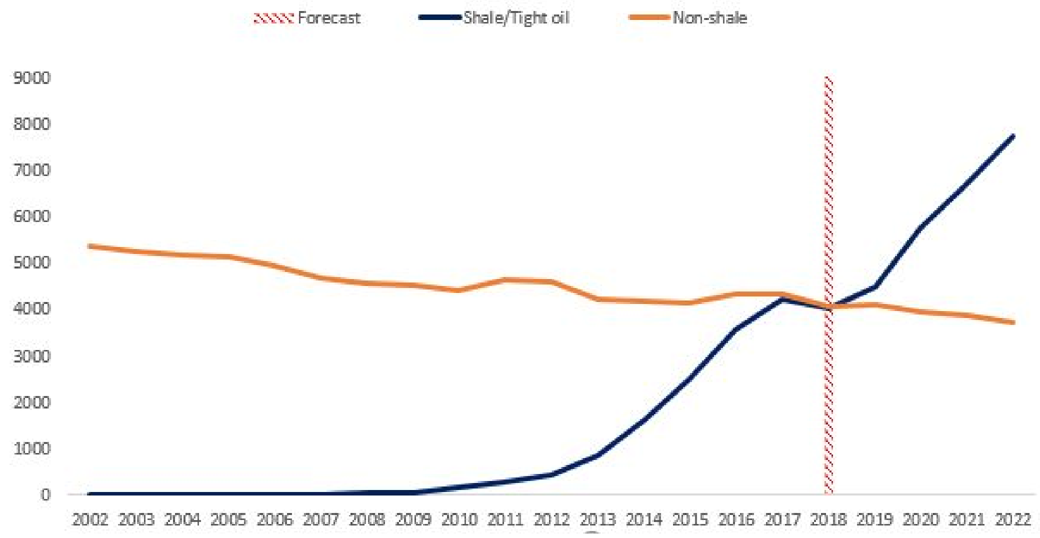
Data source: Rystad Energy (2018)

USA have recently had the largest growth in absolute number of barrels of oil from 2011-2017, equal to ~3,521 kbbl/d. Two of the largest crude oil producing countries are OPEC members, Saudi Arabia and Iraq, while Russia have in the past agreed to production cuts of the oil cartel.

1.2 US shale oil boom

In recent years US shale oil[1] producers were responsible for the “shale boom” dating back to 2009 (Crooks, 2015), which changed the rules of the game in the oil industry. The main difference between shale oil and non-shale oil (referred as well as “conventional oil”) is the geologic rock formation with low permeability, which requires hydraulic fracturing technology to extract the oil (Bjørnland et al 2017) (see section 1.2.1).

Figure 4: Crude Oil production from the U.S. by type over time*



**Non-shale includes offshore production, sand oil and other onshore production*

Data source: Rystad Energy (2018)

In the last decade shale oil producers became important players in the oil industry due to their steady increase in volume of oil produced. While the US is currently producing at a record high level we can see above that the recent jump in US oil production was driven mostly by shale oil rather than non-shale oil production. Furthermore, it was shown that besides the surge in the U.S. shale oil production in recent years, the growth rate of global oil production since June 2014 has been modest (Baumeister & Hamilton, 2015).

[1] In this paper, we use the terms ‘shale’, “tight oil” and “unconventional oil” interchangeably. Similarly with “conventional oil” and “non-shale”

In 2017 shale oil production surpassed non-shale production for the first time in US history. Rystad Energy predicts that in the coming years, this trend will continue with an increasing gap between the two (see Figure 5). The United States is expected to account for more than 80 percent of global oil production growth in the next 10 years and it will produce 30 percent more gas than Russia by that time, according to International Energy Agency (IEA, 2017). US is still a net oil importing country, measured by imports minus exports, however IEA (2017) estimates that US will become a net exporting country within ten years.

