Survival of the fittest: US oil productivity during business cycles

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Abstract

In this paper, we study production behavior in US oil production, and assess how the recent oil price variability and business cycles have affected the supply of oil. In contrast to previous supply studies in the oil industry, which traditionally focuses on supply differences between regions (mainly OPEC vs non-OPEC countries), our data is separated into production of conventional oil and shale oil to examine to what degree supply response differs between these. We address this problem by investigating the relationship between WTI oil price and activity of US conventional oil and shale oil sector. For the analysis, we assess the activity as the total production levels of conventional crude oil and shale oil during the business cycles, the productivity of conventional crude oil and shale oil during the business cycles, and finally the rig count for conventional sector and shale oil during the business cycles. By estimating a supply function, based on a modification of Griffin (1985), supply elastiseties for conventional oil- and shale oil are conducted. We find that while the supply elasticity for conventional oil is negative and significant the supply elasticity of shale oil is positive and significant, indicating that the shale oil sector are competitive compared to the conventional sector. The supply of conventional oil is hence less vulnerable to the business cycles, and will therefore insure that a stable supply persist by operating as a buffer. Our results also indicate increased productivity in periods with lower oil price, suggesting that reduced income is a strong incentive to increase efficiency. Further, we find that during the period of reduced oil prices, fewer new oil fields are developed, providing higher productivity in existing fields from learning and experience on the site.

Introduction

With the shale oil revolution, US crude oil supply almost doubled from about 5 million bbl/d in 2008 to peak supply in March 2015 at 9.6 million bbl/d (Figure 1), and its effect on US and global economy has been studied in several papers (Kilian, 2016; Manescu and Nuno, 2015). The production growth ended more than two decades of declining oil production, as the introduction of new technology coincided with high oil prices. Although considered a costly oil production, supply from shale oil continued to increase until the recent turn in oil prices. In this paper, we study production behavior and examine how recent oil price and business cycles have affected the supply of US crude oil production, and if it has affected conventional oil and shale oil production differently?

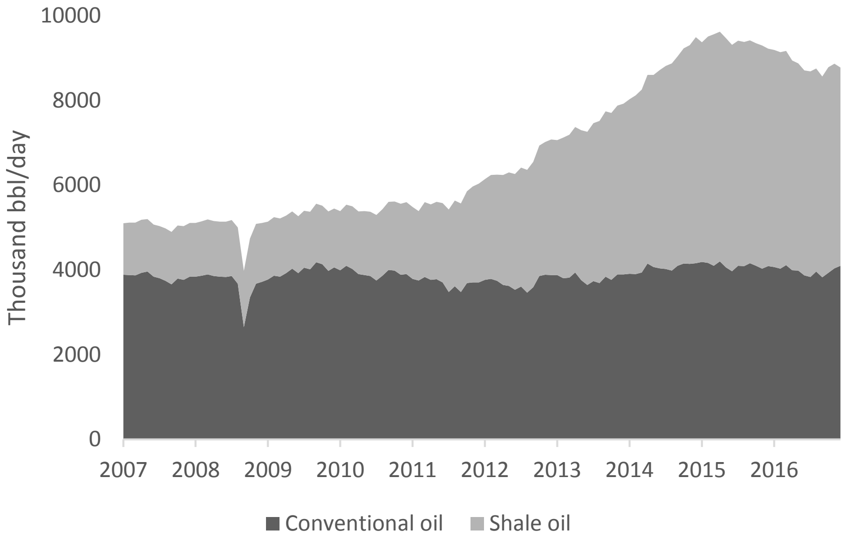

Figure 1: Crude oil production from conventional oil fields and shale oil fields in US from January 2007 to December 2016.

Since the seminal work of Schumpeter (1934), there is a large literature investigating the economic effect of a business cycle. Among the most important stylized facts is that as the business cycle improves wages increase and labor productivity decrease. When the cycle bust, the opposite is true as pressure on wages are reduced and labor productivity increase as low-productivity workers leaves and remaining workers work harder. Given the importance of oil as an input in energy production as well as other industries, there is also a large literature discussing the importance of the oil price in influencing business cycles (Hamilton, 1983; 2009; Kilian, 2016; Manescu and Nuno, 2015) and how different industries react to a business cycle (among them the petroleum industry) (Jaimovich and Floetotto 2008; Christiano and Fitzgerald 1998).

