A real options based model and its application to China's overseas oil investment decisions

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1 Oil price is the most important attribute which can reflect oil investment value. It's the most important factor in oil investment.
2 The investee countries' investment environment can reflect their inherent situation. Investment environment will have great impact on the return and risk when a firm launching overseas investment. It's an important trade off. See further discussion in Dollar et al. (2003), Hallward-Driemeier et al. (2003).
3 Exchange rate can directly reflect the relationship between investor and investee countries. However, the contracts for international upstream investments are normally based on USD terms. But exchange rate has played an important role in foreign investment. first, USD is the conversion of currences between host country and investee country, the amount of investment will be defined through the negotiation between the host country (oil companies) and investee country, so the cross rate between the two countries will be an important trade off. Second, the revenue of the oil project which operating in investee country will be converted from the investee country's currency to host country's currency so that it can be reflected as a part of total revenue in host oil company's accounting report, and the exchange rate will have great impact on the accounting item - exchange gains or losses. See further discussion in Eichengreen (1999), Frankel (1999).

1 Introduction

Oil resources in the world are not well distributed in the sense that the oil resources of many industrialized and less industrialized countries (such as the OECD European countries, Japan, China, and India) cannot meet their demand for oil for domestic economic development. Consequently, these countries engage in oil-resource exploration and development worldwide through international or state-owned oil companies. On the one hand, by this means, they can obtain a stable overseas oil supply to ease pressure on their domestic energy supply; on the other hand, they can offset to some extent the adverse effects of high oil prices on their economies. Oil-resource investment is a complex decision-making process, with several distinctive features such as large capital budgets, long construction periods, and high uncertainty of investment. The risks of overseas oil investment arise mainly from the uncertainties of oil prices, investee countries' investment environment, exchange rates, and exploration and recovery technology. The real options approach can bring flexibility and strategic value into oil-investment evaluation. The investor country can be viewed as having an American-style option to invest in overseas oil resources, can evaluate

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the critical value per unit of oil reserves (here meaning recoverable reserves) in different countries, it is possible to compare their oil-investment risk by ranking their values of the Option Value Index (OVI). China's overseas oil investment is taken as an example and the empirical results show that the model developed here can provide useful advices for its overseas oil investment program. The research will probably be helpful to other investor countries as well for looking to invest in overseas oil resources.

The remainder of the paper is organized as follows: Section 2 provides a literature review, Section 3 contains a description of the model; Section 4 uses China as an example to present an empirical analysis, and Section 5 presents conclusions and opportunities for further work.

2. Literature review

2.1. Real options

Myers and Tullumb (1977) and Ross (1978) were the first to introduce a “real” financial option pricing approach. In this approach, investors use the efficient market hypothesis, portfolio theory, and trading strategies to predict the project's future cash flow and maximize the project value under known market information. Because the value of options is real, the greater the future uncertainty, the greater the project value should be. Myers (1984) pointed out that discounted cash flow techniques have weaknesses in evaluating investments with significant managerial flexibility, and consequently people tend to use either decision analysis or the option pricing approach when evaluating these kinds of investments. When McDonald and Siegel (1986) first developed a real options valuation model, they assumed that both the project value V and the investment I followed geometric Brownian motion and used the option pricing approach to solve max 2^V = V/I. Many studies have been done which apply the real options approach to evaluate natural-resource investments, but most have focused on the evaluation of individual projects. Brennan and Schwartz (1985) first introduced a real options approach to natural-resource investment and presented a way of valuating an asset with great volatility in its output commodity price. Assuming that the price of minerals followed geometric Brownian motion, they used real option model to define the optimal management strategy for a mine, including mine evaluation by replicating the portfolio to determine permanent abandonment and temporary closure rules under uncertainty. Paddock et al. (1988) developed a model of offshore oil leases and used it to define optimal investment rules for undeveloped offshore oil reserves. They thought that the option pricing approach had three advantages over the discounted cash flow method: 1) it requires significantly less data because it uses market information efficiently; 2) it incurs less computational cost and is less subject to error; 3) it provides a guide for the optimal timing of development. Based on work by Smith and Nau (1995), Smith and McCardle (1996, 1999) used decision analysis based on dynamic programming and option pricing theory to study the issue of the valuation of oil resources. They developed and analyzed a model of an oil property, studied the optimal suspension, decision-making for exploration and development, and the optimal time to invest. They also considered other effects on oil-property valuation such as production control and decision-makers’ attitudes towards risk.

Recent real option researches trend to study the compound option structures and the relationship between investment and uncertainty. Kulatilaka and Perotti (1998) had provided a strategic rationale for growth options under uncertainty and imperfect competition. They had pointed out that higher uncertainty means more opportunity rather than simply larger risk and their results contradict the view that volatility was a strong disincentive for investment. Sarkar (2000) had shown that in certain situations, an increase in uncertainty could actually increase the probability of investing, and thereby has a positive impact on investment. Smit and Trigeorgis (2004) had presented an approach that integrated real options and game theory to strategic investment. Their treatment of strategic investment extended the potential of real options by combining it with game theory to capture the competitive dimensions and endogenous interactions of strategic decisions between the firm and its competitors. Copeland and Antikarov (2005) attempted to provide the foundation for establishing a consensus on methodology. They had proposed an outline of a standard procedure and presented a five-step solution process (MAD approach) for defining real options and for valuing corporate projects in which such options were an important source of expected value. Their paper also responded to criticisms of both the theory and practice of real options made by Borison (2005a), Borison (2005b) had responded Copeland and Antikarov (2005)'s criticisms, several misunderstandings was argued in his paper like use of ‘Undocumented Adjustments’, application of No-Arbitrage Conditions which Copeland and Antikarov (2005) had mentioned in their paper.

The real options approach is well suited to estimate future uncertainty in natural-resource investments. Brennan and Schwartz (1985) and Paddock et al. (1988) assumed that commodity prices follow geometric Brownian motion and that a project's future volatility depended only on its commodity output price volatility. Smith and McCardle (1999) assumed that both oil prices and oil productivity followed geometric Brownian motion, so that the project's future volatility involved the integration of oil-price and productivity uncertainties. Costa Lima and Suslick (2006) thought that among all the input parameters, future volatility was by far the most critical parameter in option pricing models. However, they did not believe that the project's future volatility could be considered equivalent to the fluctuation of its commodity output price. Rather, they estimated project volatility by considering both commodity prices and operating cost evolved as geometric Brownian motion and used their model to evaluate a hypothetical gold-mine project. The result showed that project volatility was higher than that of commodity prices except under very unrealistic industry conditions.

