Optimal Switching Strategy between Oil and Gas Resource for Independent E&P Companies under the Price Risk

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Abstract

Since the global oil crisis starting from the mid 2000s, oil and gas prices have been more volatile than other commodity prices. Under this circumstance, it is increasingly important to diversify oil and gas reserves from the perspective of Independent E&P companies that have relatively small production capacity.

This paper presents a real option method for analyzing the production behavior of the Independent E&P companies in the presence of uncertain revenues and irreversible costs that come from product choice between oil and gas. The paper identifies optimal level of threshold price of oil and gas by employing a real option model. To estimate the optimal threshold level of price, we use the model which contains the remaining reserve as another state variable with the price. The results are shown that the Independent E&P companies tend to have more economic feasibility on the oil development project in comparison with the natural gas project. In addition, the thresholds are largely determined by volatility of the price and remaining level of reserve, and maximum extraction capacity. This paper provides sensitivity analysis with those variables in terms of changes on threshold points.

1. Introduction

Since the global oil crisis starting from the mid 2000s, oil and gas prices have been more volatile than other commodity prices. Meanwhile, Oil and Gas exploration and production(E&P) companies are generally classified as three categories; National, Major International, and Independent E&P

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company. Each of these companies has its own unique characteristics and so that they are differently responding to such market volatility. At first, National Oil Companies(NOCs), so-called state-controlled companies, remain firmly in control over the vast majority of the world's petroleum resources. Moreover, they have dramatically increased their level of petroleum exploration and production investment over last 10 years in order to sustain their international market power. These aspects arise from the epidemic of resource nationalism. Particularly, resource rich-nations' NOCs has aggressively expanded its international market share over the past decade.

Secondly, Major International Oil Companies(IOCs) have over the past decade tried to figure out the challenges in company's growth, particularly on the increasing difficulty to procure the proper level of the reserve. Increasing resource nationalism among oil-production countries has seen major IOCs' share of global reserve diminish from about 85% in the late 1960s to less than 17% at present. In addition, due to the available production level of oil and gas has more related to the geological and technological progress than ever before, most of IOCs have struggled with the financial burden of maintaining market level. In 2009, even when global crude oil prices doubled, most of these IOCs reported severe reduction in earnings, some as much as 70%, due to weak global crude oil demand. However, most of IOCs have more advanced technology and experience in finding and development sector than that of the NOCs and Independent companies. Therefore, they believe that this advantage will help companies to resolve the challenges in market. In this sense, they consider several business strategies for their sustainable growth, such as joint venture with NOCs or indigenous companies, expanding size of the upstream sector through M&A.

On the other side, however, most of independent E&P companies are often faced with political risk originated from the confiscation possibilities, partial government regulations and market risk arise from the price volatility and financial crisis. Generally, independent oil companies have largely relied on financial institution, such as commercial and investment banks, in order to sustain their level of exploration. In this sense, they tend to be more vulnerable to the financial risk associated with the high dependency on debenture capital and more sensitive to the market price change and volatility. Under this circumstance, independent E&P companies continue to innovate internally, and try to have pioneering competitive advantage over the IOCs and NOCs, which they then leverage through diving into specific field or area. The development and initial rapid growth of natural gas production from shale and oil sands by independent companies is one kind of examples. However, the establishment of shale field or oil sand is becoming more competitive and some IOCs bring enormous capital to this industry, and thus natural gas prices remain in low value so that independent companies have to create new and more pliable business strategies within established shale or oil sand field. In other words, most of independent companies confront the challenges that they must choose the appropriate production and E&P investment strategy between extracting oil and gas associated with the changes in market price of oil and natural gas.

Generally, most E&P projects have two important characteristics. First, they are inevitably required to invest enormous costs at the beginning of the projects, hence they are largely irreversible. Second, decision makers of the projects have two choices whether invest now or delay, allowing the firm to wait new information about market conditions. In other words, the E&P companies have to take a risk with the initial process of the investment, and they also have the option to optimally start the project until it is projected to make sufficient profits. If the project has two such characteristics, irreversibility and uncertainty, real option analysis is considered as appropriate analytical approach to measure the value of project.

