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Zhongmin Wang and Qing Xue

1616 P St. NW
Washington, DC 20036
202-328-5000 www.rff.org

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Abstract

This paper documents the evolution of the market structure of the modern shale gas drilling industry in the United States from birth to maturity. Modern shale gas drilling represents a major revolution in the energy industry. The industry was highly concentrated during its experimental stage and became less concentrated during its expansion stage, attracting a long tail of infrequent drillers. The evolution of this industry is different from the standard industry life cycle documented in the literature because this industry is driven only by process innovations. Our findings have policy implications for countries new to shale gas development.

Key Words: shale gas, market structure, concentration

JEL Classification Numbers: L11, L71, Q4

Contents

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Introduction

A large body of literature in economics, management, and related disciplines has studied the life cycle of various industries (e.g., Abernathy and Utterback 1978; Abernathy and Clark 1985; Klepper 1996). See Peltoniemi (2011) for a recent review of this industry life cycle literature. A key question addressed in this literature is the extent to which the evolution of industries exhibits the standard industry life cycle, which, according to Klepper (1997: 149), is that "initially the market grows rapidly, many firms enter and product innovation is fundamental, and then as the industry evolves output growth slows, entry declines, the number of producers undergoes a shakeout, product innovation becomes less significant, and process innovation rises." This standard industry life cycle is a very good characterization of many manufacturing industries with rich opportunities for both product and process innovations (e.g., automobile manufacturing), but it is less good at characterizing service industries (Galouj and Savona 2009) or cultural industries (DeFillippi et al. 2007).

In this paper, we document the evolution of the market structure of an extractive industry—the shale gas industry. Shale gas is natural gas produced from shale formations, an unconventional source of natural gas that is technically more difficult to develop than conventional sources of natural gas. It is interesting to study the evolution of this extractive industry for at least two reasons. First, our study contributes to the industry life cycle literature by studying an industry where there is no scope for product innovation—the shale gas industry produces an essentially homogeneous product (i.e., natural gas), and the evolution of the industry was driven by process innovations only.

Second, it is important to understand the evolution of the shale gas industry in and of itself. Due to innovations in extraction technologies (e.g., horizontal drilling and hydraulic fracturing), the shale gas industry experienced an extraordinary boom over the past decade or so, accounting for only 1.6 percent of total US natural gas production in 2000, but an astonishing

* Zhongmin Wang, Fellow, Resources for the Future, wang@rff.org. Qing Xue, China University of Petroleum (Beijing), Xueqing_cup@163.com. The authors thank DrillingInfo for providing the data set and answering many questions, and Alan Krupnick for helpful comments.

40.4 percent by 2012 (Energy Information Administration 2014a). This boom has "dramatically changed the energy future of the United States" (Joskow 2013: 339). The boom has also spurred interest in exploring for shale gas resources elsewhere (e.g., China, Mexico, Argentina, Poland, the United Kingdom, and Australia). However, scholars know little about the evolution of the market structure of the shale gas industry in the United States.

Our study is based mainly on a proprietary shale gas drilling data set. We find that modern shale gas drilling in the United States exhibits two distinct stages: a long experimental first stage and a rapid scaling-up second stage—the shale gas boom. During the experimental stage, the profitability of shale gas drilling was gradually proved by, in effect, a single firm that made both incremental innovations and a major breakthrough in extraction technologies. During the scaling-up stage, modern shale gas drilling became less concentrated and attracted a large number of infrequent drillers. However, even during this second stage, a limited number of large independent oil and gas companies drilled the overwhelming majority of modern shale gas wells, and infrequent drillers made a negligible contribution to shale gas drilling.