2.2. Investment environment

The present research has added an investment–environment factor to the valuation of overseas oil resources. As a necessary external condition, investment environment has a great impact on the collaboration between investor and investee. The study of regional investment evaluation began at the late 1960s, after which various methods of evaluation have been established. Investment–environment evaluation is a comprehensive approach involving integration of both qualitative and quantitative analysis, but mainly depends on quantitative analysis. The measurement of the investment environment is based on the establishment of an index system. The survey by Litvak and Banting (1968) of a large number of business people in the United States, Canada, and South Africa proposed a comprehensive and uniform method (cold–hot comparative analysis) to compare different countries’ investment environments, focusing mainly on seven important factors. Stobaugh (1969) proposed a hierarchical evaluation method incorporating the insights of soft environment research. He started with the investee–country government’s restrictions and incentive policy with respect to foreign direct investors and analyzed the impact of micro-factors on the investment environment. On the basis of Stobaugh’s research, Mun and Ho (1979) proposed multi-factor and key-factor evaluation methods. They divided the factors that affected the investment environment into eleven categories, each category made up of several subelements. Other representative evaluation methods include Dow’s cooperative dynamic analysis, country risk rating, and similarity calculations. These methods evaluate a specific region’s investment environment from different perspectives, some focusing on the study of macro-factors.
and some on concrete environmental assessment. The “Ease of Doing Business” scale developed by the World Bank is the authoritative index system for evaluating different countries’ investment environments. It uses simple averaging statistical methods to integrate each factor’s effect on a country’s investment environment (see Djankov et al., 2002, 2003a,b, 2006, 2007).

Nordal (2001) used the real options approach to study the impact of risk in emerging-market countries on foreign direct investment by adding country risk to project valuation. He believed that it was not a simple task to quantify country risk as a part of the valuation of actual investments. He cited the International Country Risk Guide (ICRG) published by Coplin and O’Leary (1994) and paid great attention to variables which can reflect country risk, such as government bonds. His research defined a country-state variable, and assuming that this variable followed geometric Brownian motion. The country risk can be determined directly by the country-state variable, and changes in the variable can be reflected by information from the country’s stock market. He used country-risk indicators based on time series to estimate the state variable and analyzed the correlation between oil prices and the risk existing in oil-producing countries. He also gave a numerical example to estimate the impact of country-risk volatility on an oil-project investment.

3. Model

Oil investment can be divided into several stages, as mentioned by Cortazar and Schwartz (1997). They had modeled the oil field in three different stages. Stage 1 is before committing to the development; Stage 2 is during development; and Stage 3 is during production. According to Kulatilaka and Perotti (1998), when facing multi-stage business with competitors existing, a firm should value real investment not only taking into account its strategic value but also the alternative value for not investing. All of these will affect the firm and its competitors’ decisions. The investment decision making at different stages will have strategic effects, especially with competition existing, these features are very similar to oil investment projects. So the evaluation of single oil investment project can be studied under compound option structure. This paper focuses on the initial stage of overseas oil investment. The model developed here is based on the real options approach and considers the effects of three major economic uncertainties (oil prices, investment environment, and exchange rates) on oil valuation. It is a broad model that can be used by every oil investor country to value overseas oil resources. Its output is the critical value per unit of oil reserves for each country and the ranked results for oil-investment risk.

3.1. Valuation of overseas oil reserves

In the model developed here, overseas-oil-investment revenue is a function of oil prices, exchange rates, and the investee country’s resource tax rate, that is:

\[ H_0 = (1 - T_i)P \cdot E, \]

where \( H_0 \) is the revenue per unit of oil production calculated in the investor country’s currency; \( P \) is the investee country’s local oil price in units of local currency/barrel; \( E \) is the exchange-rate factor between the investor and investee currencies; and \( T_i \) is the resource tax rate in the investee country. Because the investment environment has a great impact on achieving return on overseas oil investment, it is included in the evaluation of oil-investment revenue. Considering the investment environment, the adjusted revenue is:

\[ H = \frac{1}{S} H_0 = (1 - T_i) \frac{P \cdot E}{S}. \]

where \( H \) is the investment–environment-adjusted revenue from oil investment in the investor country’s currency; \( \frac{1}{S} \) is the investee country’s investment–environment multiplier; and \( S \) is the evaluation value of the investment environment (the evaluation of \( S \) will be discussed in Section 3.3).

The value of overseas oil reserves (meaning the value per unit of oil reserves) is a function of investment–environment-adjusted revenue, that is:

\[ V = V(H). \]

Assuming that the time available for decision-making is infinite, oil investment \( I \) (here \( I \) is the investment per unit of oil reserves) is constant and will be invested at the initial stage. It is important to identify energy price behavior in this model. Bessembinder et al. (1995) had used the term structure of futures prices to test whether investors anticipate mean reversion in spot asset prices. Their empirical results showed that for crude oil the magnitude of the estimated mean reversion is large. Geman and Roncoroni (2006) had analyzed the special features of electricity spot prices in a market pool. They had introduced a class of discontinuous processes exhibiting a “jump-reversion” component to properly represent these sharp upward moves shortly followed by drops of similar magnitude. There also a lot of scholars that had assumed that oil price follow a geometric Brownian motion in their real option model (Paddock et al., 1988; Dixit and Pindyck, 1994; Smith and McCardle, 1999; Chorn and Shokhor, 2006). The model developed here refers to their work and oil price \( P \), exchange rate \( E \), and investment environment \( S \) are assumed to follow geometric Brownian motion:

\[ dP = \alpha_P dt + \sigma_P dZ_P, \]

\[ dE = \alpha_E dt + \sigma_E dZ_E, \]

\[ dS = \alpha_S dt + \sigma_S dZ_S, \]

where \( dZ_P, dZ_E, dZ_S \) are independent increments of a Wiener process, \( dZ_P = \varepsilon_{P}\sqrt{dt}, \quad dZ_E = \varepsilon_{E}\sqrt{dt}, \quad dZ_S = \varepsilon_{S}\sqrt{dt} \). \( \varepsilon_{P}, \varepsilon_{E}, \varepsilon_{S} \) are normally distributed random variables with mean 0 and standard deviation 1; \( \alpha_P, \alpha_E, \alpha_S \) represent drift parameters; and \( \sigma_P, \sigma_E, \sigma_S \) represent variance parameters.