This paper analyzes the business behavior of TOP 50 small cap independent E&P companies and suggests optimal investment threshold point of oil and gas price derived from real option approach. The first step in this paper is to derive the optimal value function for both initiate the project and hold an option to wait. Then we obtain optimal threshold points from the value functions which are determined by the two state variables; reserve and price.

2. Literature review

The fundamental aspect of extractive activity in nonrenewable resources such as oil and gas are influenced by the price of each product. Traditional models of firm's production decisions suggest that production will take place when the present value of cash flows from a production exceeds the opportunity cost of the capital employed. This paper uses a traditional real option model introduced by Dixit and Pindyck(1994) and Brennan and Schwartz(2001). These studies analyze firm's behavior in the presence of the difference switching cost between starting and stopping operation. Also, those studies present numerical examples that are based on the market for cooper. In their analysis, however, they have some crucial assumption in order to make simplifying the analysis,

Compared to those conventional approach, Mason(2001) suggests an entry-exit model which considers the characteristics of non-renewable resources-that of scarcity. He points out that this assumption is obviously at odds with the important aspects of non-renewable resources. Therefore, he suggests the model which contains the reserve of the resource as another state variable. Dias et al(2003), use Monte Carlo simulations together with non-linear optimization to find an optimal development strategy for oil fields when considering three production alternatives.

This paper mainly uses Mason(2001)'s two state variables model. Dissimilar to Mason's model, however, the paper uses simple E&P project model in order to apply each firm's behavior in the presence of each firm's real financial data. Hence, it can provide us more simple and broad understanding on the firm's behavior by estimating each company's optimal threshold point.

The paper is structured as follows. The model is described in section 3. In this section, the optimal value function is derived and thereby the solution of optimal threshold point considering the changes of two state variables, reserve and price, is solved. The empirical analysis is presented in section 4. Before presenting an empirical result, sensitivity analysis, the influence of some crucial parameters on optima threshold price, is presented. We then define the relative threshold price ratio between oil and gas price in order to evaluate the effectiveness and suitability of these firms' strategies. Lastly, we offer some concluding remarks and suggestion for further work in last section.

3. Model[4]

Suppose a firm partaking in a market for petroleum resources. Consider that starting an operation, the initial attempts to develop the new oilfield involves an initial cost I_i. The price of oil and gas at instant t are P_{ot} and P_{1t}, respectively. We assume that extraction cost at every instant time is some fixed at C_i.

Similar to the Mason's model(2001), there exists a maximal rate of extraction q_c, and now we assume that this maximal upper bound of extraction rate is related to the remaining level of reserve at instant t, R_{it}. For instance, q_c is extraction rate so that it is expressed as percentage value. Thus the absolute instant level of extraction q_{it} is bounded by $q_c R_{it}$, where $q_{it} \leq q_c R_{it}$.

Now the instant profit flow of the oilfield development project is expressed as

$$\pi_{it} = P_{it} q_{it} - C_i \tag{1}$$

As we explained earlier, remaining level of reserve R_{it} is linked to instant level of extraction q_{it}. Therefore, the changes in reserves can be expressed as

$$dR_{it} = -q_{it} dt \tag{2}$$

Now, we assume that the price of the resources follows the random process. In other words, firm's decisions whether active or inactive are determined by given price, and we assume that the given spot price follows a geometric Brownian motion,

$$dP_{it} = \mu_P P_{it} dt + \sigma_P P_{it} dz \tag{3}$$

where dz is the increment of a Wiener process, the equation (3) is implies that the instant profit flow is known, however, the future return of the firm is lognormally distributed with mean $(\mu_P - \frac{1}{2}\sigma_P^2)$t and variance σ_P^2t.

