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Stimulating Shale Gas Development in China

A Comparison with the US Experience

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Abstract

In this paper, we use the US shale gas experience to shed light on how China might overcome the innovation problem inherent in exploring and developing shale gas plays with complex geology. We separate shale gas development into two stages, an innovation stage and a scaling-up stage, with the first presenting a much bigger challenge than the latter. Our analysis suggests that China's national oil companies offer the best hope for overcoming the innovation problem. China's policy of opening shale gas development to new entrants is a market-oriented reform that can be justified on various grounds, but the new entrants will not play a major role in overcoming the innovation problem even though they may help scale up production later on.

Key Words: shale gas, innovation, China

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1. Introduction

China has large reserves of shale gas and a strong demand for natural gas because of its need to reduce the use of coal. It is not surprising, then, that the Chinese government has adopted a number of policies to promote the development of shale gas. In this paper, we use the US shale gas experience to shed light on the question of how China might successfully develop a shale gas industry. The question of developing a shale gas industry in an environmentally responsible way is taken up by Krupnick et al. (forthcoming).

Our starting point—based on both theory and the US experience—is that shale gas development involves two stages. In the innovation stage, firms need to invest in technology innovations that make it profitable to produce shale gas. Once profitability has been proved, shale gas development enters the scaling-up stage, during which production of shale gas is increased and expanded to plays of similar geology. We argue that China has to go through an innovation stage because of the complex geological features of its shale gas plays, and our analysis suggests that China’s policy of opening up shale gas development to new entrants (e.g., Chinese firms other than China’s national oil companies (NOCs)) will not help overcome the innovation problem, even though it may help scale up production after the innovation problem has been overcome.

We contend that China’s NOCs are the country’s best hope for overcoming the innovation problem. China’s NOCs enjoy overwhelming advantages over new entrants in terms of technology, experience, financial resources, and policy. The question is how to motivate the NOCs to invest in shale gas drilling. Supporting our conclusion is a recent announcement by China Petrochemical Corporation (Sinopec 2014), one of China’s NOCs, that it made significant

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breakthroughs in the exploration and development of a shale gas field in China's Sichuan province, where it plans to build an annual production capacity of 5 billion cubic meters (Bcm) by 2015.¹

The rest of the paper proceeds as follows. In section 2, we argue that the fundamental economic problem with developing a shale gas industry is how to lower cost through innovations, and we explain why China has to go through an innovation stage. In section 3, we review the US shale gas experience, with a focus on the factors that helped the country overcome the innovation problem. In section 4, we elaborate the fundamental differences between the US and Chinese oil and gas sectors, and we then review the current shale gas policies in China. In section 5, we explain why new entrants have little incentive to drill shale gas wells in the short run and why the NOCs are China's best hope for overcoming the innovation problem. Section 6 concludes.

2. The Innovation Problem

The fundamental economic problem with developing a shale gas industry is how to lower cost through investments in drilling and innovation. Once drilling in a shale gas play has proven profitable, further capital investment in exploration and development in it or similar plays is easy to attract, if shale gas drilling is open to profit-seeking investors. Therefore, it is useful to separate shale gas development into two stages. The first stage is the development of cost-effective extraction technologies, which can only be achieved through learning by doing and innovations. This stage can thus be termed the innovation stage. Once technologies are proven cost-effective, shale gas development enters the second, scaling-up, stage, which is to increase production. Continued technology improvements in the second stage help improve profitability and expand development into new plays.

A basic economic principle is that a competitive industry structure with a large number of firms and free entry is better at scaling up production than a highly concentrated industry structure with entry barriers. Firms in a highly concentrated industry with entry barriers have the incentive to restrict output. However, a competitive industry structure is not necessarily better at innovating than a highly concentrated industry structure. Indeed, the relationship between market

¹ We note that an article published by *21st Century Economic Report*, a major commercial newspaper in China, on June 18, 2014 questioned whether Sinopec's volume of shale gas production in the Sichuan area contains conventional natural gas. The article can be found at <http://q.stock.sohu.com/news/cn/028/600028/3391483.shtml>

structure and innovations is a complicated one. See Schumpeter (1943), Arrow (1962), and industrial organization textbooks for explanations.

When thinking about the relationship between market structure and innovations in the context of shale gas industry, it is important to recognize that innovations in shale gas development requires large amount of sunk investments in drilling and fracking. Small firms do not have the financial resources or technical expertise to make such investments. Large firms may have the financial and technical capacity, but their incentive to innovate may be weak. They may have better investment opportunities. For example, investments in conventional oil and gas, at least when their prices are high, yield higher expected returns with fewer risks. In addition, few technologies in the oil and gas industry are patentable and licensable, so an important issue is how to appropriate returns for costly investments. In the context of China, as we shall discuss in section 4, firms' incentive to invest in shale gas drilling is also affected by a number of non-market factors that are not present in the United States.

One could argue that the rapid technological innovations in hydraulic fracturing and horizontal drilling in the United States can be adopted in China, removing the need for any protracted innovation stage. However, it appears that no short cuts will be available.

