Investment in deepwater oil and gas exploration projects: A multi-factor analysis with a real options model

【Abstract】 Deepwater oil and gas projects embody high risks from geologic and engineering aspects, which exert substantial influence on project valuation. But the uncertainties may be converted to additional value to the projects in the case of flexible management. Given the flexibility of project management, this article extends the classical real options model to a multi-factor model which contains oil price, geologic and engineering uncertainties. It then gives an application example of the new model to evaluate deepwater oil and gas projects with numerical analytical method. Compared with other methods and models, this multi-factor real options model comprises more project information. It reflects the potential value deriving not only from oil price violation but also from geologic and engineering uncertainties, which provides more accurate and reliable valuation information for decision makers.

【Keywords】 Investment decision; Real options; Multi-factor model; Option pricing; Deep water

1 Introduction

Deepwater petroleum investment has attracted much attention since offshore oil and gas resources are taking a larger portion of worldwide energy potentials. However, due to marine geographical environment, deepwater oil and gas development projects contain higher geologic and engineering risk than onshore or continental shelf projects. This situation increases the total amount of investment and the complexity of decision-making process. On one hand, the volatility of oil price causes more flexibility value for the deepwater projects which demand a longer duration for exploration. On the other hand, since the technical risk of deepwater projects under development is much bigger than onshore or continental shelf ones, the effects of engineering and technological uncertainties on the value of deepwater projects are significant. Under this background, the traditional theory of net present value cannot provide sufficient reliable reference for the decision making of deepwater oil and gas investment, because the value of flexibility from the uncertainties in oil price, engineering and technology cannot be measured under the rigid assumptions. Therefore, the real options method base on uncertainty analysis is more suitable to evaluate deepwater oil and gas projects.

The real options theory, originating from the financial option, regards the value from management flexibility as an option which could generate revenue. In 1997, Myers analyzed the value of real options of additional investment opportunities for the first time. Since then, the flexibility value of real investment has received ongoing attention. Dixit and Pindyck (1994) summarized the research achievements of real option and presented a systematic exposition of its construction and application. Firstly, they described the statistic characteristics of the uncertainty factor which influences the cash flow significantly. Secondly, they determined the functional relationship between uncertainty factor and the revenue and established the equation by non-arbitrage portfolio. Thirdly, derive the equation to the real options model based on the assumptions and boundary conditions.

Since Brennan and Schwartz (1985) and Paddock et al. (1988) evaluated the natural resources investment by adopting real options method, the research of real options method has gradually cleared up. Dias (2004) presented an overview of real options models to evaluate investments in petroleum exploration and production projects. He pointed out that oil price was the only random variable in almost all the real option models and empirical studies, and other technical factors were assumed to be constant which could be obtained from engineers before the evaluation. In his review, petroleum project was considered as a long-term investment and production process during which the fluctuation of oil price could influence its economic value significantly. It could increase the flexibility value by adjusting production according to the oil price fluctuation. Due to the importance and financial attribute of oil price, simulation for the stochastic characteristics of oil price was a focus in real option research.

However, factors affecting the flexibility value of oil and gas projects are not limited to oil price, especially in the case of deepwater oil and gas exploration and development projects. The flexibility of geologic cognition and engineering technology also have an important influence on the projects. The geologic and technological information will be more accurate with increasing investment. The investors could make better decisions with the additional knowledge to realize flexibility value which may be ignored by net present value method. In the theory of real options, the additional information and flexible management are valuable. If the flexible value of an underlying project is larger than its required investment, the project will be profitable. In order to evaluate the comprehensive flexibility value, a multi-factors real options model should be established with geologic and technological factors in addition to price factor.

Attempts to set up a multi-factors real options model have been made in recent 5 years. Cortazar et al. (2008) added the information of geology and technology to the model of Brennan et al.(1985) to evaluate the copper mine. But the study was not intensive. It didn’t analyze the relationship between information uncertainty and the flexibility value, and failed to describe the establishment or application of the model.