In this study, the value of the project is not only the function of the time t and the market price P_{it}, but also the function of instant level of reserve R_{it}. To clarify this, now we fix the notation, letting $\mathrm{F}^i(\mathrm{P}_{it}, R_{it}, t)$ denote the value of the inactive behavior or the value of the option to invest, and letting $\mathrm{V}^i(\mathrm{P}_{it}, R_{it}, t)$ denote the value of the active firm or value of the oilfield development project.

First, we begin with the value of the project. The Bellman's fundamental equation of optimality for the project is as follows.

$$\rho V^i = \pi_{it} + \frac{1}{dt} E\left(\frac{\partial V^i}{\partial t} dt + \frac{\partial V^i}{\partial R} dR_{it} + \frac{\partial V^i}{\partial P_i} dP_{it} + \frac{\partial^2 V^i}{\partial {P_i}^2} (dP_{it})^2\right) \tag{4}$$

[4] The model part presented in this section is largely based on Mason's(2001) model

Expand dP using Ito's Lemma and rearranging other variables, the Bellman's equation of optimality is now becoming the Hamiltonian-Jacobi-Bellman(HJB) equation,

$$P_{it}q_{it} - C_i \; - \; q_{it}\frac{\partial V_i}{\partial R} + \; \mu_P P_{it} V_P^i \;\; + \; \frac{1}{2}\sigma_P^2 P_{it}^2 V_{PP}^i \;\; - \; \rho V^i = \; 0 \qquad (5)$$

Mason(2001) explained that because the profits are linear in the extraction rate, the maximization problem on this HJB equation is linear in constant extraction level q_{it}. It implies that the marginal impact of extraction is constant and thus the solution of this problem is zero, if the marginal impact is negative and maximum level, if the marginal impact is positive(It is usually known as Bang-bang problem). Therefore, we can assume that the firm decides to extract at the rate $\mathrm{q}_{it} = \mathrm{q}_c R_{it}$. Thus we can rewrite the equation (5) into

$$P_{it}q_{it} - C_i \; - \; q_c R_{it}\frac{\partial V^i}{\partial R} + \; \mu_P P_{it} V_P^i \;\; + \; \frac{1}{2}\sigma_P^2 P_{it}^2 V_{PP}^i \;\; - \; \rho V^i = \; 0 \qquad (6)$$

The solution of the equation (6) which is the optimal value function for the project is consist of the sum of two components, general solution derived from the homogenous equation must be speculative components of value of the project and derived from non-homogenous equation represents the total expected present value of the profit from operation.

Firstly, the general solution to the homogeneous component of the equation (6) can be expressed as $V^i = A(P_{it}R_{it})^{\beta}$, where A is a constant that is yet to be determined and the parameter. With this form, $\partial V^i/\partial R = -q_c\beta_1 V^i$, $P\partial V^1/\partial P = \beta_1 V^i$, and $P^2\sigma^2\partial^2 V^i/\partial P^2 = \beta_1(\beta_1 - 1)V^i$. Therefore, the unknown parameter β_1 must satisfy the restriction

$$-\rho \; + \; (\mu_P - q_c)\beta \;\; + \; \frac{1}{2}\beta(\beta - 1)\sigma_P^2 = \; 0 \qquad (7)$$

Then, we can confirm that there are two values of β, one is positive and the other is negative. The two values are $\beta_1 = 0.5 - (\mu_P - q_{c)}/\sigma_P^2 + \sqrt{\left[(\mu_P - q_{c)}/\sigma_P^2 - 0.5\right]^2 + 2\rho/\sigma_P^2} \; > \; 1$, and $\beta_2 = 0.5 - (\mu_P - q_{c)}/\sigma_P^2 - \sqrt{\left[(\mu_P - q_{c)}/\sigma_P^2 - 0.5\right]^2 + 2\rho/\sigma_P^2} \; < \; 0$, and thus the general solution of equation (6) can be expressed as the linear combination of the form

$$V^i = B_1(P_{it}R_{it})^{\beta_1} + B_2(P_{it}R_{it})^{\beta_2} \qquad (8)$$

Next, the particular solution to the non-homogeneous component can be obtained from the equation (6) as follows

$$V^i = \; \omega P_{it}R_{it} - \; C_i/\rho \qquad (9)$$

where $\omega = q_c / (\rho + q_c - \mu_P)$. Then the complete solution of equation (6) is

$$V^i = B_1(P_{it}R_{it})^{\beta_1} + B_2(P_{it}R_{it})^{\beta_2} + \omega P_{it}R_{it} - C_i/\rho \quad (10)$$