A number of studies has been conducted for explaining pricing and production behavior in the petroleum industry. Mabro (1992) gives an excellent review of some of these earlier studies. Griffin (1985) illustrated how supply response can be explain by either a competitive model, a cartel model, a target revenue model or a property right model. Furthermore, several papers considers the response in oil supply from changes in oil price, with the majority assessing OPEC and its ability to act as a cartel. (Jones, 1990; Ramcharran 2001; 2002). Hamilton (2013) concludes that the oil industry from 1973 to 1996 was the age of OPEC, as OPEC adjusted their supply according to non-OPEC supply in order to maintain a target price or target revenue. However, since 1997, Hamilton identifies a new industrial age for the petroleum industry, as OPEC now adjust its supply according to changes in the oil price. OPEC and non-OPEC supply is typically segmented in previous literature, and Dees et al. (2007) show that non-OPEC supply is inelastic to changes in the oil price, while OPEC announcement have an immediate effect on the oil price[1].

Other papers consider production levels and demand shocks, and Güntner (2014) show that short run price-elasticity is close to zero, and finds no short-term response in supply from oil price changes within the same month. Cologni and Manera (2014) find a relationship between supply and global demand, and for some countries, they also identify asymmetric effects. According to Gallo et al. (2010), the oil price is dependent on the oil supply, while oil consumption depends on the oil price.

Ringlund et al. (2008) find a positive relationship between rig activity and oil prices in non-OPEC regions. This is intuitive as rig activity characterizes the investment level in the oil industry, typically dependent on high oil prices. A recent study by Apergis et al (2017) shows that both rig counts and crude oil price have a positive relationship to the total production in US.

Estimating a supply function of US crude oil production, our model is an extension of these earlier papers, but while these papers main focuses on supply differences between OPEC and non OPEC members, we are focusing on differences between conventional oil and shale oil production. We also go further in explaining the production behavior; by investigate WTI crude oil price influence on both production, productivity and sector size.

To explore the relationship between WTI crude oil prices and production, productivity and sector size, we first perform visual analyses where plots of productivity, production and number of rigs together

[1] A large strand of literature considers OPEC announcements effect on the oil price (Demirer and Kutan, 2010; Schmidbauer and Rösch, 2012; Louita et al, 2016; Lin and Taurakis, 2010).

with WTI crude oil price will be conducted. Second, we apply a multivariable regression model to the data. A supply function based on a modification of Griffin's model, is estimated using data from the major shale oil regions and for US production in total from January 2007 to December 2016.

The rest of the paper is organized as follows: In section two, we present the data. Results from the econometric model are presented and discussed in section three, before some conclusions are offered in section four.

Methods

Building on the work of Griffin (1985) and Ramcharran (2002), we are specifying a supply function for conventional oil and shale oil as:

$$lnQ_{ct} = \beta_0 + \beta_p lnP_{t-n} + \beta_t t + \beta_s lnQ_{st} \quad (1)$$

$$lnQ_{st} = \beta_0 + \beta_p lnP_{t-n} + \beta_t t + \beta_c lnQ_{ct} \quad (2)$$

where Q_{ct} and Q_{st} are the production in 1000 bbl/day of conventional oil and shale oil in time period t. P_{t-n} are the lagged WTI crude oil price, where the length of the lag (n) depend on the relationship with the production variable, which will be conducted prior to the estimation by testing for highest level of correlation. t is a time trend, controlling for technology change and other factors that has a constant change in time. The last term is the supply of crude oil from the opposite sector - in the conventional sector it is the supply of shale oil, and in the shale oil sector it is the supply of conventional oil. Finally, the β's are parameters to be estimated.

