Leverage and the Oil Industry – Analysis on the Firm and Production Level *

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Abstract

This paper analyzes the relationship between debt and the production decision of companies active in the exploration and production of oil and gas in the United States. Over the last couple of years, the development and application of innovative extraction methods, like hydraulic fracturing and horizontal drilling, led to a considerable increase in United States (US) oil production. In connection with these technological changes, Domanski et al. (2015) identify another important economic development in the oil industry: largely debt-driven investments in the oil sector. The extensive use of debt was fostered by the macroeconomic environment of low interest rates and investors looking for yield in the aftermath of the financial crisis. Additionally, the rising prices in the commodities markets until mid 2014 led to higher asset valuation and thus to higher return expectations fueling a virtuous circle. This increased investment activity, especially in the US, raised the production capacity and as a consequence contributed to a higher production of oil and natural gas. This trend continued in spite of the oil price decline in 2014, whereas the oil price slump in 2008 led to a reduction in oil production, which seems to be the more plausible reaction.

The aim of this paper can be split into two research questions. The first research question is whether debt and leverage affects production decisions of companies active in the exploration and production (E&P) of crude oil and natural gas. The second research question then is, if the technological changes in the industry and the increased indebtedness of US oil companies led to a markedly different reaction in their production decision following 2014 compared to the similar price decline in 2008. A potential reason for the absence or delay in cutting back production after the price drop in 2014 could be supposedly higher leverage prior to the price decline. These questions are addressed using a novel dataset combining financial data on publicly listed firms and their production data on well level.

Keywords: Corporate Finance, Oil Industry, Debt, Leverage, Dynamic Panel Data, Energy Economics

JEL classification: C33, C58, G01, G31, Q40

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1. Introduction

In 2014, the price of crude oil markedly declined following a period of relative stability, during which it stayed at around $100 after a relatively quick recovery from the subsequent decline following the financial crisis in 2008. Compared to previous episodes of oil price declines, it appears to be more difficult to identify a single underlying cause explaining the persistently low prices of crude oil. It rather appears to be a result of the interplay between multiple factors, both on the demand and supply side of the global market for crude oil. It appears that market participants underestimated the expected crude oil production and at the same time overestimated the demand for oil which was mainly subdued by weaker than expected global growth. On the demand-side of the market, the major determinant for decreasing oil prices was an unexpectedly sharp deterioration in global economic activity (Baumeister and Kilian 2016). An additional effect on the demand side identified by Baffes et al. (2015) is the relatively strong appreciation of the US dollar, which makes dollar denominated crude oil imports more expensive in local currencies and thus could lead to a lower demand. However, this hypothesis is contested and the estimated impact of this effect varies between studies and Baumeister and Kilian (2016) are skeptical of any explanation based on exchange-rate movements.

In the global context of oil-producing countries, the most important decision affecting the supply of oil was the announcement by the Organization of the Petroleum Exporting Countries (OPEC) to not curtail their production in November 2014, which might have resulted in a loss of market share. Additionally, the easing of geopolitical tensions resulted in higher than expected production in the Middle East and the sanctions and counter-sanctions following the conflict between Russia and Ukraine had less impact on European oil and natural gas markets (Baffes et al. 2015, 13). Another development on the supply-side was the emergence of the US shale industry, which repeatedly surprised markets by exceeding the estimates for the crude oil production and thus also put downward pressure on crude oil prices. However, the supply from these unconventional sources might be more price elastic, since they are less capital-intensive and the lifecycle is much shorter, compared to conventional oil projects (Baffes et al. 2015, 13). These characteristics and the observation of a sharp reduction in active oil rigs already led some to the conclusion that the shale oil producer in the US might have replaced Saudi-Arabia as the swing producer for the world crude oil market.[1]

Baumeister and Kilian (2016) emphasize the importance of unexpected movements in oil supply. Especially, if a curtailment of the oil production is widely expected, then a positive oil supply shock leads to additional price fluctuations in the crude oil market. Accordingly, Baffes et al. (2015, 20) identify the main driver of the recent oil price drop on the supply-side of the market. The demand-side related factors, decreasing the oil

[1]The Economist - *After OPEC - American shale firms are now the oil market's swing producers* (14 May 2015)

price, had their biggest impact at the end of 2014 and thus can't explain the prolonged period of low crude oil prices from 2015 to 2017.

It is important to disentangle the different effects on the demand and supply side of the crude oil market in order to react accordingly. This is particularly important for central banks to anticipate movements in the price level and ensure financial stability. Following the great recession, quantitative easing in connection with low interest rates led to an increase of corporate loans via the risk-taking channel of monetary policy. This in turn also has implications for financial stability, since a crash in the corporate bond market in the oil producing sector could have grave implications for the whole financial sector.

Thus, it is important to analyze the relationship between oil production and debt proposed by Domanski et al. (2015) in order to identify underlying mechanisms and reactions of the companies to exogenous price shocks. Domanski et al. (2015) analyze how the build up of debt in the oil industry following the great recession[2], and the decline in oil prices might affect the production decisions of the oil industry. This price decline mainly has two effects, it leads to lower valuation of oil companies' assets and of course reduces the cash flow of companies substantially, especially if they haven't sold their production via futures contracts. In connection with the much higher debt levels in the industry this led to increased leverage and financial pressure. The oil companies can respond in two ways. They can either scale down on debt-financed investment or sell assets, which subsequently would lead to lower production in the future. Nevertheless, in order to generate enough cash flow to service their debt, oil companies could attempt to keep up the production levels or even increase them. This adds to the downward pressure on oil prices. It is thus particularly important to further analyze the companies' resilience and the main factors preventing the occurrence of contagious illiquidity episodes, which could jeopardize the soundness of the whole sector.[3]

This implies that the focus of this paper is only on E&P companies in the US and not on oil producing countries with their mostly state-owned or at least state-controlled companies. The structural differences between these two types of companies also leads to different decision-making processes, since state-controlled companies are more exposed to political influences and do have more complex objective functions than smaller companies in a fragmented and distributed market. Additionally, for the many of these state-controlled companies, the crude oil price is not exogenous, since their market share is too big and they are able to influence prices directly with their production decisions.

Using quarterly data for over 300 companies from 2000 to 2016, this paper empirically analyzes the relationship between the financial situation of oil and gas E&P companies and their production of hydrocarbons. It is then possible to disentangle the different

[2] International Energy Agency (2014, 52ff.) provides a summary of the recent trends in energy investments.

[3] Domanski et al. (2015) focus not only on oil companies in the US, but also analyze the reactions of oil exporting countries.

financial conditions affecting the production decision. As the data covers both the oil price decline in 2008 and the last one in late 2014, it is possible to compare the firms' behavior in the aftermath of both events.

Another advantage of this novel dataset is the use of detailed well level data that allows for studying the production decisions in great detail. It offers the opportunity to analyze companies' behavior with regard to the location and the characteristics of the oil well to get a better understanding of the economic fundamentals behind the decisions. It thus expands previous research, e.g. Lehn and Zhu (2016), by (i) using a more detailed dataset and (ii) applying a different, more suitable empirical methodology, namely a dynamic panel data model.

The analysis in this paper focuses for the most part on companies active in the E&P of oil and gas. Since most companies have both oil and gas operations, it's not possible to solemnly focus on oil companies. Therefore, if not stated otherwise, oil industry refers to companies active in both, the E&P of oil and natural gas, hence there is no distinction made between the two different hydrocarbons. Additionally, the term oil well refers to all wells for the production of oil or natural gas, no matter for which of the two they were initially drilled.