In the model, the volatility of investment–environment-adjusted revenue from oil investment \( H \) comes from three components, oil...
price $P$, exchange rate $E$, and investment environment $S$. As Borison (2005b) had mentioned in his response, the volatility of the entire asset is a function of the volatility of the components. This paper refers to Smith and McCardle (1999)’s processing method and let $H$ also follows geometric Brownian motion:

$$dH = \alpha_H \delta H dt + \sigma_H \delta H dz_H.$$  

(7)

where $dz_H$ is an independent increment of a Wiener process; $\alpha_H$ is a drift parameter, $\alpha_H = \alpha_H + \gamma_H - \gamma_S$; and $\sigma_H$ is a variance parameter reflecting the volatility of overseas oil investment:

$$\sigma_H^2 = \gamma_{E,E}^2 + \gamma_{S,S}^2 + 2 \gamma_{E,S} \sigma_E \sigma_S - 2 \gamma_{E,S} \sigma_E \sigma_S.$$  

(8)

where $\gamma_{E,E}$, $\gamma_{S,S}$, and $\gamma_{E,S}$ are the correlation coefficients among oil price, exchange rate, and investment environment. Smith and McCardle (1999) had set these correlations to 0, which meant that the oil price was completely determined by the market and the production capacity. Based on the research of Fan et al. (2008), there exists a spillover effect between exchange rates and oil prices, so we believe that nonzero correlations also exist among oil price, exchange rate, and investment environment.

At time $t$, the value per unit of oil reserves can be written as:

$$V(H, t) = (H - C) dt + E\left[V(H + dH)e^{-\rho dt}\right].$$  

(9)

where $\rho$ is the investee country’s discount rate and $C$ is the oil-production cost per barrel. Using the Ito lemma to expand the right-hand side and eliminate the terms that tend to 0 faster than $dt$, let $\frac{\partial V}{\partial H} = 0$. Then $V(H)$ satisfies:

$$\rho V(H) = \frac{1}{2} \sigma_H^2 H^2 \rho V''(H) + \alpha_H H V'(H) + (H - C).$$  

(10)

The current model assumes that the return from oil investment comes from two sources: the first is the expected value of the drift rate $\alpha_H$, and the second is the convenience yield, similar to dividend payment, which is $\delta$. At equilibrium conditions, the discount rate is $\rho = \alpha_H + \delta$. $\delta$ can reflect to a certain extent an operating oil project’s cash flow. Paddock et al. (1988) discussed how to estimate the parameter $\delta$, but they did not consider the impact of resource tax rate. In the current work, a resource tax has been incorporated into the estimation of $\delta$:

$$\delta = \frac{\alpha_H (1 - T_I) - C (1 - T_2) - bP}{bP}.$$  

(11)

where $\alpha_H$ is the rate of decline in oil production, $P$ is the oil price, $C$ is the oil-production cost, $T_I$ is the resource tax rate, $T_2$ is the income tax rate, and $b$ is the ratio between the value of oil reserves and the oil price per barrel.

Gruy et al. (1982) analyzed a number of private sales of developed oil reserves, and their results indicated that the value of oil reserves was approximately 1/3 of the price of oil per barrel. This is referred to as the 1/3 rule. This rule was also supported by Paddock’s analysis (Paddock, 1982) of the oil-production stocks from the London and Scottish Marine Oil Company, Ltd., which were traded on the London Stock Exchange, as well as of similar securities traded in the United Stock Exchange, as well as of similar securities traded in the United Kingdom. These securities were financial claims to the net revenues of developed oil reserves and were valued and marketable in developed capital markets.

Based on Kretzschmar et al. (2008)’s research, Non-OECD market O&G (oil and gas) countries tended to production sharing contracts (PSC⁵), while OECD areas tended toward concession contracts. They had assumed the rate of state taxation participation was deterministic, and was based on terms and rates in existence at January 2006. This paper refers to their work to assume each country’s resource tax rate is deterministic, too. For the countries with non constant tax rates (PSC countries), the model will adopt their ten years average resource tax rate as deterministic rate.

The present value per unit of oil reserves for each country can be determined based on current oil prices, exchange rates, and investment environment. The question is when or under what conditions to invest in oil reserves; the oil-investment decision is equivalent to determining when to execute the permanent calls option. In the next section, the oil-investment option model will be introduced.

### 3.2 Oil-investment option model

Let $F(H(t))$ represent the value of oil-investment opportunity (equivalent to oil-investment option value). The return on oil investment will be $V - I$, where $I$ is the investment per unit of oil reserves. In the context of this research, this investment will not result in cash flow until the investment option has been executed. Therefore, the only payoff for holding the option is its value increment. According to the option pricing method developed by McDonald and Siegel (1986) and Dixit and Pindyck (1994), a continuous-time differential equation results:

$$\rho F(H, t) = E\left[\frac{dF(H, t)}{dt}\right].$$  

(12)

Here once again the Ito lemma can be used to expand $dF(H, t)$, and setting $\frac{\partial F}{\partial H} = 0$, the oil-investment option satisfies:

$$\rho F(H) = \frac{1}{2} \sigma_H^2 H^2 \rho F''(H) + (\rho - \delta) HF'(H).$$  

(13)

The value of oil reserves is in a neutral state only when the investment–environment-adjusted revenue from oil investment is at the critical point. Based on value-matching and smooth-pasting conditions:

$$F(H^*) = V(H^*) - I,$n  

$$F'(H^*) = V'(H^*).$$

where $H^*$ is the investment–environment-adjusted revenue which satisfies both conditions corresponding to the critical value per unit of oil reserves $V(H^*)$ and the option value $F(H^*)$. This means that the value of oil reserves in different countries is equal to the entire cost of investment (direct cost plus opportunity cost of oil investment).

### 3.3 Evaluation of the investment–environment multiplier

The investment environment refers to the positive or negative impact of external conditions in specific regions on achieving investment objectives. According to the World Bank definition, the investment environment is the total effect of various factors on the future inputs and expected returns of enterprises (World Bank, 2002). Overseas oil investment is a complicated process which is obviously impacted by each investee country’s social, cultural, political, and economic environment, and therefore the investment environment

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⁵ PSC agreements typically provide oilfield operators with guarantees to cover a return on their capital costs and, in exchange, impose a reserve entitlement structure that contractually escalates oilfield participation sharing by the local government based on the price of oil and in some cases the volume of oil pumped.
plays a significant role in overseas oil investment. We have added an investment–environment variable to the real options valuation model, assuming that it has a multiplier effect on oil-reserve valuation. Each country’s investment environment is measured by its multiplier. A country with a better investment environment will have a larger multiplier, it also has positive effect on its oil reserves valuation, and vice versa. It is possible to calculate the multiplier by evaluating the investment–environment index. We use the “Ease of Doing Business” index developed by the World Bank (2007a) to evaluate different countries’ investment environments. The “Ease of Doing Business” index evaluates investment environments in 178 countries using 10 topics with 42 indicators and ranks their economies from 1 to 178. The index is calculated as the ranking on the simple average of country percentile rankings on each of the 10 topics covered in “Ease of Doing Business”. The ranking on each topic is the simple average of the percentile rankings on its component indicators. Based on the research of Djankov et al. (2002, 2003a,b) and the introduction of ranking methodology (Djankov et al., 2005) issued by World Bank, the specific calculation method is as follows: 