Our results suggest that some common perceptions in the literature on the market structure of the US shale gas industry are inaccurate. For example, without citing any empirical evidence, Hu and Xu (2013: 22) state that the US shale gas industry was created by "thousands of small- and medium-sized enterprises." Stevens (2012: 7; 2013: 9) asserts that shale gas drilling in the United States was dominated by "'momma and poppa' companies." Scholars are correct to recognize that the concentration of the natural gas industry in general is very low (e.g., Davis 2015). Indeed, there are thousands of natural gas firms in the United States, and many of these firms are quite small—they retain few employees and drill only a few natural gas wells in a year (Independent Petroleum Association of America 2012–2013). However, modern shale gas drilling requires much more sophisticated extraction technologies than does conventional natural gas drilling. Indeed, without major technological breakthroughs, the shale gas boom would not have occurred (Wang and Krupnick 2015).

Data and Industry Background

Our data come mainly from DrillingInfo, a market research firm that focuses on the oil and gas industry and whose data are often used in trade publications (e.g., Browning et al. 2013) and in government reports (e.g., Energy Information Administration 2014b). We supplement DrillingInfo data with data from the Louisiana Department of Natural Resources and the Pennsylvania Department of Environmental Protection, government agencies that publish shale gas drilling data for their states.

Our analysis focuses on the number of wells drilled rather than the volume of shale gas produced because drilling data (i.e. which firm drilled which well in what area and in what year) are of much higher quality than well-level production volume data.

The focus of our paper is on the six major modern shale gas plays—Barnett, Marcellus, Haynesville, Eagle Ford, Woodford, and Fayetteville. A shale gas play refers to a more or less continuous area with exploitable shale gas resources. The word "modern" is used to emphasize that, to produce natural gas from these shale plays, it is necessary to use sophisticated modern hydraulic fracturing technologies to stimulate the shale reservoirs in these plays so as to increase permeability. The six major modern shale gas plays accounted for nearly 92 percent of total US shale gas production in June 2013 (Sieminski 2014).

As a comparison, we also study Devonian shales in the Appalachian basin. Devonian shales are shallower and geologically less complicated than the modern shale gas plays. For this reason, firms have used simple extraction technologies to drill wells in Devonian shales since the 1920s. Federal legislation in the late 1970s and early 1980s promoted the development of Devonian shales and other types of unconventional natural gas, and the development of Devonian shales played a role in motivating a private firm, Mitchell Energy and Development (hereafter Mitchell Energy), to begin development of the first modern shale gas play—the Barnett play in Texas—in the early 1980s (Wang and Krupnick 2015). Mitchell Energy was the largest natural gas producer in northern Texas at the time. Gas production from Devonian shales is quite small, but a comparison of Devonian shales with the modern shale gas plays helps to explain the mechanisms underlying the observed market structure.

Results and Discussion

Figure 1 shows the number of wells drilled each year,[1] from 1982 through 2012, in the six modern shale gas plays, and the number of firms that were active in these plays each year. Both the annual number of wells drilled and the annual number of active firms were very small until about the year 2000, after which both variables started to increase dramatically. The annual number of wells drilled increased from 193 in 2000 to a peak of 6,962 in 2011 then decreased to

[1] We say that a well was drilled in year x if the completion date of that well was in year x. If the completion date is not available, we use the spud date. In the rare cases where the spud date is also unavailable, we use the first production date of the well to determine the year in which the well was drilled.

5,365 in 2012. The annual number of active firms increased from 15 in 2000 to a peak of 248 in 2008 then decreased to 162 in 2012.

Figure 1 reflects the fact that modern shale gas drilling has experienced two distinct stages: an experimental first stage, which began in the early 1980s, and a scaling-up second stage—the shale gas boom—which began in the early 2000s. During the experimental stage, shale gas drilling essentially took place in the Barnett play only. During this stage, only three wells were drilled in a modern shale gas play other than the Barnett play. Figure 2 provides more information about the experimental stage. It shows, by year, the number of wells drilled by Mitchell Energy, the number of wells drilled by its competitors, and the number of active firms, from 1982 to 2000. Mitchell Energy drilled the overwhelming majority of the Barnett wells before 2000. By 1999, Mitchell Energy had drilled a total of 482 Barnett wells, and its competitors together drilled only 102. The disparity is even more pronounced from 1982 through 1995, when Mitchell Energy drilled 264 Barnett wells, and only 20 were drilled by its competitors.

