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Short Communication

Patent analysis to identify shale gas development in China and the United States

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HIGHLIGHTS

- We analyzed shale gas-related patent applications in the USPTO and SIPO.
- We clustered shale gas patents by text mining patent abstract.
- Differences were observed in shale gas technologies developed in the U.S. and China.
- We proposed the policies of shale gas exploration and development based on patent analysis.

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ABSTRACT

Shale gas has become an increasingly important form of hydrocarbon energy, and related technologies reflect the geographical characteristics of the countries where the gas is extracted and stored. The United States (U.S.) produces most of the world's shale gas, while China has the world's largest shale gas reserves. In this research, we focused on identifying the trends in shale-gas related technologies registered to the United States Patent and Trademark Office (USPTO) and to the State Intellectual Property Office of the People's Republic of China (SIPO) respectively. To cluster shale-gas related technologies, we text-mined the abstracts of patent specifications. It was found that in the U.S., the key advanced technologies were related to hydraulic fracturing, horizontal drilling, and slick water areas, whereas China had a focus on proppants. The results of our study are expected to assist energy experts in designing energy policies related to technology importation.

1. Introduction

Shale gas, which is extracted from shale formations, has become an important source of natural gas in North America (Arthur et al., 2008). The importance of shale gas lies in the very wide distribution of shale formations which are present to a greater or lesser extent in the majority of the countries of the world. It is expected that shale gas will come to play a large role in meeting worldwide energy demands and will become a significant part of the energy mix policy of many countries. The world's identified shale gas reserves amount to 187 TCM (trillion cubic meters) (Energy Information Administration (EIA), 2011), which could provide for at least 60 years of worldwide energy consumption. Because of the huge reserves and diverse worldwide distribution of shale gas (Energy Information Administration (EIA), 2012), many countries are trying to explore and develop the use of this resource by acquiring relevant core technologies.

With the growing interest in shale gas, many studies have focused on this resource. Sultan (2013) examined how shale gas may affect oil prices and argued that it will lead to a crisis in the Arab Gulf countries. Wakamatsu and Aruga (2013) also researched how the United States' shale gas revolution affected the Japanese gas markets. However, no studies have used an analysis of patents to explore the different patterns in technology development for different countries.

The United States (U.S.) is the country that possesses the most advanced technology for shale gas exploitation. The U.S. promotes the environmentally-sustainable development of shale gas resources, conducts joint technical studies to accelerate the development of shale gas resources, and promotes shale gas investment in China (Lee, 2009). While other countries have an interest in shale gas, they lack the advanced technologies needed to extract this resource (Global Energy Cooperation Center (GECC), 2012). China has attempted to use subsidies and a reduction or waiver of the related fees or taxes to motivate stakeholders to develop shale gas extraction technologies. However, as there are geological difficulties involved and the shale reserves are located in an arid area, this trial has not been successful

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(Hu and Xu, 2013) since the existing technology requires a lot of water so that the U.S. technology, as it stands, is not suitable in China.

The main purpose of this paper is to identify the development status of shale gas technology in China as compared to that in the U. S. Using a text-mining method, we compare the patterns of the patent applications made to the United States Patent and Trademark Office (USPTO) and to the State Intellectual Property Office of the People's Republic of China (SIPO). The patents submitted to the USPTO or SIPO do not necessarily represent the level of technological development of those countries. However, those patents related to technologies that need protection and are applicable in the U.S. or Chinese market would be registered in the USPTO or the SIPO. Such patents represent the needs of the shale gas markets in the U.S. and China, respectively, so an analysis of the patents in each patent office can provide us with information regarding the status of the shale gas development environment in the respective country.