Let \( R_{ij} \) be a country’s percentile ranking on indicator \( j \) which belongs to topic \( i \), so:

\[
R_i = \frac{1}{n} \sum_{j=1}^{n} R_{ij}, (j = 1, 2, \ldots n).
\]  

(14)

The simple average of a country’s percentile rankings on each of the ten topics is calculated, giving the country’s comprehensive percentile ranking result:

\[
S = \frac{1}{m} \sum_{i=1}^{m} R_i, (i = 1, 2, \ldots m).
\]  

(15)

Finally, it is possible to rank each country’s investment environment using \( S \) (one can view \( S \) as a country’s investment–environment index). Countries with a small value of \( S \) have a good investment environment and high ranking, and vice versa. To reflect the investment environment’s multiplier effect on oil-reserve valuation, it is possible to take the reciprocal of \( S \) and define \( \frac{1}{S} \) as the investment–environment multiplier. This is a country’s relative investment–environment indicator, for instance, Norway's and Brazil's percentile ranking results are 0.19 and 0.56, so their investment environment indicator, for instance, Norway’s and Brazil’s percentile – where \( Q \) is the rate of production decline (%/year); and \( \rho \) is the rate of production decline (%/year); and \( \theta \) is the economical production life, where oil reserves can be approximately expressed as \( Q = \frac{q_0}{\theta} \) if \( \theta \) is large enough. The expected net present value (NPV) of the oil reserves is:

\[
NPV = \int_0^T \left(He^{-\rho (\theta - \omega)} - Ce^{-\omega T} \right) d\tau, \tau \in (0, \theta).
\]  

(17)

The expected NPV of oil reserves can be written as \( NPV = q_0 \left( \frac{He^{-\rho (\theta - \omega)}}{\theta} - \frac{Ce^{-\omega T}}{\omega} \right) \) if \( \theta \) is large enough. The expected NPV per unit of oil reserves is \( NPV = q_0 \left( \frac{H}{\theta} - \frac{C}{\omega} \right) \). When \( H > C \), the solution form of the option value and the value per unit of oil reserves can be determined as shown in Eqs. (18) and (19) (McDonald and Siegel, 1986; Dixit and Pindyck, 1994):

\[
F(H) = A_1 H^{\beta_1}, \quad (18)
\]

\[
V(H) = \begin{cases} 
K_i H^{\beta_1}, & H < C \\
B_2 H^{\beta_1} + \omega \left( \frac{H}{\omega} + \delta - \frac{C}{\omega + \rho} \right), & H > C. 
\end{cases} \quad (19)
\]

where \( A_1, K_i, B_2 \) and \( \beta_1, \beta_2 \) are undetermined coefficients and \( \beta_1 \) and \( \beta_2 \) are known constants:

\[
\beta_1 = 1 - \frac{\rho - \delta}{\sigma^2} + \sqrt{\left(\frac{\rho - \delta}{\sigma^2} - \frac{1}{2}\right)^2 + \frac{2\rho}{\sigma^2}}, \beta_1 > 1. \quad (20)
\]

\[
\beta_2 = 1 - \frac{\rho - \delta}{\sigma^2} - \sqrt{\left(\frac{\rho - \delta}{\sigma^2} - \frac{1}{2}\right)^2 + \frac{2\rho}{\sigma^2}}, \beta_2 > 1. \quad (21)
\]

Solving for \( K_i, B_2 \) using the boundary conditions that \( V(H) \) and \( V'(H) \) are continuous at the point \( H = C \):

\[
K_i = \frac{C^{1 - \beta_i}}{\beta_1 - \beta_2} \omega \left( \frac{\beta_2}{\beta_1 - \beta_2} - \frac{\beta_2 - 1}{\omega + \delta} \right); \quad (22)
\]

\[
B_2 = \frac{C^{1 - \beta_2}}{\beta_1 - \beta_2} \omega \left( \frac{\beta_1}{\omega + \delta} - \frac{\beta_1 - 1}{\omega + \delta} \right). \quad (23)
\]

Based on value-matching and smooth-pasting conditions, the solution for \( A_1 \) is of the form:

\[
A_1 = \frac{1 - \beta_2}{\beta_1 - \beta_2} \omega H^{\rho (1 - \beta_i)} \left( \frac{\beta_2 H^{\rho (1 - \beta_i)}}{\beta_1 - \beta_2} \right) \left( \frac{\omega \theta}{\omega + \theta} \right) + I, \quad (24)
\]

where \( H^* \) is the solution of Eq. (25):

\[
(\beta_1 - \beta_2) B_2 H^{\beta_2} + (\beta_1 - 1) \omega \theta H^* - \beta_1 \left( \frac{\omega \theta}{\omega + \theta} + C + I \right) = 0. \quad (25)
\]

Eq. (25) has a unique solution for \( H^* \) when \( H^* > C + \frac{\omega \theta}{\omega + \theta} I \) (Dixit and Pindyck, 1994), so numerical results for \( H^* \) can be obtained by substituting various countries’ oil prices, exchange rates, investment–environment multipliers, interest rates, production costs, and other data into Eqs. (18)–(25). Then the critical value per unit of oil reserves \( V^* \) and the option value \( F^* \) can also be calculated. To compare different countries’ critical values per unit of oil reserves, the Option Value Index (OVI) for oil can be used to measure the oil-investment risk in different countries (Dixit and Pindyck, 1994):

\[
K = \frac{V^*}{T}. \quad (26)
\]

Here the larger the value of \( K \), the greater is the oil-investment risk in the country. Oil investment risk does not only depend on the three major uncertainties (oil price, exchange-rate and investment environment), but also depend on other input parameters like oil production cost, taxation rate and so on. All of these factors (each country’s oil-resource and economic factors) have contributed to the oil investment risk.
4. Evaluation of China's overseas oil-investment activity

Here China's overseas oil-investment activity will be taken as an example to explain the functioning of the model. Various investee countries' critical value per unit of oil reserves and oil Option Value Index (OVI) values are calculated as of the time when China was developing its overseas oil-investment activities in 2006. The data cited below are based on each country's actual situation in 2006.

4.1. Data preparation

4.1.1. Country selection

The selection of target countries for overseas oil investment is made primarily according to the share of the country's oil reserves as a proportion of the total reserves of the region (BP, 2007) and according to whether or not China's three major oil and gas companies currently have oil and gas business in the country<sup>6</sup>. Twenty-six target countries were selected for overseas oil investment, including North America (3), Central and South America (6), Europe and Eurasia (4), the Middle East (4), Africa (4), and the Asia-Pacific region (5), as shown in Fig. 1.