A key element in these models is β_p, which is measuring the supply elasticity, or the degrees of supply change for a 1% change in price. If $\beta_p > 0$ the supply function is positively sloped and the competitive model is supported, while a $\beta_p < 0$ indicate that the supply-curve is backward bending and that the target-revenue theory (TRT) is supported.[2]

In addition to the supply functions, we will also estimate productivity and sector size models. In these models the dependent variable will be replaced by productivity measures (q_{ct} and q_{st}) which is

[2] TRT were developed by Ezzati (1976), Cremer and Isfahami (1980), Teece (1982) and Griffin (1985).

production on conventional and shale oil per rig in time period *t*[3], and sector size measures (S_{ct} and S_{st}), which is the number of rigs operated in conventional and shale oil formations in time period *t*.[4] Following Apergis *et al* (2017), rig count are used as a proxy for current and future production capabilities, this is also the industry standard that Baker Hughes reports, and pronounce as an "important business barometer for the drilling industry and its suppliers" (www.bakehughes.com). Ringlund et al (2008) uses rig counts an indicator of the exploration effort and field development taking pace. In our study, we will use rig count synonymous to sector size.

Data

The paper considers monthly data from EIA on rigs and production in US oil fields from January 2007 until December 2016. The last decades provides a good window to investigate the impact of the business cycles in the crude oil industry, as prices as been volatile and reaching historical highs. In contrast to fore instance Griffin (1995) our sample period, includes phases of price increase and price decrease, and are therefore providing a framework for examining production behavior.

In the sample, we differentiate between conventional oil fields and oil fields in tight oil formation where shale oil is a considerable part of the production. The tight oil fields consists of Bakken, Eagle Ford, Niobrara, Permian and Utica region.[5] The conventional oil field consist of the total US production of conventional crude oil.

Figure 2 presents the development of WTI and production (1000 bbl/d) of conventional oil and shale oil over time. Besides some up and downs, the main picture shows that the total production has increased over the period. This is particular visible from 2012 to 2015, where the production of shale oil approximately doubled. With the relatively stable production of conventional oil over this time frame, the production of shale oil surpassed the conventional oil production August 2013, and has since then been higher for shale oil. However, we observe a falling trend in supply of shale oil following the price decrease in 2014. Since the top month of April 2015 the supply of shale oil has been steadily declining, and are now approaching the level of conventional oil.

[3] Our measure of productivity is hence a partial measure of productivity, in contrast to the traditional total factor productivity measure (TFP) which is the ratio between production and all factors of production.
[4] For the productivity and sector size model the last element in equation (1) and (2) will be omitted.
[5] In an earlier version of the paper the filed Haynesville and Marcellus was also included in the shale oil sample, but were removed from the sample as they are mainly gas plays.

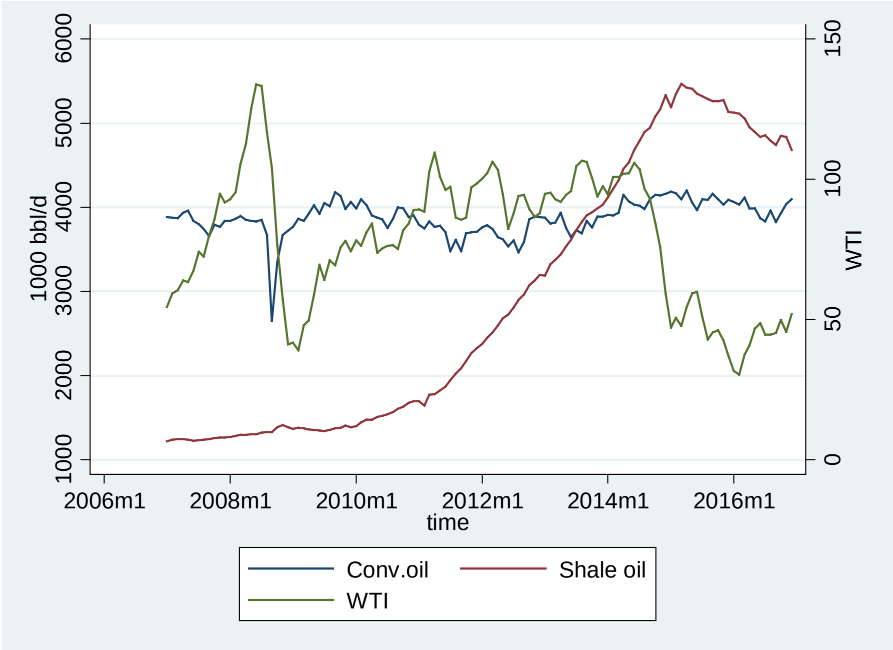

Figure 2. WTI and production (1000 bbl/d) of conventional oil and shale oil over time

The development in productivity and WTI are presented in figure 3.