The following section 2 presents the two different strands of literature, which serve as the starting point for the subsequent empirical analysis. The first part discusses the industry-specific characteristics and their implications for the analysis. Additionally, literature on the economic importance of the energy markets and especially literature on the impact of demand and supply shocks is reviewed. The second part of section 2 provides an overview over the theoretical and empirical corporate finance literature addressing the relationship between companies' capital structure and their performance or production decisions respectively. The theory and literature review section then concludes by synthesizing both strands of literature in order to provide the foundation for the empirical analysis.

2. Theoretical Considerations & Related Literature

2.1. Economics of Oil and Gas Production

In order to empirically address the hypotheses raised in the article by Domanski et al. (2015), it is necessary to first give an overview over the specific characteristics of the oil and gas E&P industry. Therefore, the following part focuses on the limitations by geological and technological boundaries and their economic implications and how this changed following the increased usage of hydraulic fracturing, commonly referred to as „fracking“ and horizontal or directional drilling. These two technologies were already known in the industry for quite some time, early hydraulic fracturing for example was developed during the 1940s, although not widely used (Fitzgerald 2013, 1338).[4]

It was only in connection with the discovery of more unconventional reservoirs, basically source rock formations containing oil and natural gas, and the technological improvements to the directional drilling and fracking process that increased the production and led to the ‚shale gas boom'. This, of course, was also driven by the economics of relatively high natural gas prices during the early 2000s and the declining productivity of conventional US gas production, which provided an additional stimulus for the application of the novel combination of directional drilling and fracking (Rogers 2011, 123).

These changes to the industry also have implications for the investment decisions faced by the companies. They increase the responsiveness of the oil supply by reducing the time lag between the investment decision and production. Thus, the companies can increase their production faster, since the time horizon becomes much shorter. Additionally, the lower investment costs and the shorter life of a shale oil well reduce the problem of sunk costs and thus make it easier to lower production levels in response to price signals (Dale 2016, 370-372). Nevertheless, the costs of the drilling and fracturing process increased during the first decade of the 2000s, since the use of more sophisticated drilling technologies make it necessary to use more expensive rig equipment. Additionally, the hydraulic stimulation of the reservoir prior to the first production adds to the drilling costs. This effect is reinforced by the fact that the well servicing industry is very concentrated and only few companies control a major share of the market. (Fitzgerald 2013, 1353ff.)

This implication was empirically addressed by Gilje et al. (2017) and they found that even during periods of severe contango the companies did not immediately adjust their production. Even though it would be better to curtail production in the present in order to sell it for a higher futures price. This can probably be explained by the theory of sunk costs, which applies to unconventional oil wells and, to a higher degree, to the existing conventional wells, which have a longer life-cycle.

Due to this technological boundaries in the reaction of the production and the irreversibility of an investment decision, the oil industry is a prime example to empirically study the real options theory. This theory was developed to explain companies' decisions about investments, when these involve sunk costs. Using the observable drilling activities of companies, Kellogg (2014) is able to show that changes to the price volatility do have an impact and the magnitude is consistent with the optimal response postulated by the theoretical model. However, one has to keep in mind that the period covered in this study is from 1993-2003 and thus it does not take into account the structural changes most probably accompanying the wide spread adaption of directional drilling and hydraulic fracturing. In an earlier paper, Hurn and Wright (1994) also apply this the-

[4] For a more detailed explanation on the technological details and developments, please see Fitzgerald (2013) and the references therein.

ory on investment decisions on North Sea oil operations and, contrary to Kellogg (2014) they conclude that in contrast to the oil price and the level of reserves, the volatility of oil prices does not affect the time to exploitation.

In a related paper, Moel and Tufano (2002) use data on mine openings and closings and empirically show that a real options model is able to explain the decisions to open or shut down a mine. Another paper by Dunne and Mu (2010) analyze how the uncertainty in futures prices does affect the investment decisions of individual US oil refineries.

A possible explanation for the non-responsiveness of oil production to changes in the oil price is offered by Anderson et al. (2014). The non-responsiveness is based on the empirical observation that over the period from 1990 to 2007 the oil production from existing oil wells in Texas was inelastic to either changes in the spot or expected future prices. In contrast to production the authors discover that indeed the drilling activity of companies is highly correlated with oil prices. Therefore, the authors use Hotelling's (1931) model of exhaustible resource extraction and reformulate it as a drilling problem, since the companies can decide when to drill, but can't influence the reservoir pressure and thus production. Although, one has to keep in mind that especially after 2007 the production from unconventional sources increase considerably and this probably made the supply more elastic to changes in prices. In connection with the Hotelling principle, Thompson (2001) analyze the impact of backwardation in non-renewable resource markets and show that oil companies face two decisions. First, they need to decide on the investment in the production capacity and subsequently need to determine the level of production.

The paper by Gilje et al. (2017) also addresses the hypotheses by Domanski et al. (2015) and empirically analyzes the relation ship between the drilling decisions of companies and their leverage. Using detailed project level data they are able to show that highly leveraged firm move forward with project completion, although it would have been more profitable to protract the completion during contango periods. The explanation of this behavior can be found in the decision of equity holders to sacrifice long term returns in order to enhance collateral in the short term, because this behavior is more pronounced just before debt renegotiations.

Another closely related paper which also analyzes the relationship between the level of debt and the production of oil companies is the study by Lehn and Zhu (2016). They can show that indeed the price decline affects oil companies differently, according to their leverage. Their results indicate that highly leveraged companies reduce their investments and at the same time increase the production from existing investments. The focus of this paper is only on the period from 2011 to 2015 and thus only includes the latest decline in crude oil prices. The present paper is closely related to the two studies mentioned last and thus builds on their research, but at the same time extends the analysis and the methodologies employed.

Borenstein, Kellogg, et al. (2014) Difference between the global crude oil price and the wti cushing price, since the supply in the US increased so much it changed the pricing of crude oil.

2.2. Relationship between Financial Situation and Production Decisions

Besides the literature on the decision making process and the distinctive characteristics of companies' investments in the E&P sector. The aim of this section is thus to provide an overview on the determinants of the structure of the liability side of the balance sheet of companies and how the debt level and investments affect the production decision.

The review article by Frank and Goyal (2007) gives a very comprehensive overview on different theories on the determinants of debt financing. The two main strands of theories to explain companies' decision between debt and equity financing can be subsumed under the two umbrella terms trade-off and pecking order theory. The trade-off theory basically assumes that a companies' decision maker, to reach an optimal level of leverage, needs to balance the trade-off between the tax benefits of debt and the deadweight costs of bankruptcy. This balancing leads to a target leverage ratio and deviations from this target are gradually eliminated over time.[5] The pecking order theory is mostly based on literature on adverse selection, which in this context implies that there exists a ranking between different sources of financing. The theory states the hypothesis that firms prefer internal to external finance and if external finance is used, then it prefers debt to equity. Frank and Goyal (2007, 17-24) provide an excellent summary on the motivation of this theory based on the adverse selection and the agency theory behind the pecking order.