We clustered the patents based on the results of a text-mining process in order to identify the technological characteristics to be protected in each country. Because shale gas technology represents a new, innovation-based paradigm which is being actively commercialized in the twenty-first century (Medlock, 2012), investigating the status of the shale gas patents registered to the patent office of a specific country has many important implications for determining energy policies. We expect to identify the different demands in shale gas technology in the U.S. and China in terms of shale gas exploration, development, and production by observing how patent application trends differ between the USPTO and SIPO. The results can help guide policy makers in developing energy policies, as well as provide companies with information on the technologies needed to develop their own shale gas fields in both markets.

2. Methods

To identify the developments in shale gas technology, we used the patent database available from http://www.wipson.com//, covering the granted patents that were registered with the USPTO and SIPO from 1975 to 2013. We singled out 269 patents by searching for the terms "shale gas" in the title, abstract, specification, or claims. We examined the patent application patterns for both patent offices and compared the patent IPC codes, main applicants, and applicant nationalities.

In addition, we used text mining to cluster the terms found in the abstracts of the patents related to shale gas. Technology clustering is a method used to categorize technologies that share similar characteristics (Lee and Song, 2011). Tseng et al. (2007) applied text mining to their patent analysis, and Santo et al. (2006) showed that text mining is useful in patent technology clustering.

To cluster the patents using abstract data, we first parsed and filtered the text to reduce the number of terms. Secondly, we conducted a singular value decomposition (SVD) to reduce the dimensions of the weighted term-by-document matrix, since the matrix formulated after the text parsing and text filtering process had a high dimension with p (number of terms) columns and n (number of patents) rows. By applying an Expectation-Maximization (EM) algorithm with SVDs (Abbas, 2008), we established clusters composed of similar patents along with keywords which represented the technological field of each cluster.

3. Results

First, we looked for patent application patterns in the USPTO and SIPO (Fig. 1). We found that the number of shale gas-related patents in the USPTO had been increasing since 2002 while in the SIPO there had been a sharp increase since 2010. The increase in shale gas patent applications since 2002 is related to the sharp growth in the commercial production of shale gas from 2006 (Fig. 2). Examining the patent registrations by year shows that China was slower than the United States to engage in this industry.

We also examined the IPC codes of the shale gas patents (Table 1). In terms of differences between the USPTO and SIPO, 60% of the USPTO patents had the E21B code, which is related to drilling, whereas the SIPO patents had a wider distribution of IPCs —15% were G01N, 28% were E21B, and 16% were C10B. Thus, the shale gas industry in the U.S. is more focused on drilling, which is related to shale gas mining.

We also examined the applicants for the shale gas patents. Table 2 shows the top three applicants to the USPTO and SIPO respectively. The majority of patent applications in the SIPO were made by national universities, whereas in the USPTO, the majority of applications came from oil companies. This is because the commercialization of the shale gas industry is already completed in the U.S., and companies thus have patent authority. By contrast, China is still in the initial stage of shale gas exploration, which includes horizontal drilling and fracturing. CDX Gas, LLC and Vitruvian Exploration, LLC are affiliated companies, and Schlumberger Technology Corporation is one of the biggest oil and gas companies in the U.S.

We examined the ratio of the applicant's nationalities for both patent offices and found that 92% of the patent applicants to the SIPO were Chinese, while 96% of the applicants to the USPTO were people from U.S. Thus, there are only a few international patents in the shale gas area and we regard that the patents from each country represent the technological developments of the country.

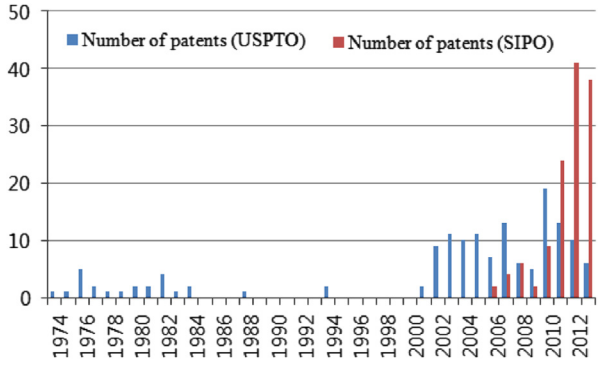

Fig. 1. Number of registered patents.

