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Different behaviors in natural gas production between national and private oil companies: Economics-driven or environment-driven?

Binlei Gong

Department of Agricultural Economics and Management, School of Public Affairs, China Academy for Rural Development (CARD), Zhejiang University, 866 Yuhangtang Road, Hangzhou 310058, PR China

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ABSTRACT

This paper investigates firm-level efficiency in the petroleum industry during the period 2009–2015. A Jackknife model averaging method and two stochastic frontier models are utilized to estimate the input-output relation more accurately. The derived efficiency is then decomposed to predict the effect of various efficiency determinants with an emphasis on gas ratio and ownership. A significantly negative effect of natural gas ratio (in production portfolio) on efficiency is found for both National Oil Companies (NOCs) and privately-owned International Oil Companies (IOCs). This finding implies that the decline in natural gas ratio for IOCs is economics-driven, and the incline in gas ratio for NOCs is environment-driven. Therefore, the environmental objective is the NOCs' third non-commercial objective, alongside subsidizing below-market energy prices and offering excessive employment, as found in the literature. Governments may consider the transfer of subsidies from low energy prices to clean energy promotion, which leads to energy saving and emissions reduction.

1. Introduction

Given the severe pollution of coal and the slow growth of renewable energy, an abundant production of natural gas guarantees the supply of electricity under some requirements of emissions reduction, and hence balances the sustainable development of environment and economy. Therefore, coal and renewables are the competing sources of natural gas from a consumers' perspective. Many studies (Robinson et al., 2013; Simsek and Simsek, 2013; Wei et al., 2010) analyze the characteristics of these sources economically and environmentally. However, the major competitor to natural gas, from a producers' perspective, is crude oil, as petroleum enterprises decide the share of oil and gas in their production portfolio, which to some extent determines the supply of natural gas. Since natural gas produces fewer emissions than crude oil and coal, improving the share of gas production in petroleum industry benefits the environment from two perspectives. On the one hand, natural gas can be utilized to directly replace coal in electricity generation. On the other hand, gas is an alternative to oil in the transportation sector, which causes up to 40% CO_2 emission reductions (Hekkert et al., 2005).

Using data on 54 large petroleum firms, this paper finds that the average share of natural gas in portfolio decreased from 42.69% in 2009 to 40.96% in 2015, which implies that gas production might be less effective than oil production. In order to prove that such a decline in the gas ratio is economics-driven, the impact of natural gas share on firm-level efficiency needs to be estimated. In the little research that studies the efficiency of oil and gas firms, the focus is the difference between National Oil Companies (NOCs) and privately-owned International Oil Companies (IOCs) (i.e., the effect of ownership), and no one has studied the impact of natural gas ratio. Hartley and Medlock (2008) argue the major difference between IOCs and NOCs is that the IOCs focus on a commercial objective, while the NOCs have a wider range of non-commercial objectives due to political pressure. If the decline in gas ratio is economics-driven, as we expected, a sharper fall should be observed among IOCs, since they pay more attention to economic performance. This paper finds that the gas ratio decreased from 45.86% in 2009 to 42.18% in 2015 for IOCs, which further supports our hypothesis. However, an incline in gas ratio from 35.18% to 38.06% for NOCs is observed during the same period, which is either the result of political pressure for environmental reasons or the different effects of gas ratio on IOCs and NOCs.

This paper aims to investigate the effect of gas ratio on firm-level efficiency for large petroleum companies and to check whether this effect is different in NOCs and IOCs. In the first step, this paper uses the Jackknife model averaging method and two stochastic frontier analysis (SFA) to estimate the input-output relation and derive firm-level

E-mail address: gongbinlei@zju.edu.cn.
URL: http://person.zju.edu.cn/en/gbl.

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efficiency, the robustness of which is checked using a data envelopment analysis (DEA) and the adjustment of input categories. Then, the efficiency scores are decomposed using an efficiency determination equation to predict the effect of gas ratio for NOCs and IOCs. The potential endogeneity problems in both SFA and efficiency decomposition are carefully checked and addressed.

There are three central contributions of this paper to the studies of the petroleum industry: 1) the stochastic frontier models used allow non-monotonic time-varying efficiency, which better captures the fluctuations in economy than the frontier models used in the literature; 2) a model averaging method is introduced to combine the advantages of paramedic and semi-parametric estimation of efficiency; and 3) to our knowledge, this is the first study to estimate the efficiency of petroleum companies after the financial crisis, and the first to address the effect of gas ratio. Moreover, the empirical results show that the effect of gas ratio on efficiency is significantly negative and indifferent between IOCs and NOCs, which implies the decline in gas ratio for IOCs is economics-driven, and the incline in gas ratio for NOCs is environment-driven. This paper suggests governments replacing price subsidy with clean energy promotion, which leads to energy saving and emissions reduction.

The remainder of the paper is structured as follows. Section 2 reviews related literature. Section 3 introduces the model. Section 4 describes the data employed. Empirical results are presented and policy implications are given in Section 5. Section 6 draws a conclusion.