Empirically the same authors examine different factors, which are affecting the capital structure decisions of companies. Besides company-specific factors they also identify industry-specific ones, which might be relevant for this empirical study as well (Frank and Goyal 2009).[6] In a related paper Kayhan and Titman (2007) found empirical evidence for the trade-off theory and that additional variables might affect the determination of the leverage ratio. The decision on how much to produce is of course not only influenced by the capital structure of the company, but it is even more closely related to the investment decisions of a company, especially past ones. Therefore, it is important to identify factors influencing the level of investment. One contested variable is the level of cash flows and there are a series of papers from two groups of authors arguing over the importance and implications for the relationship of cash flow levels for investment (Fazzari, Hubbard, and Petersen 2000; Fazzari, Hubbard, Petersen, et al.

[5]For a detailed discussion on the differences of static and dynamic trade-off theory and the empirical research, please see Frank and Goyal (2007, 6-17).

[6]The factors and their effect on leverage are median industry leverage (+), market-to-book assets ratio (-), tangibility (+), profits (-), log assets (+), and expected inflation (+)

1988; Kaplan and Zingales 1997, 2000)

The paper by Lang et al. (1996) empirically finds a negative relationship between the leverage and the future growth of companies, if companies don't have enough growth opportunities. In a study by Stanca and Gallegati (1999) the authors use a vector autoregression on company level panel data in order to address the dynamic relation between financial conditions and the investment of the firm. Thus, the authors explicitly model the endogeneity of this relationship and present evidence that imperfections on capital markets play an important role in explaining aggregate dynamics.

Another strand of literature studies the relationship of market structure, capital structure and the output decision of a company. These studies can show that the structure of the product market and the capital structure of a company influence its output decision. In this literature an important factor is the limited liability effect of debt, which basically creates an incentive for the equity holder to only use debt financing for investments (Brander and Lewis 1986; Phillips 1995). Fosu (2013) is another paper focusing on the relationship between leverage and the degree of competition within an industry.

On an aggregate level there is another important factor which increased the debt-level in the energy sector, namely the quantitative easing of the Federal Reserve Bank in the US. The risk-taking channel of the monetary policy in connection with the relatively high oil prices contributed to increased capital flows into the energy sector and the corporate bond market. There are several empirical studies analyzing the importance and the extent of the risk-taking channel, please see for example Borio and Zhu (2012), Delis et al. (2017), and Dell'Ariccia et al. (2017)

3. Creating the Data Set

To analyze the relationship between the financial conditions of companies and their production decision it was necessary to collect not only financial data, but also detailed data on their production. This made it inevitable to compile the dataset from two distinct data sources, since all available data was not sufficient for an in depth analysis of this topic.

The quarterly financial data is taken from the CapitalIQ database and covers all companies headquartered in the US or Canada falling into the Standard Industrial Classification (SIC) code 1311, which includes companies primarily engaged in the exploration of oil and gas field properties. The selection of this quite narrow definition is done to solely focus on the relationship between the financial situation and the production decision. For vertically integrated companies that are active across multiple stages of the value chain it would be more difficult to identify this effect, as these companies have additional sources of revenues. This would then make it much more difficult to identify the relationship between the financial situation and the exploitation of the available production capacity.

While, data on the production of these companies is provided in the CapitalIQ database it does not offer a sufficient granularity to analyze the production decision in great detail. Therefore, the data on oil production is taken from an industry-specific database provided by DrillingInfo[7]. Based on the companies in the financial dataset the detailed oil well data for the period from 2000 to 2016 is obtained from the DrillingInfo database. This database has the advantage that it includes not only the base data of the oil well, but also detailed production data for oil, natural gas and water. The base data of an oil well consists of information on the location, like basin, reservoir, formation and field and political subdivisions like state and county. Additionally, it also includes the drilling type, so it's possible to differentiate between directionally, horizontally and vertically drilled wells, although this information is not available in all cases.[8] The possibility to differentiate the oil well according to the drilling type is especially valuable, since it is possible to analyze the impact the new technologies have and if the technology adoption led to firm-specific effects.

The combination of the two datasets is achieved by using a hybrid matching approach, initially using R (R Core Team 2017) in connection with the *stringdist* package developed by Loo (2014) to automatically generate matches based on the similarity of companies' names. In the next step, each match is manually checked using additional base data on the companies. In all cases, where a match couldn't be completely verified by a manual check, the data was discarded and not included in the final dataset.

This procedure resulted in an unbalanced quarterly dataset covering the period from Q1 2000 to Q2 2016 and consisting of nearly 343 different companies, of the initially 153 companies 53 are present throughout the whole sample period and 190 companies enter into the sample after the start of the sample period. Together with the 172 companies dropping out of the sample, this results in around 150 companies being in the sample at each quarter. Even though there is quite some fluctuation in the data set, the average duration of a company in the sample is marginally above 27 quarters or nearly seven years. Furthermore, the information why companies drop out of the sample is also included in the data and thus can be analyzed in more detail.

In order to analyze companies' reaction, price time series for crude oil and natural gas are included in the empirical analysis. In case of crude oil, the spot price of West Texas Intermediate (WTI) measured at Cushing, Oklahoma in $ per Barrel (bbl) is used. This is the benchmark for crude oil in the continental US. In case of natural gas, this role is fulfilled by the Henry Hub distribution point in Erath, Louisiana, which is reported in $ per million British thermal units (mmBtus).

To assess the extent of contango or backwardation in both markets, New York Mercantile Exchange (NYMEX) futures prices for delivery in the four consecutive months

[7]DrillingInfo is a private company based in Austin, Texas providing detailed oil industry data. Please see http://info.drillinginfo.com for more information.

[8]Additional data on the oil wells is available, although not used in this study.

following the trade date are included. All price time series are obtained from the U.S. Energy Information Administration (EIA).

In order to assess the companies' exposure to price changes of their main output, the share of crude oil and natural gas as part of their total energy production is calculated. Therefore, the production volume of both resources is converted into the common energy unit, i.e. British thermal units (Btus) with the standardized conversion factors published by the EIA. Thus, the companies can be differentiated according to their exposure to price fluctuations of crude oil or natural gas and it is possible to analyze if the companies' production decision in response to price fluctuations is varying with the relative importance of one of their main outputs.

4. Empirical Analysis

4.1. Exploratory Data Analysis

This section summarizes the dataset and highlights the aspects, which are already offering interesting insights and are important for the subsequent empirical analysis as well. In order to examine the validity of the constructed dataset, the aggregate crude oil production of the individual companies is compared to official data on the total crude oil production in the US.

Figure 1 depicts the development of US crude oil production. It shows that the observable increase in total crude oil production, starting in 2008, is mainly driven by the increased production from unconventional sources. In order to provide further evidence for the validity of the company level dataset, Figure 2 is based on the aggregated production data and shows the total volume of crude oil differentiated across the different drilling technologies used in the production. However, the aggregate volume in the sample comprises between 20% and 38% of the total production in the US,[9] the overall development of the oil production, especially the increase after 2008, is well represented in the company level data.

Additionally, when looking at the different technologies and the development of their production volume over time, it is apparent that the production from horizontally drilled oil wells can be used as a proxy for production from unconventional sources. Especially, since the increase in oil production in the company level data can be attributed to the increasing crude oil production from horizontally drilled oil wells.

Figure 3 shows that the production of natural gas develops similar to the total oil production. It can be seen, however, that the increase in production volume apparently started a bit earlier than for crude oil, since an uptick in production from horizontally drilled wells can be observed, already in 2007.

[9] The share ranges from 22% in Q2 2002 to 38% in Q1 2015, although for most quarters after 2008 the share is above 30%.