The uncertainty factors and flexibility need further demonstration. Fan et al. (2010) built a multi-factors real options model and applied it to the oil investment decision. However, the research didn’t consider the two important factors of geologic and technological uncertainties. It introduced the exchange rate and resource tax rate to the model, none of which has a significant effect on the flexibility value for deepwater oil and gas projects. They proposed to adjust oil price to exchange rate and tax rate and then substituted the volatility of oil price in the classical real options model for the integration of the three volatilities. However, the integration is meaningless because their integrated factor has no difference from a single factor in essence. Furthermore, the tax rate doesn’t have the stochastic characteristic.

Our multi-factors real options model and its application into deepwater projects will make several contributions to the literatures. In the aspect of random factors, we analyze three of the most important factors: oil price, geologic information and engineering information based on the characteristics of deepwater oil and gas projects. We also integrate the three factors based on the stochastic process theory. In the aspect of real options model, we extend the single factor model with geologic and technical factors to better describe the flexibility value of deepwater oil and gas projects on the basis of the integration model because the partial differential equation for three factors is too complex to get solution. In the aspect of application, we provide an example to show the practical significance of key parameters and introduce the method of parameter assignment. We also apply the real options model to value a deepwater project under the typical production-sharing.

This paper is organized as follows: In the second section we will describe and integrate the variables with stochastic process theory. In section 3 the multi factors real options model will be established based on the integration model and the non-arbitrage approach. In section 4 we will discuss the parameters assignment. In section 5 we will apply the model into a deep water oil and gas project and analyse the optimal investment decision. Section 6 will be the conclusions.

2 Three factors affecting the value of flexibility in deepwater oil and gas projects

Considering the characteristics of marine geographical environment, the flexibility value of deepwater oil and gas project is determined not only by the volatility of oil price but also by the uncertainty of geology and engineering technology. If the exploration and development scheme is adjusted based on the additional information, the economy value of project could be increased.

The flexibility value of geology conditions implies the unremitting objectives of minimization of investment and maximization of profit since the geology information updated as the project proceeds helps make the investment budget preciser. In the oil and gas industry, the investment in prospection gives investors the priority over next stage's activities. So these investors have more prominent opportunities due to their information privilege. The flexibility of technology implies the potential cost saving and production increase in the process of exploration and production with the uncertainties gradually clarified and problems solved. On the other hand, under the background of whole block development, the flexibility of technology implies the value maximization for all projects located in the same area since investors could properly design overall development program and share the facilities among different projects in that area. Besides, the flexibility value of oil price changes could never be neglected since deep water oil and gas development projects always take many years. Investors and their management team can adjust their actual production according to price of the time under specific technology and engineering conditions, so as to realize the best economic value of oil and gas reserves.

Geology conditions, technologies and oil price are the main factors that affect the real options value of deepwater oil and gas projects. This study carries out the study of these three factors first, and builds a multi-factor real options model on such basis.

There are two requirements in the simulation of random factors. Firstly, the model should be concise enough for practical use and could accurately render the dynamic characteristics of random factors since the purpose of simulation is to construct financial models and realize necessary computation rather than to make predictions on future situation. Secondly, many financial models are built on the basis of Ito lemma by now, however the random factor models are also needed to follow Brownian movements as basic variables do.

2.1 Oil price simulation

There are always a lot of researches on the simulation and prediction of oil prices due to the importance of petroleum in world economy and international relationships. It has been proved that the fluctuation of oil price follows random walking process with sudden increases or jumps at certain periods. Dixit and Pindyck (1994) described the oil price with several models. They pointed out that the Geometric Brownian Motion (GBM) should be a foundational model and the mean reverting model could describe the stochastic characteristics of oil price more accurately since oil price fluctuated around the cost of oil production which was stable. But the difficulty and the cost of oil exploitation have increased rapidly with soaring demand during the past two decades. This change has been reflected in the oil price fluctuation (see Figure 1), so the mean reverting model is not that accurate to describe the characteristics of oil price.

Fig.1 The fluctuation of oil price

Compared with mean reverting model, GBM is more appropriate to embody oil price movements, as GBM conforms to both the stochastic characteristics of oil prices and the two requirements mentioned above.