It is not for a lack of reserves. The official estimate of technically recoverable reserves in China by the Ministry of Land and Resources (MLR 2013) is 25.1 trillion cubic meters (Tcm). According to the Energy Information Administration (2013, XX-8), the estimate is even larger: 17.7 Tcm in Sichuan Basin, 6.1 Tcm in Tarim, 1.0 Tcm in Junggar, 0.45 Tcm in Songliao, and another 6.3 Tcm in geologically more complex basins, for a total of 31.5 Tcm. Other estimates are all above 20 Tcm (Dong et al. 2012).

However, the geology of shale gas resources in China is considerably less favorable than it is in North America, according to engineers inside and outside China (e.g. Dong et al. 2012; EIA 2013). For this reason, significant innovations in fracturing technology will be needed. According to EIA (2013, XX-8), "most Chinese shale basins are tectonically complex with numerous faults—some seismically active—which is not conducive to shale development." The EIA report notes that the southwestern quadrant of the Sichuan Basin is the most promising shale gas play in China due to its relatively favorable geology, water resources, existing pipelines, and access to major urban markets. But its "considerable structural complexity, with extensive folding and faulting, appears to be a significant risk for shale development," according to PetroChina engineers quoted in the report (XX-9). In another report (Stevens et al. 2013, 1), the same authors add that the southwestern quadrant of the Sichuan Basin has "significant geological

challenges, such as numerous faults (some active), often steep dips, high tectonic stress, slow drilling in hard formations, and high H₂S and CO₂ in places.”

Shell, through a production-sharing contract with China National Petroleum Corporation (CNPC), has been drilling shale gas wells in the Sichuan Basin for several years. Shell’s experience illustrates the complexities of the geological setting. According to Stevens et al. (2013, 4), Shell’s drilling and testing indicated good resource potential but poor geology: there are “significant fault-related problems, such as frequent drilling out of zone and resulting doglegs that complicated well completion.” Spegele and Scheck (2013) report that Sichuan Basin’s “rough terrain, poor infrastructure and deeply buried formations present tough technical challenges” for Shell.

These challenges have led to large short-term losses. By late 2013, Sinopec had reportedly invested a total amount of US\$0.37 billion in shale gas development, and CNPC a total of \$0.64 billion (*China Securities Journal* 2013).² However, by late 2013, Sinopec had only produced a total amount of 2.58 billion cubic feet commercial shale gas, and CNPC a total of 2.47 billion cubic feet (NEA 2013). Since the wellhead natural gas price is about \$9.06 per million cubic feet (Mcf) in Sichuan (He 2013) and the subsidy for shale gas is \$1.81 per million cubic feet, a generous estimate of the two national oil companies’ total revenue from shale gas production is \$54.4 million. This implies that the two companies’ short-term loss from shale gas development by late 2013 is close to \$1 billion.

3. The Shale Gas Experience in the United States

In this section, we focus on the factors that helped the United States overcome the innovation problem and scale up the industry. Our discussions in this section borrow heavily from Wang and Krupnick (2013), who offer a much more detailed answer to the question of what led to the shale gas boom in the United States.

3.1. How Did the United States Overcome the Innovation Problem?

Starting in the late 1970s, the US federal government adopted a number of policies to promote the development of new sources of natural gas in response to the severe natural gas shortage caused by price ceiling regulations that set interstate natural gas prices at levels below

² It is assumed that CN¥1 = US\$0.16.

the competitive market price. These policies took the form of research and development (R&D), fiscal, and incentive pricing programs that set the stage for the increased production of tight gas and coalbed methane and, later, the boom in shale gas. Private entrepreneurship from Mitchell Energy also played a key role in jump-starting the shale gas boom.

It is useful to point out that some of the technology innovations important for shale gas development were developed by the oil industry in their effort to explore and produce oil instead of unconventional natural gas. Horizontal drilling and 3-D seismic imaging are two such examples. Horizontal drilling, for example, first achieved commercial viability in oil wells in the late 1980s and was applied to gas wells later.

3.1.1. R&D Programs

In 1975–1976, the US Energy Research and Development Administration initiated an unconventional natural gas research program, which the US Department of Energy continued after its creation in 1977. The R&D projects were implemented by the agency's technology centers, national laboratories, universities, and private firms.

The unconventional natural gas research program had three separate sub-programs: a shale gas program, a tight gas program, and a coalbed methane program. The shale gas program targeted Devonian-age gas shales underlying vast areas of the eastern United States. The shale gas program helped assess the resource base, introduce more sophisticated technology, and revitalize shale gas drilling in the Appalachian basin. The shale gas program did not cover the Barnett shale in Texas, but some of the technologies and methods developed by the program were applied in the Barnett shale. Mitchell Energy, in its early years of developing the Barnett shale, viewed the Devonian shale as an exploration and production analog, suggesting that the success of the shale gas program likely played a significant role in motivating Mitchell Energy to initiate the development of the Barnett shale.