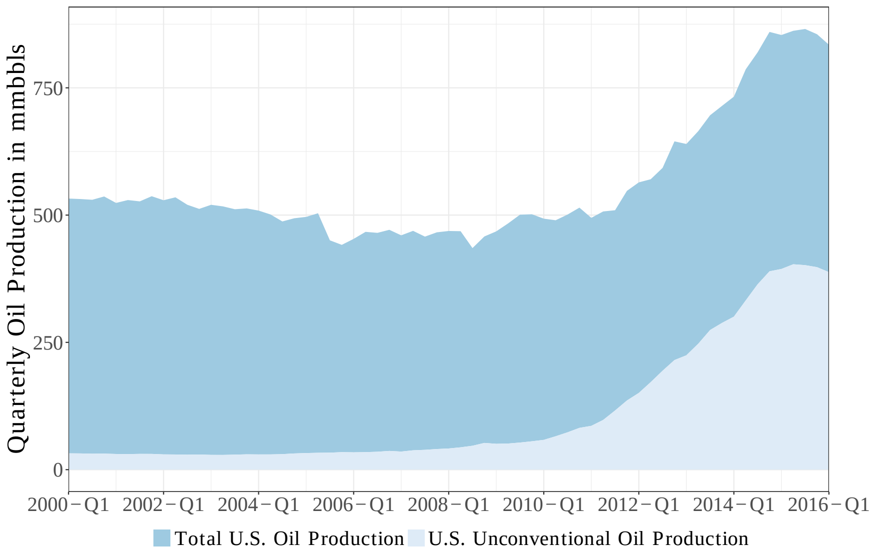

Figure 1: Development of Conventional and Unconventional US Oil Production.
Source: Crude oil production (EIA 2017a) and tight oil production estimates (EIA 2017c))

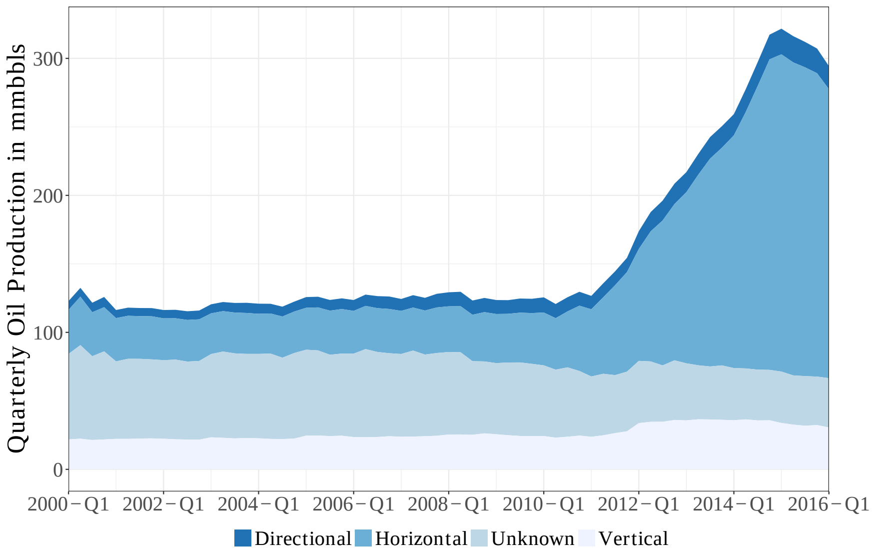

Figure 2: Development of aggregated oil production for different drilling technologies
Source: Own calculations based on data provided by DrillingInfo

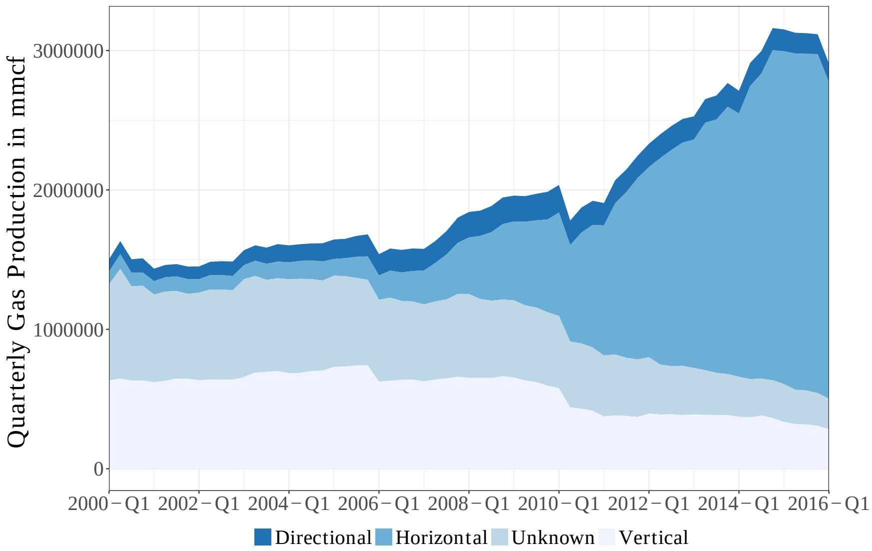

Figure 3: Development of aggregated gas production for different drilling technologies.
Source: Own calculations based on data provided by DrillingInfo

The development of the WTI crude oil and natural gas prices for the US is displayed in Figure 4. The main difference in the development is that, unlike the price for crude oil, the price for natural gas does not quickly recover following the price decline in 2008. The different trajectory of the price time series is also expressed by the diverging development of the contango following the peak of high prices in 2008. The Henry Hub natural gas spot price is in contango until 2013. So during these periods, the futures prices were higher than the spot prices, which provides an incentive to curtail production to exploit resources at a later point in time. This incentive was much greater in case of natural gas, since the periods of contango were much longer and the price did not recover as much as in the case of crude oil. The observable periods of contango and backwardation are similar to those studied by Gilje et al. (2017), although the actual numbers and the extent of contango differ because of different time horizons of the future contracts used in the calculation.

The diverging trajectory of the two fossil fuel prices is especially interesting, since it offers the possibility to distinguish between the firms' reaction to these two different price changes. Especially, it's interesting to analyze the reaction of the companies to the protracted period of lower prices in the natural gas market starting in 2008. This episode could probably provide insights into the response of the companies to the period of lower crude oil prices following the decline in the second half of 2014. Basically, the idea is to analyze the reactions of companies in gas markets after 2008 and if it's possible to draw

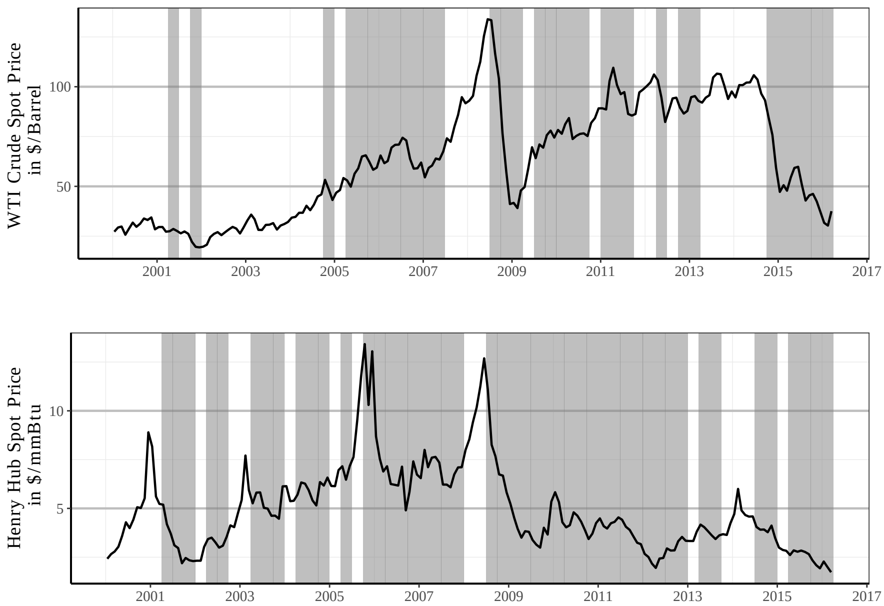

Figure 4: Development of WTI crude oil and Henry Hub natural gas spot prices. Shaded areas indicate quarters during which the futures prices were higher than the spot price.
Data source: WTI price time series (EIA 2017d) and Henry Hub Natural Gas price time series (EIA 2017b)

conclusions for the crude oil market, reaching a similar situation, just six years later.