Then, the simulation model of oil price will be:

$$dP_t = \mu P_t dt + \sigma_P P_t dW_t \tag{2.1}$$

Where, P_t is the oil price at time t, W_t is a Wiener process, μ and σ_P are constants.

Assuming an initial price of P_0, use the Ito stochastic integral to solve the equation and we will get the following:

$$P_t = P_0 \exp\left(\left(\mu - \frac{\sigma_P^2}{2}\right) t + \sigma_P W_t\right) \tag{2.2}$$

2.2 Simulation of technological and geologic factors in engineering

Technological and geologic factors in engineering can substantially affect the overall economic values of deepwater oil and gas exploration projects as economic factors on the product market do, and must be included in the evaluation model.

Deepwater exploration technology is under quick evolution. Specialists and technicians are exploring better methods to describe geology, technological conditions and risks in the seabed. Their ideas and models can be quite different, and most of them end up in describing various geologic and technological factors in the form of probabilities. Therefore, probability theory can be used to study the geologic and technological uncertainties in the evaluation model for deepwater oil and gas exploration projects. However, most technological models in engineering involve various parameters, which are complicated and confidential, and cannot be directly used in economic models. Thus the model with geologic and technological uncertainties must be designed with comprehensive study of technological methods in engineering to meet the requirements of evaluation model.

All random variables in stochastic system can be described by stochastic process. According to researches, engineering and technology data follow normal distribution with certain features, and can be described by stochastic differential equation [10]. Engineering technology denotes a wide range of factors with correlations among some of them, and it is unpractical to clarify each of them in an economic model. Thus geologic and technological factors in engineering will be taken as one comprehensive factor in simulation and analysis.

Hereby define a one dimension geology-technology factor *G*, which follows Brownian movement with zero drift and constant volatility.

$$dG = G\sigma_G dW_G \tag{2.3}$$

Where, σ_G is volatility, dW_G is standard Wiener increment.

2.3 Variables integration

Previous analysis of treatment for oil prices and geologic and technological factors with stochastic model expands how to put uncertain technological factors separately and directly into evaluation model, so as to provide preciser evaluation results for deepwater oil and gas assets. However, it is over sophisticated to put both factors *P* and *G* into a proper model together with the application of Ito lemma. Therefore factor *P* and factor *G* will be technically integrated into one factor to build a three-factor model (Ito, 1957).

Both Oil price (*P*) and geology-technology (*G*) give impacts on the value of deepwater oil and gas projects, where *P* is mainly affected by market dynamics, and *G* by geologic conditions in seabed and achievements in technological development. Therefore assume factors *P* and *G* are independent, which means:

$$dW_P dW_G = 0 \tag{2.4}$$

And let $Z \equiv F(P,G)$ (2.5)

According to Ito lemma, we bring Eq. (2.1) and Eq.(2.3) into this equation and get:

$$dZ = \left(F_P P\mu + \frac{1}{2}F_{PP}P^2\sigma_P^2 + \frac{1}{2}F_{GG}G^2\sigma_G^2\right)dt + F_P P\sigma_P dW_P + F_G G\sigma_G dW_G \tag{2.6}$$

In order to make Eq.(2.6) solvable and ensure the effectiveness of evaluation model, we apply the principle of value additivity of stochastic process by Itō’s (2010) and get:

$$Z \equiv F(P, G) = PG \quad (2.7)$$

Given that factors P and G following standard Wiener process, and they both are independent and unrelated incremental variables, Eq.(2.7) is correct according to Ito's theory and the two stochastic processes can be superimposed to get:

$$\frac{dZ}{Z} = \mu dt + \sigma_P dW_P + \sigma_G dW_G \quad (2.8)$$

Hence the new variable *Z* embodies the same drift rate with oil price *P* but larger volatility than *P*:

$$\sigma_Z = \sqrt{\sigma_P^2 + \sigma_G^2} \quad (2.9)$$

3 Modeling

3.1 Hypothesis in modeling

Actual economic problems are far more diversified and complicated. A series of hypothesis are established in accordance with problem particularity and research targets for simulation and computation, so as to better describe and solve problems with mathematic modeling. The fundamental hypotheses in real options modeling for deepwater oil and gas exploration projects are as follows:

