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ORIGINAL PAPER

An economic evaluation method of coalbed methane resources during the target selection phase of exploration

Dong-Kun Luo[1] · Liang-Yu Xia[1]

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Abstract Because forecasting a development program during the target selection phase of exploration for coalbed methane (CBM) is impossible, the conventional method that relies on a conceptual (or detailed) development program cannot be used during the economic evaluation of CBM resources. Hence, this study focuses on establishing an economic evaluation model based on the characteristics of the target selection phase. The discounted cashflow method is applied to the construction of the model with the assumption that there is a uniform distribution of production wells. The computational error generated by the assumption is corrected by introducing a correction factor based on the production profile of single CBM wells. The case study demonstrates that the blocks lacking economic value can be screened out, and the most advantageous targets can be found by computing the resource values in the best- and worst-case scenarios. This technique can help to reduce wasted investments and improve the quality of decision-making in selecting targets for exploration.

Keywords Coalbed methane · Exploration target selection · Economic evaluation · Scenario analysis

✉ Liang-Yu Xia
xialiangyu_paper@sina.com

[1] School of Business Administration, China University of Petroleum (Beijing), Beijing 102249, China

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1 Introduction

According to the standard "Specifications for Coalbed Methane Resources/Reserves" (DZ/T 0216-2010) issued by the Ministry of Land and Resources of the People's Republic of China, coalbed methane (CBM) exploration is divided into a target selection phase and an exploration phase (Ministry of Land and Resources 2011). In the target selection phase, a comprehensive study of data, obtained by exploration and analogy, geological surveys, and coal mine production, is conducted to locate CBM exploration targets for the resource evaluation phase. The CBM resources selected in the target selection phase are classified as prospective resources.

Economic evaluations must be performed for CBM resources (reserves) at various phases of the exploration to satisfy the economic efficiency principle (Ministry of Land and Resources 2011; Attanasi 1998; Moore 2012). However, most economic evaluations currently target CBM reserves at or above a proven level (Kirchgessner et al. 2002; Robertson 2009; Zhang et al. 2004; Wang et al. 2004). A few scholars (Mu and Zhao 1996), who studied economic evaluation methods for the exploration phase, have recommended the use of adjusted conventional natural gas evaluation parameters to perform economic evaluations in resource-rich areas that have been explored only at a low level. However, studies on CBM's economic evaluation methods in the target selection phase are rare.

The discounted cashflow method is the most widely applicable economic evaluation methods. Applying the discounted cashflow method to the evaluation of CBM resources usually relies on a conceptual or detailed development program (Shimada and Yamaguchi 2009; Wong et al. 2010; Sander et al. 2011; Robertson 2009; Sander and Connell 2014; Chen et al. 2012a; Zhou et al. 2013; Yang

2008; Cao and Wang 2011).However, during the target selection phase, drilling and exploration work have yet to begin; therefore, no conditions exist for forecasting the development program, which makes it difficult for the conventional methods and procedures to be used to perform an evaluation. Due to the present difficulties with economic evaluation, geological evaluation remains the primary method used during the target selection phase (Zhao and Zhang 1999; Wang et al. 2009; Liu et al. 2001; Chen et al. 2012b; Hou et al. 2014).

The economic value of resources is jointly determined by many factors, including geological issues (Li et al. 2000). If the exploration targets are screened only using geological parameters, some resources that have superior geological conditions but little economic value may enter the exploration sequence and remain until their lack of economic value is shown. Because this situation can cause investments to be wasted unnecessarily, building an economic evaluation method that can promote decision-making during the target selection phase is necessary.

The discounted cashflow method is still employed to build the economic evaluation model, but it is used in an approach that is based on the characteristics of the target selection phase, and it is different from the traditional method, which depends on the use of development programs.

2 Economic evaluation model and target selection

2.1 NPV method

Commonly used evaluation indices in financial evaluations based on the discounted cashflow method include the financial net present value (NPV), the internal rate of return, and the payback period (National Development and Reform Commission 2006; Ministry of Construction of the People's Republic of China 2010).The financial NPV is the best indicator for economic evaluations of oil and gas resources (Luo 2002). Therefore, the financial NPV was selected as the basis for a CBM economic evaluation model. The formula for calculating the financial NPV is as follows:

$$\mathrm{NPV} = \sum_{t=0}^{T} (CI - CO)_t (1+i)^{-t} \quad (1)$$

where, CI is the cash inflow, CO s the cash outflow, t is the number of the evaluation period (t takes value between 0 and T), I is the benchmark discount rate, and T is the number of evaluation periods.