One obvious reaction can be observed following the common decline and the subsequent increase in crude oil prices that the median share of oil on the total energy production increased. This is a strong indication that companies shifted their focus on extracting the relatively more valuable crude oil, although in total the production from both energy sources increased considerably.

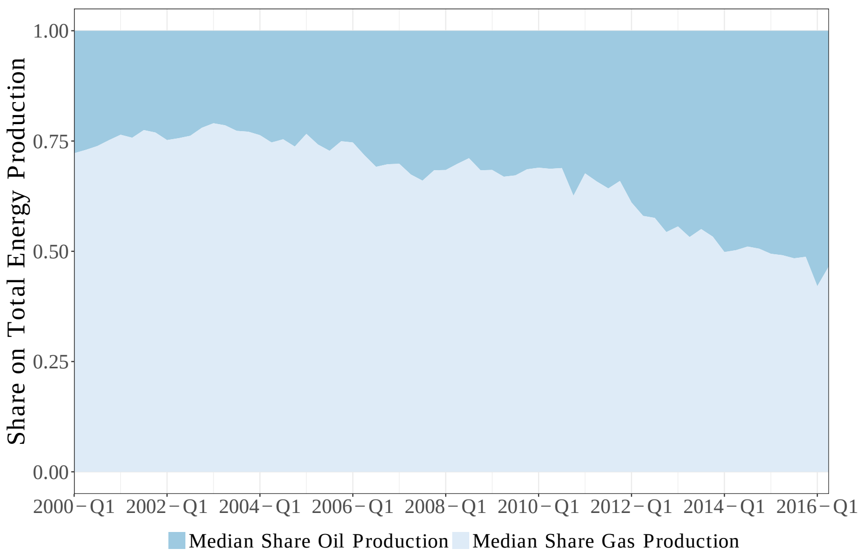

Figure 5: Development of the median production from different energy sources.
Source: Own calculations based on data provided by DrillingInfo

In this analysis leverage is based on the book value and defined as the sum of the total long term debt and debt in current liabilities divided by the total value of assets. In Figure 6 the development of median leverage across all companies in the sample is depicted. Beginning in 2000 the leverage decreases until reaching the lowest point in the third quarter in 2005. After a peak of nearly 0.3 during the great recession it again falls until in 2011 it starts to increase again and in 2016 it again reaches the level of 0.35, previously only seen at the beginning of the 2000s. The development of leverage in this sector also reflects the impact of the risk-taking channel, since the increase leverage is mostly due to increasing levels of debt and not based on deteriorating asset valuations over this horizon.

To analyze the impact leverage might have on the production, the companies are categorized into quartiles according to their leverage just prior to the price decline in the third quarter of 2008 and the fourth quarter in 2014.

It is also important to note that small companies in this sample actually are quite

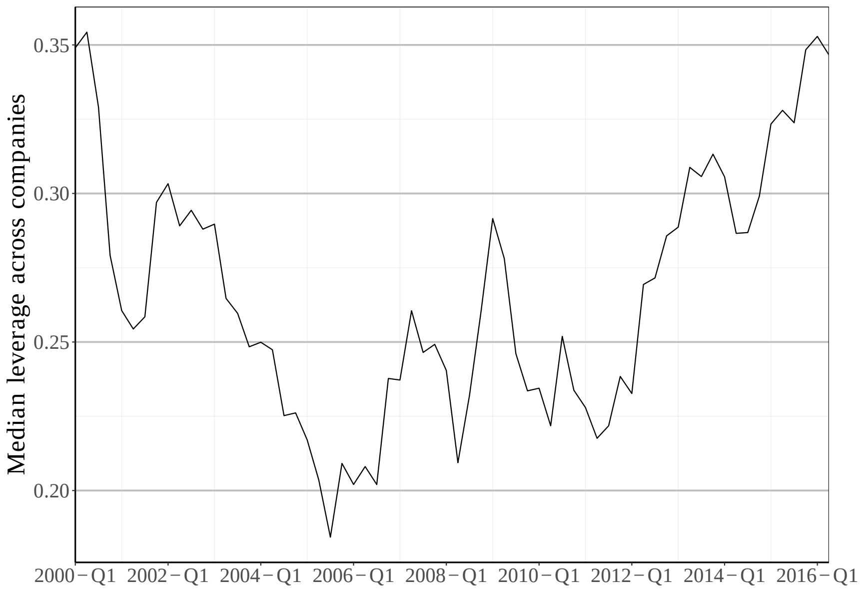

Figure 6: Development of the median leverage across all companies.
Source: Own calculations based on data provided by Compustat

large, since a lot of small companies are not publicly listed as noted in Bond et al. (2004, 24). This contributes to a selection bias and creates additional problems in connection with the survivorship bias, because only surviving companies are present over the whole sample period. However, it is possible to address this question in more detail and determine the factors which influence the probability of a company dropping out of the sample.

In order to analyze if the adoption of new technologies is affected by a companies' leverage. The share of oil and gas production from conventional and unconventional for the four leverage quartile and its development over time is depicted in Figure 7 and 8. It can be seen that irrespective of the leverage quartile a company was in before the oil price decline in 2008 the adoption of new production technologies and thus the production from unconventional sources increases with a similar trend and pattern. This indicates that higher leverage did not act as a constraint on the companies and their adoption of new technologies. On the contrary, it appears to be the case that companies which in 2008 were in the three highest leverage quartiles more strongly increased the share of production from unconventional sources. This is also evident, when looking at the growth rates of the production for each leverage group. The production of oil from unconventional sources increased from the third quarter of 2008 to the first quarter of 2016 by 239% for the fourth leverage quartile and only by 126% for the lowest

Leverage Percentile	2008 Q2			2014 Q3		
	No.	Assets	Debt	No.	Assets	Debt
1^{st} *Quartile*	33	9.38	6.20	33	9.46	6.85
2^{nd} *Quartile*	36	8.52	7.82	36	8.36	7.92
3^{rd} *Quartile*	35	7.95	7.23	36	7.60	7.19
4^{th} *Quartile*	35	7.07	7.10	36	7.17	6.79
Non-calculable Leverage	5	8.04	5.82	7	8.68	5.97

Table 1: Comparison of the number of companies for each leverage group prior to price declines in 2008 Q2 and 2014 Q3 and their average logarithmic value of total assets and debt.