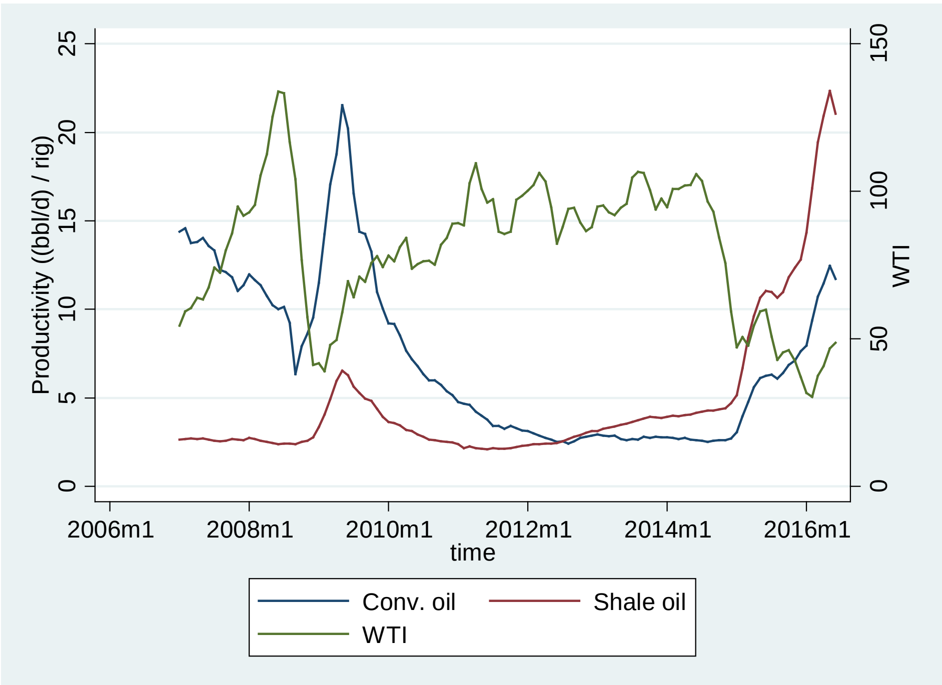

Figure 3. WTI and productivity (bbl/d per rig) over time for conventional oil and shale oil.

First, we observe that shale oil productivity has improved for the average producer; from being only 1:10 compared to productivity in conventional fields in 2007, the productivity of shale oil surpassed conventional oil in 2012 and has since then been higher. The latest year the productivity of shale oil has been approximately twice the size of conventional oil. Second, our results on productivity point to an increase in productivity during downturns, when oil price is reduced. This effect is also visible for conventional oil production during both periods of oil price decline (2008 and 2014). The opposite relationship between productivity and state of the economy is also visible for periods of economic boom. This is particularly noticeable of the price increase in 2007 and 2009 but also for the relatively smaller price increase in 2016.

Figure 4 shows the rig counts for the US oil production from shale- and conventional oil.