1.2.1 Key differences between conventional and unconventional oil production

There are important differences between non-shale oil to shale/tight oil. Traditionally, firms were extracting below-ground reserves of oil solely by drilling vertically to allow the oil that is trapped between rocks to spill out and be collected in the surface (Bjørnland et al, 2017). The hydrocarbon simply flows from high concentrated areas with high pressure to lower pressure areas. On the other hand, oil found in shale and other tight geologic formations have very low permeability[2], making conventional methods unsuitable to extract the resource. Taking advantage of hydraulic fracturing technique allowed US producers to extract shale oil and significantly increase domestic oil production, which made them less reliant on oil imports (EIA, 2017).

Shale producers use hydraulic fracturing combined with drilling activity, which involves stimulating the rock formations with fracking fluid; water, sand and chemicals in high pressure to fissure the rocks and create cracks from which the oil will come out and later be pumped. To tap onto the shale oil, the producer should first drill vertically and then turn approximately 90 degrees to continue drilling *horizontally*. At the completion phase further drilling and fracturing is required to let the oil come out.

[2] Permeability is a characteristic that allows the oil and gas to flow through the rock.

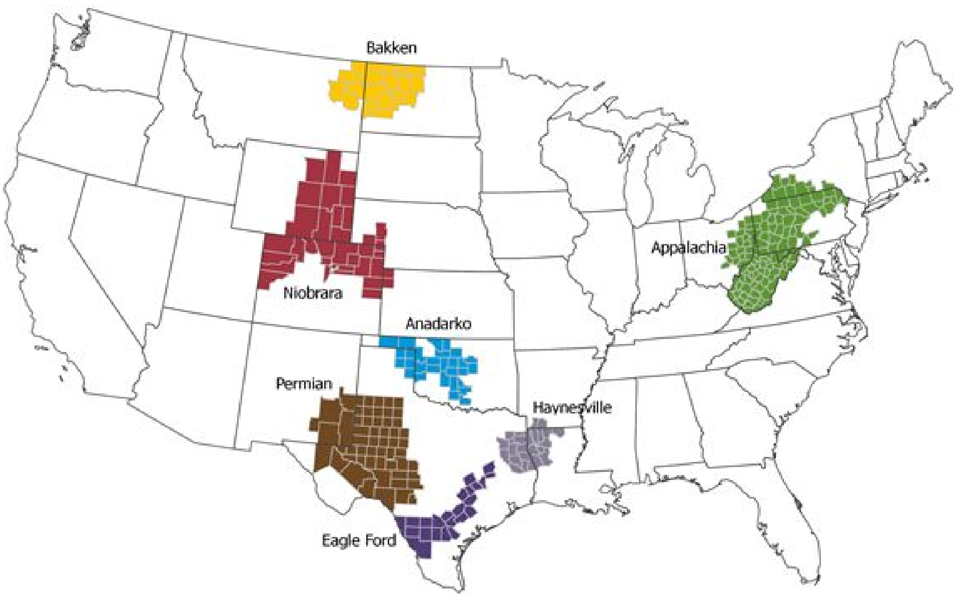
1.2.2 Productivity development and drilling and completion of wells

In order to measure the well-level productivity, the common benchmark used is Estimated Ultimate Recovery (EUR). It is found based on the total amount of hydrocarbon extracted from a single well. It more than doubled in volume between 2012-2016 in horizontal US shale oil according to Rystad. Reasons for recent improvement were; (1) technological, as the well became longer and able to allocate more oil (2) learning by doing, meaning that producers have been experimenting and found the sufficient amount of hydraulic fluid and pressure in fracturing the shale, (3) geological, when producers shifted their production to the most prolific and profitable areas (Meyer, 2017).