	Leverage Quartile 2014				
Leverage Quartile 2008	1^{st} *Quartile*	2^{nd} *Quartile*	3^{rd} *Quartile*	4^{th} *Quartile*	Non-calculable leverage 2014
1^{st} *Quartile*	11	4	3	4	13
2^{nd} *Quartile*	4	10	9	4	9
3^{rd} *Quartile*	5	8	9	3	11
4^{th} *Quartile*	–	1	5	9	21
Non-calculable leverage 2008	17	14	11	18	140

Table 2: Companies' transition from leverage quartiles in 2008 to 2014.

quartile[10]. In case of natural gas the differences between the leverage groups are less pronounced and vary between 28% for the third leverage group and 102% for the highest leverage group[11] The difference between the two fossil fuels is mainly due to a much higher initial production from unconventional sources in case of natural gas already in 2008. Across all leverage groups the production from conventional sources decreased substantially.

To analyze the relationship between the adoption of new technologies and the companies' leverage quartile, the movements between the leverage quartiles from 2008 to 2014 are categorized into upward, downward and no movement. In Figures 9 and 10 is displayed and it can be observed that the adoption of new technologies is not associated with companies moving into a higher leverage quartile. Rather it can be seen that the share of unconventional oil production increased more strongly for companies which moved into a lower leverage quartile in 2014.

[10]The growth rate for the second and third quartile are 173% and 132%, respectively.
[11]The growth rate for the first and second leverage quartile is 81% and 86%, respectively.

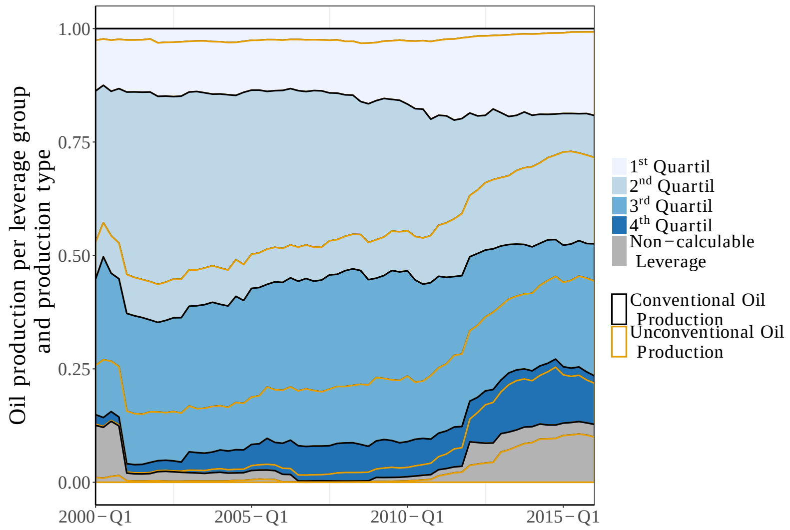

Figure 7: Total oil production differentiated by production type and leverage quartile of the companies in 2008. Yellow line separates the production types with conventional share above and unconventional share below.

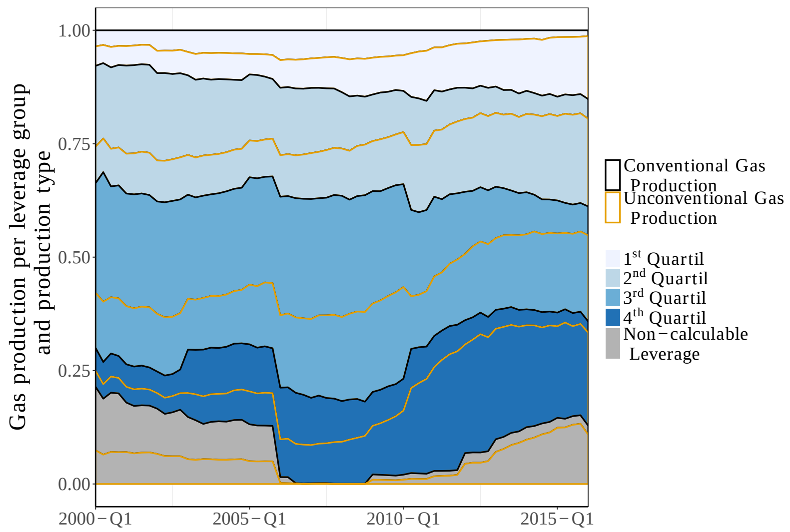

Figure 8: Total gas production differentiated by production type and leverage quartile of the companies in 2008. Yellow line separates the production types with conventional share above and unconventional share below.

The movement into a lower leverage group could be seen as an indicator that especially the possibility of unconventional production techniques and their considerably

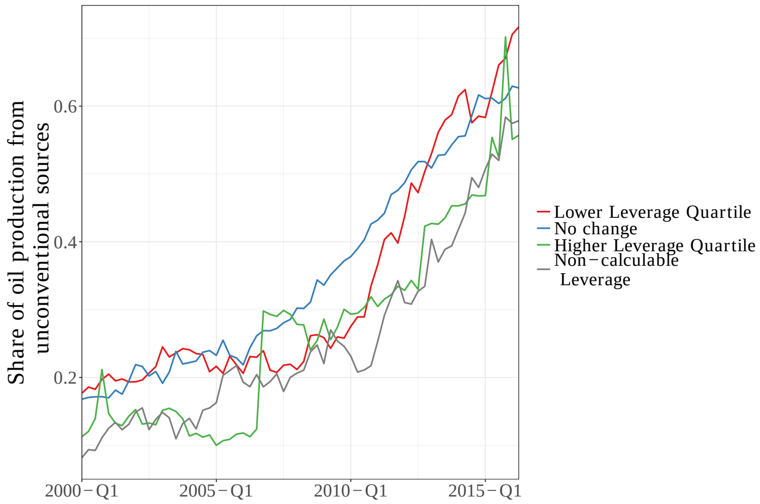

Figure 9: Share of oil production from unconventional sources differentiated by companies' leverage transition from 2008 to 2014.

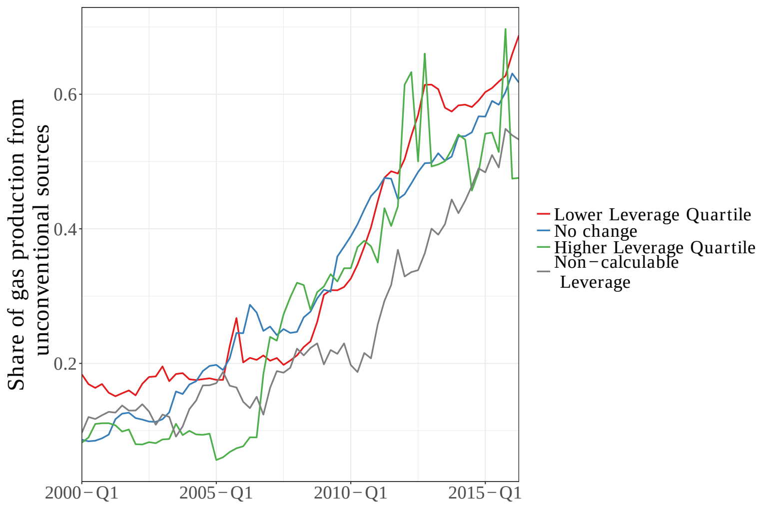

Figure 10: Share of gas production from unconventional sources differentiated by companies' leverage transition from 2008 to 2014.

lower upfront investment volumes allowed the increase of production capacity with lower investment volumes. Although it has to be considered that before the oil price drop in 2014 the asset valuation of companies might be relatively high as well.

