The Economic Evaluation of Tight Oil Development under Uncertainty: Example of Development in China

Xiaozheng Liu[1)]

Abstract

Economic evaluation plays an important role in tight oil development, and it is a common issue in the oil industry to conduct a reasonable and convincing economic evaluation. In this study, an improved analytical method using the Net Present Value method and real options method is proposed to quantitatively evaluate the economic efficiency of tight oil development. The economics of tight oil development is influenced by uncertainties such as geological factors, technical factors, and external factors including policy factors, resulting in multiple effects. According to the results of the analysis, the improvement of the economic efficiency of the tight oil development contributes to the progress of the development technology, and if the progress of the development technology is realized, the further enhanced effect can be obtained. Also, preferential policies are important for tight oil development and have different promotion effects depending on the development areas. The results of the analysis in this study are not limited to tight oil development in China but may lead to similar considerations and conclusions regarding unconventional oil resource development projects in other regions.

Keywords

tight oil, economic evaluation, uncertainty, optimization

1. Introduction

Tight oil, an unconventional oil, is widely distributed worldwide and has high development value (Zhang et al., 2012; Jia, Zheng and Zhang 2012; EIA, 2013; Liu et al., 2013; Qiu et al., 2013; Liu et al., 2016; Zhu et al., 2018). Tight oil, which could not be developed until now, has been actively commercialized and put into practical use since 2000 due to advances in development technology and preferential policies. However, because the reserve characteristics, production characteristics, and development technology of tight oil are different from those of conventional oil and have uncertainties, the economic evaluation of tight oil development is considered important (Liu et al., 2012; Du et al., 2014; Huang et al., 2016; Zheng et al., 2017; Li et al., 2017).

The uncertainties in tight oil development are large: (1) geological factors, (2) technical factors, and (3) external factors including policy factors. Geological factors refer to the geological features of the tight oil reservoir and are the basis for the development of the tight oil. The success or failure of the development depends on the analysis of geological factors and the assessment of reservoirs with favorable conditions for economically tight oil development (Jiang et al., 2014; Liu, 2018). The technical factor is the technology developed around the development of tight oil, which is an important key in the development of tight oil (Tang et al., 2019). To increase the economic efficiency of tight oil development, it is essential to improve development technologies related to

[1)] Institute for North East Asian Research, The University of Shimane. E-mail: xiaozheng_liu@hotmail.com

horizontal wells and fracturing as well as to reduce capital expenditures. The external factors are mainly the environment surrounding the development of tight oil, such as preferential policies and crude oil prices. Good external factors are important for tight oil development (Sun et al., 2015). In America, to promote unconventional resource development, funding and preferential policies were implemented for unconventional resource development, including tight oil. Without the preferential policies of the Government of America, it is believed that conventional resource development, including tight oil, will not succeed. On the other hand, crude oil prices have a significant impact on oil development, including unconventional resources. For example, the situation of unconventional resource development changed significantly when crude oil prices started to rise in 2004. In March 2020, crude oil prices fell sharply, making tight oil production unprofitable.

These three uncertainties affect the economic evaluation of tight oil development. In particular, it is essential to reduce the cost of developing tight oil and to increase the economic efficiency of development by improving development technology and providing incentives including subsidies. To date, evaluations of tight oil development have focused on independent uncertainties and have not taken into account these uncertainties in a comprehensive manner.

In this study, we evaluate the economic efficiency of tight oil development in China under uncertainty. The features of this study are as follows. (1) To evaluate the economic efficiency of tight oil development, an improved analytical method utilizing the Net Present Value (NPV) method and real options method is proposed. (2) Distinguish clearly the economics of tight oil development by development areas under uncertainty. The analytical model presented in this study is not limited to tight oil development in China, but may give similar considerations and conclusions for unconventional oil resource development projects in other regions.

In an attempt to achieve this goal, this study will proceed as follows. First, an analytical method is presented, and an improved analytical method is proposed after examining the application and the problems of the NPV method and real options method. Next, in the economic evaluation of the development of the tight oil, the parameters including uncertainty are examined and set. Next, we examine the evaluation values obtained by the improved analytical method under assumed conditions to evaluate the economic efficiency of tight oil development and consider the promotion effect of preferential policies on tight oil development. Finally, the summary of this study is described.

2. Analytical Method

2.1. Traditional NPV Method and its Limitations

The NPV method is often used to evaluate the economic efficiency of large investment projects with high risks, including oil development. The basic idea of the NPV method is to evaluate an investment by discounting it to its present value in consideration of the time value of future cash flows expected to be invested, and it has been recognized as an investment that is profitable if the net cash flow is positive. The economic evaluation formula for investment using the NPV method is as follows.

$$NPV = \sum_{t=1}^{T} \frac{C_t}{(1+r)^t} - K \qquad (1)$$

In Formula (1), *NPV* is the economic evaluation value, C_t is the cash flow of the t year, *T* is the investment period, *r* is the interest rate, and *K* is the amount of investment such as initial capital investment.

The NPV method has a disadvantage in that it does not take into account the flexibility of investment decision-making at all, since the expected cash flow is fixed. Therefore, even if an unexpected situation may occur in the middle of a project, decision making such as investment timing or development change (renewal, reduction, and withdrawal) cannot be considered depending on the development environment. Also, the interest rate used to discount cash flows to present value is set higher by incorporating the risk if the uncertainty of future cash flows is predicted to be high. As a result, the present value of future cash flows is evaluated lower as the risk is higher. Although the NPV method provides an economic evaluation of investment decisions at a specific time and for specific investments, it does not indicate that it is more advantageous to change the timing of investments depending on changes in the development environment.

2.2. Application and Challenges of the Real Options Method

In recent years, as a way of dealing with flexibility, the real options method used in financial engineering has been used in economic efficiency assessments in areas with high uncertainty such as pharmaceuticals, industries with high flexibility such as materials, and resource development industries that require large initial investments. The real options method is considered to be effective because oil development including tight oil is highly uncertain and requires a large initial investment. The analysis of the real options method uses a variety of methods to calculate the value of options, allowing the selection of appropriate calculation methods depending on the characteristics of different projects and can be divided into discrete-time and continuous-time types.