Why was Mitchell Energy essentially the only driller during the early years of modern shale gas development? Drilling in the modern plays, at that time, was not profitable, and the long-term prospects for drilling in modern shale plays as a viable industry were highly uncertain. The vast majority of natural gas firms were too small to have the financial resources or technical capability to make risky investments in shale gas drilling. Mitchell Energy, however, needed to find a new source of natural gas supply and had the financial resources and the technical capability. See Wang and Krupnick (2015) for a review of why and how Mitchell Energy developed the Barnett play.

What caused shale gas drilling to transition from the experimental stage to the scaling-up stage around the year 2000? A number of factors played a role, but two are particularly important. First, after making many incremental innovations in developing the Barnett play, Mitchell Energy finally achieved a major breakthrough in hydraulic fracturing in the late 1990s, which dramatically lowered cost and improved the profitability of drilling Barnett wells. Second, Devon Energy, one of the largest natural gas producers in the United States, acquired Mitchell Energy in 2002. Devon Energy combined the hydraulic fracturing technologies developed by Mitchell Energy with horizontal drilling and other technologies, which significantly increased the productivity and profitability of shale gas drilling. See Wang and Krupnick (2015) for more details.

Figure 3 shows, for each year between 1990 and 2012, the percentage of wells drilled by the top four active firms in the year and the proportion of active firms that drilled no more than five wells in the six modern plays during the entire sample period (1982 through 2012). The percentage of wells drilled by the top four firms each year was 100 percent prior to the late 1990s because Mitchell Energy was essentially the only driller in the modern shale plays at that time. The four-firm concentration ratios experienced sharp declines in the early 2000s, when the boom in shale gas drilling started. The four-firm concentration ratio reached a trough of 32 percent in 2005. We use the term "infrequent drillers" to refer to those firms that drilled, at most, five wells in the six modern plays during the entire sample period. Before the late 1990s, the proportion of infrequent drillers was essentially zero. Since the early 2000s, however, the proportion of infrequent drillers in each year has never been lower than 23.8 percent (in 2011).

Figure 4 presents the (natural) log number of wells drilled by each firm in the six major shale gas plays from 1982 through 2012, sequenced from the largest firm to the smallest. There is a long tail of infrequent drillers, but the overwhelming majority of wells are drilled by a relatively small number of firms. Of the 681 firms that drilled wells in the six modern plays, nearly 34 percent drilled a single well, and 27 percent drilled only two to five wells. These infrequent drillers drilled 779 wells in total, about 2 percent of the 40,272 wells drilled in the six modern plays during the sample period. In contrast, the four most active firms (Chesapeake Energy, Devon Energy, XTO Energy, and Southwestern Energy) together drilled 15,589 wells, or 39 percent of the total. The top 30 firms drilled 30,874 wells, or 77 percent of the total. Of these top 30 drillers, 27 are independent oil and gas exploration and production companies and only two (SWEPI LP, a subsidiary of Shell, and Chevron) are integrated oil and gas companies. The major integrated oil and gas companies invested relatively little in shale gas drilling until the late 2000s, when they purchased some of the independent gas drillers (e.g., ExxonMobil's purchase of XTO in December 2009).

Why did shale gas drilling become less concentrated during its expansion stage? The main reason is that, once drilling technologies achieved profitability, the barrier to entry became low, mainly because natural gas producers, large and small, typically outsource the drilling and fracturing of a well to specialized oil and gas service companies. Large gas producers employ their own engineers to plan and design wells, but very small producers outsource even the planning and design function to service companies. Beyond paying the service companies, these small natural gas producers need only to lease land and mineral rights from private landowners. The cost of securing a single lease can be small, and most of the cost is not sunk: leases can be resold to other producers. Note that private ownership of mineral rights is unique to the United

States. The fact that a lease can be resold attracts some firms to speculate. A speculating firm leases land and mineral rights not to drill but in order to sell the rights at a higher price later. However, a lease typically requires the leasing firm to drill at least one well within a certain period if the lease is not to be forfeited. This incentive perhaps explains the large observed number of firms that drilled a single well.