1) Oil price *p* follows GBM process, and its convenience yield is the function of oil price;
2) The geology-technology variable follows Brownian movement;
3) Investment return *r* is known and constant;
4) The reproduction cost of investment portfolio is negligible;
5) The real options value *V(Z, t)* in the form of variable *Z* and time *t* is second order differentiable, and follows Ito lemma;
6) The compound option is perpetual since oil and gas exploration contracts last for many years.

3.2 Model establishment

Establish the evaluation model on the basis of no-arbitrage portfolio theory. Assume *F(Z, τ)* is the price function of petroleum futures bought at time *t* with expiration time at *T*, where *τ=T-t*. According to Ito lemma, the instant yield of the futures is:

$$dF = \left(-F_\tau + \frac{1}{2}F_{ZZ}\sigma^2 Z^2\right)dt + F_Z dZ \quad (3.1)$$

Where, F_Z and F_{ZZ} are first and second order partial derivatives.

And with Eq.(2.7) we have:

$$F_P = F_Z \cdot G, \quad F_{PP} = F_{ZZ} \cdot G^2 \quad (3.2)$$

Then we generalize such an investment portfolio: An investor goes long on one unit of crude oil in the spot market and goes short on $(F_P)^{-1}$ unit of crude oil as underlying asset in the future market. Suppose no dividend to be paid. According to Eq.(3.1) and Eq.(3.2), the rate of turn for this portfolio is:

$$\frac{dP}{P}+\frac{C(Z)dt}{P}-(PF_P)^{-1}dF=(PF_P)^{-1}\left[F_PC(Z)-\frac{1}{2}F_{PP}\sigma^2P^2+F_\tau\right]dt \qquad (3.3)$$

Where, C(Z) indicates convenience yield. Under the no-arbitrage principle of efficient market, the investment return of above portfolio equals to market return, which means:

$$\frac{1}{2}F_{PP}\sigma^2P^2+F_P(rP-C)-F_\tau=0 \qquad (3.4)$$

The boundary condition is:

$$F(P,G,0)=P \qquad (3.5)$$

With Eq.(3.1), Eq.(3.2) and Eq.(2.8) we have:

$$dF=F_P[P(\mu-r)+C]dt+F_PP\sigma dz \qquad (3.6)$$

Deepwater oil and gas exploration involves special risks and tremendous investments, and the economic value is mainly affected by oil price *P*, geology-technology *G*, accumulative investment *I*, and time *t*. Take *V* for the value of petroleum asset, and with Eq.(3.8) we get：

$$V\equiv V(G,P,I,t)=V(Z,I,t) \qquad (3.7)$$

With Ito lemma Eq.(3.7) it changes into:

$$dV=V_ZdZ+V_IdI+V_tdt+\frac{1}{2}V_{ZZ}(dZ)^2 \qquad (3.8)$$

Let *q* be per unit investment, *λ*—average income tax rate, *γ*—rate of success in exploration, thus the after tax cash flow of the exploration project will be:

$$\gamma V-q-\lambda V \qquad (3.9)$$

In order to get the partial differential equation of project value (*V*), we build another investment portfolio: buy one unit of oil asset and sell the same unit of oil futures, then the investment return will be:

$$dV+[\gamma V-q-\lambda V]dt-(V_P/F_P)dF$$

$$=\frac{1}{2}\sigma^2Z^2V_{ZZ}-qV_I+V_t+(rP-C)V_P+[\gamma V-q-\lambda V] \qquad (3.10)$$

In light of no-arbitrage principle, the portfolio return is equal to market return r_V. With Eq.(3.2) we have:

$$\frac{1}{2}\sigma^2Z^2V_{ZZ}-qV_I+V_t+(rP-C)V_Z+q-(r+\lambda-\gamma)V=0 \qquad (3.11)$$

Take deepwater oil and gas exploration projects as perpetual real options, then the operational period t is infinite. When an investor is operating one project, he also keeps seeking for other potential exploration blocks to ensure continuous cash inflow, which means t in the equation is not a variable ($V_t=0$), and the value of real options is only related to its price and the geology-technology uncertainties.