1.3 Shale oil production in the US by region

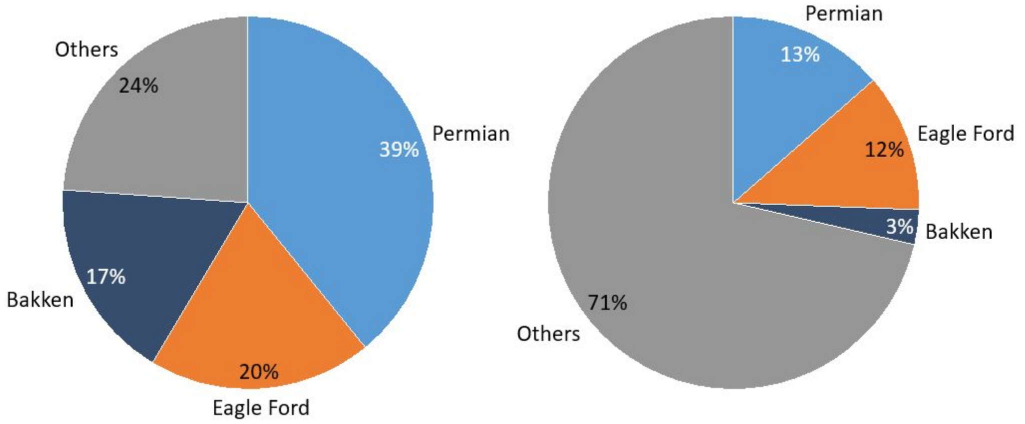
US shale production is distributed across the country and can be identified in 7 key tight oil and shale gas regions (EIA).

Illustration 1: Geography of key tight oil and shale gas regions



In January 2018 the 7 regions produced on average ~5.259 mb/d. Among the 7 regions, the largest ones by production of oil are Permian (~2.266 mb/d), Eagle Ford (~1.185 mb/d) and Bakken (~1.036 mb/d). The remaining four regions accounted for ~1.043 mb/d in Jan. 2018. Naturally, the focus of this assignment will be on the three largest shale oil regions (fields).

Figure 5: Distribution of US shale oil (left) and gas (right) production by region



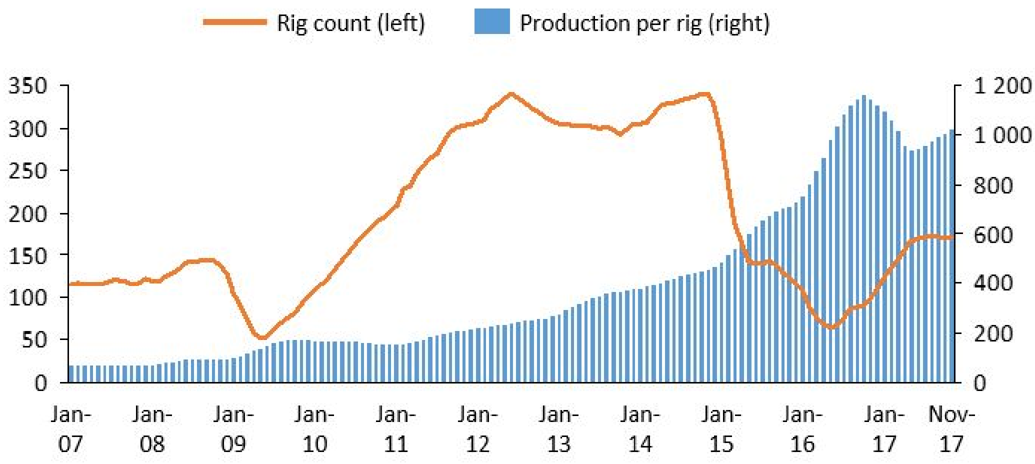
Data source: EIA (2018)

1.4 Historical development of shale productivity

Figure 6 below points out that the production per rig have been increasing significantly in the past 10 years, at an increasing rate, except for two bumps in 2009 (post financial crisis) and 2016 (post major downturn in oil prices). At the same time looking at the rig count creates an opposite picture; While the rig count falls production per rig increases, which makes sense mathematically. However, an investor that looks solely at recent change in rig count may adopt false expectations about the level of output for a firm or a region in the short term (Kjus 2017).

Figure 6 gives an indicator of the shale oil flexibility. In January 2009, there were 345 rigs in operation, which had risen to 1,600 by September 2014. Most of these rigs are mainly considered to be used in the shale industry. When the oil price plunged down to 30$/b due to OPECs flooding strategy of the market between September 2014 and February 2016, the number of oil rigs declined from 1,600 to 400. This would indicate that shale producers can be flexible in reducing production when the oil price is not sufficiently high.