2.2.1. Discrete-time Types

The discrete-time types evaluation methods include the binomial model, the ternary model, the quaternary model, and the multinomial tree, and the binomial model is often used. The binomial model is a method for estimating the present value of the investment when the investment activity is in good condition (probability of a rise in present value) and the present value when the investment activity is in bad condition (probability of a decline in present value), and calculating the economic efficiency evaluation value of the real options based on these two scenarios to derive the evaluation value. For example, the formula for the one-period binomial model is as follows.

$$C = \frac{PC^{+} + (1-P)C^{-}}{1+r}, \left(P = \frac{(1+r)V - V^{-}}{V^{+} - V^{-}}\right) \qquad (2)$$

In Formula (2), *C* is the economic valuation value of the real options, *P* is the risk-neutral probability, C^{+} and C^{-} are the present value in good times and the present value in bad times, *V* is the total cash flow, *V+,* and *V-* are the cash flow in the first period in good times and the cash flow in the first period in bad times respectively, and *r* is the interest rate.

The advantage of the binomial model is that it can be applied to analyses that assume all types of options due to the lattice structure. On the other hand, since the binomial model is a discrete inference model, the theoretical value of the options cannot be determined accurately (Shinoda, 2006).

Application of the binomial model in oil and natural gas generally uses the drilling success rate to predict two scenarios and to calculate an estimate for each (Planning and Research Department of Petroleum Corporation, 2002). In the development of conventional oil and natural gas, the method of binomial model is considered to be suitable because it has been developed over a long period, has a wide knowledge and experience, and can predict the drilling success rate in risk analysis. On the other hand, in the development of unconventional oil and natural gas, the history of development is short and it is difficult to predict the success rate of drilling. Also, when two scenarios (rise in present value) are predicted using the fluctuation rate of crude oil prices, they are regarded as the value evaluation of financial futures and are not reflected in the economic efficiency of tight oil development. This suggests that the binomial approach is inadequate for the economy of the current stage of tight oil development.

2.2.2. Continuous-time Types

Continuous-time types evaluation methods include the Black-Scholes model and the Monte Carlo simulation. Among them, the Black-Scholes model is often used. The Black-Scholes model developed by Myron S. Scholes and Fisher Black had the following formula.

$$C = SN(d_1) - Ke^{-rT}N(d_2) \qquad (3)$$

In Formula (3), *C* is the economic valuation value of the real options, *S* is the present value, *K* is the strike price, *r* is the interest rate, and *T* is the investment period. Further, since σ is the volatility and the economic evaluation value of the real options in Formula (3) is calculated, the standard normal distribution functions *N (d1)* and *N (d2)* are shown below.

$$d_1 = \frac{\ln(S/K) + (r + \sigma^2/2)T}{\sigma\sqrt{T}}$$

$$d_2 = \frac{\ln(S/K) + (r - \sigma^2/2)T}{\sigma\sqrt{T}}$$

Formula (3) does not pay dividends from the underlying asset. Once the five parameters of present value, strike price, interest rate, investment period, and volatility are known, the economic valuation of tight oil development is calculated. The five parameters are described below.

The present value (*S*) is the price of the underlying asset. The present value of oil development is the total development revenue minus operating expense and taxes, which varies from year to year.

The strike price (*K*) is also called the initial investment amount invested in the project. The initial investment in oil development is mainly spent on drilling and fracturing of wells (CAPEX: capital expenditure).

The interest rate (*r*) is the interest rate on government bonds and other safe-haven bonds based on the investment period. This is because the face value increases as the interest increase with time after the purchase of the security bond, and the higher the interest rate of the security bond, the higher the real option value.

The investment period (T) is the period of the investment and can be adjusted to the tiered options. In general, the longer the investment period, the higher the value of the options. However, in the case of tight oil development, this is not limited to the exponential decrease in production.

The volatility (σ) is the investment risk and is reflected in the standard deviation of the return rate of the return. The greater the volatility, the greater the risk, and the higher the real options valuation. The volatility can be estimated from the cash flows of development projects or quoted from the volatility of similar projects in the past. The biggest advantage of the Black-Scholes model is that you can easily calculate the real options value by obtaining five parameters. It is also expected that modifications to the Black-Scholes model will enable its application to economic evaluation, including investment in oil development.

On the other hand, several problems remain in the analysis of the Black-Scholes model of oil development. For example, (1) among the many uncertainties, the valuation of the present value of an options investment is integrated into only five parameters, and the validity of the valuation model is questioned. (2) Crude oil prices and oil reserves are not reflected, and they are concentrated in the volatility of a single scale of probability theory, which is not necessarily appropriate for economic evaluation. (3) The geological conditions of oil fields are extremely complex, and it is difficult to estimate volatility. In this case, a new problem arises in how to set the volatility. (4) Since uncertainty always exists and there is a time lag between the decision of development investment and the occurrence of investment, the economic evaluation cannot be maximized in practice. (5) An overestimated value may be presented. When calculating the value of options, $N(d_1)$ becomes zero before $N(d_2)$, so the real options value only approaches zero and does not become negative. Therefore, the evaluation value by the real options method is higher than that by the NPV method.

2.3. Previous Studies and Proposals for Improved Analytical Method

Studies on the economic evaluation of unconventional resource development including tight oil in China have been increasing since 2012. For example, Liu et al. (2014) described the characteristics of tight oil development and the importance of economic efficiency evaluation and estimated that the economic efficiency of development could be achieved by reducing drilling costs by evaluating the economic efficiency of development using the NPV method in the concentrated zone of tight oil in the Songliao Basin Jinbao Oilfield, without taking into account the reduction rate of tight oil production. Huang et al. (2016) proposed an evaluation method for the developing economy of unconventional oil and natural gas in three rankings based mainly on geological characteristics. Ning et al. (2017) evaluated the economics of tight oil development in the Changqing Oilfield by selecting reservoirs in the core area, focusing on the horizontal section of the horizontal well and the number of fracturing stages related to capital expenditure, setting three assumed price cases ($40 per barrel, $60 per barrel, $80 per barrel), and estimated the economics of development using the NPV method. Hu et al. (2018) proposed that the following six factors are important for the economy of tight oil development: (1) discovery of a new oil reservoir in a mining site that has successfully produced crude oil, (2) economic evaluation and development of the core area, (3) increased oil extraction through refracturing, (4) reduction of capital expenditures through optimization of drilling and finishing techniques, (5) hedging transactions, and (6) associated gas extraction.

These studies were limited to economic assessment using the NPV method and geological assessment in the core area. As the development of tight oil has high risks and opportunities, the uncertainty of development is not reflected in the economic evaluation.