4.1.2. Tax, exchange, and interest rates

Income-tax data have been obtained from the foreign-investment database of the Ministry of Commerce of China. The highest level of taxation has been chosen because of the large scale of oil investment and the trend of each country's protective policies relative to the oil industry. Exchange-rate data come from the database of the World Bank. Each country's long-term deposit interest rate is used as a risk-free rate to represent the discount rate, except for the United States and Britain, where the three-month interest rate on treasury bonds is used to replace the discount rate. Interest-rate data also come from the World Bank database (World Bank, 2007b). To assess the value of oil reserves, it is necessary to calculate the risk-free rate after income tax, \( \rho = (1 - T_2) r \). It is assumed that each country's resource tax rate is equal to zero because specific data could not be obtained in every case.

4.1.3. Oil-production costs

Oil-production costs vary widely in different countries. The International Energy Agency (IEA) (2003) has published oil-production costs in various regions. In this work, the inflationary cost index published by IEA (2006) was used to estimate oil-production costs in 2006. The nominal oil-production cost rose by 177% from 2002 to 2006, and thus different countries' oil-production costs in 2006 can be estimated. It is apparent that the Middle East has the lowest average cost and North America the highest.

4.1.4. Volatility measurement

The evaluation of oil reserves is closely related to the volatility of oil prices. There are wide variations in oil prices because of differences in oil quality and other characteristics of producing areas. We have analyzed the correlations of several representative regional oil prices and found that these regional oil prices are highly correlated with West Texas Intermediate (WTI) oil prices (Table 1). This phenomenon also reflects the nature of oil as an international commodity. Therefore, the volatility of WTI prices is used to represent international oil-price fluctuations. Calculation of the standard deviation of

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<sup>6</sup> Oil-reserve data in different countries come from the BP World Energy Statistical Review 2007. Chinese oil companies' overseas operations were reported in the 2006 annual reports from China's three major oil companies.
the logarithm of 10-year WTI spot prices for 1997–2006 shows that the actual oil-price volatility during this period was 16.5%.

It is difficult to quantify the fluctuation of each country’s investment environment. In our paper, it was found that the consumer price index (CPI) could serve as a reflection of a country’s degree of policy stability. Some oil-investee countries have highly unstable policies which often lead to huge price fluctuations and the deterioration of the investment environment. Therefore, each country’s CPI volatility is used as a proxy variable to reflect its investment–environment change. A country’s CPI volatility can be estimated by calculating the standard deviation of the logarithm of its CPI index for 1997–2006.

The exchange rate used for conversion from RMB (Chinese currency) to the investee country’s currency has been transformed to a real exchange rate. As a result, it is possible to estimate the real exchange-rate volatility by calculating the standard deviation of the logarithm of the exchange rate for 1997–2006. Exchange-rate and CPI data all come from the World Bank database.

Oil-investment volatilities in different countries can be calculated by substituting oil prices, exchange rates, and investment environment volatilities into the model. Each country’s correlation coefficients among oil prices, exchange rates, and investment environment measures are also calculated using WTI spot prices, exchange rates, and CPI index data for 1997–2006.

4.1.5. Rate of production decline and calculation of convenience yield

Different areas experience different rates of oil-production decline. For this research, oil-production-decline rate data published by IEA (2006) for different regions have been used. According to the IEA and CPI index data for 1997–2006, measures are also calculated using WTI spot prices, exchange rates, and investment environment volatilities into the model. Each country’s correlation coefficients among oil prices, exchange rates, and investment environment measures are also calculated using WTI spot prices, exchange rates, and CPI index data for 1997–2006.

4.2. Results and discussion

This section discusses two possible situations. (S1) ignores the risks of each country’s exchange-rate and investment–environment volatilities, assuming \( c_E = c_S = 0 \). Only oil-price risk is considered in calculating each country’s OVI, \( K(P) \); it was common to use oil prices as the only uncertainty to represent investment risk in previous oil-resource valuation models. (S2) considers all three uncertainties: oil prices, exchange rates, and investment environment, and uses integrated investment volatility to calculate each country’s OVI, \( K(H) \).

For ease of comparison, we assume that the investment amounts in different countries per unit of oil reserves are the same, \( l = 80 \) RMB/barrel (Table 2). By comparing each country’s OVI per unit of oil reserves and comparing results between the model presented here and the “Ease of Doing Business” report (World Bank, 2007a), it is possible to draw the following conclusions:

The uncertainties of the investment environment and exchange rates have a great impact on different countries’ critical value per unit of oil reserves. The results in (S1) and (S2) are inconsistent because (S2) considers investment–environment and exchange-rate uncertainties. In (S1), the average OVI in Africa and in North America differs little, being respectively 1.76 and 1.41. However, in (S2), because Africa has higher investment–environment and exchange-rate uncertainties than North America, the average OVI in Africa (2.14) is also higher than that in North America (1.36). Obviously (S2) is in agreement with the actual situation. Clearly, it is not accurate to consider oil prices as the only uncertainty in evaluating overseas oil investment, but rather it is necessary to consider the integrated uncertainties of oil prices, exchange rates, and the investment environment.

Countries with low oil-production costs do not have a low critical value per unit of oil reserves. As can be seen from Table 2, the Middle East has the lowest average oil-production cost, 21.87 RMB/barrel. The highest oil-production cost is in North America (65.17 RMB/barrel), and the second highest is in Europe and Eurasia (65.17 RMB/barrel). However, in (S2), the OVI in the Middle East (2.02) is higher than that of North America (1.36) and of Europe and Eurasia (1.66). That is mainly because in (S2), the oil-investment uncertainty (which combines the uncertainties of oil prices, exchange rates, and the investment environment) in the Middle East is higher than that in North America and in Europe and Eurasia, so low oil-production costs do not mean low oil-investment risk. Therefore, it is not advisable to pursue solely low oil-production cost when making overseas oil investments.

Countries with larger oil-investment uncertainties always have higher OVI. Based on the results in (S2), for example, Peru has an oil-investment volatility of 15.4%, and its corresponding OVI is 1.28; Indonesia has an oil investment volatility of 28.8%, and its corresponding OVI is 2.61. As can be seen from the distribution of these countries in Fig. 2, with few exceptions (like Kuwait and the Russian Federation), there is a general trend for the countries with larger oil-investment uncertainties always to have a higher critical value per unit of oil reserves. Although Sarkar (2000) had pointed out that in certain situations, an increase in uncertainty can actually have a positive impact on investment. He used the probability of investing to prove that the notion of a negative uncertainty–investment relationship is not always correct. However, the model developed here hasn’t considered the probability of oil investing. This paper uses the Option Value Index (OVI) to measure and compare different countries’ oil-investment risk. This means that when considering different oil projects with the same investment amount, the oil-project value with high oil-investment risk should be higher than that for a project with lower oil-investment risk. Obviously higher return should be required when investing in countries with larger oil-investment risks.

