Research of Environmental Regulation, Technical Progress and the Development of Shale Gas Industry—A Case Study of the USA

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Abstract. Shale gas industry has a broad prospect in China. To learn from the shale gas industry in the USA, this paper compared China with the USA in the aspects of production, environmental regulation and technical progress of shale gas industry. Furthermore, we took American shale gas industry as an example in the part of empirical research, in order to study the relationship among environmental regulation, technical progress and industrial development of shale gas innovatively. We find that environmental regulation affects the shale gas production, and it also has indirect effect on production through technical progress. The conclusions provide valuable lessons to Chinese shale gas industry.

Introduction

China consumes large amount of energy every year. Before 2015, China has used the most primary energy in the world for 6 years. Meanwhile, China is the largest energy producer in the world. About 19.1% of energy in the whole world are produced by China. In spite of the fact, China has unreasonable energy structure. There are more coal than petroleum and natural gas. So China consumes much more traditional energy and less clean energy. However, traditional energy, especially, coal, have bad serious environmental impacts.

Shale gas revolution in the United States leads the development of shale gas in China, which in some extent solves Chinese energy problems. It is a good choice to replace the traditional energy sources. With rich shale gas resources, China highlights the importance of shale gas’s strategic position, and has established policies to support the healthy development of shale gas industry. Many scholars has proved the cleanness of shale gas by LCA method (Jiang et al.(2011)[1], Burnham et al. (2012)[2], Laurenzi et al.(2013)[3], Heath et al.(2014)[4]). However, some scholars states that in the process of shale gas extraction, it caused different kinds of environmental pollution, such as air, water and soil pollution [5, 6, 7].

Environmental regulation is the most common method to reduce pollution caused by exploring shale gas. This paper makes contributions to study the relationship among environmental regulation, technical progress and shale gas industry’s development. In order to study this relationship, this paper tries to analyze the situation of shale gas and does the empirical research by using American data. The result will provide helpful experience for Chinese shale gas industry.

Present Situation and Problems Analysis of Shale Gas Industry

China has richest shale gas resources in the world. The technical recoverable reserve of shale gas in China is about 1115 trillion cubic feet according to the EIA. In addition, the shale gas is environmental-friendly energy resources. Therefore, shale gas industry has a strategic position in China. The policy, fiscal incentives and subsidies support its development. However, with the rapid development of shale gas industry, the pollution which the shale gas exploration causes has caught people's attention. In the process of exploration, shale gas will cause air, water and soil pollution in varying degrees.

In order to limit the environmental impacts, regulation is the most useful method. Compared with the United States’ environmental policy enforcement of shale gas industry, China has poor
environmental regulations, which reflects from the following aspects: first, shale gas exploration lacks targeted environmental regulations. Most of regulations are applied to all industries. Second, the regulation methods are monotonous. There are more command-and-control environmental regulations, almost no market-based regulations. Third, there are no uniform criterions and technique standards to follow in shale gas industry.

The Empirical Analysis

The Variables Selection and Data Sources

(1) Dependent variable
The empirical study collects the production of shale gas in the USA as the dependent variable. The production data come from 12 states from 2007 to 2015, including Arkansas, Colorado, Kentucky, Louisiana, Michigan, Montana, New Mexico, North Dakota, Oklahoma, Pennsylvania, Texas and West Virginia.

(2) Independent variable
First, this paper uses DEA-Malmquist Productivity Index to evaluate the technical progress (TEF) of shale gas. DEAP2.1 software calculates the DEA-Malmquist Productivity Index of 21 companies. Shale gas exploration is one of their main businesses. To calculate the DEA-Malmquist Productivity Index, we need input data including the number of employee, operating costs and net productive wells. Besides, output data are also needed including production and operating revenue.

Second, the paper chooses financial expenditure that EPA delivers to each state separately to value the level of environmental regulation (ER). The targets of EPA contain of developing and enforcing environmental regulations, devoting to reduce pollution and protecting human health. Therefore, the expenditure of department of environmental protection in states can reflect the level of environmental regulation. The data is provided by the US Spending website.

Third, GDP measures economic development level of a country or a region. Normally, developed countries need more energy, which means the better a country develops, the more energy the country needs.

Lastly, we collect the number of natural gas productive wells as one of explaining variables (WELL). According to the companies’ annual report, each company explores some natural gas wells annually. Considering the success rate of exploring, the empirical study only chooses wells which have been in production. Normally, more productive wells means more production of shale gas.

Empirical Study

The Analysis of DEA-Malmquist Productivity Index. According to the data of 21 companies which explores shale gas, the result of DEA-Malmquist Productivity Index shows below (Table 1).

| Year       | Malmquist Productivity Index (TFP) | Technical Efficiency Index (EF) | Technology Change Index (TF) | Scale Efficiency Change Index (SE) |
|------------|----------------------------------|---------------------------------|------------------------------|-----------------------------------|
| 2007–2008  | 1.01                             | 1.04                            | 0.97                         | 1.07                              |
| 2008–2009  | 0.88                             | 1.07                            | 0.83                         | 0.98                              |
| 2009–2010  | 1.10                             | 0.98                            | 1.13                         | 0.97                              |
| 2010–2011  | 1.12                             | 0.98                            | 1.15                         | 0.97                              |
| 2011–2012  | 1.01                             | 0.96                            | 1.05                         | 0.95                              |
| 2012–2013  | 1.08                             | 0.98                            | 1.10                         | 1.00                              |
| 2013–2014  | 1.17                             | 1.11                            | 1.05                         | 1.03                              |
| 2014–2015  | 0.86                             | 1.02                            | 0.85                         | 1.09                              |
| Average    | 1.03                             | 1.02                            | 1.02                         | 1.01                              |
From 2007 to 2015, the average Malmquist productivity index is 1.03, which means American shale gas industry has been growing at 3% averagely. Malmquist productivity index is decomposed into technical efficiency index, technology change index and scale efficiency change index. These three average indexes are all above 1, which reflects American shale gas industry has been growing healthily, relying on scaling up production and developing technology.