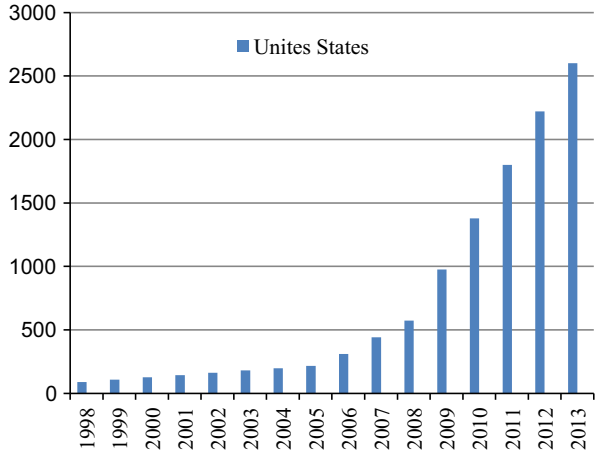

Fig. 2. Natural gas production in the United States (Energy Information Administration (EIA), 2013).

Table 1
IPCs of shale gas patents.

IPC	Percentage	Description
E21B	45%	Earth or rock drilling to obtain oil, water, and minerals
C10B	9%	Destructive extractive distillation of carbonaceous materials for production of gas, coke, tar or similar materials
G01N	8%	Investigating of analyzing materials by determining their physical properties
G01V	6%	Geophysics and gravitational measurements to detect objects
C10G	6%	Cracking hydrocarbon oils, production of liquid hydrocarbon mixtures, and recovery of hydrocarbon oils from oil-shale, oil-sand, or gases

Table 2
Top three applicants for shale gas patents.

Patent office	Applicants	Number of patents
SIPO	China University of Petroleum, Beijing	7
SIPO	UNIV SHAANXI SCIENCE & TECH	6
SIPO	Southwest Petroleum University	4
USPTO	CDX Gas, LLC	27
USPTO	Schlumberger Technology Corporation	15
USPTO	Vitruvian Exploration, LLC	14

We applied text mining to cluster the terms found in the abstracts of the patents related to shale gas. Table 3 shows the results of the text clustering. In this case, the total number of patents (n) was 269, broken down into 145 from the USPTO and 124 from the SIPO. We used a total of 40398 terms (p) and set the maximum SVD dimension as 25, an adequate value to conduct the clustering analysis. EM algorithms were applied to the SVDs for clustering. Considering the number of patents, we controlled the number of clusters to be lower than 10.

Cluster no. 1 is comprised of technologies related to the slick water used during hydraulic fracturing, which is the core technology in shale gas extraction.

Cluster no. 2 covers technologies related to the retorting and distillation of shale gas for the separation of shale, gas, and oil at the shale gas well. These technologies include methods for the refining of hydrocarbons from shale gas and shale oil production.

Cluster no. 3 includes technologies related to water treatment, especially the recycling of water from the wellbore. These technologies can be applied to shale gas exploration and development, waste water treatment, and other environmental technologies related to ground water.

Cluster no. 4 includes technologies related to the hydraulic fracturing and drilling systems used for the development of shale gas. Shale gas in the U.S. was first produced commercially in 1821. This gas came from the organically rich Devonian Shale in the Appalachian Basin (Curtis, 2012). However, the ability to produce gas from shale formations is a great technological barrier to the continuous exploitation of shale gas. Since 2000, the development of technologies for horizontal drilling and hydraulic fracturing has led to a paradigm shift in the oil and gas upstream industry (Jarvie, 2012). This cluster includes the core technologies used in hydraulic fracturing and drilling for shale gas production.

Cluster no. 5 features wellbore technologies. A wellbore is a hole that is drilled to aid in the exploration and recovery of natural resources such as oil and gas. For the effective development and production of shale gas, directional and horizontal wellbore technologies are very important. The SIPO has no patents in this cluster indicating that the technologies in that patent office are less focused on wellbore technologies for shale gas development and production.