A few other R&D programs helped develop technologies that have been important for shale gas development. These include the programs on tight gas and coalbed methane as well as a number of other government-funded R&D programs that are independent of the unconventional gas programs. For example, a few programs made critical contributions to the development of microseismic fracture monitoring, which has been playing a critical role in optimizing the way shale gas wells are hydraulically fractured.

3.1.2. Fiscal Policy and Incentive Pricing

Innovation in natural gas extraction in the United States also benefited from incentive pricing and tax credits. By mandate of the Natural Gas Policy Act of 1978, the wellhead prices for Devonian shale and coal seams were deregulated in November 1979, which created a big advantage for these new gas sources. In the early 1980s, deregulated natural gas was selling at more than twice the price of regulated natural gas. The price of tight gas was not quickly deregulated, however.

The Crude Oil Windfall Profits Tax Act in 1980 provided tax credits for the production of unconventional fuels, and this credit was implemented under Section 29 of the Internal Revenue Code. Section 29 tax credits applied to Devonian shale, coal seams, tight gas, and a few other fuels. Unconventional gas wells spudded between January 1, 1980, and December 31, 1992, were eligible for the tax credits, and production from eligible wells continued to receive credit until December 31, 2002. Initially \$0.52/Mcf, the credit was increased to \$0.94/Mcf in 1992 (Hass and Goulding 1992, 3). During much of this period, the national average wellhead natural price was between \$1.5/Mcf and \$2.5/Mcf.

The tax credit for tight gas was fixed at \$0.52/Mcf in the early 1980s, which was smaller than that for Devonian shale or coalbed methane. Tight gas also lost tax credits for some years.

Gas producers had to select either Natural Gas Policy Act incentive pricing or Section 29 tax credits. This requirement, however, did not affect Devonian shale or coalbed methane much because their prices were deregulated in late 1979 and producers naturally selected tax credits thereafter. It is useful to note that Mitchell Energy filed the Barnett shale as a tight gas formation, probably because the Natural Gas Policy Act of 1978 only mentioned Devonian shale and the Barnett shale was not Devonian shale.

No studies have rigorously examined the impact of these financial incentives on the development of unconventional natural gas, but trade publications generally agree that they reduced the risk of investing in unconventional natural gas resources and, as a result, spurred investment in development activities and technology improvement.

3.1.3. Private Entrepreneurship

It is worth emphasizing that a large number of small- and medium-sized oil and gas firms exist in the United States, but it was a single firm—Mitchell Energy—played an overwhelming role in developing the Barnett play in Texas in the 1980s and 1990s, and it was the successful development of the Barnett play that jump-started the shale gas boom. From 1982 through 1995,

Mitchell Energy completed 264 Barnett wells, while its eight competitors together completed only 20.

Why is it that no other firms made large amount of investments in the Barnett play in the early years? One reason is that it was not profitable to do so in the short run, and long-run returns were highly uncertain. Another reason is simply that the vast majority of the natural gas firms were too small to have the financial resources or technical capacity to make risky investments in shale gas. Mitchell Energy was unique in that it had an idiosyncratic need, the financial resources, and the technical capability to experiment with drilling shale gas wells, and it was also in a position to minimize the financial losses from drilling shale gas wells. In addition, the company was motivated by the incentive to appropriate large returns from its investments and innovations.

Mitchell Energy's initial motivation to drill shale gas wells in the Barnett was to find a new source of natural gas to fulfill its long-term natural gas supply contract with an interstate natural gas pipeline company. In the early 1980s, the company expected its production of conventional natural gas to decline in a decade or so.

Mitchell Energy was in a financial position to undertake some risky investments in shale gas drilling. In 1981, Mitchell Energy was the largest gas producer in North Texas and a diversified, publicly traded firm whose business included not only the exploration, production, gathering, and processing of natural gas but also drilling rigs and real estate operations. Its long-term natural gas supply contract also provided the firm with some financial flexibility by guaranteeing considerably higher natural gas prices than the market dictated.

However, even for Mitchell Energy, financial considerations were sometimes a constraint for investment in shale gas drilling. For example, when natural gas prices declined in 1986 because of the oil price crash, the firm significantly reduced its capital expenditure on high-risk long-term projects, including drilling in the Barnett play.

Mitchell Energy was able to minimize the financial losses from drilling Barnett wells in the early 1980s because it drilled in an area where shale formations overlapped with conventional gas formations. All the early Barnett shale gas wells were deepened to the Barnett formation from shallower formations so that Mitchell Energy had the option of producing gas from the shallower formations, thus greatly reducing the risk and cost of drilling shale gas wells.

The firm also had access to a mechanism by which it obtained large financial returns for its investments in innovations. It leased large tracts of land and the associated mineral rights at low prices early on and later sold the land, the innovations it had made, and the know-how it had

accumulated at a much higher price. This mechanism overcame the difficulty of monetizing technology innovations in the oil and gas industry and was made possible by the private land and mineral rights ownership system in the United States.