4.2. Panel Data Analysis

The empirical analysis of the relationship between leverage and the production of fossil fuels faces several challenges, of which endogeneity is the most important one. Therefore, it is of utmost importance to appropriately set up the econometric model in order to prevent biased and inconsistent parameter estimates. One of the most important issues is the endogeneity, which is inherent in most corporate finance data sets. Roberts and Whited (2012) provide a very comprehensive overview on the causes of endogeneity and how these can be overcome. The most fundamental problems arise from measurement errors, because in corporate finance the book value of debt might not reflect the true market value (Roberts and Whited 2012, 13-17). Another important problem stated by Roberts and Whited (2012, 11) is the simultaneity of the variables commonly used in empirical corporate finance, since there are simultaneous effects, which might affect exogenously modeled variables as well as the endogenous variable. The following tables present some preliminary results. Due to the technical extraction processes the production of oil and natural gas is highly persistent and therefore the one period lagged production is included as an additional explanatory variable in the estimation.

	log(Total Oil Production)			
	Coefficient	Standard error	t-stat	p-value
log(Total Oil Production)$_{t-1}$	0.948***	0.004	243.745	0.000
log(Total Assets)	0.032***	0.012	2.771	0.006
log(EBITDA)	0.022**	0.010	2.134	0.033
Leverage	0.002	0.004	0.425	0.671
log(WTI Spot Price)	0.025	0.021	1.209	0.227
constant	−0.533***	0.093	−5.721	0.000
R^2	0.934			
Observations	6327			
F statistic	17 968.161			

Table 3: Pooled OLS estimating the impact of leverage on the production of crude oil.

The preliminary results indicate that Leverage might have an impact on the production decisions of companies, although the effect is not statistically significant for the production of natural gas.

The econometric modelling of this relationship faces a couple of problems, which need to and will be addressed in future versions of this paper. It is important to complement the empirical analysis with some robustness checks in order to make sure that the results are not statistical artifacts. Especially, since Frank and Goyal (2007, 31-35) highlight the problems associated using book leverage and the implication that has for the econometric modelling. Additionally, in early empirical work Titman and Wessels (1988) found evidence that leverage varies with the companies' size.

In order to assess the performance of various estimation techniques developed to

	log(Total Oil Production)			
	Coefficient	Standard error	t-stat	p-value
log(Total Oil Production)$_{t-1}$	0.586***	0.044	13.424	0.000
log(Total Assets)	0.084***	0.032	2.660	0.008
log(EBITDA)	0.035***	0.012	2.906	0.004
Leverage	0.027*	0.015	1.810	0.071
log(WTI Spot Price)	−0.117**	0.055	−2.130	0.034
constant	−1.305***	0.269	−4.848	0.000
R^2-within	0.517		σ_u	1.539
R^2-between	0.895		σ_e	0.657
R^2-overall	0.928		ρ	0.846
Observations	6327			
No. Companies	289			
F statistic	48.066			

Table 4: Estimation with firm fixed effects measuring the impact of leverage on the production of crude oil.

counteracting the biases introduced in dynamic panel data Flannery and Hankins (2013) create simulated corporate finance data. They are trying to include all data related issues, normally observed in such data, like missing, correlated or endogenous independent variables. Based on these results they can show that the best estimation techniques strongly depends on the issues present in the data, although it seems that the estimation technique developed by Blundell and Bond (2000) appears to be best in most cases. Therefore, the next step is the implementation of this method and the estimation of the proposed relationship. Perhaps it is possible to complement this approach with the results found by Petersen (2009), who analyzes different approaches estimating the standard errors in corporate finance data sets.

Another option would be to use a difference-in-difference approach like Gilje et al. (2017), where there are basically two treatments. The first treatment is high and low leverage and the second treatment is the occurrence of contango or backwardation. The implementation of this methodology would of course allow the comparison of the results and determine if there are differences between the decision of drilling new oil wells and the level of production. .

Additionally, Sigmund et al. (2017) are in the process of publishing code to estimate a panel vector autoregression framework and this would offer the opportunity to explicitly incorporate the endogeneity present in this data set. In a next step the most promising option is to implement a GMM estimation of this relationship in order to address the most probably biased and inconsistent estimates.

	log(Total Gas Production)			
	Coefficient	Standard error	t-stat	p-value
log(Total Gas Production)$_{t-1}$	0.933***	0.004	217.170	0.000
log(Total Assets)	0.065***	0.013	4.908	0.000
log(EBITDA)	0.022*	0.011	1.931	0.054
Leverage	0.059*	0.036	1.653	0.098
log(WTI Spot Price)	−0.064***	0.024	−2.699	0.007
constant	0.182*	0.101	1.805	0.071
R^2	0.928			
Observations	6290			
F statistic	16 236.009			

Note: *p<0.1; **p<0.05; ***p<0.01

Table 5: Pooled OLS estimating the impact of leverage on the production of natural gas.

	log(Total Gas Production)			
	Coefficient	Standard error	t-stat	p-value
log(Total Gas Production)$_{t-1}$	0.514***	0.048	10.637	0.000
log(Total Assets)	0.094**	0.042	2.271	0.024
log(EBITDA)	0.027*	0.014	1.934	0.054
Leverage	0.093	0.150	0.622	0.535
log(WTI Spot Price)	−0.194***	0.066	−2.940	0.004
constant	3.371***	0.400	8.431	0.000
R^2-within	0.451		σ_u	1.856
R^2-between	0.954		σ_e	0.707
R^2-overall	0.924		ρ	0.873
Observations	6290			
No. Companies	286			
F statistic	29.436			

Note: *p<0.1; **p<0.05; ***p<0.01

Table 6: Estimation with firm fixed effects measuring the impact of leverage on the production of natural gas.

5. Concluding Remarks

This paper analyzes the relationship between the leverage of companies and their production decision using a novel data set. In the first part of the paper the theoretical background on the economics of the crude oil and natural gas production is provided. Additionally, a short overview on the determinants of the financial structure is provided and the problems facing an empirical analysis are discussed. The exploratory data analysis shows that the novel data set on the company level is capable of describing a sizable part of the domestic crude oil production in the US. Additionally, the data set offers a lot of opportunities, which are not yet exploited. It is especially interesting to analyze the impact of directional drilling and hydraulic fracturing and if this might have changed the economics of oil and gas exploration. The preliminary results of a pooled panel estimation already provide some hints on the determinants of the production level and it appears to be influenced by companies' leverage. This also provides the starting point for future research, which will be mainly concentrated on improving the dynamic panel data analysis, by implementing a more appropriate methodology.