Cluster no. 6 relates generally to shale gas exploration and development technologies, including those for sampling, analyzing, fracturing, and drilling for shale gases and other hydrocarbons. Technologies in this cluster comprise a large proportion of the patents found in both the SIPO and USPTO (Table 3) because this cluster contains general technological patents relevant to shale gas exploration and development.

Cluster no. 7 embraces technologies related to proppants and other materials used in the fracturing of shales and recovery of shale gas. Proppants are particles such as sand, gravel, or other materials (e.g. sintered bauxite or ceramic beads) that are suspended in drilling fluid during formation fracturing to keep (prop) open the cracks in the rock when the fluid is withdrawn.

4. Discussion

The U.S. Energy Information Administration (EIA) (2011) reported that the U.S. has 24.41 TCM of shale gas reserves, which represents the world's second largest supply. In 2000, shale gas accounted for only 1% of the natural gas production in the U.S., but this proportion rose to over 20% in 2010. Due to its exploitation of shale gas, the U.S. became the world's largest gas-producing country in 2009. The EIA predicts that by 2035, 46% of the natural gas supply in the U.S. will come from shale gas (Energy Information Administration (EIA), 2011). As a result of the shale gas revolution, the United States will become one of the world's major exporters of natural gas.

Considine et al. (2010) estimated that shale gas from Marcellus had generated $3.9 billion and created 44,000 jobs in 2009. In the long term, the U.S. government predicts that shale gas development will create 600,000 jobs over 10 years. In 2013, the unemployment rate decreased to 7.3% due to shale gas development. In 2014, the U.S. government abolished some forms of red tape in order to support shale gas investments.

With the world's largest population and second-largest economy, China has huge energy demands. The country plans to meet those demands by producing shale gas, of which it possesses an estimated 36.10 TCM of the global reserves (Energy Information Administration (EIA), 2011), the world's largest proportion. By 2035, China aims to derive 62% of its natural gas from shale gas sources Chinese government announced its intention to investigate the national distribution of shale gas and to produce 6.5 BCM (billion cubic meters) by 2015 (Global Energy Cooperation Center (GECC), 2012). In 2011, China implemented public bidding for shale gas exploration rights among Chinese private companies. The government also put in place a new policy to encourage shale gas development in the form of a 0.2 RMB/m^3 subsidy for shale gas producing companies and 0.2 RMB/kw h for companies that connect shale gas and generators (Global Energy Cooperation Center (GECC), 2012).

Despite the Chinese government's efforts to develop shale gas, Hu and Xu (2013) identified four challenges the Chinese shale gas

Table 3
Results of text clustering.

Cluster ID no.	Technology terms	Frequency (percentage)			
		USPTO		SIPO	
1	Aqueous carrier liquid, particulate material+particulate agglomerates gravity network slickwater+material	11	4%	1	0%
2	Destructive distillation shale oil+oil shale combustion distillation retort heat coke+oil+furnace	29	11%	30	11%
3	Oxidation filter flow back+treatment outlet+technical field amount water+application+shale gas	5	2%	10	4%
4	Wells problems fluids+well equipment+pressure drilling	41	15%	28	10%
5	Bore pattern+subterranean zone+bore+pattern+surface+zone entry junction+region+embodiment	29	10%	0	0%
6	Sample data properties+formation+rock+end methods+pressure+fracture+hydrocarbon	28	10%	33	12%
7	Agent preparation resistance+period density steps characteristics+product+material+proppant+temperature	2	1%	22	8%

industry is confronted with. The first is China's lack of advanced technologies. Secondly, water pollution and emissions of carbon dioxide and methane cause environmental problems. Thirdly, the Chinese shale gas basins lack water resources because there is little precipitation in the main areas of their occurrence. Finally, the shale gas industry in China depends on the maintenance of good relations with the local communities.