As we explained earlier, the last two terms, the particular solution, is the expected discounted value when the firm is required to keep operating until the resources are exhausted, and the first two term is speculative components of the firm's value when the firm invest the project. Now, consider the situation that the price goes to zero, then the value of the project should go to zero, $V^i(0) = 0$. In other words, with no prospect of a profit flow, the value of the project has to be zero. However, since β_2 is negative, that exponent of $P_{it}R_{it}$ goes to infinity when the price goes to zero. Therefore, the coefficient B_2 which has negative exponent should be zero. Next, according to the Dixit and Pindyck(1994), the other speculative term $B_1(P_{it}R_{it})^{\beta_1}$ represents the project's speculative bubble as price goes to infinity. In their study, they arbitrarily removed this speculative term since the investment on production facilities has no other object than to increase the production. We consider this oilfield development project, however, there exists speculative value of holding, and thus we do not remove this speculative component dissimilar to Dixit and Pindyck. Then the value of the oilfield development project is now

$$V^i = B_1(P_{it}R_{it})^{\beta_1} + \omega P_{it}R_{it} - C_i/\rho \quad (11)$$

Second, we consider the optimal value of option to invest, $F^i(P_{it}, R_{it}, t)$. In this case, the Bellman's fundamental equation of optimality for a value of option to invest is

$$- q_{it}\frac{\partial F^i}{\partial R} + \mu_P P_{it}F_P^i + \frac{1}{2}\sigma_P^2 P_{it}^2 F_{PP}^i - \rho F^i = 0 \quad (12)$$

As with the equation (6), the general solution to homogeneous equation can be expressed as the form of $F^i = A(P_{it}R_{it})^{\beta}$. The steps that follow are exactly same as the value of the project. Accordingly, the solution to this equation is also same as the value of the project. The parameter β must satisfy the restriction

$$-\rho + (\mu_P - q_c)\beta + \frac{1}{2}\beta(\beta - 1)\sigma_P^2 = 0 \quad (13)$$

Since equation (12) does not have non-homogeneous component, the complete solution to this equation is just same as the general solution. The complete solution is now

$$F^i = A_1(P_{it}R_{it})^{\beta_1} + A_2(P_{it}R_{it})^{\beta_2} \quad (14)$$

This complete solution represents the value of the option to invest. Therefore, if the price converge to zero, then value of the option should become worthless. Accordingly, the coefficient A_2 corresponding to the negative exponent β_{02} must be zero. Thus the solution for $\mathrm{F}^i(\mathrm{P}_{it}, R_{it}, t)$ has the form

$$F^i = A_1(P_{it}R_{it})^{\beta_1} \tag{15}$$

Then, the value of option to invest and value of the project can be written as

$$F^i = A_1(P_{it}R_{it})^{\beta_1} \tag{16}$$

$$V^i = B_1(P_{it}R_{it})^{\beta_1} + \omega P_{it}R_{it} - C_i/\rho \tag{17}$$

Now, we have to determine the value of the coefficient A_1 and B_1. However, to determine the precise value, some additional information is required. This additional information is to find the critical threshold price P_i^* which indicates the optimal price level to exercise the option to invest. At this threshold point, it will become optimal for the firm to pay the initial sunk investment cost I_i and receive the profit from the extraction. To find the threshold price P_i^*, we need to derive two optimality conditions. The first is the value-matching condition which requires that the gain in value attributed to invest should be equal to the discounted cost of initial investment. The second condition, known as smooth-pasting condition requires that marginal changes in option value F^i at the threshold price must be equal to that for the value of the project V^i.