The OVI ranking results can reflect each country’s actual oil-investment risk better than other leading indices. The ranking results

<table>
<thead>
<tr>
<th>Spot price FOB correlation</th>
<th>WTI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canadian Par Spot Price FOB</td>
<td>0.997</td>
</tr>
<tr>
<td>Mexico Isthmus Spot Price FOB</td>
<td>0.998</td>
</tr>
<tr>
<td>Mediterranean Russian Urals Spot Price FOB</td>
<td>0.993</td>
</tr>
<tr>
<td>Asia Dubai Fateh Spot Price FOB</td>
<td>0.991</td>
</tr>
<tr>
<td>Kuwait Blend</td>
<td>0.99</td>
</tr>
<tr>
<td>Europe Libyan Es Sider</td>
<td>0.996</td>
</tr>
<tr>
<td>Europe Nigerian Bonny Light</td>
<td>0.996</td>
</tr>
<tr>
<td>Qatar Dukhan</td>
<td>0.993</td>
</tr>
<tr>
<td>Saudi Arabia Saudi Heavy</td>
<td>0.988</td>
</tr>
</tbody>
</table>

Table shows the correlation coefficients between West Texas Intermediate (WTI) oil prices and representative regional oil prices (like Canadian Par Spot Price FOB, Mexico Isthmus Spot Price FOB, Mediterranean Russian Urals Spot Price FOB, Asia Dubai Fateh Spot Price FOB and so on). WTI and Regional oil prices data come from EIA. The data length is ten years, from 1997 to 2006.

---

7 Paddock et al. (1988) estimated oil-price volatility as 30% based on 30 years of oil-price data. Gibson and Schwartz (1991) found the yearly oil-price volatility to be 33%. The volatility of oil prices changes depending on the time interval studied. Earlier calculations of oil-price volatility included the period of the oil crisis of the 1970s, when oil prices experienced sharp ups and downs because of the production restrictions of OPEC. During the time period studied here, there were no significant ups and downs in oil prices, but only a steady increase. Although oil prices have been rising rapidly since 2002, the actual increase is much smaller than the increases during the oil crisis, and oil-price volatility is also less.
from the current model and from “Ease of Doing Business” are different because the latter is used to measure each country's comprehensive investment environment. We have used the World Bank results as an investment-environment multiplier together with other model input parameters (oil prices, exchange rates, oil-production costs) to calculate each country’s critical value per unit of oil reserves. The OVI ranking results are based on each country's oil-resource and economic factors, so they can better reflect each country's actual oil-investment risk. Certain countries with low rankings on “Ease of Doing Business,” like Vietnam and Algeria, may achieve high rankings in this research. This means that, although these countries do not have a generally attractive investment environment, their domestic oil resources are worth investing in. For most of the OECD countries, like Norway, the United States, Canada and Australia, they are highly ranked both in “Ease of Doing Business” and in the paper. This means that these countries are favorable choices for overseas oil investment. Moreover, it should be acknowledged that some “improper results” occurred maybe as a result of investment environment proxy variable.

4.3. Sensitivity analysis

Because of discrepancies among data from different countries, Nigeria was chosen as an example to study the sensitivity of different parameters’ effects on evaluation of the model developed here. The intent is to consider the effect if each parameter changes by 1% (if r changes by 1%, this means that r will be r×(100% + 1%), or r(100%–1%)). The results can be seen in Table 3.

Using sensitivity analysis, it can be determined that the OVI of Nigeria is most sensitive to oil-investment volatility and convenience-yield change, followed by changes in taxes and interest rates; oil-

Table 3

<table>
<thead>
<tr>
<th>Countries</th>
<th>Proved reserves at end of 2006 (thousand million barrels)</th>
<th>Income tax T2 (%)</th>
<th>Interest rate r (%)</th>
<th>Oil-production cost C (RMB/barrel)</th>
<th>Oil-production-decline rate ω (%/year)</th>
<th>Option value index K(P)</th>
<th>Option value index K(H)</th>
<th>Ranking results by K(H)</th>
<th>Ranking results in DB</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>29.92</td>
<td>34.00</td>
<td>5.02</td>
<td>71.84</td>
<td>11.00</td>
<td>1.42</td>
<td>1.33</td>
<td>6</td>
<td>3</td>
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<tr>
<td>Canada</td>
<td>17.09</td>
<td>37.62</td>
<td>1.83</td>
<td>71.84</td>
<td>11.00</td>
<td>1.36</td>
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<td>7</td>
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<td>Mexico</td>
<td>12.91</td>
<td>35.00</td>
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<td>55.08</td>
<td>8.00</td>
<td>1.45</td>
<td>1.31</td>
<td>5</td>
<td>41</td>
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<td>41.98</td>
<td>8.00</td>
<td>1.77</td>
<td>1.76</td>
<td>16</td>
<td>101</td>
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<tr>
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<td>25.00</td>
<td>13.93</td>
<td>61.46</td>
<td>8.00</td>
<td>2.20</td>
<td>2.19</td>
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<td>113</td>
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<td>41.98</td>
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<td>1.79</td>
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<td>83</td>
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<td>Ecuador</td>
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<td>4.14</td>
<td>41.98</td>
<td>8.00</td>
<td>1.68</td>
<td>5.54</td>
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<td>41.98</td>
<td>8.00</td>
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<td>7.00</td>
<td>1.97</td>
<td>3.39</td>
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<td>7.37</td>
<td>45.28</td>
<td>7.83</td>
<td>1.76</td>
<td>2.66</td>
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<td>4.48</td>
<td>74.47</td>
<td>11.00</td>
<td>1.34</td>
<td>1.38</td>
<td>6</td>
<td>8</td>
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<tr>
<td>Europe &amp; Eurasia average</td>
<td>24.75</td>
<td>5.24</td>
<td>65.17</td>
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<td>12</td>
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<td>25.00</td>
<td>11.78</td>
<td>21.87</td>
<td>7.00</td>
<td>1.64</td>
<td>2.80</td>
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<td>2.55</td>
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<td>21.87</td>
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<td>1.36</td>
<td>1.35</td>
<td>7</td>
<td>33</td>
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<td>45.00</td>
<td>1.00</td>
<td>21.87</td>
<td>7.00</td>
<td>1.43</td>
<td>1.43</td>
<td>10</td>
<td>134</td>
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<tr>
<td>Middle East average</td>
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<td>5.68</td>
<td>21.87</td>
<td>7.00</td>
<td>1.74</td>
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<td>43.90</td>
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<td>1.80</td>
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<td>108</td>
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<tr>
<td>Equatorial Guinea</td>
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<td>13.50</td>
<td>43.82</td>
<td>8.00</td>
<td>1.57</td>
<td>1.67</td>
<td>15</td>
<td>106</td>
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<tr>
<td>Sudan</td>
<td>6.40</td>
<td>40.00</td>
<td>13.50</td>
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<td>8.00</td>
<td>2.41</td>
<td>2.66</td>
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<tr>
<td>Africa average</td>
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<td>7.33</td>
<td>43.86</td>
<td>7.75</td>
<td>1.76</td>
<td>2.14</td>
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<td>97</td>
<td></td>
</tr>
<tr>
<td>Australia</td>
<td>4.23</td>
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<td>3.95</td>
<td>53.00</td>
<td>8.00</td>
<td>1.39</td>
<td>1.46</td>
<td>13</td>
<td>9</td>
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<tr>
<td>Indonesia</td>
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<td>30.00</td>
<td>11.41</td>
<td>53.00</td>
<td>8.00</td>
<td>1.86</td>
<td>2.61</td>
<td>21</td>
<td>133</td>
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<tr>
<td>Malaysia</td>
<td>4.20</td>
<td>38.00</td>
<td>3.15</td>
<td>53.00</td>
<td>8.00</td>
<td>1.49</td>
<td>1.44</td>
<td>11</td>
<td>21</td>
</tr>
<tr>
<td>Thailand</td>
<td>0.45</td>
<td>30.00</td>
<td>4.44</td>
<td>53.00</td>
<td>8.00</td>
<td>1.41</td>
<td>1.40</td>
<td>9</td>
<td>17</td>
</tr>
<tr>
<td>Vietnam</td>
<td>3.25</td>
<td>25.00</td>
<td>7.63</td>
<td>53.00</td>
<td>8.00</td>
<td>1.49</td>
<td>1.30</td>
<td>3</td>
<td>94</td>
</tr>
<tr>
<td>Asia-Pacific average</td>
<td>30.60</td>
<td>6.12</td>
<td>53.00</td>
<td>8.00</td>
<td>1.53</td>
<td>1.64</td>
<td>12</td>
<td>97</td>
<td></td>
</tr>
</tbody>
</table>