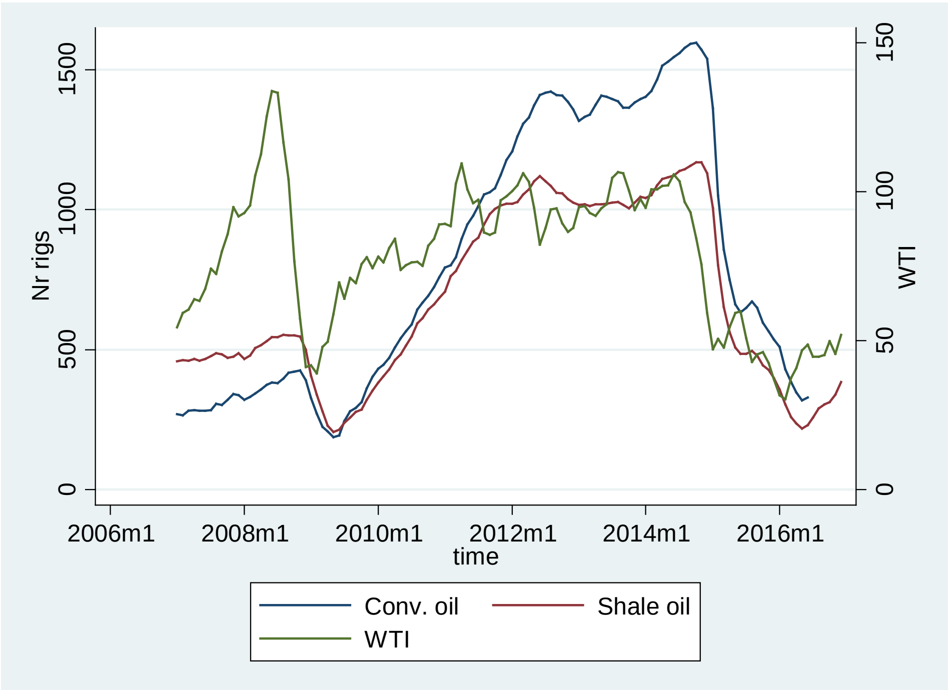

Figure 4: WTI and sector size (rig counts) over time for conventional oil and shale oil.

As can been seen form the figure the number of rigs in the conventional and shale oil sector follow each other closely. This is supported by an estimated correlation confident of 0.966. Price is also found to have a close relationship with rig counts for both conventional and shale oil, with correlation coefficients of of 0.414 and 0.556 respectively.[6]

[6] To investigate if there is a lower threshold oil price at which many producers go out of business, we investigated if there was a break in this relationship. We could however not find there to be a threshold price that caused such a break.

Results

While looking at a plot can be valuable as a first shot to understand a relationship between two variables, a full multivariate model is necessary to understand the full picture. Prior to the estimation of the production, functions the lag length of price (*n*) need to be conducted.

To find this we calculate the correlation matrix between production/productivity/rig count and lagged WTI oil price. The coefficient are presented in table 1. From the table we see that there is a negative relationship between relationship between production and oil price for both conventional sector and shale oil. The same is true for the productivity, while for the rig counts we find a positive relationship with oil price. However, in the same manner as for the plots, one should not give these results to much weight as, there might be more variables effecting the supply decision, and focusing on one at the time might give biased result. Establishing the full a multivariable model later in this section, on the other hand, allows us to isolate the main effects and are hence giving a more correct estimate of the effects.

Table 1. Correlation between production/productivity/rig count and lagged WTI oil price.[a]

	wti_t	wti_{t-1}	wti_{t-2}	wti_{t-3}	wti_{t-4}	wti_{t-5}	wti_{t-6}
Production Conv.oil (Q_{ct})	-0.4081	-0.4597	-0.5007	**-0.5191**	-0.4959	-0.4443	-0.3749
Production Shale oil (Q_{st})	**-0.3894**	-0.3548	-0.3163	-0.2772	-0.2341	-0.1902	-0.1452
Productivety Conv. oil (q_{ct})	-0.3920	-0.4667	-0.5318	-0.5742	**-0.5877**	-0.5705	-0.5226
Productivety Shale oil (q_{st})	-0.6807	-0.7043	**-0.7188**	-0.7154	-0.6899	-0.6398	-0.5719
Nr. rigs Conv. oil (S_{ct})	0.4135	0.4640	0.5072	0.5366	0.5528	**0.5560**	0.5486
Nr. rigs Shale oil (S_{st})	0.5558	0.6105	0.6553	0.6828	**0.6912**	0.6807	0.6515

[a] Price-lag with the highest correlation in bold

The main reason for calculating the correlation matrix to find the price-lag with the highest correlation to production, productivity and sector size. This price variable will be incorporated into the econometric regression model. For both production, productivity, and sector size we find that that the reaction time is shorter for the shale oil than conventional oil sector. We believe this is related to technological leapfrogging, since the technology use in shale oil extraction is newer and more advanced than the one used in conventional oil extraction. The differences in response time between the conventional sector and shale oil is however largest for production; here the current price has the highest effect on shale oil, while the price lag with the highest correlation with conventional oil production is three months. For productivity, the delay is longer for both conventional and shale oil, with a four mounts lag for conventional oil and two months for shale oil. For rig count we find the lag time to be a longer than for production and productivity, but the difference between conventional and shale oil is only one month, with a price-lag of four months for shale oil, and five months for conventional oil.