Before obtaining the threshold point, note that the value of option to invest and project are related to the product of the state variables, P_{it} and R_{it}. In this sense, we define the term

$$X_{it} = P_{it}R_{it} \tag{18}$$

Then, the value function (16) and (17) become

$$F^i = A_1(X_{it})^{\beta_1} \tag{19}$$

$$V^i = B_1(X_{it})^{\beta_1} + \omega X_{it} - C_i/\rho \tag{20}$$

The threshold price P_i^* generates the critical threshold value X_{it}^* where the value-matching condition and smooth-pasting condition are satisfied. First, the value-matching condition can be expressed as

$$A_1(X_{it})^{\beta_1} = B_1(X_{it})^{\beta_1} + \omega X_{it} - \frac{C_i}{\rho} - \mathrm{I}_i \tag{21}$$

$$\beta_1 A_1(X_{it})^{\beta_1 - 1} = \beta_1 B_1(X_{it})^{\beta_1 - 1} + \omega \tag{22}$$

where $\omega = q_c \,/\, (\rho + q_c - \mu_P)$. Combining these two conditions allow us to derive the optimal threshold value X^*_{it}

$$X^*_{it} = \frac{\beta_1}{\omega(\beta_1 - 1)}\left(\frac{C_i}{\rho} + I_i\right) \tag{23}$$

4. Empirical analysis

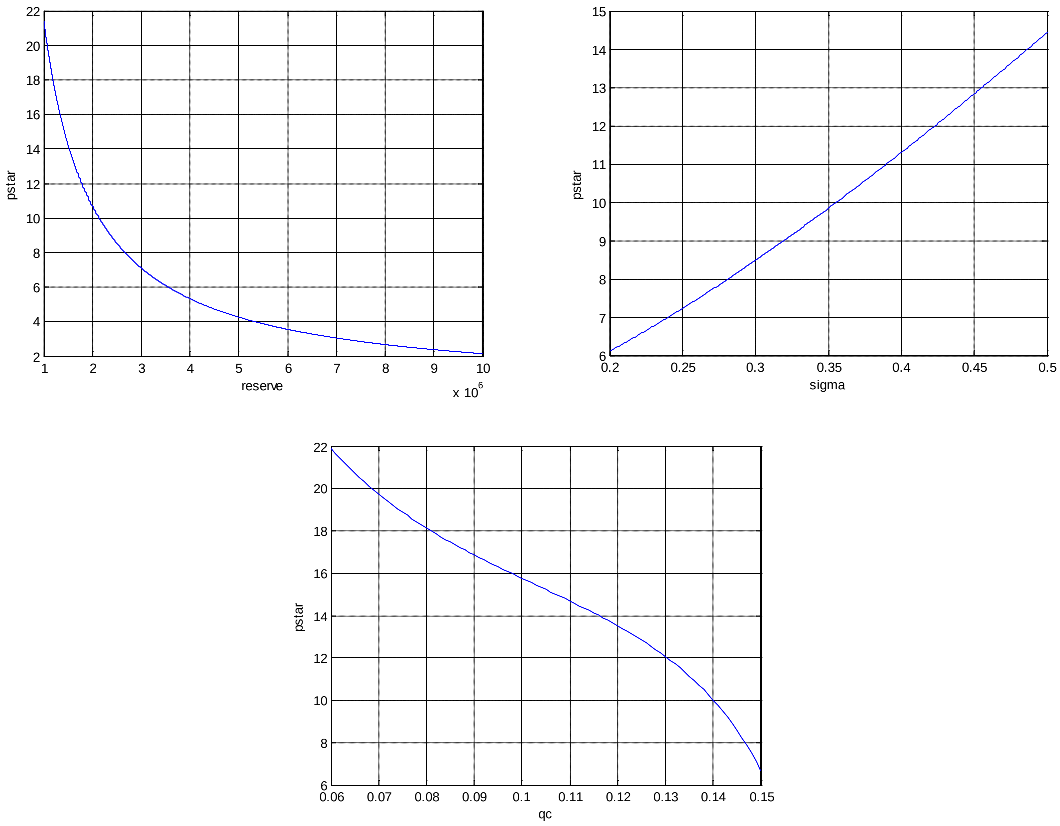
In this section, we use the model introduced in previous sections to evaluate the value of the project and waiting option. To analyze this, we use real financial data for Independent E&P companies' data. Before we focus on real data analysis, however, it is necessary to take a sensitivity analysis for some crucial parameters in order to examine the firm's strategic behavior arise from the changes in market condition. These are the value of the parameters that are used in the section