2. Literature review

Although the petroleum industry is an important market in the world, very little research to date has studied the productivity and efficiency of oil and gas companies (Eller et al., 2011; Hartley and Medlock III, 2013; Wolf, 2009). Al-Obaidan and Scully (1992) use both deterministic and stochastic frontier analysis (SFA) on cross-sectional data of 44 oil and gas companies to estimate the efficiency. They use assets as the capital input, number of employees as the labor input, and either revenue or physical products as the output to estimate firm-level efficiency, and find NOCs are less efficient than IOCs. Thompson et al. (1996) study the efficiency of 14 major petroleum enterprises in the U.S. oilfield market, using a non-parametric DEA for the period 1980–1991. Gong (2017) introduces spatial techniques into the production function to capture the interactions among oil and gas service companies and then derive total factor productivity (TFP). Gong (2018) evaluates the impacts of new shale techniques (hydraulic fracturing and directional drilling) on SFA-derived firm-level efficiency in the global oilfield service industry. It is worth noting that the last three papers study oilfield service firms rather than petroleum enterprises.

Instead of using firm-level data, Managi et al. (2004) analyze the productivity and efficiency of the offshore Gulf of Mexico oil and gas industry, using well-level and field-level data in a DEA model. A similar dataset is utilized by the same group of scholars in Managi et al. (2006), who adopt a SFA model with the Battese-Coelli (BC) estimator so that time-varying efficiency can be derived. In these two studies, quantities of oil and gas production are used as output variables.

Hartley and Medlock (2008) provide three reasons to use revenue rather than production as output to estimate firm-level efficiency. Firstly, physical output such as oil and gas produced may fail to catch the impact of subsidies (e.g., a lower domestic price) as the result of political pressure on NOCs. Secondly, a usual method to aggregate the multiple products (e.g., oil and gas) is to calculate their relative value at market prices. Thirdly, revenue figures are usually easier to collect than the quantities of various products. Empirically, Wolf (2009) shows the strong correlation between physical outputs and revenue in oil and gas companies. Recent literature (Eller et al., 2011; Hartley and Medlock III, 2013) prefers to use revenue as the output in estimating the efficiency of the oil and gas companies.

In terms of inputs employed for petroleum firms, Al-Obaidan and Scully (1992) use only assets and number of employees. Wolf (2009) adds the sum of oil and gas reserves as the third input to produce oil and gas. Although total assets are kept as an input because they cover other capital than the reserves, Wolf (2009) emphasizes that total assets reflect accounting rather than economic value, which might be severely distorted by inflation. Therefore, Eller et al. (2011) remove total assets from the input portfolio and further separate oil reserves and gas reserves as two different inputs. Finally, Hartley and Medlock III (2013) add refining capacity as an input on the top of the input portfolio in Eller et al. (2011). This paper follows Hartley and Medlock III (2013) by including number of employees, oil reserves, gas reserves, and refining capacity as the four inputs, since this avoids the distortion of total assets mentioned in Wolf (2009), but considers the two most crucial assets including reserves and refining capacity.

Besides inputs and outputs, the last important thing to be decided is the econometrical method that captures the input-output relation. SFA and DEA are the two most widely used methods to estimate firm-level efficiency given inputs and outputs. SFA is a parametric method that allows a stochastic term to control the noise, but requires assumption of the functional form. DEA is a nonparametric linear programming method that relaxes the rigid functional assumption but does not account for statistical noise. They are also the main competing models in the efficiency analysis of the petroleum industry. As mentioned above, Managi et al. (2004) and Managi et al. (2006) employ DEA and SFA to study the offshore Gulf of Mexico oil and gas industry using the same dataset, respectively. Moreover, both DEA and SFA are utilized in Eller et al. (2011) and Hartley and Medlock III (2013). This paper uses different SFA models to estimate firm-level efficiency and a DEA model to check its robustness.

However, the key interest in the literature is the effect of ownership on efficiency. Hartley and Medlock (2008) present a model of NOCs and find they have a wider range of non-commercial objectives, such as domestic consumer surplus and employment. Political pressure forces them to provide domestic subsidy by below-market energy prices and excessive employment, which raises input-output ratio and reduces efficiency. Many scholars (Al-Obaidan and Scully, 1992; Eller et al., 2011; Hartley and Medlock III, 2013; Wolf, 2009) study the difference between NOCs and IOCs, and find that the former group is less efficient than the latter, empirically. Al-Obaidan and Scully (1992) find NOCs on average are only 63–65% as efficient as IOCs. Wolf (2009) also claims that NOCs are 20–30% less efficient than private oil companies. Eller et al. (2011) and Hartley and Medlock III (2013) further introduce an efficiency decomposition equation as a second-step regression after SFA or DEA, aiming to estimate the effect of ownership when other things are equal. Both these studies find a significantly lower efficiency level of NOCs than IOCs. This paper also decomposes efficiency to predict the impact of efficiency determinants more accurately, but with an emphasis on natural gas ratio instead of ownership.

3. Methodology

3.1. Efficiency Measurements

The main approach used by this paper to measure efficiency is stochastic frontier analysis, which was initially proposed by Aigner et al. (1977) and Meeusen and Van den Broeck (1977). Given cross-sectional data, a stochastic frontier production function model equals the deterministic frontier production function plus a symmetric random error variable in the form

$$Y_i = f(X_i)\bullet \mathrm{TE}_i \bullet \exp(\nu_i), \tag{1}$$

where Y_i is the output of firm i, and X_i is the vector of inputs and other regressors. $f(\bullet)$ is the function that decides the frontier, which provides the highest attainable output given inputs. TE_i measures the technical efficiency from 0% to 100%. ν_i is the stochastic part that accounts for measurement errors, which is typically assumed to follow a normal