On the other hand, the real options method is a developing evaluation method for oil development, and its theoretical research and practical application are steadily progressing. Options applications in oil development include building new models based on options theory and using the NPV and real options methods (Black-Scholes model).

Previous studies have attempted to use the real options model in various ways. For example, an attempt to add two evaluation factors, recoverable reserves, and oil prices, to the real options model (Luo and Wang, 2007; Li and Liu, 2014), would reflect development risks but would not be appropriate for assessing the economics of tight oil development. This is because minable reserves are generally evaluation factors using the economic evaluation of conventional oil and are not appropriate for the economic evaluation of tight oil development. The risk of recoverable reserves in tight oil development is limited, but the risk of production in areas where recoverable reserves are confirmed is higher and more important. Also, the economic efficiency of oil development was evaluated by adding evaluation factors such as investment remuneration rate to the options scale (Chen et al., 2014; Wang and Zhang, 2017). Since the history of tight oil development is too short to predict the investment reward rate, it is considered inappropriate to use the investment reward rate in the economic evaluation of tight oil development.

On the other hand, two main modifications utilize the NPV method and the real options method: (1) an amendment that modifies the Black-Scholes model and then combines the NPV method (Zhang, 2002), and (2) an amendment that directly combines the NPV method and the real options method (hereinafter the combination method) (Ju and Sun, 2011; Ma and Cai, 2014; Cui et al., 2018). The basic idea of the combination method is to add an option's premium to the conventional NPV method to obtain the value of flexibility, and even if the NPV evaluation value is negative, if the total value obtained by adding the real options evaluation value is positive, the timing of development investment is derived as a judgment condition. Although the combination method is a useful method for evaluating the economic efficiency of project development, if the economic efficiency evaluation of project development is double-counted, and especially if the evaluation value of the NPV method becomes positive, the economic efficiency evaluation value of project development will further expand and become overestimated.

In this study, we propose an improved analytical method using the NPV method and the real options method based on previous studies. The improved analytical method introduces an investment optimism coefficient, complements the two evaluation methods, and is reflected in project flexibility. The formula for the improved analytical method is as follows.

$$\begin{aligned} CNPV &= (1-\alpha)NPV + \alpha C \\ &= (1-\alpha)\left(\sum_{t=1}^{T}\frac{C_t}{(1+r)^t} - K\right) + \alpha(SN(d_1) - Ke^{-rT}(d_2)) \end{aligned} \quad (4)$$

In Formula (4), *CNPV* is the economic evaluation value by the improved analytical method, *NPV* is the economic evaluation value by the NPV method, *C* is the economic evaluation value by the real options method (Black-Scholes model), and α is the Investment Optimism Coefficient. The economic evaluation value by the improved analytical method is an economic evaluation value by the NPV method when the Investment Optimism Coefficient $\alpha = 0$, and an economic evaluation value by the real options method when the Investment Optimism Coefficient $\alpha = 1$.

The Investment Optimism Coefficients in Formula (4) evaluate the three development environments of geology, technology, and external, and set the respective Geological Investment Optimism Coefficient (α_1), Technical Investment Optimism Coefficient (α_2), and External Investment Optimism Coefficient (α_3) to quantify the decision of investment will. A good development environment will enable the production of tight oil to be profitable and its development to proceed. An Investment Optimism Coefficient of 1 is used to give a very good opportunity in the development environment. On the other hand, if you give a very disadvantageous opportunity in a development environment, the Investment Optimism Coefficient is 0. In this way, the uncertainty of tight oil development can be reflected in the Investment Optimism Coefficient to evaluate the economic efficiency of the development.

The novelty of the proposed improved analytical method includes the following three points. (1) Avoiding underestimation by the NPV method and overestimation by the real options method, it is possible to capture the roles of both static revenue valuation (NPV method) and dynamic profitability valuation (real options method). (2) To capture the role of the NPV and real options method, we introduce a variable investment optimism coefficient as a weight rather than a fixed weighted average, reflecting greater flexibility in the development process. (3) By introducing a weighted average of Investment Optimism Coefficient, it is possible to avoid double counting of valuation values when compared with the combination method, and the large value obtained by the real options method is less affected overall.

3. Parameters Review and Setting

In the economic evaluation of tight oil development using the proposed improved analytical method, several parameters are set as follows. Besides, examples of development in China are cited from references to obtain parameter settings.

3.1. Technological Progress and Capital Expenditure

Over the past ten years, the capital expenditure per unit in America has been decreasing due to improvements in development technology, and the development of tight oil has been promoted. As a result, the economic value of tight oil development can be increased and further development projects can be promoted. Drilling horizontal wells in America currently costs $1.8 million to $2.6 million (Yang et al., 2019). On the other hand, in China over the past few years, the acquisition of technology for developing tight oil and the domestic production of development equipment have reduced capital expenditures and increased the economic efficiency of developing tight oil. For example, in recent years, drilling costs at the Jilin Oilfield have been reduced by 40% to 55% (Guo et al., 2019).

In this study, we refer to the Songliao Basin Jinbao Oilfield as an example of tight oil development in China. The plan for the development of the "Bao 1" Well belonging to the Jinbao Oilfield is to carry out 8 stages of fracturing in the horizontal well (length of the horizontal section: 700 m). "Bao 1" Well capital expenditure RMB 36,935,000, or about US $5.55 million (RMB 6.65 per $1) (Liu et al., 2014).

Therefore, referring to the above-mentioned circumstances of tight oil development, three scenarios of capital expenditures (strike price) are established. Specifically, $5.55 million is set Baseline Scenario, $4.16 million as a 25% Improvement Scenario, and $2.78 million as a 50% Improvement Scenario. The capital expenditure of a single tight oil well depends on the reservoir to be developed. Also, capital expenditures for oil fields containing tight oil vary among developers in the same development area. In this study, no distinction is made.

3.2. Crude Oil Prices

Crude oil prices are set in three cases. Specifically, from 2000 to 2019 the average annual oil price in the international oil market (WTI: West Texas Intermediate) will be set at $62 per barrel for Oil Price Reference case, the lowest at $26 per barrel for Low Oil Price case, and the highest at $100 per barrel for High Oil Price case.