Define the value of deepwater projects under perpetual operation $V(Z,I)$, then the maximum project value with optimal output level satisfies the following requirement:

$$\frac{1}{2}V_{ZZ}Z^2\sigma_Z^2 + (rZ - C)V_Z + qV_I - q - (r + \lambda + \gamma)V = 0 \quad (3.12)$$

The boundary conditions are:

$$\begin{aligned} &V(0, I) = 0 \\ &V_Z(0, I) = 0 \\ &lim_{Z\to\infty} V_{ZZ}(Z, I) = 0 \end{aligned} \quad (3.13)$$

Eq.(3.12) together with Eq.(3.13) establish the multi-factor real options model under conditions of uncertainty, and it is generally difficult to obtain analytical solutions for the model. In most situations, numerical simulation method is adopted instead.

4 Variable simulation and parameter analysis

4.1 Variable simulation

Section 2 has described the oil price, geologic factor and technological factor by using stochastic differential equation (SDE), and solved the SDE to get the key parameters of the equation. We have also integrated the three factors and built up the integration model. Figure 4.1 shows the simulation results of the factors based on the SDE and integration model.

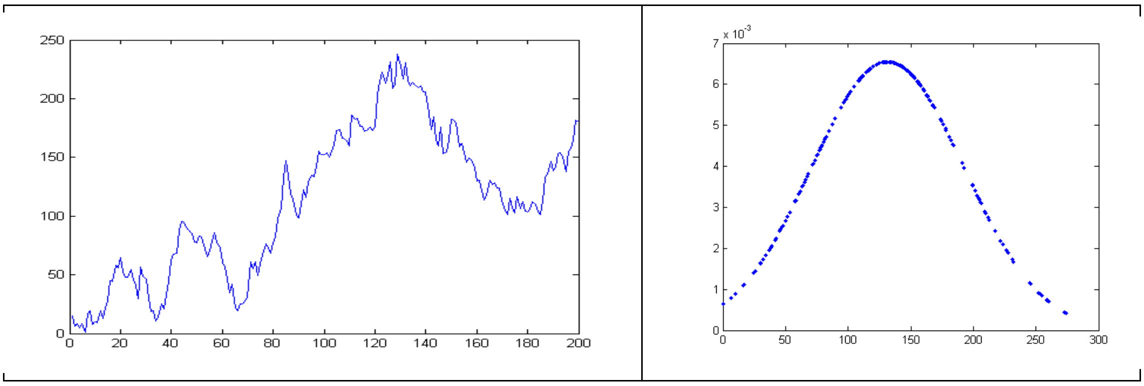

Fig. 4.1 The stochastic simulation and Gauss fitting of oil price

We collect WTI oil price data for 10 years and plot it for comparison analysis and get figure (4.2).