Figure 6: Rig count vs. production per rig for the 3 largest regions (monthly averages)

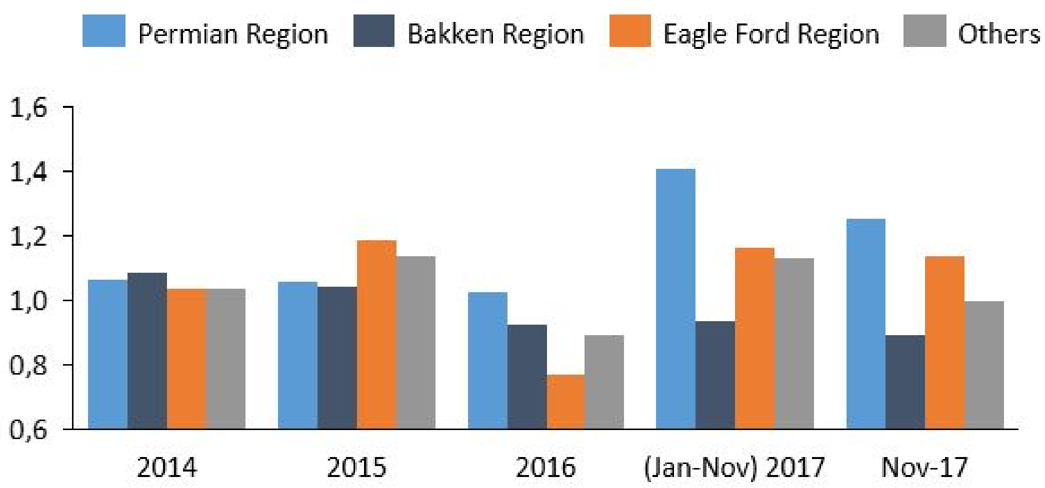


Data source: EIA (2018)

For that reason, it is appropriate to take into account the existence of "Drilled but Uncompleted Wells", or DUCs. Firms may drill wells but hold up its completion for many reasons, among them are contractual requirements underlined in the licence, expectation for higher oil prices around the corner and so on. Therefore, it is more suitable to look at drilled/completed ratio for the firm or region of interest to get a better understanding of the short term flexibility to increase a firm's output.

Figure 7: Drilled/completed ratio for wells in the 3 largest regions

Permian, Eagle Ford and Bakken. Average annualized ratio.



Data source: EIA (2018)

Figure 7 illustrates what seems like irregular trends in the drilled/completed ratio in the last 4 years. Permian has the highest ratio driven by the highest level of DUC's in the whole country. On the other hand while Eagle Ford increased its ratio in the past four years, Bakken showed a decreasing trend. Another reason for the variation is the existence of bottlenecks, or capacity constraints in completing or drilling a well that matters for the firm a great deal in adjusting their production.

2.0 Related literature

2.1 Oil price shocks and causality between supply and demand

The interaction between the oil market and the world economy has been a subject of great interest for a long time for macroeconomists and researchers in general. Especially the relationship between oil price shocks and its relation to supply and demand for oil. There are several researchers that have focused their research on theoretical explanations for oil price shocks and their origins, however there are particular two dominant views that emerged in previous literature:

(1) According to Hamilton (1983; 1985), the supply side is the major determinant of explaining oil price shocks. Furthermore, he argues that oil price shocks are driven by exogenous disruption in world petroleum supply which is associated with wars or conflicts in post-war data. (2) This is opposed to Kilian's (2009) view who used a structural vector autoregression (SVAR) method and identified demand as a more decisive driver than supply in explaining the oil price fluctuations after the 1970s. Kilian (2009) also went on to argue that there exists a two-way causality between the oil market and the macro economy, where demand and supply shocks in the oil market lead to different macroeconomic outcomes.