3.3. Tax, Subsidies, and Preferential Policies

Taxes related to oil development in China include resource tax, tax increase, corporate income taxes, mining royalty, and special oil gain levy. The resource tax is set at 5%, the tax increase at 17%, and the corporate income taxes at 25%. The mining royalty will be set at 6 levels: (1) exemption of 1 million tons or less of annual gross production; (2) exemption of 1 million to 1.5 million tons at 4%; (3) 1.5 million to 2 million tons at 6%; (4) 2 million to 3 million tons at 8%; (5) 3 million to 4 million tons at 10%; and (6) over 4 million tons at 12.5%. The special oil gain levy be classified into 6 categories: (1) no more than $65 per barrel of oil; (2) $65 to $70 (Include upper limit) for 20% (deductions: 0); (3) $70 to $75 (include upper limit) for 25% (deductions: $0.25/bbl); (4) $75 to $80 (include upper limit) for 30% (deductions: $0.75/bbl); (5) $80 to $85 (include upper limit) for 35% (deductions: $1.5/bbl); and (6) more than $85 for 40% (deductions: $2.5/bbl). If taxes are not reduced or exempted, the above taxes related to Chinese oil development will be deducted in calculating the present value.

Subsidies for unconventional resource development were provided by the Chinese government to promote unconventional natural gas (coal bed gas and shale gas). From 2012 to 2015, subsidies for shale gas developers were calculated based on a subsidy standard of RMB 0.4 for every 1 m3 of shale gas extracted, which reached 15% of the wholesale price of natural gas at the time and was then reduced. In this way, subsidies for coal seam gas and shale gas development are provided mainly for three years. In the future, for tight oil development, subsidies for a period of up to three years from the designated year and up to 15% of the crude oil prices may be provided.

In our previous study (Liu, 2020), we analyzed several preferential policies in multidimensional criteria. As a result, it was suggested that the economic efficiency of tight oil development would be enhanced by providing development subsidies when crude oil prices fell below a certain level and by providing tax incentives when crude oil prices rose. Also, the combination of development subsidy and tax incentives has a better incentive. For this reason, in this study, development subsidies are provided at crude oil prices of $62/bbl (include $62/bbl) or less and for a certain period (from the first to the third year of development) of $9.3/bbl (average crude oil prices $62 x 15%). As for tax breaks, part of the tax payable for oil development (resource tax, tax increase, and special oil gain levy) will be exempted during the development period (five years) when the crude oil prices are $62/bbl or more. In the evaluation of policy factors in this study, we adopt a single preferential policy and do not combine development subsidies with tax incentives.

3.4. Development Revenue and Present Value

The present value in oil development is the total development revenue minus operating expense and taxes, which varies from year to year. The items related to gross development revenue are production volume and production decline rate for each development area.

3.4.1. Development Areas

Tight oil development is underway in China. According to the actual development situation in China, the production volume of the highest tight oil in the development area averaged 20 tons per day in the first year (Yang et al., 2013; Wu et al., 2014). The average daily development area for the first year is around 10 tons (Fan et al., 2015; Zeng et al., 2015; Ning 2015) and 10 tons or less (Song et al., 2015). Tight oil production is related to reservoir formation conditions, physical properties, and fracturing, and is also related to development revenues.

Therefore, to clarify the economic efficiency of each development area, based on the status of tight oil development in China, we will divide the development area into three development areas. Specifically, it is set that the oil production volume of a single well in the first year is 20 tons per day in Core Area 1, 10 tons per day in Core Area 2, and 5 tons per day in Favorable Area. Also, there are many cases in which productivity is affected due to the existence of considerable heterogeneity in the same reservoir, and such factors are not considered in this study.

3.4.2. Production Decline Rate

Unlike conventional oil, the production decline rate of tight oil tends to decrease exponentially. In other words, the production of tight oil peaks in the first few weeks and months after production, and then decreases rapidly. The average rate of decline in production in the three areas driving America tight oil production (Bakken-Three Forks, Eagle Ford, Permian Basin) is estimated to be 49% after one year, 38% after two years, 30% after three years, 20% after four years, and 20% after five years (Leonardo, 2013). This production behavior of tight oil affects the income from the development of tight oil. Likely, the well will not have development value after five years of production due to reduced production. Measures to address the impact of reduced production of a single well include continuous drilling in the same area and refracturing of the same well.

In China, research is being conducted to understand the production characteristics of tight oil. The production behavior of tight oil is related to geological conditions, the length of horizontal sections of horizontal wells, and the number of stages of fracturing, and is divided into three stages: "initial", "transitional period", and "anaphase" (Wang, 2016; Wei et al., 2016; Ning et al., 2017). In "initial", after two to six months, production peaks and then decreases rapidly (Bi et al., 2018). On the other hand, in "transitional period", the output is 50% to 70% of that at the start of production, and the maintenance time is three to five years (Wu et al., 2018). Then it enters the "anaphase" phase of production, where it is around 10% to 20% of the initial production (Xu et al., 2016; Wei et al., 2018). The production characteristics of such tight oil in China are about the same as those in America.

Therefore, in calculating the amount of tight oil production, the rate of production decline for each fiscal year is set in consideration of the characteristic of an exponential decrease from the start of production. Concretely, development areas are not distinguished, and they are 50% in the 2nd year, 38% in the 3rd year, 30% in the 4th year, and 20% in the 5th year.

3.4.3. Operating Expenses

The operating expense of tight oil development varies from an oil field to an oil field, is mainly the cost per unit of production. Operating expenses include production and operation costs associated with oil will production, such as labor, management, transportation, and facility maintenance costs associated with oil will production, and in some cases, production bonuses are paid. Therefore, referring to the operating expense of the Jinbao Oilfield of $73.2/ton (RMB 486.5/ton; RMB 6.65 per $1) (Liu et al., 2014), set the operating expense at $9.9/barrel (0.135 tons per barrel).

3.5. Investment Optimism Coefficient

The Investment Optimism Coefficient can be divided into the Geological Investment Optimism Coefficient (α_1), the Technical Investment Optimism Coefficient (α_2), and the External Investment Optimism Coefficient (α_3). Specifically, they are as follows.

First, we take the Geological Investment Optimism Coefficient (α_1) is calculated. In setting the geologic Investment Optimism Coefficient, based on the above three development areas, $\alpha_1 = 1$ in Core Area 1, $\alpha_1 = 0.5$ in Core Area 2, and $\alpha_1 = 0$ in Favorable Area.