Infrequent drillers are more likely than frequent drillers to drill vertical wells, which are cheaper than horizontal wells. The proportion of wells that are vertical rather than horizontal is 70.8, 61.1, 40.3, 23.9, and 9.5 percent for firms that drilled 1, 2–5, 6–30, 31–500, and at least 501 wells, respectively. One interpretation is that infrequent drillers are more likely to be speculators who have little incentive to drill expensive wells. Another interpretation is that infrequent drillers may be more likely to drill in areas that do not require horizontal drilling.

Because the entry barrier to drill Devonian shales is lower, we expect a longer tail of infrequent drillers for Devonian shales. Figure 5 presents the annual number of wells drilled and the annual number of active firms in the Devonian shales from 1920 to 2012. The sharp upswing in the number of Devonian wells drilled in the early 1980s was caused by the incentive policies introduced by the US federal government in the late 1970s and the early 1980s to promote the development of Devonian shales. Figure 6 shows, for each year between 1930 and 2012, the percentage of wells drilled by the top four firms in the year and the proportion of active firms that drilled no more than five Devonian wells from 1930 to 2012. The four-firm concentration ratio in the Devonian shales experienced declines in the late 1970s and the early 1980s, when the US federal government introduced its incentive policies. The proportion of infrequent drillers in most years is quite large: the median proportion from 1930 to 2012 is 42.7 percent and the average is 44.5 percent. Figure 7 shows the (natural) log number of wells drilled by each firm in Devonian shales from 1920 through 2012, sequenced from the largest firm to the smallest. Nearly 71 percent of the 1,818 firms that ever drilled in the Devonian shales drilled only a single well, and 19 percent drilled only two to five wells. These infrequent drillers, 90 percent of the total, drilled merely 15.9 percent of the 14,314 Devonian wells in our sample.

Conclusion

In this paper, we have documented the evolution of the market structure of the modern shale gas industry in the United States from birth to maturity. Modern shale gas drilling experienced a long experimental stage during which a single firm drilled the overwhelming majority of wells. During the scaling-up stage, the industry became less concentrated and exhibited a long tail of infrequent drillers. Even during the scaling-up stage, a limited number of

firms drilled the vast majority of wells in the modern shale gas plays, and infrequent drillers made a negligible contribution to shale gas drilling. The barrier to entry was high during the experimental stage but low during the expansion stage, and major breakthroughs in extraction technologies caused the transition from the experimental stage to the expansion stage. The evolution of the market structure of the shale gas industry differs from the standard industry life cycle because this industry produces a homogeneous product and is driven only by process innovations.

Countries new to shale gas development have public ownership of mineral rights, so the governments in those countries can control the types of firms that are allowed to develop their shale gas resources. It is not surprising that policymakers and scholars in those countries, when deciding their entry policies, want to know what types of firms developed shale gas in the United States. Our paper is the first to provide a rigorous answer to this question. The geological and physical characteristics of shale gas reservoirs in other countries differ from those of the shale gas reservoirs in the United States, implying that shale gas development in other countries will likely have to experience an experimental stage during which innovations must be made to prove the profitability of shale gas drilling in those countries. Our findings suggest that small firms, if they are allowed to enter, are unlikely to drill a significant number of shale gas wells during the experimental stage when investments in shale gas drilling are risky and the profitability of shale gas drilling has yet to be proved.