According to formula (1), the primary task of calculating the NPV index is to forecast the amount of cashflow generated by follow-up exploration and development activities, including cash inflow and cash outflow. The cash outflow includes exploration investments, development investments, liquidity, operating costs, business taxes and surcharges, and adjusted income taxes. The cash inflows include sales income, subsidy income, asset residual value recovery, and liquidity recovery (Ministry of Construction 2010). Asset residual value recovery is not considered because it is offset by the cost of land restoration cost when the well site is abandoned.

The procedure for applying the discounted cashflow method to evaluate oil and gas projects involves several steps. First, a conceptual (or detailed) development program is constructed that includes drilling and recovery projects, ground engineering projects, and the site's capacity for construction and annual gas production. Next, the essential constituents of the cashflow are estimated based on the development program. Finally, the financial evaluation indices are calculated based on the cashflow (Ministry of Construction 2010). Evaluation is difficult to perform using this procedure because it is hard to obtain the required geological, technical, and economic information during the target selection phase. Therefore, building an economic evaluation model that targets the characteristics of the target selection phase is necessary.

2.2 Characteristics of the target selection phase

Although drilling and exploration are not performed during the CBM target selection phase, the amount of CBM resources can still be inferred from geological parameters obtained from coal mine exploration data, such as the coal's rank, thickness, depth, pressure, and gas content (Zhang et al. 2002; Liu et al. 2001), and the amount of recoverable resources can be determined using geological analogy forecasts (Wang et al. 2003).

The number of development wells can be inferred from the recoverable area and the control area of a single CBM well. Although the total number of wells can be estimated, simulating and forecasting the production profile is impossible because gas testing cannot be performed by drilling exploration wells, and production data from test wells (a well group) cannot be obtained (Kang et al. 2012; Shao et al. 2013; Yang et al. 2008).Therefore, a well-drilling plan cannot be formulated based on the production profile of a single well or well group. Moreover, the well-drilling plan significantly affects economic evaluation results because it is also the basis for estimating the annual investment into drilling and recovery engineering projects. This problem must be resolved appropriately.

2.3 Economic evaluation model

2.3.1 Modeling approach and procedures

The modeling approach and procedures (Fig. 1) were established according to the characteristics of the target selection phase. The steps are as follows:

(1) Use geological information on the coalfield to infer the availability of CBM resources through a comprehensive study. Determine the conversion rate for turning resources into reserves and the recovery ratio based on analogous geological conditions; calculate the amount of recoverable reserves; and estimate the amount of exploration work required to verify the amount of reserves simultaneously.

(2) Comprehensively consider the recoverable reserves, market scale, and demand for gas (Luo and Xia 2009). Formulate a productivity plan that includes the amount of resources produced, the construction capacity, the annual gas supply capacity, and the number of years that this amount of gas can be supplied. If the amount of recoverable reserves is large but the market demand is small, determine the effective resource capacity and formulate a plan based on the market demand. If the amount of recoverable reserves is small but the market demand is large, formulate a plan according to the recoverable resource capacity that ensures a stable gas supply over a certain period of time. Determine the number of production wells through the gas-bearing area and the designated single well control area (the well distance).Assuming the wells drilled are uniformly distributed across the production period, the number of wells drilled annually is the total number of wells divided by the length of the production period.

(3) Cashflow estimate: Estimate the exploration investment based on the exploration workload. Estimate the annual drilling and recovery engineering project investment based on the number of production wells per year. Estimate the ground engineering project investment based on the construction capacity. Estimate the sales income based on the annual gas production capacity. Estimate the operating costs based on the gas production capacity and the number of wells. Calculate other cash inflows and outflows based on the relevant provisions.

(4) Based on the cashflow estimate, establish an economic evaluation model that uses the financial NPV formula. Because investments of the same amount that occur at different times have different time values, the discounted present values are also