Based on the bibliographic trends in shale gas patents, we identified several tendencies regarding patent applications and the production of shale gas. As seen in Figs. 1 and 2, the increase in shale gas patent applications since 2002 has been related to a dramatic increase in the commercial production of this resource since 2006. In China, we observed an increase in the number of patent applications from 2010 and while this could lead to a growth in China's commercial shale gas production in the near future, Chinese shale gas currently accounts for only 0.1% of the world's total production (Energy Information Administration (EIA), 2013). The results of this analysis can assist shale gas investors in their investment decisions in China.

We found that in the U.S., the main shale gas patent applicants are private oil companies, especially independent alternative energy companies. In contrast, in China, the majority of the applicants are national universities. This reflects the fact that, in the U.S., the technologies for shale gas exploration, development, and production are already in the commercial domain. In China, the technology rights belong to institutions with fewer connections to commercialization because all natural hydrocarbons in China come from onshore and offshore areas owned by the government (Hu and Xu, 2013). We recommend that China accept cutting-edge technologies for shale gas development and production from the private sector, including from independent alternative energy companies in the U.S.

By clustering the patent terms related to shale gas technologies, we identified the differences in the technological focus between the U.S. and China. The USPTO had more patents than the SIPO in cluster No. 1, which represents the technologies related to the slick water used in shale gas fracturing. This is because the technologies for slick water and other hydraulic fracturing additives are more advanced and commercialized in the U.S. than in China. As Hu and Xu (2013) pointed out, China is challenged by a lack of water resources for the development of shale gas resources, which limits its technological potential somewhat. Because China faces a lack of slick water, Chinese engineers have been attempting to develop suitable proppants that can be used to recover shale gas with a lower consumption of water resources. This tendency is evident in the number of Chinese patents in cluster No. 7, which is related to proppants technology. The core technology in shale gas production is cluster No. 4, which deals with hydraulic fracturing and horizontal drilling. In this area the U.S. has more patents than China, reflecting a technological gap between these two countries in the shale gas industry. Countries with high reserves of shale gas, such as Argentina, Mexico, Russia, and the United Kingdom (U.K.), must develop technologies in cluster No. 4 for the effective production of shale gas.

5. Conclusions and policy implications

Based on a patent analysis and text mining, we found that Chinese shale gas development is limited by a lack of technologies, especially in clusters 4 and 5, which are related to hydraulic fracturing and directional drilling technologies. Therefore we recommend that the Chinese government import core technologies from U.S. shale gas companies by M&A or technology transfer. Opening the natural gas exploration and development rights to foreigners would also be beneficial in order to accelerate the commercialization of China's domestic shale gas reserves. Second, since China is experiencing problems with water supply and environmental issues, it is highly recommended that investment should focus on the development of shale gas technologies that require less water in their application.

This paper quantitatively investigated the level of shale gas development by identifying the relevant patents in the USPTO and SIPO and applying a text clustering method. The clustering method can be used as a tool to measure the status of technologies in those countries which have a high shale gas reserves potential. Countries lacking the advanced technologies for shale gas extraction can utilize our approach to obtain information on the core technologies for the practical commercialization of shale gas and what kind of technologies they require for the development and production of shale gas.

This research contributes to our understanding of how shale gas technology differs between China and the U.S.; however, it presents some limitations. Firstly, we did not consider the patent specifications' quality. Backward citations can be used as an indicator of the value or quality of a patent. Taking into account the quality of the patents would have led to a more accurate understanding of the technological development status. However, the SIPO does not provide backward citation information. Secondly, transferred patents' rights and the resulting royalty information can also be important indicators of the countries' technological development. However, information regarding patent royalties and right transfers usually cannot be identified through open access patent application data. Upon the availability of such data, one may also enhance our approach by examining shale gas patent developments in other countries such as Argentina, Russia, Mexico, and the U.K., which are also developing shale gas production technologies. These areas are left for future research.

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