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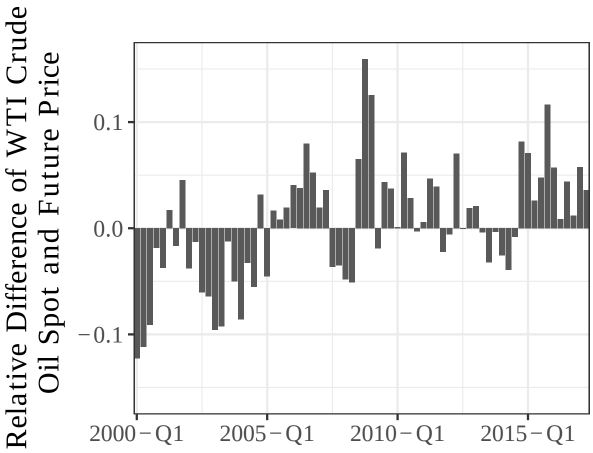
Appendices

A. Development of differences between spot and future markets



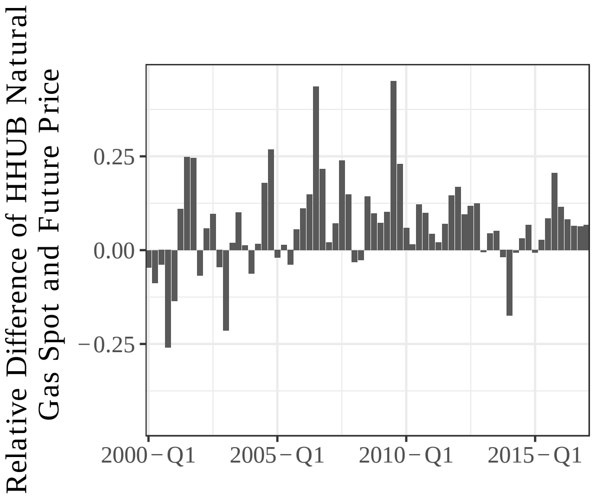


Figure 11: Relative difference of WTI crude oil and Henry Hub natural gas spot and future prices. Positive differences indicate periods of contango and negative differences periods of backwardation.
Data source: WTI price time series (EIA 2017d) and Henry Hub Natural Gas price time series (EIA 2017b)

B. Development of the share of gas production from unconventional sources for different leverage groups

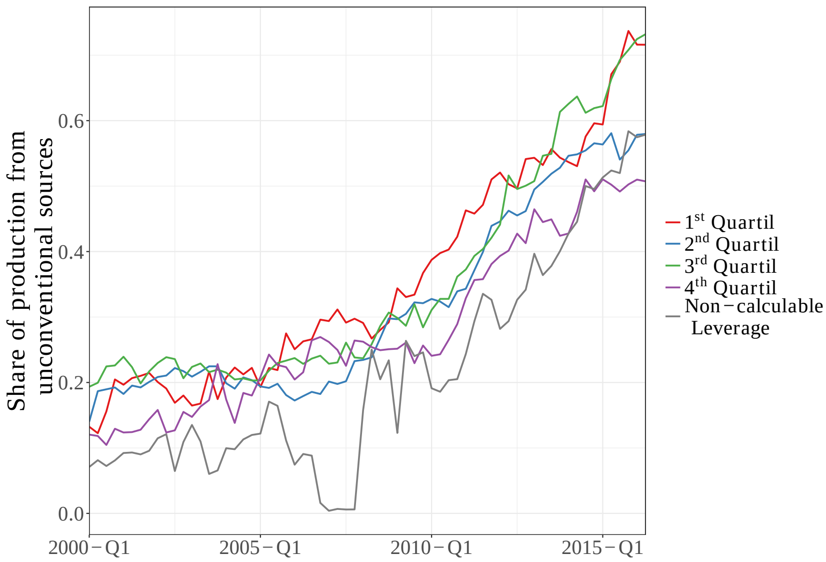


Figure 12: Share of oil production from unconventional sources, based on the leverage quartile of the companies in 2008
Source: Own calculations

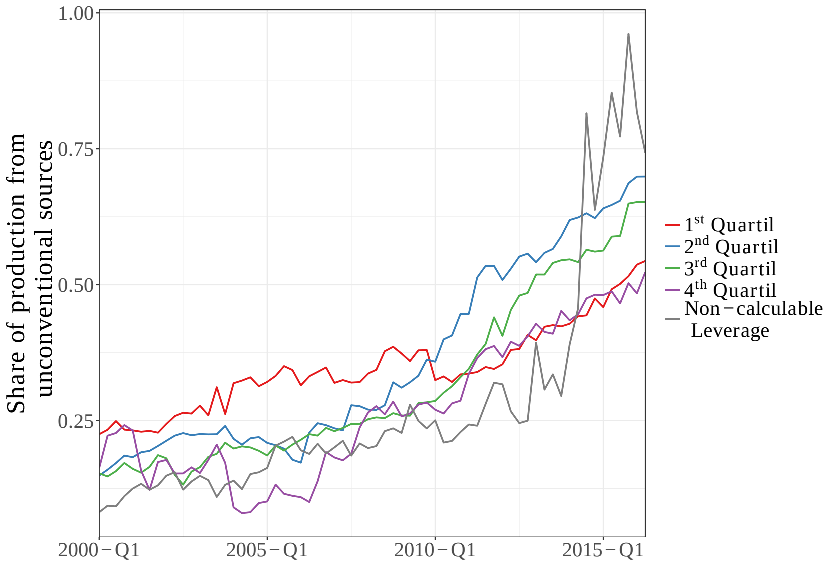


Figure 13: Share of oil production from unconventional sources, based on the leverage quartile of the companies in 2014
Source: Own calculations

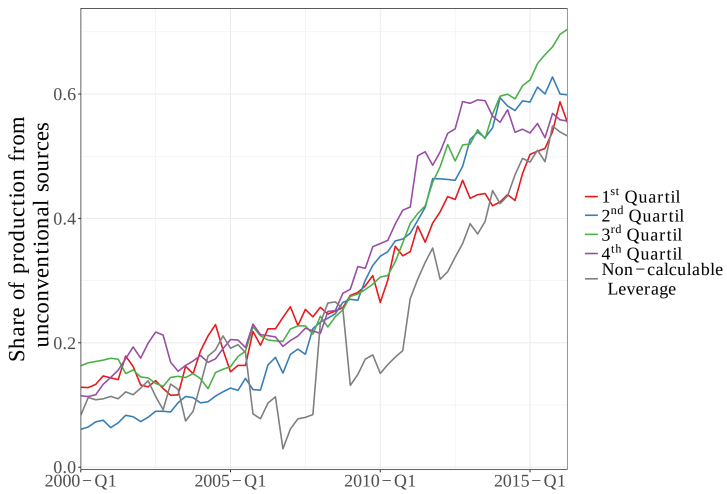


Figure 14: Share of gas production from unconventional sources, based on the leverage quartile of the companies in 2008
Source: Own calculations

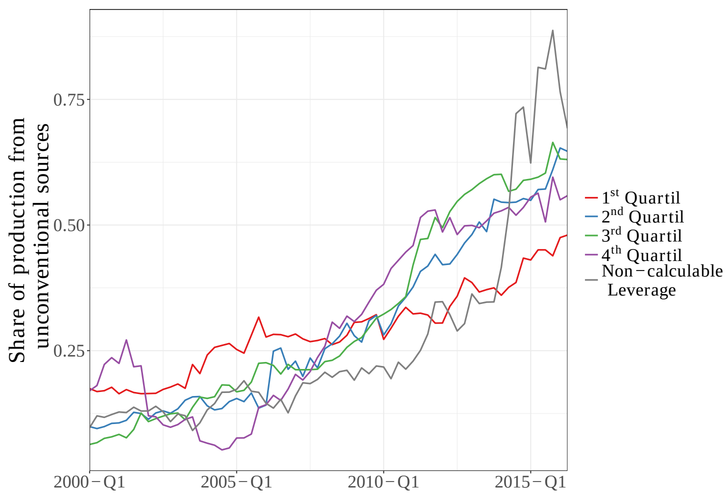


Figure 15: Share of gas production from unconventional sources, based on the leverage quartile of the companies in 2014
Source: Own calculations