Finally, Mitchell Energy had the technical capability to experiment with drilling shale gas wells. With financial assistance from the US Department of Energy, it had conducted in 1978 what was, at the time, the largest massive hydraulic fracking in a tight gas formation. Mitchell Energy quickly applied massive hydraulic fracking to the Barnett shale. The company employed service firms to conduct routine tasks, but it was its own excellent team of geologists and petroleum engineers that gradually accumulated geological knowledge, found numerous ways to incrementally reduce production cost, and came up with the major breakthrough of slick water fracking that dramatically reduced cost without negatively affecting gas production.

It is also useful to note that Mitchell Energy drilled more than 800 vertical shale gas wells in the Barnett play before it was sold to Devon Energy for a price of US\$3.5 billion in January 2002, but it attempted to drill only four horizontal wells due to technical and financial constraints. Soon after purchasing Mitchell Energy, Devon Energy started to drill horizontal wells and quickly achieved great success in doing so. As a result, in 2003, Devon Energy filed permits to drill more than 80 horizontal wells. After Devon Energy's success became public in July 2003, 25 competing firms filed for permits to drill more than 100 horizontal wells, signaling that the innovation problem had been overcome. Why was Devon Energy able to drill horizontal wells? As one of the largest independent oil and gas operators in the world, with assets of \$13.2 billion in 2001, it had better technical and financial capabilities.

3.2. How Did the US Shale Gas Industry Scale Up?

Unlike during the innovation stage, when firms lack the incentive to innovate, profit-seeking firms have strong incentives to invest in shale gas plays of similar geology once drilling is proved profitable in a play. Hence, if government does not impose entry restrictions, firms naturally scale up the industry in their pursuit of profits. This proved to be the case in the United States.

Two government policies further helped scale up the US shale gas industry. The first is the deregulation of wellhead natural gas prices—for Devonian shale and coal seams in late 1979 and all natural gas sources in 1989. Without price control, natural gas prices remained high through much of the 2000s. Because firms had proved that drilling and fracking technologies were cost-effective around 2003, high natural gas prices attracted existing firms and new entrants

to invest heavily into shale gas drilling, which is an important reason the shale gas industry scaled up quickly in the 2000s.

The second policy is open access to interstate natural gas pipelines. The United States already had an extensive network of pipelines to transport natural gas before shale gas became a major gas resource. The pipeline open-access policy, which was implemented in the 1980s and early 1990s, mandates that interstate pipelines offer transportation services only, on a nondiscriminatory basis. This policy helped generate a more competitive wholesale market and made it easier for gas-producing firms to sell their natural gas to downstream users.

4. Current Shale Gas Development in China

We begin this section with a discussion of the fundamental differences between the oil and gas sectors in China and in the United States, which provides the necessary context for the review of current shale gas policies in China that follows.

4.1. Fundamental Differences in the US and Chinese Oil and Gas Sectors

The oil and gas industry in the United States is vertically separated. Oil and gas field services (e.g., drilling) are largely provided by service firms (e.g., Schlumberger) that are independent from the oil and gas operators (e.g., ExxonMobil and Devon Energy). Nor do oil and gas operators typically own or operate natural gas pipelines. There are no entry restrictions to natural gas exploration and development. In fact, many independent natural gas firms exist, some of which are small while others are large. The large independent natural gas firms (e.g., Mitchell Energy and Devon Energy) played a critical role in overcoming the innovation problem. The US system of private land and minerals rights also incentivized natural gas firms to invest in shale gas drilling.

In China, however, most segments of the oil and gas industry are dominated by three major national oil companies: China National Petroleum Corporation (CNPC), Sinopec, and China National Offshore Oil Corporation (CNOOC). In 2011, the market share of CNPC, Sinopec, and CNOOC was, respectively, 59.5 percent, 21.9 percent, and 13.8 percent in oil production, and 71.1 percent, 11.7 percent, and 15.2 percent in natural gas production (CNPC 2011). The rest of the market share belongs to Shaanxi Yanchang Petroleum Group, a much smaller oil and gas company owned by Shaanxi province.

The three NOCs are all vertically integrated, and they control not only the upstream sector of the oil and gas industry but also the oil and gas service sector and the oil and gas

pipelines. The three NOCs together control more than 90 percent of the many Chinese oilfield service companies, and the sizes of China's oilfield service companies are small, and market concentration is low (GF Securities 2012). CNPC and Sinopec control China's trunk natural gas pipelines.

The three NOCs are majority-owned by the Chinese state,³ but they are not directly run by a governmental agency. An International Energy Agency publication (Jiang and Sinton 2011, 7) characterizes the relationship between the NOCs and the Chinese government as follows: “[T]hey are not government-run. Their observed behavior is the result of a complex interplay between individuals and groups associated with the firms, and whose interests are not always aligned, and where commercial incentive is the main driver. Despite some instances of coordination, there seems to be a high degree of independence of the NOCs from government, and sometimes of subsidiaries of the NOCs from their headquarters.” The NOCs are certainly different from typical private firms. After all, the top leaders of NOCs are directly appointed by the central government, so they are not only company executives who respond to commercial incentives but also political appointees who may respond to political incentives.