Next, we take the Technical Investment Optimism Coefficient (α_2) is calculated. Because the permeability and porosity of the tight oil reservoir are low, the drilling well cannot produce commercial quantities of tight oil. To increase the economic efficiency of tight oil development, multi-stage fracturing is required in horizontal wells. In recent years, a horizontal length of 4,572 m (15,000 ft) has been achieved in shale drilling in America (Shale Gas Reporter, 2017), and 60 stages of fracturing have been achieved. In China, on the other hand, horizontal oil well drilling in the shale layer achieved development results in 2014 for a 2,100 m horizontal section (Ye, 2014), and 30 stages of fracturing were completed in 2016 (Weng et al., 2015). Therefore, in setting the Technical Investment Optimism Coefficient, assuming that the US tight oil development level is 1, the Technical Investment Optimism Coefficient in China is $\alpha_2 = 0.5$, and the Technical Investment Optimism Coefficient for the development example (length of the horizontal section: 700 m; fracturing: 8 steps) in this paper is 0.2.

Finally, we take the External Investment Optimism Coefficient (α_3). In setting the External Investment Optimism Coefficient, the Investment Optimism Coefficient is further divided into crude oil prices and development policies. Based on the above three oil price cases, the Investment Optimism Coefficient (α_{31}) of crude oil prices are assumed to be $\alpha_{31} = 1$ for High Oil Price case, $\alpha_{31} = 0.5$ for Oil Price Reference case, and $\alpha_{31} = 0$ for Low Oil Price case. On the other hand, based on the development policy for tight oil development, the Investment Optimism Coefficient of development policy is $\alpha_{32} = 1$ for deregulation, $\alpha_{32} = 0.5$ for tax payment as it is, and $\alpha_{32} = 0$ for stricter regulations. Since there is currently no preferential development for tight oil development in China, the Investment Optimism Coefficient of development policy is 0.5.

Based on the above discussion, Table 1 shows the Investment Optimism Coefficient for investment taking into account geological, technological, and external factors.

Table 1. Investment Optimism Coefficient with geological, technical, and external factors

Geological Investment Optimism Coefficient (α_1)	Technical Investment Optimism Coefficient (α_2)	External Investment Optimism Coefficient (α_3)		Investment Optimism Coefficient (α)
		Crude oil prices (α_{31})	Development policy(α_{32})	
Core Area 1: 1	0.2	Oil Price Reference case: 0.5	0.5	0.6
		Low Oil Price case: 0	0.5	0.5
		High Oil Price case: 1	0.5	0.7
Core Area 2: 0.5		Oil Price Reference case: 0.5	0.5	0.4
		Low Oil Price case: 0	0.5	0.3
		High Oil Price case: 1	0.5	0.5
Favorable Area: 0		Oil Price Reference case: 0.5	0.5	0.2
		Low Oil Price case: 0	0.5	0.2
		High Oil Price case: 1	0.5	0.3

3.6. Other

3.6.1. Investment Period

The investment period shall be five years. In petroleum development projects, no additional investment will be made for a single well within five years because the amount of capital investment is not fixed. To reduce production over the next five years and beyond, investment such as refracturing will be carried out to increase oil production and its economic value will enter another optional stage. Dividends shall not be paid during the five-year development period.

3.6.2. Interest Rate

Interest rates refer to United States government bonds. As of January 6, 2020, the five-year interest rate on United States treasuries was 1.75% and the yield was 1.57%. Refer to it and set the interest rate of 1.70%.

3.6.3. Volatility

The volatility, the profit risk, needs to be estimated from the cash flow of the tight oil development project. Therefore, the volatility is set at 50% for simplicity.

4. Results and Discussion

Before the economic evaluation of tight oil development, the validity and applicability of the improved analytical method will be confirmed. Next, technical factors are evaluated, and then the effects of preferential policies on tight oil development are discussed.

4.1. Validity and Applicability of the Improved Analytical Method

To confirm the validity and applicability of the improved analytical method, in the Baseline Scenario (initial investment of $5.55 million) of the developed technology, four evaluation methods (NPV method, real options method, combination method, and improved analytical method) are compared and examined. Specifically, three oil price cases, namely Oil Price Reference case, Low Oil Price case, and High Oil Price case, are set and economic evaluation values in three oil price cases are calculated for each development area (Core Area 1, Core Area 2, and Favorable Area), and then they are compared, examined and considered.

4.1.1. Oil Price Reference Case

In the Oil Price Reference case, economic evaluation values for five years are calculated for each of the four evaluation methods for three development areas, and the results are shown in Table 2. Based on the results in Table 2, the economic evaluation of the three development areas is as follows.

Table 2. The economic evaluation of tight oil development in Oil Price Reference case (Unit: ten thousand USD)

Development areas	Evaluation methods	Year 1	Year 2	Year 3	Year 4	Year 5
Core Area 1	NPV method	-307	-185	-94	-23	24
	Real Options method	5	62	143	221	283
	Combination method	-302	-123	49	198	307
	Improved analytical method	-120	-37	48	123	179
Core Area 2	NPV method	-431	-370	-324	-289	-266
	Real Options method	0	7	28	56	83
	Combination method	-431	-363	-296	-233	-183
	Improved analytical method	-259	-219	-183	-151	-126
Favorable Area	NPV method	-493	-462	-440	-422	-410
	Real Options method	0	0	4	11	19
	Combination method	-493	-462	-436	-411	-391
	Improved analytical method	-394	-370	-351	-335	-324

(1) The economic evaluation of Core Area 1 in the Oil Price Reference case has three characteristics. First, although the economic evaluation values differ according to the four evaluation methods, they are all positive within five years, suggesting that they have the economic efficiency of Core Area 1. Second, by introducing the value of options, the suggested development benefits of the three valuation methods are accelerated by the NPV method. Also, the period in which the improved analytical method generates development benefits is the third year, which is the same as the evaluation value of the combination method. As a result, the improved analytical method can take advantage of the characteristics of the NPV method and the real options method and is considered to be applicable. Thirdly, the higher the value obtained by the combination method exceeds the break-even value (zero), the greater the profit and the less stable it is. On the other hand, since the improved analytical method introduces a weighted average, it avoids double counting such as the combination method, and provides a gradual transition value, which is considered to be valid.