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Figures

Figure 1. Annual Number of Wells Drilled and Active Firms in Major Modern Shale Gas Plays, 2000–2012

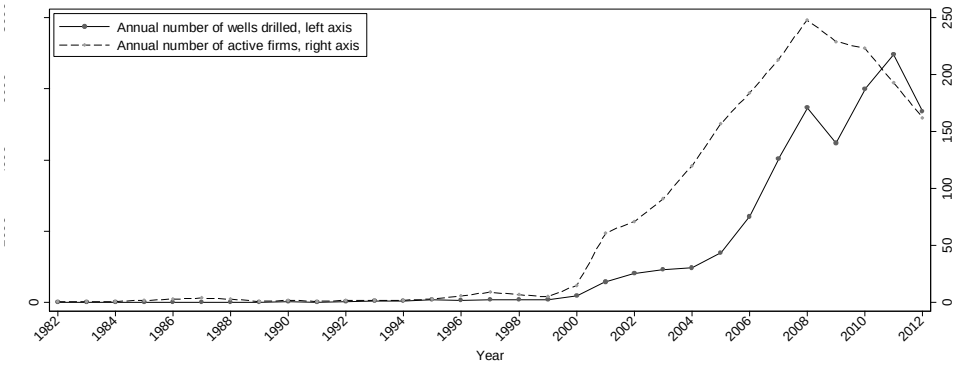

Figure 2. Annual Number of Wells Drilled by Mitchell Energy and Its Competitors, and Annual Number of Active Firms, 1982–2000

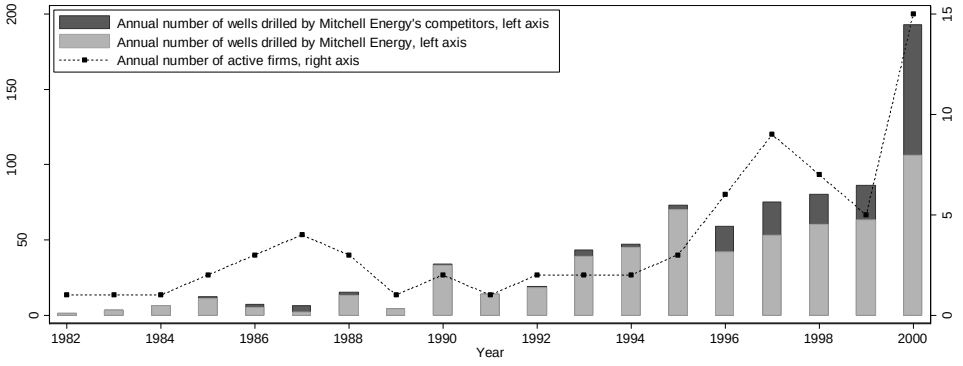

Figure 3. Proportion of Active Firms that Drilled at Most Five Wells in Major Shale Gas Plays, and Proportion of Wells Drilled by Top Four Firms Each Year, 1982–2012

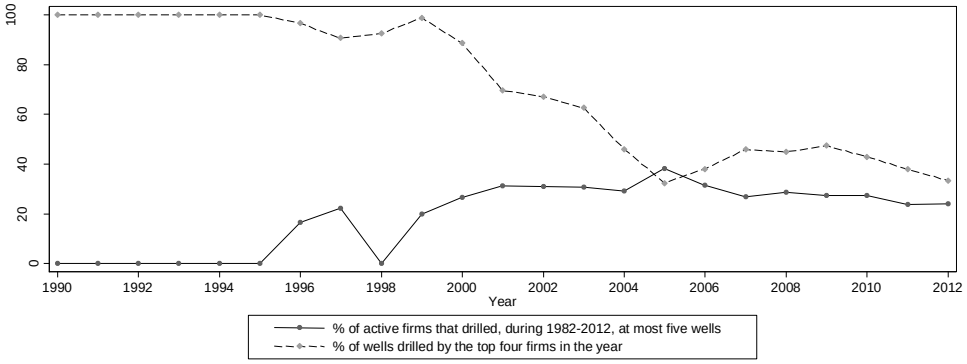

Figure 4. Natural Log Number of Wells Drilled by Each Firm in Modern Shale Gas Plays, Largest to Smallest, 1982–2012