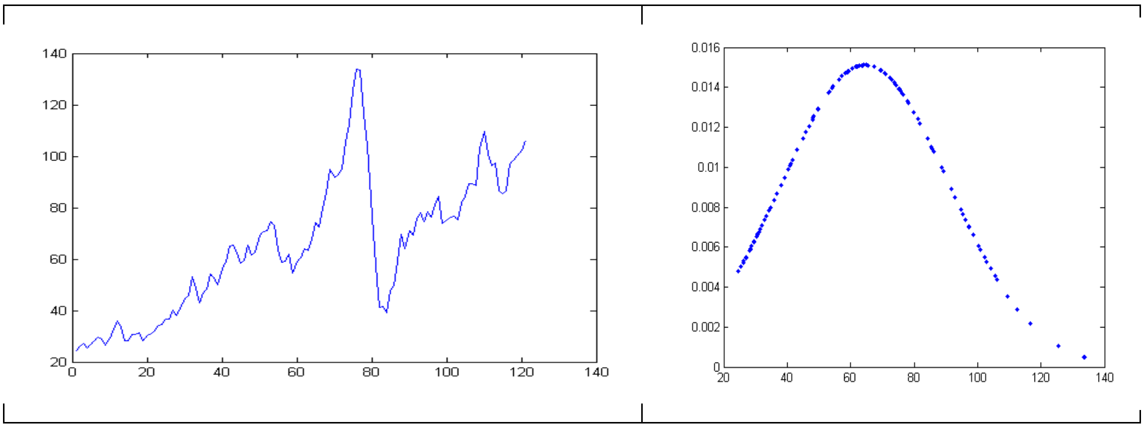

Fig. 4.2 The plot and Gauss fitting of WTI oil price

Figure (4.1) and (4.2) indicate that the simulated movements and actual oil price movements share the same characteristics of stochastic process if excluding unpredictable sudden jumps caused by political or economic emergencies. Therefore the simulation model above and the eigenvalues acquired successfully reflect the characteristics of real oil price movements, and the basic form of the model conforms to Wiener process, thus it can be used in financial models for oil and gas assets evaluation.

Simulation results of the geology-technology factor G and the integrated three factors are shown in figure (4.3) and figure (4.4).

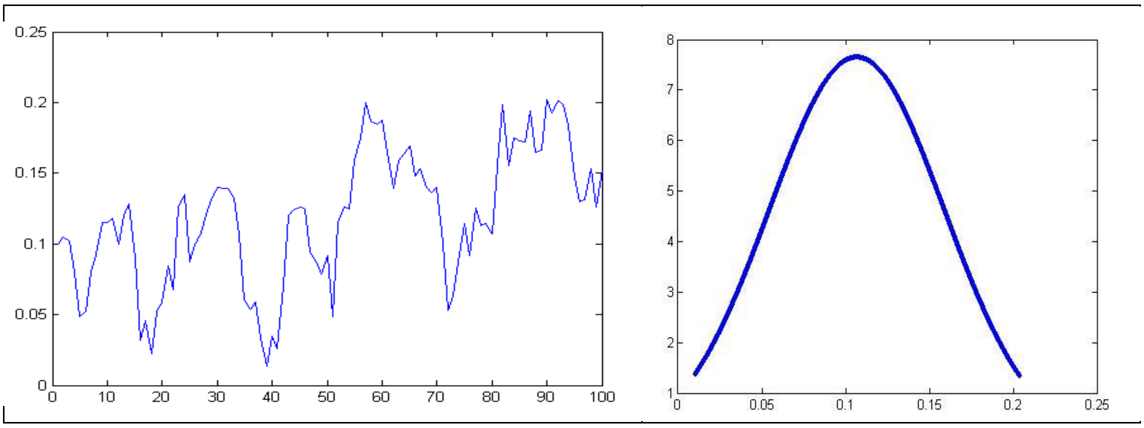

Fig. 4.3 The stochastic simulation and Gauss fitting of geology-technology factor