Table 1 : Financial parameters

μ_P	Annual drift rate of price	20%
σ_P	Annual volatility of price	40%
ρ	Annual discount rate	4%
q_c	Production capacity	6%
R_{it}	Reserve	100MMbbl
I_i	Total investment	80MUSD
C_i	Operating cost	50MUSD

At first, we check the relationship between reserve and optimal threshold price which are two state variables in the model. As we can see from Figure 1, the optimal threshold price is decrease with increasing oil or gas reserve. This is natural, since sufficient level of reserve corresponds to the higher market value of the firm, the optimal threshold price is decrease with increasing the expected net present value of the project. Another important variable is oil and gas price volatility. The optimal price sensitivity to this variable can be seen in figure 1. In this case, increase in price volatility can lead to increase in optimal price level. The larger volatility pushes up the threshold price p^* because the firm needs to have a price high above the break-even price to be certain that the project has positive expected NPV when the volatility is high. Lastly, we take sensitivity analysis for maximum production capacity and optimal threshold price. Higher production capacity pushes down optimal threshold price level because this will increase the expected NPV of the project. The reason is because the firm which has high level of production capacity can make their production strategy more efficiently in response to the market changes: when the market price goes up, then the firm can produce more, and this will increase the firm's expected NPV.

Figure 1 : Sensitivity analysis



Now, we proceed with the empirical analysis using real financial data. The estimated data contains financial information for Independent E&P Companies. To specific, it reveals the details of total oil and gas reserve, annual production level, and operation and development cost for the each of 57 North America Independent E&P companies from 2004 to 2008. Before estimating each company's optimal investment point, we should obtain all the parameters from the real data. First, the sum of acquisition, exploration & development cost and finding cost are used as initial Investment cost I_i. Lifting cost[5] is used as Operation cost C_i, and drift rate and volatility of oil and gas price are obtained from the daily based data provided by EIA(Energy Information Administration) from 1997 January to 2011 August.

Using those parameters, we can obtain each firm's optimal investment price through the equation (23) we derived in section 3. In order to examine the each firm's different extractive activity that are attributed to the different size of the firm, we classify the independent E&P companies into three categories; small-size, mid-size, and large-size[6]. This classification is based on each firm's different market value and annual revenue.

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[5] Lifting costs includes following costs : transportation cost, labor costs, costs of supervision, costs of operating the pumps, electiricity, repairs, depreciation.

[6] Large : 19 firms, Mid : 18 firms, Small : 20 firms

To assess the economic feasibility of investment, now we consider p / p^* as an investment index which indicates economic feasibility of the project. If the index p / p^* is greater than 1, then the project is regarded as having economic feasibility so that it will allows the firm to have a willingness to invest the project, otherwise, the project is not profitable. Now, we obtain these indices separately with respect to oil and gas investment project for each company from 2004 to 2008. The estimation results are shown in the table below.