The Chinese state, represented by the central government, owns oil and gas mineral rights. Land rights are separate and belong to the state in the case of urban areas but are collectively owned in rural and suburban areas. The separation of land and mineral rights can lead to conflicts between the NOCs and local interests (Hu and Wu 2007). Chinese policies on oil and gas mineral rights require the NOCs to register their blocks of oil and gas resources with MLR and cede their control over oil and gas resources if they do not make investments in a timely matter. However, this latter requirement has not been enforced (Zhang 2012). Nearly 80 percent of the most prospective shale gas reserves overlap with conventional oil and gas reserves, and according to an MLR (2012) notice, the exploration rights to the overlapping areas have been granted to the NOCs.

4.2. Current Shale Gas Policies in China

The Chinese government is taking a much more active role than the US government did in planning the development of shale gas. In March, 2012, the Ministry of Finance (MoF), MLR,

³ They each have a subsidiary listed on the Hong Kong and New York stock exchanges (e.g., PetroChina, Sinopec Corp., and CNOOC Ltd.), and the subsidiary holds most of the best assets of the parent companies. The parent companies are the majority shareholders of the listed companies.

National Development and Reform Commission (NDRC), and National Energy Administration (NEA) jointly issued the *12th Five-Year Plan for Shale Gas*. This 15-page document covers the status of shale gas development in China and the main challenges, targets, tasks, policies for developing shale gas. In particular, this planning document sets a specific and aggressive shale gas production target of 6.5 Bcm for the year of 2015. In October 2013, NEA introduced a shale gas industrial policy in a three-page document that declares shale gas development is a new national strategic industry.

The Chinese government has adopted R&D policy and fiscal policy to promote shale gas development. It has also decided to open shale gas development to new entrants and has sought to reform natural gas pricing and pipeline transport of natural gas.

4.2.1. R&D Policy

The five-year shale gas plan is quite vague on R&D policy, mentioning two items without providing any details. First, a research program on critical technologies for shale gas exploration and development is to be established as a major national science and technology project. Second, a national shale gas R&D center was established in 2010. This shale gas R&D center is part of the Research Institute of Petroleum Exploration and Development, which is a research arm of CNPC. This document also states that the government encourages using most advanced technologies already developed outside of China, developing advanced technologies domestically, and establishing shale gas development demonstration areas. Shale gas R&D was also highlighted in the *National Energy Technology 12th Five-Year Plan* issued by NEA in December 2011. The Chinese government has already supported several large shale gas R&D projects through its *National Basic Research Program of China (973 Program)* and other major science and technology funding schemes.⁴

It is difficult to compare these R&D policies with those adopted by the US government, partly because of the lack of details on China's shale gas R&D programs and partly because of the fact that most of the shale gas R&D activities will be carried out by CNPC and Sinopec. The shale gas industrial policy document states explicitly that oil and gas firms are the main entities

⁴ We gathered through various channels a list of 9 large shale gas R&D projects the Chinese government has supported through its major science and technology funding schemes since 2011. The budget for each of these research projects is in the range of US\$2-6 million, and the grantees are research arms of CNPC or its subsidiaries, Yanchang Petroleum Group, two universities, and a research center of the Chinese Academy of Sciences.

for shale gas technology innovations, reflecting the fact that China's oil and gas exploration and development technologies are concentrated in the three NOCs.

4.2.2. Fiscal Policy and Incentive Pricing

In November, 2012, MoF and NEA jointly issued a notice announcing a fiscal subsidy policy of \$1.81/Mcf for shale gas to be effective from 2013 to 2015 (MoF and NEA 2012). The subsidy may be subsequently adjusted according to the development status of shale gas. The subsidy represents about 21 percent of the average citygate price for natural gas in China—that is, the price a utility pays when it receives gas from a transmission pipeline—in the second half of 2013. An official from MLR said publicly that the definition for shale gas in the subsidy notice is too narrow. According to this official, only 5–7 Tcm of the 25 Tcm of shale gas reserve MLR estimated for China satisfies the shale gas definition (Wang 2012). However, most of the shale gas blocks in the second round of auctions—described in the next section—are eligible for the subsidy.

The shale gas industrial policy document issued by NEA contains two additional fiscal policies. First, two types of mineral resource fees are reduced or waived for shale gas development. Second, tariffs are waived for importing equipment for shale gas development that cannot be domestically produced. NEA also states that incentive value-added taxes are to be studied. However, MoF reportedly holds the opinion that the existing subsidy and other fiscal policies already satisfy the need for shale gas development in China, and it will not offer more favorable fiscal policies (Hu 2013).

The well-head price of shale gas, similar to that of coalbed methane, is to be unregulated. However, the citygate price of shale gas and coal bed methane may be subject to price gap regulation, depending how they are sold and transported.⁵

The Chinese policy of deregulating shale gas prices is similar to what the US government did. In terms of fiscal policy, the duration of the announced subsidy in China is much shorter than that of the shale gas subsidy adopted by the US government.