Bjørnland et al (2015) used a factor-augmented vector autoregressive (FAVAR) model to distinguish groups of countries and how these groups might differ in the manner they affect the real price of oil. They find that the demand from Asian countries (and particularly China) is more than twice as important than demand from emerging economies to explain the fluctuations in the real price of oil and in oil production.

2.2 Shale oil development

The recent surge in shale production has led to a great interest towards the supply side and the behavior of shale producers. Financial services firm Raymond James (2017) has stated that one of the biggest myths in the oil market is that US shale production will flood the market at 35 $/b oil price. According to Kjus (2017) shale producers need about 50 $/b wellhead price to generate positive cash flow on full cycle. Kilian and Baumeister (2015) also emphasize that there are certain factors that could dampen the boom in shale production. Reduced investor financing connected to negative cash flow, infrastructure bottlenecks in terms of the transport of oil and limited recoverable shale oil stocks being some of the major concerns.

Questions concerning how the shale producers might respond differently to production, drilling and completion of wells for a certain oil price opposed to the response of conventional producer has recently gained significant attention. Also, to what extent the development of shale oil can be a stabilizer of the oil price due to its flexibility has received increased interest from researchers and the media in general. Researchers particularly focused on two main areas that can be be categorized as (1) optimal resource extraction, and (2) supply elasticity in short- and long-run.

(1) The resource extraction literature typically seeks to characterize firms' optimal extraction choice and legacy rates[3]. A theory that was often applied in the extraction literature is the Hotelling rule (see for example Bjørnland et al 2017; Anderson et al 2014). In order to apply the Hotelling (1931) theory one has to define oil reserves as an inventory, and the choice and timing of production as an intertemporal decision of when to decrease the underground inventory. For

[3] Legacy rates or or depletion rates indicate the decline in production for an oil well or field

producers to behave according to Hotelling, they must be able to allocate extraction across different periods.

(2) Previous literature has paid considerable attention to the demand and supply elasticity where short and long-run elasticities are compared. The findings has largely been that gas and oil supply elasticities are inelastic once a well has been drilled and moreover that supply tend to be less responsive in the short run than in the long-run (Griffin (1985); Hogan (1989); Pesaran (1990); Jones (1990); Dahl and Yücel (1991); Ramcharran (2002); Smith (2009) andGriffin and Teece (2016).

Previous studies have not found the Hotelling theory to hold. Newell et al (2016) looked at conventional and unconventional gas producers in Texas and found similar evidence to Anderson, Kellogg and Salant (2014), which investigated conventional and unconventional oil producers in Texas. They all have found that the quantity produced from already producing wells is not elastic or price insensitive. An important thing to notice is that the papers mentioned above do not include data from 2016 and 2017, where the biggest increase in productivity took place and bottlenecks started to influence production (Seeking Alpha, 2017) (see section 1.2.2).

Bjørnland et al (2017) investigated the flexibility of shale producers in terms of production as well as completion of wells, opposed to the flexibility of conventional producers, in the Bakken area in North Dakota. In contrary to previous research they find that the extent to which a producer is flexible in choosing production and timing of completion depends on whether they have shale wells or non-shale. Furthermore, they find that that unconventional extraction technology is much more flexible in allocating output between periods using the spread between the spot price and different future prices as an indicator of prices in coming periods. These results indicate that unconventional oil producers behave more consistently with the Hotelling rule than previous research has found.

3.0 Research question

Our research paper will focus on shale producers in the large shale plays (fields), namely Permian, Eagle Ford and Bakken, and to what extent the elasticity of production and well completion depend on the production type (shale or non-shale). In previous literature researchers have focused on one particular field and have not tried to compare different fields. Data from EIA[4] imply great heterogeneity in the shale oil areas in terms of increase in productivity as well as the ratio between drilled but uncompleted shale oil wells (DUCs) to a completed well. Furthermore, previous research have found that short-term production type elasticity behaves similarly in a non-flexible fashion in response to prices in Texas (Permian and Eagle Ford) (see Anderson 2014 and Newell et al 2016) whereas shale producers behave more flexibly than the conventional producers for Bakken, with 95% confidence (see Bjørnland et al (2017).