Table 2 : Estimated Investment Index

		2004	2005	2006	2007	2008
Small-firm	p_o/p_o^*	4.86	6.28	4.74	4.93	9.90
	p_g/p_g^*	0.94	1.15	0.78	0.70	0.90
	$(p_o/p_o^*)/(p_g/p_g^*)$	5.15	5.44	6.07	7.04	10.2
Mid-firm	p_o/p_o^*	8.52	6.78	6.79	4.90	7.91
	p_g/p_g^*	1.36	2.41	1.09	2.25	1.42
	$(p_o/p_o^*)/(p_g/p_g^*)$	6.28	2.81	6.21	2.18	5.55
Large-firm	p_o/p_o^*	5.17	0.98	7.39	7.92	9.00
	p_g/p_g^*	1.45	2.73	1.12	3.02	1.34
	$(p_o/p_o^*)/(p_g/p_g^*)$	3.57	0.36	6.61	2.62	6.70

As we seen this table, the independent E&P companies have some peculiar aspects on the results. For one, it presents that the economic feasibility of oil drilling project is higher than that of gas project. Particularly, small firms have more significant gap between them compare to mid and large size firms. Second, the economic feasibility of gas projects is gradually improving from small-firms to large-firms.

There are some reasons for that, firstly, natural gas price is more volatile than oil price. As we seen earlier in the sensitivity analysis, high volatility drives option price goes up and thus optimal threshold price will be increased. Accordingly, a firm becomes less willing to invest new drilling projects on gas field. Therefore, this makes the oil drilling projects to have higher profitability than gas extracting projects. The second reason is attributed to its characteristics of natural gas industry. Like most other commodities, natural gas can be stored for an indefinite period time. However, the exploration, production, and transportation of natural gas take more time and require more advanced technology compare to those of oil industry. Especially, the transportation of natural gas is closely linked to its storage. This storage of natural gas requires the use of specialized refrigeration equipment so that it is positively necessary to have sufficient funds and well-organized transport network to sustain a certain level of profit. However, the Independent companies' activities are mainly confined to extraction and production(upstream) segment. Historically, the IOCs which have well-organized transport network and storage techniques, called vertical integration, tend to dominate the natural gas industry. Indeed, we may be able to infer that these important aspects on the Independent E&P companies are originated from these two specific reasons.

Additionally, we estimate simple regression between annual reserves replacement additions and the investment index p / p^* for 57 companies. The results are shown in the table 3.

Table 3 :

	ΔR_O	ΔR_g
Constant	-0.08495*** (0.01245)	-0.00523* (-0.00432)
p / p^*	0.31425** (0.15125)	0.38194** (0.21204)

*** : 10% ** : 5% ***: 1% significant level**

The estimation results show that the investment index p / p^* is positively effect on the firm's reserve replacement addition. Therefore, most of independent companies have considered the uncertainty arise from the changes in market price and irreversible features on oil and gas drilling project when they decide whether additional development should be allowed to undertake or not.

5. Conclusion

This paper analyzes the optimal threshold prices to invest oil or gas drilling project by considering the scarcity which is crucial features of non-renewable resources. To estimate this, we use the model suggested by Mason(2001) which contains the remaining reserve as another state variable. The obtained threshold points determine the investment option value and expected net present value of the project considering oil and gas price uncertainties and firm's present reserve level and maximum extraction capacity applying the real options approach. Sensitivity analysis presents that firm's reserve level and maximum extraction capacity are negatively related to optimal threshold price since these can be expected to increase future cash flow of the project. In empirical analysis section, we find the specific aspects of the Independent E&P companies. First, they tend to have more economic efficiency on the oil development project in comparison with the natural gas project. Second, the indices for investment of gas projects are gradually improving from small-firms to large-firms. Then, we established that these aspects may come from the substantial volatilities of the gas price and the specific features of gas industry. Finally, we estimate simple regression between firm's annual reserves replacement additions and the investment index p / p^*. As a result, we can conclude that the investment index p / p^* is positively effect on the firm's reserve replacement addition.

For further work, the model needs to be developed to precisely incorporate important features specific to the Independent E&P companies. This paper, however, does not take into account the specific features of the Independent companies.

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