⁵ See Zhao (2013) for more details of the pricing reform.

4.2.3. Opening Shale Gas Development to New Entrants

The oligopoly structure of the oil and gas industry is viewed by many in China, including some government officials, as one of the major factors hindering the development of unconventional natural gas in China (Pan et al. 2011). According to this view, the oligopoly structure precludes competition and potential investment from more firms, and the appropriate policy response is to open shale gas development to new entrants.

As a first step of implementing this policy, MLR tendered its first round of shale gas block auctions in June 2011. Six firms were invited to submit bids for four shale gas blocks. The six firms are the three NOCs, the provincial oil company, and two state-owned firms that are engaged in coal bed methane exploration and production. In the end, Sinopec and Henan Coal Bed Methane Corporation each won a shale gas block.

The second step was the State Council's approval of shale gas as a new type of mineral in December 2011. This step, on the one hand, allows MLR to open shale gas development to new entrants, including privately owned firms. On the other hand, it allows the NOCs to keep their control over conventional oil and gas resources.

In September 2012, MLR conducted a second round of auctions, which included a total of 20 shale gas blocks that do not overlap with conventional oil and gas resources. The sizes of the blocks range from 369 to 2,307 square kilometers, totaling about 20,000 square kilometers, and most blocks are about 1,000 square kilometers. It is widely acknowledged that most of the auctioned blocks have worse geology and infrastructure than those already registered by the NOCs (e.g., Zhang 2012; Tian and Li 2013; and Zhou 2013). This round of auctions was open to essentially all domestic firms and international firms majority-controlled by domestic firms with a registered capital of at least CN¥300 million (about US\$50 million). A total of 83 firms submitted bids. In early December, MLR announced that a total of 16 firms won 19 of the 20 blocks. The auction for one block failed to attract enough qualifying bids.

Bid evaluation reportedly was based mainly on firms' finance and exploration plan (including investment amount) (Fen 2012). Auction winners have been given the right to explore the winning blocks for three years. According to official policy, if an auction winner makes the investment in exploring its winning block, it gains the right to further develop the block in the future; if it does not make the promised investment, it loses the right (Hu 2013).

The bidding results are peculiar in several aspects. First, the NOCs did not win any of the blocks, and none of the auction winners had any experience in oil and gas exploration and development. Some of the winning firms are in the business of power generation, some are

energy investment firms, and some were established just a few months before the auction. Second, the winning firms' promised investment amount is, on average, CN¥670 million per block, which is far above the reserve amount of CN¥90 million per block (Tian and Li 2013). We explain in subsection 5.1 the possible reasons for why this might have happened.

4.2.4. General Natural Gas Pricing Policy

The price of conventional natural gas and tight gas in China has long been set by Chinese governments at levels below the equilibrium market price, thus increasing quantity demanded but discouraging quantity supplied (Zhao 2011). The domestic natural gas price is also lower than its imported price. As a result, natural gas shortages often occur and are increasingly severe due partly to the recent policy of replacing coal with natural gas to reduce air emissions (Huang 2013).

In light of these problems, China has started to reform its natural gas pricing policies. In December 2011, NDRC (2011) issued a notice announcing natural gas pricing reform pilot experiments in two provinces. In June 2013, it expanded the pricing reform to all provinces (NDRC 2013). Under the new pricing system, province-specific citygate price caps are linked to the import prices of two types of substitute fuels (fuel oil and liquefied petroleum gas). However, this pricing scheme applies only to incremental volume consumption (as opposed to existing volume consumption) and nonresidential users only. This interim pricing scheme is still quite far from the ultimate goal of the pricing reform, which, according to NDRC (2011 and 2013a), is to establish a system in which all natural gas wellhead prices are determined by the market and only the price of natural gas pipeline transportation is regulated by the government.

Deregulating natural gas prices will generate stronger incentives to invest in developing conventional natural gas and tight gas—and also may help the development of shale gas to the extent that higher natural gas prices bring more profits to the NOCs so that they may have more financial resources to invest in shale gas and to build natural gas infrastructure.

4.2.5. Natural Gas Pipeline Policy

The lack of natural gas pipeline infrastructure and the lack of an open access policy to existing natural gas pipelines are often considered a hindrance to shale gas development (Pan et al. 2011). China's *12th Five-Year Plan on Natural Gas Development* stated that private firms are encouraged to invest in natural gas infrastructure projects, and operators of natural gas infrastructure are urged to provide fair and nondiscriminatory services to all customers. In February 2014, NDRC (2014) issued a new policy on the development and operations of natural

gas infrastructure that requires operators of natural gas pipelines to maintain independent accounting and to provide unused pipeline capacity to new customers on a fair and nondiscriminatory basis. Note that this is a very limited open access policy—new customers only have open access to those capacities that are currently not being used by existing customers (mainly the pipeline operators themselves) and pipeline operators do not need to stop selling natural gas. It is then not surprising that many experts think that nondiscriminatory service is hard to implement in China in the short run (Tong 2013).