(2) The development economy of Core Area 2 in the Oil Price Reference case can be found not to exist in the current development environment. The real options estimates are positive within five years, whereas the other three estimates are negative. The evaluation value obtained by the real options method is also an evaluation value of $\alpha = 1$ in the improved analytical method, and it cannot reasonably explain the timing of development profit which is

indicated earlier than the other three evaluation methods unless further improvement of development environments such as improvement of development technology and preferential policies is indicated. Based on these facts, it is assumed that the development economy of Core Area 2 cannot be expected at the present stage, and development investment will not be made. On the other hand, since the economic evaluation value obtained by the improved analytical method in the 5th year is $-126 ten thousand, which is not far from the break-even value (zero), the value will likely change from negative to positive due to improvements in the development environment, including improvements in development technology. As a result, the improved analytical method can derive more value from buried development than the combination method and provide important suggestions.

The development economy of Favorable Area in the Oil Price Reference case can be found not to exist in the current development environment. Economic evaluation values for the fifth year are negative values for evaluation methods other than the real options method. Of these, the economic evaluation value obtained by the combination method and improved analytical method is $-391 ten thousand and $-324 ten thousand respectively, which are far from break-even. To achieve the economic benefits of tight oil development, it is necessary to further improve the development environment by improving development technology and presenting preferential policies.

4.1.2. Low Oil Price Case

In the Low Oil Price case, economic evaluation values for five years are calculated for each of the four evaluation methods for three development areas (Core Area 1, Core Area 2, and Favorable Area), and the results are shown in Table 3. Based on the results in Table 3, the economic evaluation of the three development areas is as follows.

The developed economies of the three development areas in the Low Oil Price case are found not to exist in the present development environment. In the five-year investment period, valuation values obtained by the three valuation methods other than the real options method are far from the break-even value. The evaluation values obtained by the real options method are shown not to be large. As a result, the economic efficiency of development cannot be expected in the present development environment, and to obtain the economic efficiency of development, it is considered that one of the options is to choose the options of postponing development and carrying out tight oil development at an advantageous time.

Table 3. The economic evaluation of tight oil development in Low Oil Price case (Unit: ten thousand USD)

Development areas	Evaluation methods	Year 1	Year 2	Year 3	Year 4	Year 5
Core Area 1	NPV method	-481	-445	-418	-397	-383
	Real options method	0	1	6	16	29
	Combination method	-481	-444	-412	-381	-354
	Improved analytical method	-241	-222	-206	-191	-177
Core Area 2	NPV method	-518	-500	-487	-476	-469
	Real options method	0	0	1	2	5
	Combination method	-518	-500	-486	-474	-464
	Improved analytical method	-363	-350	-340	-333	-327
Favorable Area	NPV method	-537	-528	-521	-516	-512
	Real options method	0	0	0	0	1
	Combination method	-537	-528	-521	-516	-511
	Improved analytical method	-429	-422	-417	-412	-409

4.1.3. High Oil Price Case

In the High Oil Price case, economic evaluation values for five years are calculated for each of the four evaluation methods for three development areas, and the results are shown in Table 4. Based on the results in Table 4, the economic evaluation of the three development areas is as follows.

Table 4. The economic evaluation of tight oil development in High Oil Price case (Unit: ten thousand USD)

Development areas	Evaluation methods	Year 1	Year 2	Year 3	Year 4	Year 5
Core Area 1	NPV method	-212	-43	83	181	245
	Real options method	22	140	268	382	467
	Combination method	-190	97	351	563	712
	Improved analytical method	-48	85	212	322	400
Core Area 2	NPV method	-383	-299	-236	-187	-155
	Real options method	1	21	63	110	152
	Combination method	-382	-278	-173	-77	-3
	Improved analytical method	-191	-139	-87	-39	-2
Favorable Area	NPV method	-469	-427	-396	-371	-355
	Real options method	0	2	10	24	40
	Combination method	-469	-425	-386	-347	-315
	Improved analytical method	-328	-298	-274	-253	-237

(1) The economic evaluation of Core Area 1 in the High Oil Price case has confirmed three points. First, although the economic evaluation value differs according to the four evaluation methods, a high evaluation value is shown. Second, the year in which the improved analytical method yields the development benefit is one year earlier than the NPV method (year 3) because it includes the value of the options and is the same year as the combination method (year 2). Thus, the applicability of the improved analytical method can be judged. Third, due to the introduction of a weighted average of the coefficient of investment optimism, the values obtained by the improved analytical method show a gradually increasing trend, and overestimation can be avoided by exceeding the break-even value when compared with the combination method. Thus, the validity of the improved analytical method can be judged.

(2) It can be seen that the economy of Core Area 2 in the High Oil Price case does not exist in the present development environment. Economic evaluation values are negative within five years by three evaluation methods other than the real options method. These results suggest that the development economy of Core Area 2 cannot be expected in the current development environment and that no development investment will be made. On the other hand, the estimated values obtained by the improved analytical method and combination method at five years are $-2 and $-3 ten thousand respectively, both approaching break-even values. If the development environment improves, such as by improving development technologies and offering preferential policies, development value can shift from a negative value to a positive value, thereby bringing out economic efficiency. Thus, the improved analytical method is considered to be applicable without losing the characteristics of the combination method.

(3) The economy of Favorable Area in the High Oil Price case is found not to exist in the present development environment. Economic estimates for year 5 are $-355 ten thousand for the NPV method, $ 40 ten thousand for the real options method, $-315 ten thousand for the combination method, and $-237 ten thousand for the improved analytical method. Evaluation values obtained by the three evaluation methods other than the real options method are negative values. To improve the economic efficiency of development, it is necessary to further improve the development environment by improving development technologies and presenting preferential policies.

The validity and applicability of the improved analytical method are confirmed by comparing and examining the above four evaluation methods. The proposed improved analytical method reflects the value of options in the economic evaluation of tight oil development and provides useful suggestions.

4.2. Technical Factors

The impact of technological developments on the economics of tight oil development will be quantitatively assessed based on the improved analytical method and related settings described above, focusing on development investments directly related to economic efficiency. Specifically, we calculate and examine the economic evaluation values of three development technology scenarios for each development area: Baseline Scenario, 25% Improvement Scenario, and 50% Improvement Scenario.