The Relationship among Environmental Regulation, Technical Progress and Industrial Development of Shale Gas. This part will research how the environmental regulation influences shale gas production through technical progress. The panel data is provided by 12 shale gas-production states covering the years of 2007-2015. The empirical study pays more attention to environmental regulation (ER) and technical progress (TFP). Meanwhile it introduces interaction terms between environmental regulation and technical progress (TFP*ER) further. Besides, GDP and productive wells are also considered into the econometric model. The model is following.

\[ Q_{it} = \beta_0 + \beta_1 TFP_{it} + \beta_2 ER_{it} + \beta_3 TFP_{it} \times ER_{it} + \beta_4 GDP_{it} + \beta_5 WELL_{it} + \epsilon_{it}. \]  

Considering the problem of endogeneity in the model, we use GMM method. The results of regression are shown in Table 2.

Table 2. GMM Regression Result.

| Independent Variable | Model (1) | Independent Variable | Model (1) |
|----------------------|-----------|----------------------|-----------|
| TFP                  | -548.0933*** | WELL                 | 0.0007018** |
| ER                   | -6.945525*** |                      | (2.45)    |
| TFP*ER               | 8.054523***  | C                    | 209.6605   |

According to the results (Table 2), TFP, ER and TFP*ER have significant effect on 1% significance level, GDP and WELL have significant effect on 5% significance level. In detail, technical progress has negative impact on shale gas production, and environmental regulation can restrain the growth of shale gas production. That means, considering in the aspect of regulation only, shale gas-production companies have to control the discharge in production as much as possible under the strict environmental regulations. That pushes them to devote little effort to explore more shale gas. Furthermore, the coefficients of the interaction terms is significant. This result supports that environmental regulation can influence the shale gas production through technical process indirectly.

The Threshold Effect Model of Environmental Regulation, Technical Progress and Industrial Development of Shale Gas. The part above supports that technique is the bridge between production and environmental regulation in shale gas industry. And this part is aimed to clarify that there are several key points of the regulation level. These points divide the level of regulation into some levels with different effect on production through technical progress. The threshold effect model as following is designed according to model (1):

\[ Q_{it} = \beta_0 + \alpha_1 TFP_{it} \times ER_{it} \cdot I(ER_{it} \leq \gamma_1) + \alpha_2 TFP_{it} \times ER_{it} \cdot I(\gamma_1 < ER_{it} \leq \gamma_2) + \cdots + \alpha_n TFP_{it} \times ER_{it} \cdot I(ER_{it} > \gamma_n) + \beta_1 TFP_{it} + \beta_2 ER_{it} + \beta_3 GDP + \beta_4 WELL_{it} + \epsilon_{it}. \]  

We use Stata13.0 to test single, double and triple threshold, the result is shown below (Table 3).

Table 3. Threshold Effect Model.

| Threshold | p Value |
|-----------|---------|
| Single    | 0.0000  |
| Double    | 0.0167  |
| Triple    | 0.7267  |
Table 3 illuminates that the threshold effect model has double threshold value. The regression result is shown in Table 4.

| Coefficient | Threshold Value | t Value | p Value |
|-------------|-----------------|---------|---------|
| $\alpha_1 = 4.15589^*$ | ER$\leq$147.5762 | 1.88 | 0.064 |
| $\alpha_2 = 1.5334$ | 147.5762$<\text{ER}\leq$179.9543 | 0.88 | 0.383 |
| $\alpha_3 = 11.0539^{***}$ | ER$>$179.9543 | 7.18 | 0.000 |

When the environmental regulation is below 147.5762 million dollars or above 179.9543 million dollars, regulation can promote shale gas production through technology effectively. However, the level of environmental regulation is between 147.5762 and 179.9543 million dollars, such kind of effect is not significant.

When the environmental regulation is under the relatively low level, production companies spend little money controlling pollution. So they can devote more effort to develop technology. With the strength of regulation improved, this kind of mechanism cannot work, which leads to insignificant effect between 147.5762 and 179.9543 million dollars.

When the environmental regulation is on the higher level, these companies have to spend lots of money dealing with laws, paying environmental tax. They will have no incentive to produce. Therefore, in order to solve it, shale gas-production companies try to develop new, clean and efficient production technology.

**Conclusions and Discussion**

Environmental issue is the key to the development of shale gas industry. In the process of producing shale gas, it does have air, water and soil pollution. Compared with the USA, China has imperfect environmental regulation of shale gas industry. According to the empirical study, environmental regulation not only has negative effect on shale gas-production directly, but it also has positive effect on production through technology indirectly.

So the following advice should be paid attention to. Firstly, environmental regulation should be targeted and various. All laws and regulations against the pollution in China are suitable for every industry, which cannot solve the environmental problems of shale gas industry effectively. Therefore, we should design environmental regulation that is only useful for shale gas industry. In addition, it is necessary to diversify the kind of environmental regulation in China, such as environmental taxes, carbon emission trading.

Secondly, functional departments of the government should strengthen supervision to control the effect of regulation, including the performance of regulations and the use of government expenditure. Functional departments of the government concerned should work together to design environmental regulations.

Thirdly, effort should be made to develop technology of shale gas in exploration and environment protection. Not only should we need to learn the American advanced technology, but also we should develop our own drilling techniques.

Fourthly, utilizing the relationship among environmental regulation, technical progress and industrial development of shale gas. The empirical study has proved the relationship among them, we should make use of it to formulate environmental regulations according to Chinese situation.
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