Hence, we want to run econometric regressions using panel data on the different shale areas, to see if the behavior of the producers differ from one area to another. Additionally, we want to add break-even cost of producers to our regression to see to what extent the decision of shale production and completion of wells depend on the cost structure of the producers. Microeconomic analysis on well data connected to cost is a topic that has still yet to receive considerable attention in previous literature.

If we do find that the producers differ in behavior, we want to search for explanations that can potentially be found in bottlenecks (scarcity in fracking teams, water and sand resources and/or infrastructure constraints) and regulatory constraints (licenses, leases and permitting). Looking at bottlenecks is also something that is lacking in previous literature.

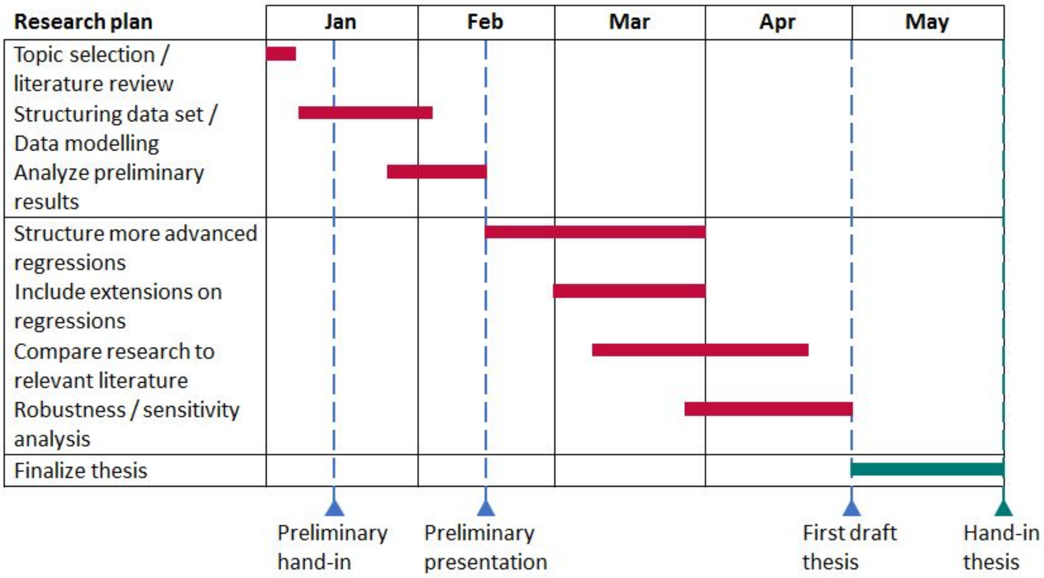
[4] Drilling Productivity Report (2018)

4.0 Description of data set

Most of our analysis will be conducted on data collected from Rystad Energy. Rystad Energy is an independent oil and gas consulting services and business intelligence data firm that offers global databases, strategy consulting and research products. Their expertise in well-data and shale production makes their database perfectly applicable for our modelling and research purposes.

The data includes production per well, drilled and completed wells, break-even, cash flow and capex of producers and differences in shale oil and gas within the shale regions. The data contains information of as much as 15,000 oil fields and more than 3,000 different companies. Before 1972, US regulatories tried to stabilize the oil price by having production targets. Due to this our analysis will focus on post-war data starting from approximately 1972 and up to current date.

5.0 Indicative outline of research plan



References

Anderson, S. T., R. Kellogg, and S. W. Salant. (2014). Hotelling under pressure. Journal of Political Economy (Forthcoming).