Table 2

OVI and ranking results of overseas oil-investee countries.

Fig. 2. Different countries' OVI and investment volatilities. It shows the relationship between each country's oil-investment uncertainties and its option value index (OVI) which based on the results in (S2). X-axis represents the investment volatility; Y-axis represents the option value index (OVI). The distribution of these countries is shown in the figure according to the calculation results of the model.
production cost does not have an obvious effect on the model evaluation. Among the three volatilities, the OVI is more sensitive to exchange-rate and investment-environment volatilities than to oil-price volatility, which also explains why exchange rate and investment environment are so important to overseas investment in oil. Compared with changes in interest rates, changes in tax rates will have a more significant effect on the OVI because the tax rate has a direct influence on an oil project’s future cash flows.

Let us see the extent of the effects, besides convenience yield and oil-price volatility. The OVI and other parameters show a consistent direction of change. For example, if production cost and interest rate increase by 1%, the OVI will increase by 0.2505% and 0.3052%, and vice versa. The magnitude of each parameter’s positive effect is greater than that of its negative effect. For example, if convenience yield and tax rate were to change by 1%, their positive effects on OVI would be 0.8174% and 0.6032%, which are greater than their negative effects, 0.5925% and 0.2895%. Sensitivity analysis can determine that an equal percentage change in one parameter will have asymmetric effects on oil-reserve evaluation. As a result, when investing in overseas oil resources, it is necessary to consider separately the positive and negative effects of various factors on oil-resource evaluation.

In this paper the oil prices volatility is based on its historical data. As oil prices in 2007 and 2008 had experienced great fluctuation, it is hard to identify the expected future oil prices volatility. High volatility of oil price should be discussed in sensitivity analysis because it is inappropriate to ignore the existence of this condition (oil prices fluctuate greatly). So here oil price volatility will be set as 20%, 25%, 30% and the results of OVI will be recalculated as \( K(HO_{20}), K(HO_{25}), K(HO_{30}) \). See details in Table 4. The ranking results will change as the input parameters changes. Our oil investment volatility estimation has considered the effects of correlation coefficients which based on historical data. As oil price volatility rises, the correlation coefficients remain unchanged. So it will lead to the inaccuracy of the result. Here we use the high oil price volatility in order to find the trend that most countries’ OVI change as oil prices volatility raises.

It can be determined that most countries’ OVI rises as oil prices volatility increases. But the range of increase is inconsistent, for example Canada’s OVI rises by 50.14% and Brazil’s OVI rises by 14.66% when oil price volatility rises from 16.7% to 30%. The diversity of rising range also can to some extent reflect the oil price impact to each country’s oil investment. Although the ranking results by \( K(HO_{20}), K(HO_{25}), K(HO_{30}) \) are different from that by \( K(H) \), but to most countries there is little distinction between the two rankings. For example the USA, Norway and Saudi Arabia also get high rankings in \( K(HO_{20}), K(HO_{25}), K(HO_{30}) \), Ecuador, Venezuela and Iran also get low rankings. There are some exceptions, take Russian Federation as an example, when the oil prices volatility is set as 30%, its OVI reduces by 8.19%, and its ranking decreases from 16 to 19. And the ranking result of Argentina changes most, from 16 in \( K(H) \) to 2 in \( K(HO_{30}) \). The differences between the two ranking results are mainly due to the correlations between each country’s oil-price, exchange-rate and investment environment. It can be shown in Table 4 that some countries have appeared greater oil investment attraction in high oil prices volatility condition.

4.4. Implications for China’s overseas oil-investment activities

The valuation of overseas oil investment should give more weight to oil prices, exchange rates, and investment-environment risk. The

| Table 3 |
| Sensitivity analysis for Nigeria. |

<table>
<thead>
<tr>
<th></th>
<th>Change in different parameters</th>
<th>Change in different parameters</th>
<th>Change in different parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>T&lt;sub&gt;y&lt;/sub&gt; increase 1%</td>
<td>0.6032</td>
<td>T&lt;sub&gt;y&lt;/sub&gt; decrease 1%</td>
<td>-0.5925</td>
</tr>
<tr>
<td>C increase 1%</td>
<td>0.2909</td>
<td>C decrease 1%</td>
<td>-0.2896</td>
</tr>
<tr>
<td>r increase 1%</td>
<td>0.3052</td>
<td>r decrease 1%</td>
<td>-0.3052</td>
</tr>
<tr>
<td>δ increase 1%</td>
<td>-0.8004</td>
<td>δ decrease 1%</td>
<td>0.8174</td>
</tr>
<tr>
<td>α&lt;sub&gt;i&lt;/sub&gt; increase 1%</td>
<td>-0.1450</td>
<td>α&lt;sub&gt;i&lt;/sub&gt; decrease 1%</td>
<td>0.1469</td>
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<tr>
<td>α&lt;sub&gt;c&lt;/sub&gt; increase 1%</td>
<td>0.2599</td>
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<td>α&lt;sub&gt;fi&lt;/sub&gt; increase 1%</td>
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<td>α&lt;sub&gt;fl&lt;/sub&gt; increase 1%</td>
<td>0.8926</td>
<td>α&lt;sub&gt;fl&lt;/sub&gt; decrease 1%</td>
<td>-0.8876</td>
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</tbody>
</table>