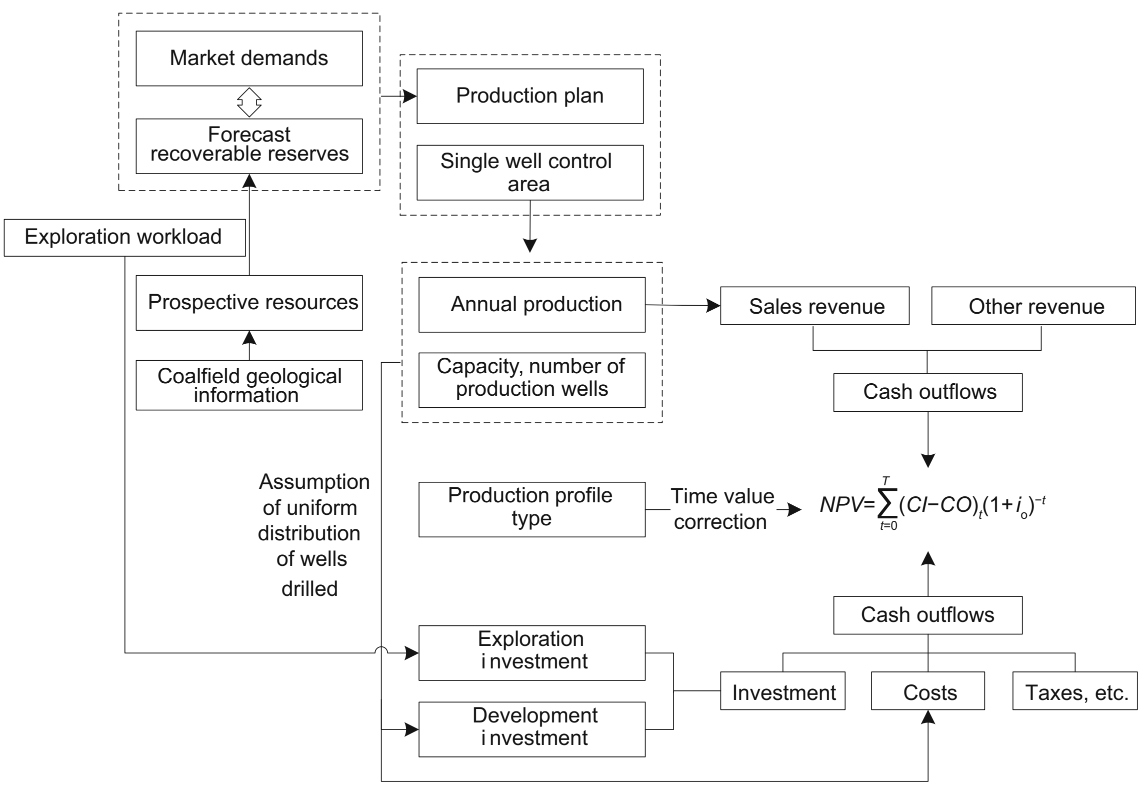

Fig. 1 The modeling flow chart

different. The assumption that drilled wells exhibit a uniform distribution changes the times of drilling and recovery of the investment in the engineering project, generating computational errors. To correct the errors, a time value correction factor is introduced into the model. The following method is used to resolve the inability to forecast and determine the designated yield fraction in the distribution of wells drilled: First, differentiate between the typical CBM single well (well group) production profile types and compute the time value correction factor for each type. If the profile type corresponding to the object to be evaluated can be determined, make the correction using the corresponding correction factor. If the affiliated profile type cannot be determined, a scenario analysis method can be used to estimate the resource values for each of the possible profile types to provide reference information for decision-making.

2.3.2 Economic evaluation model

The time value correction factor is defined as r_{COV}. The CMB economic evaluation model can be obtained using formula (1) (assuming the exploration period is one year and that the investment into the ground engineering project occurs early in the production period):

$$\begin{aligned}\mathrm{NPV} = &\sum_{t=2}^{1+T_{\mathrm{d}}} R(t)\cdot(1+i)^{-t} - I_E\cdot(1+i)^{-1} \\ &- r_{\mathrm{COV}}\cdot\sum_{t=2}^{1+T_{\mathrm{d}}} I_{\mathrm{D}}\cdot(1+i)^{-t} \\ &- I_S\cdot(1+i)^{-2} - \sum_{t=2}^{1+T_d} C_{\mathrm{L}}(t)\cdot(1+i)^{-t} \\ &- \sum_{t=2}^{1+T_d} T_{\mathrm{X}}(t)\cdot(1+i)^{-t}\end{aligned} \tag{2}$$

where T_{d} is the production period, $R(t)$ is the total income during year t, I_{E} is the exploration investment, I_{D} is the annual average drilling and recovery engineering project investment calculated with the assumption that the wells drilled are uniformly distributed, I_S is the ground engineering project investment, $C_{\mathrm{L}}(t)$ is the operating cost in year t, and $T_{\mathrm{X}}(t)$ is the amount of taxes in year t.

The time value correction factor r_{COV} is calculated as follows:

The average annual investment into the drilling and recovery engineering project is

$$I_{\mathrm{D}} = I_{\mathrm{d}} \times N \tag{3}$$

where I_d is the single well-drilling and recovery engineering project investment, and N is the annual average number of wells drilled. N can be calculated using the following formula:

$$N = \frac{A}{a \times T_{\mathrm{p}}} \tag{4}$$

where A is the area of the region that produces resources, a is the single well control area, and T_p is the production period.