4.2.1. Evaluation Results of Baseline Scenario

Economic evaluation values for the three development areas in the development technology base scenario (initial investment of $5.55 million) are shown in Table 5. In Core Area 1, the economic evaluation values in the Oil Price Reference case and High Oil Price case have already become positive values and are shown to have economic efficiency of development. On the other hand, in the Low Oil Price case, the economic evaluation value is negative, and it is recognized that there is no economic efficiency of development. For Core Area 2 and Favorable Area, the economic evaluation values are negative, indicating that even in the three oil price cases, there is no economic value for development. However, in the High Oil Price case in Core Area 2, the economic efficiency rating is $-2 ten thousand, which is close to the break-even point (zero). Therefore, the economic value of the development is expected to increase by reducing development investments and improving the external environment.

Table 5. The economic evaluation values for each development area in Baseline Scenario

Development areas	Oil price cases	Economic evaluation values (ten thousand USD)
Core Area 1	Oil Price Reference case	179
	Low Oil Price case	-177
	High Oil Price case	400
Core Area 2	Oil Price Reference case	-126
	Low Oil Price case	-327
	High Oil Price case	-2
Favorable Area	Oil Price Reference case	-324
	Low Oil Price case	-409
	High Oil Price case	-237

4.2.2. Evaluation Results of 25% Improvement Scenario

The estimated economic efficiency of the three development areas in the 25% Improvement Scenario ($4.16 million in capital expenditure) is shown in Table 6. The economies of development of the Oil Price Reference case and High Oil Price case in Core Area 1 are further enhanced compared to the base scenario for development technology due to reduced initial investment. In Core Area 1 for the Low Oil Price case, the economic efficiency of development has increased, but there is no economic efficiency due to dependency. As for Core Area 2, the economic efficiency of development has been achieved in the High Oil Price case, but not in the Oil Price Reference case and Low Oil Price case. As for Favorable Area, the three oil price cases also indicate that development is not economical. On the other hand, in the Oil Price Reference case for Core Area 2, since the economic efficiency evaluation value is $-33 ten thousand and it is not far from the break-even point (zero), further technical progress can convert the economic efficiency evaluation value from a negative value to a positive value, which may bring about the economic efficiency of development.

Table 6. The economic evaluation values for each development area in the 25% Improvement Scenario

Development areas	Oil price cases	Economic evaluation values (ten thousand USD)
Core Area 1	Oil Price Reference case	265
	Low Oil Price case	-103
	High Oil Price case	487
Core Area 2	Oil Price Reference case	-33
	Low Oil Price case	-229
	High Oil Price case	85
Favorable Area	Oil Price Reference case	-211
	Low Oil Price case	-298
	High Oil Price case	-135

4.2.3. Evaluation Results of 50% Improvement Scenario

The estimated economic efficiency of the three development areas in the 50% Improvement Scenario (initial investment of $2.78 million) is shown in Table 7. In Core Area 1, the economy of development in the Oil Price Reference case and High Oil Price case is further enhanced by the reduction of the initial investment. On the other hand, the economic efficiency of development in the Low Oil Price case is dependent and has no economic efficiency. For Core Area 2, development economics can be achieved in the High Oil Price case, but not yet in the Oil Price Reference case and Low Oil Price case. As for Favorable Area, even in the three oil price cases, economic development is not economical, but in the High Oil Price case, the economic evaluation value is $-32 ten thousand, and it is not far from the break-even point (zero). Therefore, if the external environment for development becomes more influential, economic development is expected to occur.

Table 7. The economic evaluation values for each development area in 50% Improvement Scenario

Development areas	Oil price cases	Economic evaluation values (ten thousand USD)
Core Area 1	Oil Price Reference case	359
	Low Oil Price case	-25
	High Oil Price case	584
Core Area 2	Oil Price Reference case	63
	Low Oil Price case	-130
	High Oil Price case	178
Favorable Area	Oil Price Reference case	-98
	Low Oil Price case	-164
	High Oil Price case	-32

4.2.4. Consideration of the Three Scenarios

(1) The economic efficiencies of development are improved by the advance of development technology, and the difference in the effect to enhance the economic efficiency by the development areas are recognized. Core Area 1 is the most promising, and aside from the drop in crude oil prices (Low Oil Price case), it has the economic efficiency of development and can bring about the expansion of economic efficiency effects by improving development technology. Core Area 2 does not have development economics under Baseline Scenario (three oil price cases), but it can achieve development economics under 25% Improvement Scenario (High Oil Price case), and it can enhance development economics under 50% Improvement Scenario (High Oil Price case and Oil Price Reference case). On the other hand, since the productivity of tight oil is not good in Favorable Area, the economic efficiency of development cannot be achieved even under 50% Improvement Scenario, and unless other measures are taken, the economic efficiency of development will be lost.

(2) Crude oil prices are an important point, and it has been shown that the economic efficiency of development has produced multiple effects due to both advances in development technology and oil prices. If crude oil prices exceed a certain level, the economic efficiency of development will be enhanced by promoting development technologies such as reducing capital expenditures. On the other hand, it is expected that the economic efficiency of development will be enhanced by the development technology advancing during the period of low crude oil prices, but the economic efficiency of development will not be secured. To achieve economic development efficiency, one of the options is to choose the options of postponing the development of tight oil and developing tight oil at an advantageous time.

(3) Long-term tight oil development will result in lower costs and increase the economic value of tight oil development. Tight oil development is possible because of advances in developing technologies such as horizontal wells and fracturing. These advances in development technology led to a reduction in capital expenditures and an increase in production, which in turn led to an increase in the economic value of the development. Further, in the development areas where the economic value of the development is expected, further progress in developing technology can be expected to enhance the economic efficiency of tight oil development.

4.3. Policy Factors

In the evaluation of policy factors, in addition to the above three development technology scenarios, the promotion effects of preferential policies are evaluated and considered. Specifically, development subsidy ($9.3 per barrel) will be provided in the Low Oil Price case and Oil Price Reference case, and tax incentives will be provided in the High Oil Price case (exemption from resource tax, tax increase, and special oil gain levy).

4.3.1. Evaluation Results of Oil Price Reference Case

Table 8 shows the economic evaluation values of tight oil development in the development subsidy for the Oil Price Reference case. Core Area 1 has the economic efficiency of development in the three development technology scenarios as well, and the economic efficiency of development is enhanced by providing the development subsidy. For Core Area 2, Baseline Scenario does not provide the economic benefits of development through development subsidy, whereas adding development subsidy to 25% Improvement Scenario for development technology would provide the economic benefits of development. Also, 50% Improvement Scenario in Core Area 2 has reached the level of development economics and enhances development economics by providing development subsidy. In Favorable Area, even if the development subsidy is proposed, economic evaluation values do not become positive, indicating that development is not economical.