Table shows the model sensitivity analysis result for Nigeria. Tax rate, oil production cost, interest-rate and convenience yield have been chosen to examine the effect when each of them changes by 1%. And three uncertainty parameters, oil price, exchange-rate and investment environment volatilities have also been examined in Table 2.

| Table 4 |
| OVI and ranking results when oil prices volatility rises. |

<table>
<thead>
<tr>
<th>Countries</th>
<th>Option value index ( K(HO_{20}) )</th>
<th>Option value index ( K(HO_{25}) )</th>
<th>Option value index ( K(HO_{30}) )</th>
<th>Ranking results by ( K(H) )</th>
<th>Ranking results by ( K(HO_{20}) )</th>
<th>Ranking results by ( K(HO_{25}) )</th>
<th>Ranking results by ( K(HO_{30}) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>North America</td>
<td>USA</td>
<td>1.48</td>
<td>1.72</td>
<td>2.00</td>
<td>6</td>
<td>6</td>
<td>6</td>
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<tr>
<td></td>
<td>Canada</td>
<td>1.61</td>
<td>1.87</td>
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Table shows each country’s OVI and Ranking results when oil prices volatility is set as 20%, 25%, 30%. Each country’s OVI is expressed as \( K(HO_{20}), K(HO_{25}), K(HO_{30}) \), and for easy to compare, the ranking results by \( K(HO_{20}), K(HO_{25}), K(HO_{30}) \) and by \( K(H) \) are also shown in Table 4.
results show that, first, it is not correct to consider oil prices as the only uncertainty in overseas oil investment, but exchange-rate and investment–environment risk should also be considered. Uncertainties in these three factors will have a great impact on overseas oil-reserve evaluation. Second, in overseas oil investment, low oil-production cost should not be pursued to the exclusion of everything else, because the countries with low production cost may not have a low critical value per unit of oil reserves. Moreover, oil-investee countries’ taxation systems may largely offset the cost-dilution effect on the investor country’s domestic economy downstream in the oil-industry chain. These factors all need to be considered when China carries out its overseas oil investment. Enhancing the accuracy of valuation of overseas oil resources can provide better decision support to China’s overseas oil-investment activities and help China improve its overseas oil strategy.

Some of China’s overseas oil businesses are in regions of high risk, and China needs to pay attention in the future to those countries with low critical value of oil reserves. Based on the results in (52), most of the countries where China is conducting oil-business activities rank low on the measures evaluated here; some of them have high-ranking results in the paper, but low-ranking results in the “Ease of Doing Business” report. China’s overseas oil projects are mainly concentrated in Africa (Nigeria, Sudan) and the Middle East (Iran, Syria) in countries with turbulent situations, and moreover these countries are far away from China. This means that China’s current overseas oil investments are exposed to great risk. Therefore, it is necessary to design risk-management mechanisms for the countries where China has already launched oil-business activities to reduce the influence of future uncertainty. Moreover, it is also necessary to pay attention to countries with a low critical value of oil reserves when China makes new overseas oil investments, for example in North America (Mexico, Canada) and the Asia-Pacific region (Vietnam, Australia) which have low oil-investment risk. Finally, China needs to strengthen cooperation with surrounding countries in Southeast Asia, organizing joint programs to develop regional offshore oil fields.

5. Conclusions and further work

This paper applies real options theory to study overseas oil investment and considers the integrated impact of oil prices, exchange rates, and investment–environment uncertainties on the valuation of overseas oil investment. A real options model has been developed to evaluate each country’s critical value per unit of oil reserves and to compare different countries’ oil-investment situation using the option value index (OVI). The model developed here can match several (THREE) key elements: 1) deal with overseas investment (we have considered the effects of investment environment, and exchange rates); 2) deal with oil investment (we have considered oil price, production decline rate and development cost etc.); 3) the comparability of the results from different countries (different countries’ oil-investment situation can be compared by using the option value index (OVI)).

China is considered as an example of an investor country to evaluate different investee countries’ critical value per unit of oil reserves and to offer suggestions for China’s overseas oil investment. The empirical results show that the model developed here can provide useful advices for China’s overseas oil investment program (i.e. ‘Low oil-production cost should not be pursued in overseas oil investment’. Some of China’s overseas oil businesses are in regions of high risk, and China needs to pay more attention to those countries with low critical value of oil reserves in the future, and so on). Besides, the research would probably also be helpful to other investor countries looking to invest in overseas oil resources.

However, as is well known, overseas oil investment is a complicated process with many influencing factors, and therefore it should be acknowledged that this research may have certain limitations. First, for oil investment, the theoretical model has not considered the potential reward from the acquisition of future development options. Compound option structures may give rise to a positive relationship between investment and uncertainty. Second, this research has assumed the oil price, exchange rate and investment environment to follow geometric Brownian motion and used the CPI as a proxy variable to reflect the volatility of the investment environment, which is a highly simplified approach. Third, the tax rate, interest rate and oil-production cost are constant in this model, and the impact of resource taxation on oil investment has not been considered because of the unavailability of data. Fourth, the data limitations and investment environment proxy variable had caused some “improper results”. The 1/3 rule as proposed by Gruy et al. (1982) has been used to calculate the convenience yield; this rule might be updated using more recent data. Much more data would be needed to perform a well-supported calculation. These questions will be investigated further in future work. Removing these shortcomings seems to be a fruitful avenue for further research and model improvement. And it will be a significant part of our future work to study the compound option in overseas oil investment, especially to be incorporated with oil production cost uncertainty.

Acknowledgements

Support from the National Natural Science Foundation of China under Grant Nos. 70825001, 70573104, and the Ministry of Science and Technology of China under Grant No. 2006BAB08B01 is greatly acknowledged. The authors would like to thank the anonymous referees for their helpful suggestions and corrections on the earlier draft of our paper and upon which we have improved the contents.

References


9 Here the cost-dilution effect implies that as an integrative outcome of upstream and downstream oil-company activities, the downstream production cost will rise as crude oil prices rise upstream. However, cost pressures can be lower downstream if the upstream end has benefited from rising prices and greater revenue, so that rising costs at the downstream end can be diluted. This approach ensures the profitability of the whole oil company. However, in overseas oil investment, the local taxing authority will generally keep part of the revenue from oil production, which offsets the benefit of participation in overseas oil investment for diluting domestic downstream production cost.


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