In formula (2), $\sum_{t=2}^{1+T_d} I_D \times (1+i)^{-t}$ is the sum of the drilling and recovery engineering project investments' discounted present value for each year, assuming that the wells drilled are uniformly distributed. Substituting formulas (3) and (4) into this expression yields the following:

$$\begin{aligned}\sum_{t=2}^{1+T_{\mathrm{d}}} I_{\mathrm{D}} \times (1+i)^{-t} &= \frac{I_{\mathrm{d}}A}{aT_{\mathrm{P}}}\sum_{t=2}^{1+T_{\mathrm{d}}}(1+i)^{-t} \\ &= \frac{I_{\mathrm{d}}A}{aT_{\mathrm{P}}} \times \frac{(1+i)^{T_{\mathrm{P}}}-1}{i(1+i)^{T_{\mathrm{P}}}}\end{aligned} \tag{5}$$

where $\frac{I_{\mathrm{d}}A}{aT_{\mathrm{P}}}$ is the average annual investment into the drilling and recovery engineering project, and $\frac{(1+i)^{T_{\mathrm{P}}}-1}{i(1+i)^{T_{\mathrm{P}}}}$ is the discount factor when the uniform distribution of wells drilled is expressed by r_{even}. In addition, the discount factor for the real distribution of the wells drilled is r_{act}; then,

$$r_{\mathrm{COV}} \times \frac{I_{\mathrm{d}}A}{aT_{\mathrm{P}}} \times r_{\mathrm{even}} = \frac{I_{\mathrm{d}}A}{aT_{\mathrm{P}}} \times r_{\mathrm{act}}. \tag{6}$$

The formula for computing the time value correction factor obtained from Eq. (6) is as follows:

$$r_{\mathrm{COV}} = \frac{r_{\mathrm{act}}}{r_{\mathrm{even}}} \tag{7}$$

Shao et al. (2013) have summed up four gas production modes (production profile types) for CBM wells. Mode I is used as an example in this work to explain the method for determining the time value correction factor for the distribution of wells drilled.

In Fig. 2, No. 1 is the production profile curve drawn for Mode I, and No. 3 is the annual gas supply capacity curve for the target. To meet the stable gas supply requirement indicated in No. 3, it is necessary to set up a reasonable annual well-drilling plan. The corresponding well-drilling distribution curve (No. 3) is obtained by simulating the schedule of the production plan.

Assuming there is a stable gas supply for 20 years with a benchmark discount rate of 12 %, r_{even} is 7.5. For the well-drilling distribution displayed in No. 2, r_{act} is 10.5.