Table 8. The economic analysis for each development area in the Oil Price Reference case (Unit: ten thousand USD)

Development areas	Development technology		Development subsidy
Core Area 1	Baseline Scenario	179	260
	25% Improvement Scenario	265	349
	50% Improvement Scenario	359	447
Core Area 2	Baseline Scenario	-126	-88
	25% Improvement Scenario	-33	7
	50% Improvement Scenario	63	106
Favorable Area	Baseline Scenario	-324	-305
	25% Improvement Scenario	-211	-191
	50% Improvement Scenario	-98	-77

4.3.2. Evaluation Results of Low Oil Price Case

Table 9 shows the economic evaluation value of tight oil development in the development subsidy for the Low Oil Price case. In Core Area 1, all three scenarios of development technology do not have development economics, but development economics becomes possible by presenting a development subsidy in addition to 50% Improvement Scenario. On the other hand, in Core Area 2 and Favorable Area, providing development subsidies does not bring about economic development benefits. As a result, preferential policies in the Low Oil Price case do not provide many economic benefits for the development of tight oil.

Table 9. The economic analysis for each development area in the Low Oil Price case (Unit: ten thousand USD)

Development areas	Development technology		Development subsidy
Core Area 1	Baseline Scenario	-177	-111
	25% Improvement Scenario	-103	-31
	50% Improvement Scenario	-25	53
Core Area 2	Baseline Scenario	-327	-292
	25% Improvement Scenario	-299	-192
	50% Improvement Scenario	-130	-92
Favorable Area	Baseline Scenario	-409	-391
	25% Improvement Scenario	-298	-279
	50% Improvement Scenario	-187	-168

4.3.3. Evaluation Results of High Oil Price Case

Table 10 shows the economic evaluation values of tight oil development in the tax incentives for the High Oil Price case. In Core Area 1, all three development technology scenarios have development economics, and also, if tax incentives are offered, development economics will increase and have a positive promotional effect. In Core Area 2, Baseline Scenario does not have the economic efficiency of development, but if tax incentives are offered, the economic efficiency of development is brought about. Also, the scenarios (25% Improvement Scenario and 50% Improvement Scenario) for improvement of development technology in Core Area 2 are shown to enhance the economic efficiency of development by expanding the economic efficiency evaluation value through tax incentives. In Favorable Area, tax incentives will be added to 50% Improvement Scenario to bring about economic benefits for development.

Table 10. The economic analysis for each development area in the High Oil Price case (Unit: ten thousand USD)

Development areas	Development technology		Tax incentives
Core Area 1	Baseline Scenario	400	677
	25% Improvement Scenario	487	774
	50% Improvement Scenario	584	879
Core Area 2	Baseline Scenario	-2	126
	25% Improvement Scenario	85	219
	50% Improvement Scenario	178	319
Favorable Area	Baseline Scenario	-237	-174
	25% Improvement Scenario	-135	-70
	50% Improvement Scenario	-32	36

4.3.4. Consideration of Three Oil Price Cases

The evaluation results of the above three oil price cases indicate that the economy of tight oil development can be improved through preferential policies such as tax incentives and development subsidies. Also, the development impact of preferential policies depends on oil prices, development areas, and the state of development technology. Specific promotion effects can be summarized as follows.

(1) Core Area 1 is a promising area for the development of tight oil, and except the Low Oil Price case, has the economy of development in the current technology (Baseline Scenario). Furthermore, the implementation of development subsidy in the Oil Price Reference case and tax incentives in the High Oil Price case will increase the economic efficiency of development and bring about good policy promotion effects. On the other hand, in the Low Oil Price case, the development effects promoted by preferential policies are not obtained.

(2) About Core Area 2, except for the Low Oil Price case, preferential policies, in addition to improvements in development technology, can provide economic benefits for development. In the Oil Price Reference case, the negative value of the economic efficiency evaluation value is converted to the positive value by the implementation of the development subsidy, and the policy promotion effect is observed. On the other hand, in the Low Oil Price case, even if development subsidies are provided, they cannot be converted from negative values to positive values, and no policy promotion effect is observed. On the other hand, in the High Oil Price case, the implementation of tax incentives will further enhance the policy promotion effect.

(3) As for Favorable Area, in the 50% Improvement Scenario for the High Oil Price case, the economic efficiency evaluation value approaches the break-even point (zero). Therefore, the implementation of tax incentives will change the negative value of the economic efficiency evaluation value to a positive value, which will have a policy promoting effect. On the other hand, in the Low Oil Price case and Oil Price Reference case, even if development subsidy is implemented, they cannot be converted from the negative value of economic efficiency evaluation value to the positive value and have no policy promoting effect. To promote tight oil development, it is necessary to present more favorable policies.

5. Conclusions

Economic assessment of tight oil development is an important part of providing information for decision making. In this study, an improved analytical method utilizing the NPV method and the real options method is used to evaluate the economic efficiency of tight oil development by taking an example of development in China. The results of the economic evaluation can be summarized as follows.

(1) The validity and applicability of the improved analytical method have been confirmed. Since the proposed improved analytical method introduces the real options value, it does not lose the characteristics of the combination method, and by weighting the variable Investment Optimism Coefficient, it reflects further flexibility in the process of the development project and avoids overestimation of the economic evaluation value such as the combination method.

(2) The economics of tight oil development is influenced by uncertainties such as geological, technological, and external factors, including policy factors, and have multiple effects. According to the results of the improved analytical method, the economy of tight oil development contributes to the progress of the development technology and has a policy promoting effect.

(3) The effect of policy promotion depends on the price of crude oil, the development areas, and the improvement of development technology, and the preferential policies for producing the economic efficiency of tight oil

development are limited. In Core Area 1, if the crude oil prices are maintained above a certain level, it has economic development efficiency and further enhances the economic development efficiency through preferential policies. In Core Area 2, when the crude oil prices fall below a certain level, the development economy cannot be obtained through preferential policies. On the other hand, in Favorable Area, the productivity of tight oil is not good, so the policy promotion effect will not reach the economic efficiency of development without further improvement of development technology.

(4) Tight oil development will bring long-term economic benefits. The choice of the option of delaying development when crude oil prices fall, improvement of development technology, and further expansion of the scope of preferential policies can be expected to improve economic efficiency.

Conflict of Interest

The author indicated no conflicts of interest.

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