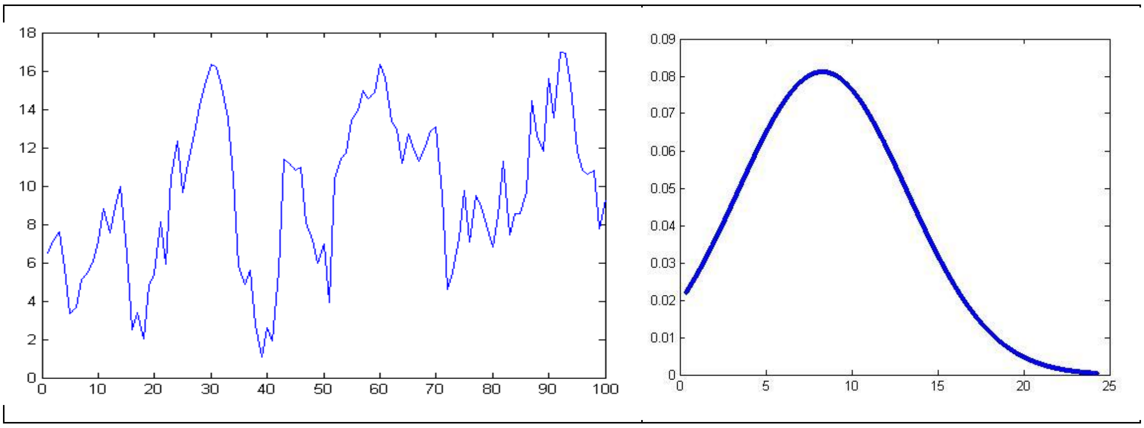

Fig. 4.4 The stochastic simulation and Gauss fitting of oil price-geology-technology factor

According to figure (4.3)~(4.4), the integration meet the hypothesis of Ito's lemma, which can be the basis of parametric estimate in multi-factor real options model. And the fitting results of integrated factor and single factor are different, which also proved that the research for multi-factor real options model makes sense.

4.1 Parameter analysis

Deepwater oil and gas exploration and development projects involve interests of many parties, which are stipulated in complicated contract clauses. In order to make the multi-factor real options model applicable, accurate and understandable, study on parameter value is conducted.

1) Value volatility of unproved reserves

Since the value volatility of unproved reserves exerts influences directly on investors' expected returns, it should be an important parameter in the real options model. A typical treatment is to conduct fitting assessment on historical data of resource reserves. But historical trading prices of reserves are usually confidential, so there are not enough data for fitting assessment. Thus alternative calculation methods for value volatility of unproved reserves are needed.

According to Gruy et al. (1982), the value of developed reserves can be predicted with oil price volatility. When project enters into the stage of exploration and production, its value will only depend on oil prices because the geologic and technical factors shall have revealed themselves. In this context, the value volatility of unproved reserve can be calculated from the volatility of P-G in our study. According to the introduction in section 2, we need to calculate the volatilities of oil prices and geology-technology factor respectively and then compute them with Eq.(2.9). However, Lu Huan (2008) provides a conciser approach to embody an integration of the two aspects by using the price-production volatility. Taking his research on reserves value of Changqing Oilfield in China for reference, we choose the price-production volatility as the base to decide the value volatility of unproved reserves.

2) Investment rate and its influence on project value

In deepwater oil and gas exploration projects, investors are confronted with many uncertain factors, which on the other hand provide them with great flexibility in project management: they can expand or hold down the investment volume according to updated geologic and technological conditions, and increase or reduce their production in consistence with market dynamics. Whereas there is one thing in common for most projects: some of the investment is irreversible despite succeeding investment policies as the initial investment is sunk or at least partially sunk. The investment in prospection is totally irreversible not matter it succeed or fail in finding recoverable resources.

Investment rate in exploration indicates the capital expenditure in search of recoverable oil and gas resources, and it’s a crucial factor for total investment returns in real options evaluation model. When oil companies increase their investment in prospection, they will acquire information about recoverable reserves with higher volume and better accuracy, and they will also have more confidence to realize greater economic value of the project. Thus it is reasonable to assume that the increase in prospection investment adds value to the project. To be more simplified, we suppose the prospection investment and project value are in positive linear correlation.

3) Success rate in exploration

Success rate in exploration changes with many factors such as location, reservoir conditions, exploration engineering and equipment, and oil companies have different success rate in their prospection works in different areas and different blocks. But it is fairly difficult to calculate or predict with limited geology and engineering information, while an alternative is to use empirical values from projects with similar location, water depth and other parameters.

4) Convenience yield rate

Convenience yield rate is a sensitive parameter in real options evaluation model. Gibson and Schwartz (1990) suggested that convenience yield was the value-added cash flow naturally derived from products, and it belonged to the holders of such products rather holders of derivative contracts. Convenience yield depended on the volume of inventory: products of less inventory and higher spot price could achieve higher convenience yield, and vice versa. Paddock, Siegel and Smith (1988) concluded that investment return of developed reserves consisted of two parts: operating profits from production sales and capital gains from intrinsic value growth of remaining reserves. Thus let convenience yield be:

$$C_t = \frac{\omega[\Pi_t - V_{bt}]}{V_{bt}} \tag{4.1}$$

Where, ω is the decline rate of production in percentage;

Π_t is after-tax profit of oil sales;

V_{bt} is oil value of developed reserves per-barrel.

