Energy Policy 112 (2018) 162–172

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

# The shale technical revolution – cheer or fear? Impact analysis on efficiency in the global oilfield service market☆

Binlei Gong[1]

*Department of Agricultural Economics and Management, School of Public Affairs, China Academy for Rural Development (CARD), Zhejiang University, 688 Yuhangtang Road, Hangzhou 310058, PR China*

ARTICLE INFO

*JEL Classification:*
D24 L71 C23 C5

*Keywords:*
Stochastic frontier analysis
Semiparametric model
Global oilfield service market
Multidivisional firms
Shale technical revolution

ABSTRACT

The shale technical revolution has reshaped the oil and gas industry dramatically but also controversially as it affects existing energy policies as well. Many related policies, such as the fracking tax in the U.S. and the shale subsidies policy in China, depend heavily on whether or not the innovation is commercially successful. This paper develops a two-step approach to evaluate the effect of the revolution on efficiency in the global oilfield service (OFS) market, which can be divided into five segments. In the first step, a new semiparametric model is introduced to evaluate firm-level technical efficiencies assuming segment-specific production functions for each of the five segments. In the second step, this study tests if companies acquiring directional drilling (DD) and/or hydraulic fracturing (HF) techniques can maintain efficiency. The empirical results show that practicing just one of the techniques will decrease efficiency. However, combining the two can produce significant spillover effects and improve efficiency. Therefore, innovation and integration are both crucial for the OFS market. Some policy implications are also discussed.

## 1. Introduction

The oilfield service (OFS) market, or oil and gas service industry, is a complex process that involves specialized technology at each step of the oil and gas supply chain. Companies in the OFS market provide the infrastructure, equipment, intellectual property, and services needed to explore for and extract crude oil and natural gas. Therefore, this market is the upstream of the petroleum industry. The global OFS market has a total market capitalization of over $4 trillion, generating total revenues over $400 billion in 2014.[2]

The shale revolution, which benefited mainly from new technologies in hydraulic fracturing and directional drilling, has resulted in a 10% compound annual growth rate (CAGR) for the OFS market over the past decade. As conventional oil and gas resources are now being exhausted, oil and gas companies are currently paying more attention to unconventional oil and gas, offshore production, and aging reservoirs to maintain a steady supply. Therefore, the revolution is also called an unconventional revolution.

Hydraulic Fracturing (HF) is a well stimulation technique in which rock is fractured by a pressurized liquid. The process involves the high-pressure injection of “fracking fluid” (primarily water containing sand or other chemical additives) into a wellbore to create cracks in the deep-rock formations through which natural gas, petroleum, and brine will flow more freely. Directional Drilling (DD) is the practice of drilling non-vertical wells, and it includes the popular horizontal drilling. This technology can hit some targets that cannot be reached by vertical drilling and can drain a broad area from a single drilling pad. The combining of two technologies, HF and DD, has led to the shale revolution. Some rock units that were unproductive when drilled vertically can become fantastic producers of oil and/or gas. The magic of converting worthless shales into productive reservoir rocks occurs in many locations, such as the Barnett Shale of Texas, the Fayetteville Shale of Arkansas, the Marcellus Shale of the Appalachian Basin, the Bakken Formation of North Dakota, and the Haynesville Shale of Louisiana and Texas. Fig. 1 illustrates the hydraulic fracturing and directional drilling activities.

The Oilfield Market Report (OMR) by Spears divides the OFS industry into five macro segments: 1) exploration, 2) drilling, 3) completion, 4) production, and 5) capital equipment, downhole tools and offshore services (capital equipment, hereafter). OMR reports segment-level revenue for the 114 public firms in the field, where 68 firms are single-division and 56 firms are multidivisional.[3] These five macro

☆ I am grateful to Spears and Associates, Inc. for providing their data and Weatherford International for giving me the opportunity to closely observe firms in the oilfield market.
*E-mail address:* gongbinlei@zju.edu.cn.
[1] http://person.zju.edu.cn/en/gbl
[2] Data from 2015 Oilfield Market Report (OMR) by Spears.
[3] 28 firms do business in two segments, 10 firms are active in three segments, seven firms have footprints in four segments, and only one firm covers all five segments.

http://dx.doi.org/10.1016/j.enpol.2017.09.054
Received 1 August 2016; Received in revised form 11 August 2017; Accepted 26 September 2017

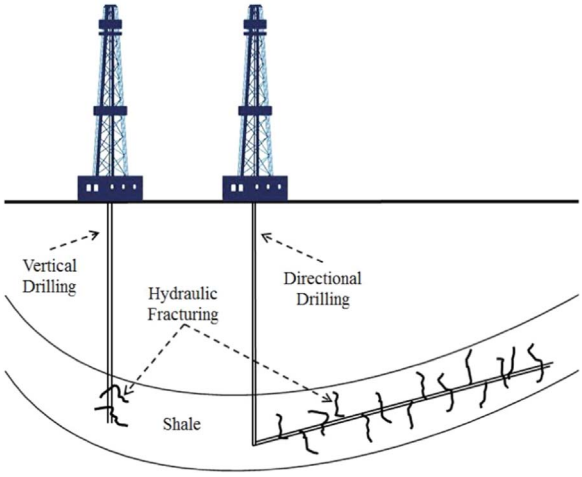


**Fig. 1.** Diagram of hydraulic fracturing and directional drilling.

segments can be further divided into 32 micro-market segments, including Hydraulic Fracturing (under "completion" segment) and Directional Drilling (under "drilling" segment). Based on OMR, the total revenue of the entire OFS market increased by 183% from 2005 to 2015, while the HF segment and the DD segment increased by 395% and 287% respectively during the same period, which implies that these two techniques are leading the development of the entire market.