The result from the regression analyses are presented in table 2. The two first column present the estimated parameters from the production function for the conventional production (Q_{ct}) and the shale production (Q_{st}) respectively, the next two the result from the productivity function (q_{ct} and q_{st}), and the last two from the sector size function (S_{ct} and S_{st}). The models has varying explanatory power, with R^2 variety from 0.292 to 0.944, but even for the model with lowest explanatory power, is relatively high compared to similar studies (Griffin 1985; Ramcharran 2002).

Table 2. Results from multivariable regression model

	Production		*Productivity*		*Sector size*	
	Q_{ct}	Q_{st}	q_{ct}	q_{st}	S_{ct}	S_{st}
β_0	7.9786 (0.000)	2.0787 (0.331)	8.6111 (0.000)	6.0376 (0.000)	-0.4267 (0.332)	-0.1194 (0.708)
β_p	-0.0789 (0.000)	0.1553 (0.000)	-1.3844 (0.000)	-1.2032 (0.000)	1.4109 (0.000)	1.4176 (0.000)
β_t	-0.0010 (0.112)	0.0161 (0.000)	-0.0147 (0.000)	0.0092 (0.000)	0.0135 (0.000)	0.0063 (0.000)
β_s	0.0875 (0.018)					
β_c		0.4945 (0.0500)				
R^2	0.2921	0.9446	0.7303	0.8448	0.7785	0.7891

p-values in parentheses

The price elasticity (β_p) are significant for all models – WTI oil price influence production, productivity and sector size for both the conventional sector and shale oil sector. The sign and magnitude of the effect do however vary between the conventional and shale sector. For the price elasticity on production (supply elasticity), we find some interesting results. While the supply elasticity is negative and significant for conventional oil supply, it is positive and significant for the shale oil supply. Hence, for the shale oil sector the competitive hypothesis is supported, but for the conventional oil sector the hypotheses of TRT is supported. Negative supply elasitsity might seem contradictory to economic theory but are supported by a number of studies examine the production behavior in oil supply. Griffin (1985) obtained negative coefficients for conventional oil supply in the USA, Ramcharran (2002) found negative and significant coefficient for Canada and USSR[7], and Krichene (2002) found a negative and significant supply elasticity for the world oil supply in the short run.

The price elasticity on productivity is negative and significant for both conventional sector and shale oil. Meaning that in times of boom (high oil price), the productivity will decrease. Hence, our result support the conclusion we drawn from the visual inspection of figure 3 in the previous section – oil price has a negative effect on productivity. These results are also supported by prevails studies (Osmundsen et al., 2010; Osmundsen and Roll, 2016, Dahl et al., 2017) finding a reduction in drilling productivity and larger cost overruns on the Norwegian continental shelf in the times of economic booms.[8] Even if oil price has a negative effect on both conventional and shale oil productivity, the magnitude of the effect is larger for the conventional sector, indicating that the shale oil productivity being more robust to conjuncture changes, than the conventional sector.

Price's effect on the sector size (nr of rigs operated) are given by the price elasticity of sector size. From the last two columns in table 2 we see that this is positive and significant for both conventional and shale oil sector. The parameter is highly elastic and the effect is equal for both sectors. The highly elastic effect indicate that a price increase will lead to a sector increase of almost 1.5. This support our negative price-elastisity in productivity. The argument goes as follows: A price increase will lead to a high demand for rigs. Which again will lead to a shortage of the most productive rigs and competent personnel. Thus, less adequate rigs and less competent personnel are being used at the margin, reducing average productivity. Moreover, at a high business cycle for the oil industry there are more likely to appear bottle necks at other crucial supply services in drilling, thus driving up the non-productive time. While a high oil price are associated with high degree of progression of field development, during the period of reduced oil prices, fewer new oil fields are developed. Assuming the best players survive, this provide higher productivity in existing fields from learning and experience on the site.

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[7] USA, however, is found to have a positive supply elasticity in this study.

[8] This is explained by a shortage of the most productive rigs and competent personnel in times of economic boom. High rig rates are associated with a strong business cycle for the oil industry. High activity levels imply scarcity of rigs and key personnel. Thus, less adequate rigs and less competent personnel are being used at the margin, reducing average productivity. Moreover, at a high business cycle for the oil industry there are more likely to appear bottle necks at other crucial supply services in drilling, thus driving up the non-productive time.