5) Market investment return

We can adopt the return on investment used in discounted cash flow analysis and adjust it according to the characteristics of assets in the same region.

5. Evaluation and decision analysis

An overseas deepwater asset operated by one of Chinese major oil companies will be applied in this multi-factor real options model. This project is under production sharing contract (PSC). At the initial stage of investment, oil price was at a relatively low level but moving upward, so the exploration scheme was conservatively designed for modest oil production since only pre-exploration had been conducted, and detailed prospection and exploration data were not available. However, At the initial decision point, the discount cash flow analysis did not show too much promise even though adjacent oil blocks showed promising economic returns, so the decision making of this project didn't only refer to DCF analysis results.

Parameters in the real options model are calculated according to the Contract and the analysis in Chapter 4 (see table 5.1).

Table 5.1 Parameter estimation

Market price of developed reserves V_b（\$/bbl）	15.38
After tax earnings Π（\$/bbl）	19.01
Total cost D（\$/bbl）	13.04
Exploration cost E（\$/bbl）	2.96
Influence of investment changes to project value V_I	1.9
Success rate in exploration γ	0.2
Production decline rate ω（%）	6.25
Investment rate q（%）	23.00
Market investment return r（%）	10.00
Convenience yield C（%）	1.50

Assume oil price at USD65$ with volatility of 0.18 and factor *G* equals 0.1 with volatility of 0.25, then the value of this project with geology-technology uncertainties amounts to USD13.53$ per barrel. In a more pessimistic scenario with higher geology-technology risks, assuming factor *G* to be 0.07, the evaluation result from the real options model suggests a project value of USD6.48$ per barrel.

While single-factor real options model is often applied to evaluate the flexibility value with uncertainties in oil price, this study suggests adopting both multi-factor real options model and net present value method to better demonstrate the uncertainties. The comparison results are shown in Table 5.2.

Table 5.2 Results of three kinds of evaluation methods

Evaluation method	NPV	Single-factor real options model	Multi-factor real options model with high G rate	Multi-factor real options model with low G rate
Result (USD/barrel)	5.76	7.38	13.53	6.48
Deviation from NPV result	-	28.13%	135%	12.5%

The results in Table 5.2 demonstrate that the multi-factor real options model can better reflect the flexibility value. Besides, projects in adjacent blocks are endowed with excellent geologic conditions. They have exhibited great potentials and delivered much higher economic returns than their initial evaluation results, which provide evidence for the effectiveness of multi-factor real options model to some extent.

On the other hand, the results under higher geology-technology risks scenario by multi-factor real options model is much more conservative than that given by single-factor model, thereby it confirms that multi-factor model is more capable in reflecting the impact of engineering factors on projects' flexibility value while single-factor model only focuses on the impact of oil prices but ignores the impact of geology and technology.

6 Conclusions

The management of flexibility value is not only embodied in the feasibility to elevate the economic value of reserves by adjusting production to oil prices. It's also shown in the flexibility to design exploration scheme according to the uncertainty of geologic information and technology, especially for deepwater oil and gas exploration projects. We analyzed several influential factors for project value with reference to the characteristics of real options in deepwater projects. We established a multi-factor real options model under uncertain conditions for project evaluation, and employed the idea of multi-uncertainty factors integration to make the model practical.

The model has been successfully applied to a real deepwater project. The evaluation result shows that the multi-factor real options model could be more accurate than the single-factor model. This multi-factor model gives investors more reliable theoretical supports to make reasonable decisions. Our sample project has been operated for more than five years, and the real practice has also showed that the estimated value with multi-factor real options model is a better approximation to reality. So multi-factor real options model could be a good reference approach for investment decisions about deepwater oil and gas projects.

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