Baumeister, C. and J. D. Hamilton. (2015). Structural interpretation of vector autoregressions with incomplete identification: Revisiting the role of oil supply and demand shocks. *Manuscript, University of Notre Dame and UCSD.*

Baumeister, Christiane & Kilian, Lutz. (2015). Understanding the decline in the price of oil since June 2014. *CFS Working Paper Series 501, Center for Financial Studies (CFS).*

Crooks, A. (2015). The US shale revolution. Retrieved from

https://www.ft.com/content/2ded7416-e930-11e4-a71a-00144feab7de

Hilde C. Bjørnland & Frode Martin Nordvik & Maximilian Rohrer. (2017). Supply Flexibility in the Shale Patch: Evidence from North Dakota. *Centre for Applied Macro- and Petroleum economics (CAMP), BI Norwegian Business School, Working Papers No 2/2017.*

Knut Are Aastveit & Hilde C. Bjørnland & Leif Anders Thorsrud. (2015). What Drives Oil Prices? Emerging Versus Developed Economies. *Journal of Applied Econometrics, John Wiley & Sons, Ltd., vol. 30(7), pages 1013-1028, November.*

Dahl, C. and M. Yücel (1991). Testing alternative hypotheses of oil producer behavior. *The Energy Journal 12 (4), 117–138.*

Griffin, J. M. and D. J. Teece. (2016). OPEC behaviour and world oil prices. Routledge.

Hamilton, J. D. (2009). Causes and consequences of the oil shock of 2007–08. *Brookings Papers on Economic Activity (1), 215–283.*

Hamilton, James D. (1983). Oil and the Macroeconomy since World War II. *Journal of Political Economy, University of Chicago Press, vol. 91(2), pages 228-248, April.*

Hamilton, James D. (1985). Historical Causes of Postwar Oil Shocks and Recessions. *The Energy Journal, International Association for Energy Economics, vol. 0(Number 1), pages 97-116.*

Hogan, W. W. (1989). World oil price projections: a sensitivity analysis. *Harvard University, Energy and Environmental Policy Center, John F. Kennedy School of Government.*

Hotelling, H. (1931). The economics of exhaustible resources. *Journal of Political Economy 39 (2), 137–175.*

Kilian, L. (2009). Not all oil price shocks are alike: Disentangling demand and supply shocks in the crude oil market. *The American Economic Review 99 (3), 1053–1069.*

Kilian, Lutz. (2016). The impact of the shale oil revolution on US oil and gasoline prices. *Review of Environmental Economics and Policy* 10, no. 2 (2016): 185-205.

Kjus, Thorbjørn (2017). Oil Market Outlook 2017, DNB Markets.

Meyer, G. (2017). US shale oil output remains resilient despite rig count fall. Retrieved from https://www.ft.com/content/73c5297e-d813-11e6-944b-e7eb37a6aa8e

Newell, Richard G. and Brian C. Prest & Ashley Vissing (2016). Trophy Hunting vs. Manufacturing Energy: The Price-Responsiveness of Shale Gas. *National Bureau of Economic Research, Inc.*

Pesaran, M. H. (1990). An econometric analysis of exploration and extraction of oil in the UK continental shelf. *The Economic Journal 100 (401), 367–390*.

Ramcharran, H. (2002). Oil production responses to price changes: an empirical application of the competitive model to OPEC and non-OPEC countries. *Energy Economics 24 (2), 97–106.*

Reuters. (2017). U.S. to account for most world oil output growth over 10 years: IEA. Retrieved 14th of January 2018 from https://www.reuters.com/article/us-oil-iea-birol/u-s-to-account-for-most-world-oil-output-growth-over-10-years-iea-idUSKBN1DG1XP

Seeking Alpha. (2017). Permian DUC Wells Surge With Massive Implications For WTI Oil Prices, Inventories And Permian Oil Producers. Retrieved 14th of January 2018 from https://seekingalpha-com.cdn.ampproject.org/c/s/seekingalpha.com/amp/article/4127133-permian-duc-wells-surge-massive-implications-wti-oil-prices-inventories-permian-oil-producers

Smith, J. L. (2009). World oil: market or mayhem?. *The Journal of Economic Perspectives 23 (3), 145–164*

U.S. Energy Information Administration. (2017). Oil: Crude and Petroleum Products Explained, Oil and the Environment. Retrieved 14th of January 2018 from https://www.eia.gov/energyexplained/index.cfm?page=oil_environment