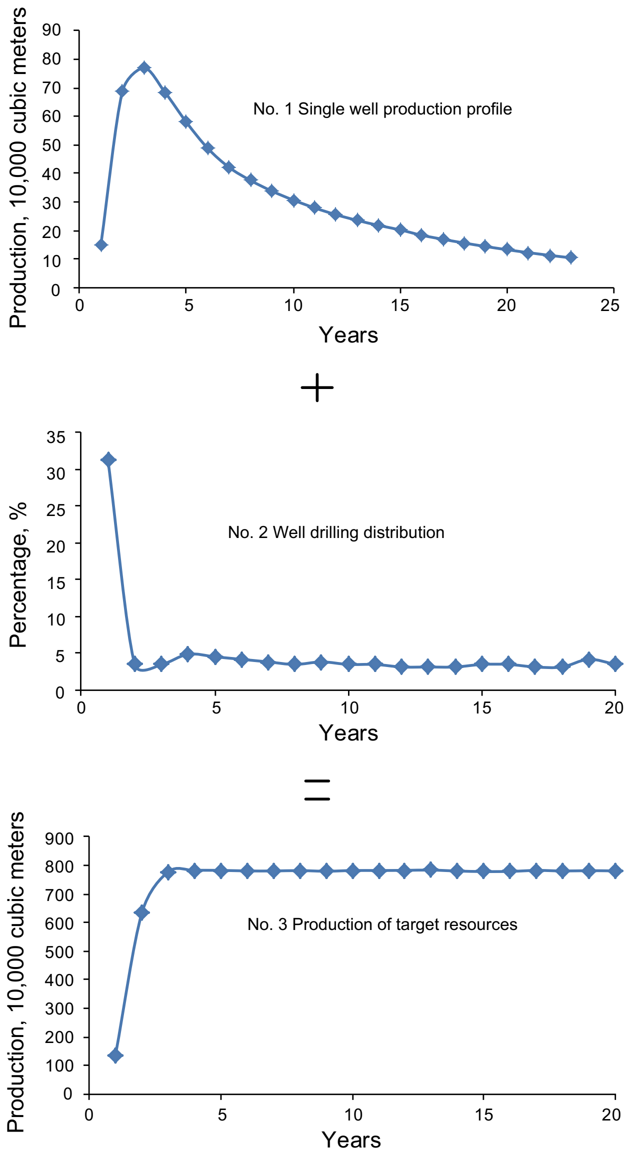

Fig. 2 Relationship between the well-drilling distribution and a single well's production profile

Therefore, the calculated time value correction factor is 1.4.

Parameter values, such as a stable production duration or gradual reduction rate, under the same production profile type, also affect the time value correction factor; however, these effects can be ignored during the selection phase under the premise of reasonable type differentiation; therefore, an average correction factor is used in the calculations.

2.4 A target selection method based on the economic evaluation

The primary factors are selected to function as scenario parameters in the economic evaluation, such as the recovery ratio, size of the single well control area, production profile type (or time value correction factor), and amount invested. Best- and worst-case scenarios are constructed based on the values of the scenario's parameter. The CBM resource NPVs for these two scenarios are calculated separately, to screen the exploration targets. If the NPV in the best-case scenario is less than 0, the target is not worth further exploration and development, and should be abandoned. If the NPV in the worst-case scenario is greater than 0, the target should have priority in exploration and development. If the NPV is greater than 0 in the best-case scenario and less than 0 in the worst-case scenario, a prudent decision should be made after undertaking further study of the evaluation target or re-evaluating it after the completion of appropriate exploratory work.

3 Case study

The resource forecast data for a specific CBM target are as follows (Tables 1 and 2):

Scenarios are constructed based on the value interval of the recovery ratio, the size of the single well control area, the value of the time correction factor, and the single well-drilling and recovery engineering project investment in Tables 1 and 2. In the best-case scenario, the recovery ratio is 40 %, the size of a single well control area is 0.5 km, the time correction factor is 1.1, the single well-drilling and recovery engineering project investment is 500,000 CNY/well, and the calculated NPV is −25 million CNY. In the worst-case scenario, the recovery ratio is 20 %, the size of the single well control area is 0.2 km, the time correction factor is 1.4, the single well-drilling and recovery engineering project investment is 1.2 million CNY/well, and the calculated NPV is −423 million CNY. This target should be eliminated based on the calculated results.

4 Conclusions

Full consideration of the data acquired while designing the method of estimating the essential cashflow constituents can ensure the operability of the established model, whereas it can lower the accuracy of its evaluation. Moreover, the implied assumption in the model affects the results of the calculations. For example, when selecting the size of the single well control area and the recovery ratio as scenario parameters during a scenario analysis, the implied assumption is that the well distance and the recovery ratio are independent, essential factors. The relationship between the two (i.e., the well distance and the target's recovery ratio are inversely related) is not considered. This assumption leads to an overly optimistic result for the best-

Table 1 Geological and technical data

Item	Unit	Value
Potential resource capacity	100 million cubic meters	2000
Conversion rate for turning resources into reserves	%	20
Recovery ratio	%	20–40
Size of the area producing resources	km^2	200
Size of the single well control area	km^2	0.2–0.5
Time correction factor	–	1.1, 1.4

Table 2 Economic data

Item	Unit	Value
Market scale	100 million cubic meters	Sufficiently large
Number of years of stable gas supply	Year	20
Exploration investment	100 million	1
Single well-drilling and recovery engineering project investment	10,000 CNY/Well	50–120
Known unit productivity ground engineering project investment	10,000 CNY/100 million cubic meters	1000
Topography and geomorphology correction coefficient	–	1.2
Unit production cost	CNY/cubic meter	0.35
Price	CNY/cubic meter	1.5
Subsidy	CNY/cubic meter	0.4
Commodity rate	%	95
Benchmark discount rate	%	20

case scenario and an overly pessimistic result for the worst-case scenario. Therefore, an actual example should be integrated to examine the model's computation error. If the error is too large, it will be necessary to develop a method for controlling it.

In addition, the differentiation between the typical CBM production profile types is a key part of evaluating the value of a resource. Although scholars (Kang et al. 2012; Shao et al. 2013) have already sorted out the types of CBM production modes from the viewpoint of an economic evaluation, the suitability of these divisions requires further study.

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