The lack of a true open access policy to its existing natural gas pipelines does not affect the NOCs' incentive to invest in shale gas drilling since they themselves operate the natural gas pipelines. It does affect the new entrants' ability to market their shale gas. However, we shall argue that the new entrants are extremely unlikely to play a significant role in the innovation stage of China's shale gas development. The policy of open access becomes much more important in the scaling up stage.

5. How Might China Overcome the Innovation Problem?

Although an independent natural gas firm played a critical role in overcoming the innovation problem in the early stage of shale gas development in the United States, we explain in this section that it is wrong to conclude that China's policy of opening shale gas development to companies other than the major oil companies will help overcome the innovation problem of its own.

5.1. New Entrants Have Little Incentive to Drill Shale Gas Wells in the Short Run

The winners of China's second round of shale gas block auctions do not have any of the advantages that Mitchell Energy enjoyed when it started to drill shale gas wells in the Barnett play. Recall that Mitchell Energy had an excellent team of geologists and engineers, expertise in fracking tight gas, favorable geology on their side, the ability to minimize financial losses, and access to a mechanism by which it could reap large financial returns from its investments. In contrast, the new entrants do not have any expertise in fracking tight gas. In fact, other than the coal bed methane firm that won a shale gas block in the first round of auctions, the new entrants do not have any experience in oil and gas drilling at all. The shale gas blocks the new entrants won have worse geology and infrastructure than the blocks where CNPC and Sinopec are drilling. The new entrants do not have access to a mechanism through which it can reap large financial returns from their potential investments in innovations because the size of their shale gas blocks is quite limited.

CNPC and Sinopec enjoy many advantages over the new entrants, yet they have incurred enormous short-term losses. Hence, it is extremely unlikely that the new entrants, if they were to drill, can avoid the fate of incurring large amount of losses in the short run. It is difficult for firms without any experience in oil and gas drilling to jump directly into shale gas drilling and to succeed in making innovations in the short run.

Not surprisingly, the new entrants are slow to make the investments they promised in their bids. The coal bed methane firm that won a shale gas block in the first round of auction is not making much progress (Li and Zhu 2013). According to Pu and Huang (2013), an MLR official said publicly at a June, 2013 symposium that “as we are facing enormous cost pressures and other problems, the speed of exploration has been slower than anticipated.” MLR held a meeting with the auction winners at the end of June 2013 to discuss reasons for their lack of progress (Tian and Li 2013). On July 29, 2013, an MLR official warned auction winners that the ministry may reduce their acreage and even revoke their exploration rights if they do not make the investments they promised (Wang 2013).

Citing statistics from the China Geological Survey, *China Securities Journal* (2013) reports that by the end of September 2013, only 14.2 percent of the planned two-dimensional seismic survey had been finished and drilling essentially had not yet started. The first exploratory well in the auctioned shale gas blocks was drilled on December 5, 2013 (Liang 2013), a full year after the auction winners were announced. Because of the slow progress made by the auction winners, the third round of auctions has been delayed.

If the new entrants cannot obtain profits in the short run, why did they submit high bids and win the auctions? One possibility is that some new entrants may have underestimated the difficulty of drilling shale gas wells, suffering from the winner’s curse. Another possibility is that some new entrants are pure speculators in that they intended to sell the exploration rights without making the promised investment in drilling. After all, the worst that can happen to a pure speculator is to give up the shale gas blocks it won. A third possibility is that some firms expected that cost-effective drilling and fracking technologies would become available in the future so that they may make profits in the long run, assuming they would be able to keep the blocks they won even if they do not make the proposed investments. So to discourage speculating firms from submitting high bids in future shale gas block auctions, it is imperative that the auction winners in the first two rounds lose their blocks if they do not make the promised investments.

Opening shale gas development to new entrants is consistent with China's policy of allowing the market to play a decisive role in economic development. It allows a few new entrants to start to acquire oil and gas exploration and development experience and expertise, which will benefit the potential scaling up of the shale gas industry in China down the road. Any investment in exploration by these firms will also help China better assess its shale gas resources. However, it is unrealistic to expect the new entrants to play a significant role in overcoming the innovation problem.

5.2. NOCs are China's Best Hope for Overcoming the Innovation Problem

China's best hope for overcoming the innovation problem is its NOCs, especially CNPC and Sinopec, because they enjoy overwhelming advantages over the new entrants in many areas.

First, CNPC and Sinopec have significant experience in developing tight gas, which is usually classified as conventional gas in China. CNPC produced about 20 Bcm of tight gas in 2011 with "mature development technologies" (Zhou 2012). China produced a total of 25.6 Bcm of tight gas in 2011, which accounts for about 25 percent of all natural gas production (Li et al. 2012). Through their years of experience in drilling and fracking tight gas, CNPC and Sinopec have acquired some advanced technologies in horizontal drilling and hydraulic fracking.