On the one hand, the shale revolution is generating massive revenues for OFS companies and is producing sufficient energy supplies. Many people cheer the low energy prices and the mitigation of the energy shortage. On the other hand, the new innovations also require huge amounts of investment, such as labor and capital inputs as well as Research and Development (R & D) spending, which is feared for the related financial risk, sustainability, and low input-output ratio.[4] It is difficult to estimate the profitability of the new techniques in practice. Public firms report total inputs and outputs, and possibly segment/division-level outputs, but not segment/division-level inputs. Therefore, it is hard to get cost information for a specific activity or segment to calculate the actual breakeven price for unconventional oil and gas.[5] As a result, whether the innovation is commercially successful is unknown.

But many energy policies depend on whether hydraulic fracturing and directional drilling techniques are earning or losing. For example, what should the tax rate of the fracking tax in the U.S. be? What subsidies should the Chinese government offer to encourage shale resource exploration and extraction? How should the renewable energy policy be adjusted to compete with shale oil and gas?

This paper evaluates whether the innovation has a positive or negative effect on firm-level efficiency using a two-step approach. If firms can maintain or even increase efficiency with hydraulic fracturing and directional drilling programs, it implies that these businesses are at least as competitive and profitable as traditional oil and gas businesses, which will reshape geopolitics and the global energy market.

Managi et al. (2004) and Managi et al. (2006) study the productivity and efficiency of the offshore Gulf of Mexico oil and gas production, using data envelopment analysis (DEA) and stochastic frontier analysis (SFA), respectively. Thompson et al. (1996) analyze the efficiency of 14 major companies in the US oilfield market, using a non-parametric DEA for the period 1980–1991. Non-academic reports on this market are generated by advisory service firms such as Deloitte[6] and Ernst & Young,[7] which predict that the companies will be more efficient in the future. But all the academic and non-academic studies fail to consider the multidivisional structure of the companies and the pure effect of new shale technologies. The oil and gas industry has been better studied (e.g., Wolf, 2009; Eller et al., 2011, and Hartley and Medlock III, 2013) using efficiency analysis. However, their focus is the difference between National Oil Companies and International Oil Companies (i.e., the effect of ownership), rather than the effect of the new shale technologies.

The OFS market is complex and can be divided into multiple segments, each using different technologies and hence following different production functions. In the first step, a semi-varying coefficient stochastic frontier model is introduced to estimate the firm-level efficiency with this multi-segment concern, which standard productivity and efficiency analysis overlooked or chose to ignore. Then, this paper explores whether hydraulic fracturing and directional drilling have a significant effect on a firm's overall technical efficiency.

This study makes three central contributions. Firstly, the semi-parametric production function considers the multi-segment characteristics of a market with multidivisional firms. Secondly, this study focuses on OFS companies, which experience much more volatility than oil and gas companies but are seldom studied.[8] Thirdly, this paper estimates the impact of the shale revolution on efficiency, which provides essential messages to companies for their operational decisions and strategies as well as to governments for their policies and management.

The empirical results show that: 1) the production function is indeed segment-variant, which supports the validation of the multi-segment assumption considered; 2) the output elasticity of labor is consistent, while the output elasticity of capital varies greatly across segments; 3) the average firm-level efficiency for the OFS market is about .4, and the distribution is positive skewed; 4) having a footprint in just a hydraulic fracturing or just a directional drilling business can decrease efficiency, but combining the two generates positive spillover effects; 5) all the findings above are robust when either a Cobb-Douglas or Transcendental Logarithmic production form is adopted.

The remainder of the paper is structured as follows. Section 2 introduces the model. Section 3 provides data descriptions. Empirical results are presented and analyzed in Section 4. Section 5 gives conclusion and policy implications.

## 2. Model

This model includes two steps. Firstly, a stochastic frontier model is used to estimate firm-level aggregated production function as well as efficiency. Secondly, the derived efficiency is regressed on dummy variables of hydraulic fracturing and directional drilling as well as other variables.

### 2.1. Step One: production function and technical efficiency

This subsection develops a partial linear semiparametric varying

[4] The shale revolution is also criticized for climate reasons. The oil and gas from shale is "worse than coal" for the climate since there is greater leakage of methane to the atmosphere in unconventional wells. Moreover, while a high supply of oil and gas decreases energy prices, it discourages the development of renewable energy. However, this paper only focuses on analyzing the economic impact of the revolution from companies' perspectives.

[5] Although some firms report a breakeven price, many of them are wide ranges rather than fixed numbers. The veracity of the reported prices is also suspect since many firms adjust their price ranges frequently and continue to produce when the market price drops far below their reported breakeven prices. Sometimes even the companies themselves find it difficult to calculate the profitability of a certain program/segment because of the joint inputs and spillover effects. Remember, oilfield is a complex process that involves many steps in the energy supply chain.

[6] https://www2.deloitte.com/content/dam/Deloitte/uk/Documents/energy-resources/deloitte-uk-energy-and-resources-outlook-for-oilfield-services.pdf.

[7] http://www.ey.com/Publication/vwLUAssets/EY-review-of-the-UK-oilfield-services-industry-January-2017/$FILE/EY-Review-of-the-UK-oilfield-services-industry-January-2017.pdf.

[8] The productivity and efficiency of oilfield firms is studied much less than oil and gas companies for two reasons: the complex multi-segment characteristics and the lack of segment-level data. This paper uses a very unique dataset to capture the multi-segment characteristics. The empirical result confirms the necessity of doing so.