In contrast to the productivity and sector size models, the estimated production function include the supply of crude oil from the opposite sector. These variables do also gives some interesting results. For both the conventional sector and shale oil, the supply of crude oil from the opposite sector has a positive and significant effect. In other word a supply increase of shale oil, will stimulate the supply of conventional oil, and a supply increase of conventional oil will stimulate the supply of shale oil. However, the magnitude of the effect is not equal. While a 100% increase in shale oil will lead to a 9% increase of conventional oil supply, a 100% increase in conventional oil will be followed by a 50% increase in shale oil supply. This may be related to the massive increase in shale oil over the sample period compared to the relative stable production of conventional oil.

The trend variable parameters (β_c) are significant for five out of six models. The only model without a significant trend variable is the production of conventional oil, which is consistent with what we found in the visual inspection (figure 2) - were no trend could be spotted for conventional oil supply. For the supply of shale oil on the other hand, figure 2 shows a strong positive trend in time. This is pick up by the model; with an estimated elasticity of 1.6% - everything else kept constant the supply in shale oil has increased by 1.6% every month. Shale oil productivity also seems to be on an increasing trend over the period, while for conventional oil productivity the trend is negative. Finally, sector size (nr of rigs in operation) do increase over the sample period, however at a higher pace for the conventional sector compared to the shale oil sector.

Conclusions

Applying new technology in tight oil formations provided a revolution with the utilization of shale oil. However, productivity was relatively low from shale oil production for many years, thus requiring a high break-even oil price. With the drop in oil prices in 2014, the oil producers were pushed for increased efficiency and utilization. However how did the producers manage to adapt the new state of economy, and are there behavioural differences between the conventional oil sector and the newcomer – the shale oil sector? This problem is address by investigating the relationship between WTI oil price and production levels, productivity and sector size for US conventional oil and shale oil sector.

For both conventional and shale oil fields, our results indicate an increase in productivity during periods with low oil prices, indicating a selection of the most efficient and profitable oil fields. In addition, improved technology with horizontal drilling and hydraulic fracturing, together with more experienced workers may also increase productivity. Over the sample period, shale oil productivity has hence multiplied. For conventional oil production, on the other hand, productivity has decreased, and the productivity of shale oil is now almost the double of conventional oil. This can be partially explained by the mature technology applied on conventional oil fields and a higher participation by established and integrated oil companies, together with a steeper learning curve for the newer shale oil sector.

This can also be related to market structure; while the shale oil industry is found to be competitive, the supply elasticity in the conventional sector is found to negative and significant - indicating that the supply curve is backward bended. The underlying reasons of these findings are not supported by our results. We do however believe that our findings could be related to the cost structure of the two sectors. Shale oil extraction is relative expensive compared to conventional oil production. If the goal of the oil companies are a stable profit rather than a higher, but also more fluctuating profit (Diewert, 1974), shale oil production should be conducted in periods of high oil price. Capacity will then be directed to shale oil filed in periods of high price, and to conventional oil field when the price are dropping. This hence explain the positive supple elasticity for shale oil and the negative elasticity for conventional oil found by the regression results, and from figure 2 the observed decline in shale oil supply following the 2014 price decrease, while the supply of conventional oil supply has been relative unaffected. The supply of conventional oil is hence less vulnerable to the business cycles, and will therefore insure that a stable supply persist by operating as a buffer.

Beside a higher supply response to a price change, the shale oil sector is also found to have a shorter response time to economic cycles than conventional oil. For both production, productivity, and sector size we find that that the reaction time to an oil price change is shorter for the shale oil than conventional oil sector. We believe this is related to technological leapfrogging, since the technology use in shale oil extraction is newer, more advanced and hence more flexible than the one used in conventional oil extraction.

As expected, we also found a positive relationship between economic cycle and sector size. An oil price drop will hence result in a general downscaling of new fields and drilling operations, creating better opportunities to exploit current fields at a higher level. Hence, to conclude, the results show an industry with the ability to adjust, and equally important, the ability to make profits at a lower oil price regime as their marginal cost is reduced.

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