Second, the NOCs are drilling in and have the exploration rights to shale gas blocks with the most favorable geology and infrastructure in China. CNPC has established two national shale gas demonstration areas—Changning-Weiyuan and Zhaotong—and has been cooperating with Shell in another, Fushui-Yongchuan. Sinopec has established one national shale gas demonstration area—Fuling—where it made major breakthroughs. By early December 2013, 60 shale gas evaluation wells had been drilled in China, all by CNPC and Sinopec.

A third advantage is that the NOCs have the right to sign production sharing agreements with international oil and gas firms and have invested billions of dollars in acquiring shale gas blocks in North America.⁶ The new entrants currently do not have this right. Even if they did, international oil firms have little incentive to cooperate with them because they currently do not

⁶ On February 25, 2013, CNOOC gained control over huge shale gas reserves in British Columbia and other assets by completing its \$15.1 billion purchase of Canada's Nexen Inc. On the same day, Sinopec agreed to buy a 50 percent stake in Chesapeake Energy's Mississippi Lime venture for \$1.02 billion. On December 14, 2012, CNPC announced that it had paid nearly \$2.2 billion to form a partnership with Canadian natural gas firm Encana to develop shale gas fields in northern British Columbia. In 2010 and 2011, CNOOC bought shale gas assets from Chesapeake Energy, and in January 2012, Sinopec bought shale oil and gas assets from Devon Energy.

have the exploration rights to the best shale gas blocks in China and it is not clear whether they will ever have access to the best shale gas blocks in China.

Fourth, the NOCs are large enough to take on financial risks. By oil and gas production volume, CNPC is the fifth-largest oil and gas company in the world, and Sinopec is twenty-third (Helman 2012).

Lastly, the NOCs have control over the vast majority of oil service firms and natural gas pipelines in China.

However, the NOCs' incentive to invest in domestic shale gas exploration and development may be limited by their better investment opportunities elsewhere. CNPC and Sinopec have made huge investments in oil exploration and development in many countries, and oil prices have been high. In addition, China has large reserves of tight gas⁷ and coalbed methane, and the technologies for developing both are much more mature. Some Chinese stakeholders argue publicly that it is logical to prioritize the development of these reserves over shale gas. For example, in his speech at the 25th World Gas Conference in Malaysia in June 7, 2012, the president of CNPC, Jiping Zhou (2012), declared, "In the near term, CNPC will still prioritize conventional gas exploration and development," but that "we are actively exploring and developing tight gas, CBM and shale gas in different stages. As for tight gas, we have found a large reserve base and owned mature development technologies, and we are now achieving a rapid increase of production. Regarding CBM, the resource distribution is already known and the technologies are basically mature, so we are well positioned to realize sizable increase of output." But as for the more challenging shale gas resource, he said, "In the near term, we will focus on resources evaluation, technological breakthroughs and pilot tests, so as to obtain the resources and technologies for massive development in the future." Sinopec's commercial incentive in investing shale gas development appears to be stronger than that of CNPC because of its much smaller natural gas production volume and proven reserves.⁸ Sinopec's natural gas production volume in 2013 is less than 25 percent of CNPC's, and its proved natural gas reserve is less than 10 percent of CNPC's.

⁷ For example, China's risked, technically recoverable tight gas reserve is 8-11 Tcm, and its proven tight gas reserve is 3.3 Tcm, about 39 percent of China's overall proven natural gas reserve (Li et al. 2012).

⁸ This is perhaps part of the reason why Sinopec is the first to achieve major breakthroughs.

The key question is then how to motivate China's NOCs to invest in shale gas development, assuming that shale gas development is economically justified. Deregulating the price of shale gas and providing subsidies will certainly help decrease the losses the NOCs will have to incur in the innovation stage. Emphasizing the importance of shale gas development by the central government is also important for motivating the NOCs. Indeed, competition between government officials and the associated cadre evaluation system in China are considered by some scholars as the fundamental driving force behind China's rapid economic development (Xu 2011). The aggressive production targets set in the 12th five-year plan for shale gas and the designation of shale gas as a new national strategic industry are two indications of the importance the central government attaches to shale gas development. The policy of opening shale gas development to new entrants, by introducing competitive pressure, can also motivate the NOCs to invest in shale gas development.

6. Concluding Remarks

The central message of this paper is that China's shale gas development path will be very different from that of the United States. China's best hope for overcoming the innovation problem lies in its NOCs, who enjoy overwhelming advantages over the new entrants in terms of technology, experience, financial resources, and policy. The new entrants have little incentive to drill shale gas wells in the short run because they do not have any prior experience in oil and gas drilling and they do not have any of the advantages Mitchell Energy enjoyed when developing the Barnett play in the United States. The policy of opening up shale gas development to new entrants, however, is a market-oriented reform that can be justified on several grounds. In the long run, China may significantly reform the structure of its oil and gas sector. Until then, the most effective way to develop China's shale gas industry is to incentive its NOCs.

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