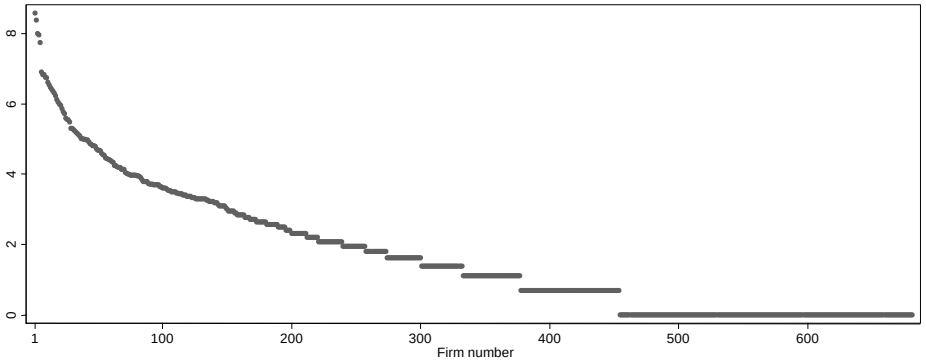

Figure 5. Annual Numbers of Wells Drilled and Firms Active in Devonian Shales, 1920–2012

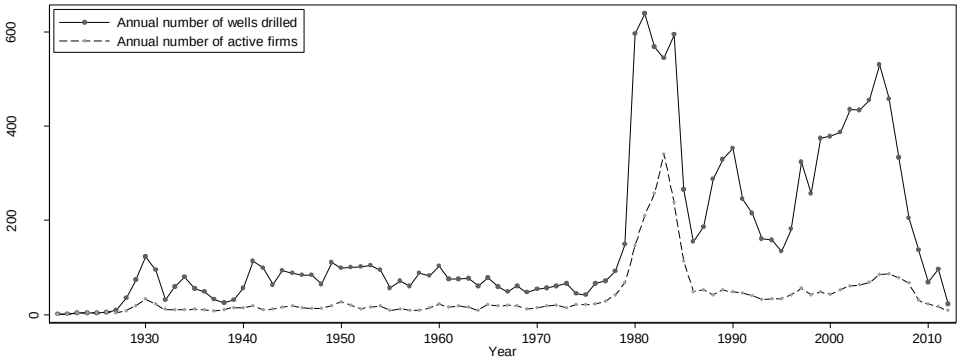

Figure 6. Percentage of Wells Drilled by Top Four Firms Each Year, and Percentage of Active Firms that Drilled at Most Five Devonian Wells,1920–2012

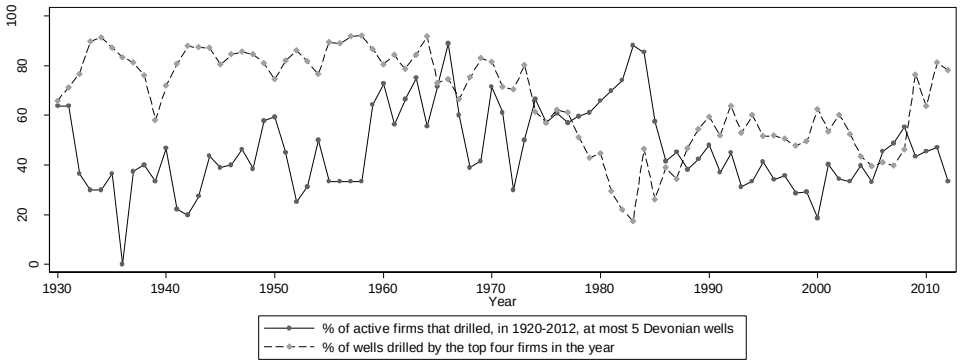

Figure 7. Natural Log Number of Wells Drilled by Each Firm in Devonian Shales, Largest to Smallest