

An improved portfolio optimization model for oil and gas investment selection

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Abstract: For oil company decision-makers, the principal concern is how to allocate their limited resources into the most valuable opportunities. Recently a new management philosophy, “Beyond NPV”, has received more and more international attention. Economists and senior executives are seeking effective alternative analysis approaches for traditional technical and economic evaluation methods. The improved portfolio optimization model presented in this article represents an applicable technique beyond NPV for doing capital budgeting. In this proposed model, not only can oil company executives achieve trade-offs between returns and risks to their risk tolerance, but they can also employ an “operational premium” to distinguish their ability to improve the performance of the underlying projects. A simulation study based on 19 overseas upstream assets owned by a large oil company in China is conducted to compare optimized utility with non-optimized utility. The simulation results show that the petroleum optimization model including “operational premium” is more in line with the rational investors’ demand.

Key words: Portfolio optimization, capital budgeting, operational premium; utility theory, risk tolerance

1 Introduction

The prominent question for decision-makers in petroleum companies is how to allocate their capital reasonably to the most valuable investment opportunities as to maximize their utility under a certain budget. Many companies employ Net Present Value (NPV) to evaluate Exploration and Production (E & P) projects to empower better investment decisions. But the optimal selection of one single project may not be the optimal allocation that can realize the maximum return with the minimum risk for the company as a whole. Despite NPV remaining a critical criterion for most capital allocating process, difficulties arise within NPV analysis when justifying projects with longer-term, huge hidden internal costs and investors’ various risk appetites. For investment decisions, risk and economic benefit are equally important. The volatilities of oil price, capital expense (Capex) and operating expense (Opex) would compound the complexity of upstream project selection. Therefore, petroleum company executives are moving on from deterministic NPV analysis to “beyond NPV” in their business planning analysis. “Beyond NPV” was formally emphasized by petroleum economists from SPE in 2012¹. Within the concept of “Beyond NPV”, the integration of key performance indicators and uncertainties is strongly emphasized. Those uncertainties, rising from

options, side effects on stakeholders’ benefits, environmental issues, and risk preferences of decision-makers, provide significant growth contribution to investment risks (Ward and Ryals, 2001; Xu, 2013; Shu et al, 2013; Jordanger and Klakegg, 2013). Evans et al (2006) argued that, to meet sustainable development criteria, the industry need to adopt a broader range of valuation approaches besides NPV analysis. One of those alternative approaches is to employ the portfolio optimization method in terms of return to risk.

Portfolio theory was firstly put forward by Markowitz (1952). The portfolio theory proposes that a portfolio can be characterized by two indicators: the expected return of the portfolio and the variance of the expected return. The target of portfolio optimization is to minimize the variance for a given expected return or maximize the expected return for a given risk (Markowitz, 1952). This theory assumes a perfect market and that the investor’s utility function of portfolio return is quadratic. Using variance as an indicator of risk can penalize both negative deviation and positive deviation from average. Markowitz revised the optimization model and proposed two new portfolio risk indicators: the below-mean semi variance and the below-target semi variance (Markowitz, 1959). Markowitz portfolio theory is supported by Fisher’s

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separation theorem. The Fisher separation theorem proposes that the security portfolio optimization model doesn't need to include individual risk preference because of the underlying hypothesis of risk-free and identical borrowing-lending interest rates that investors can take advantage of frictionless transactions to achieve the optimal state (Fisher, 1906; Tobin, 2005). Thus, the target of "expected return maximization" becomes equivalent to the target of "expected utility maximization" if we ignore investors' risk preferences and the forms of their utility functions. Therefore, the portfolio optimization theory proposed by Markowitz (1952) uses "expected return maximization" instead of "expected utility maximization".

Many industry sectors, such as aerospace, cogeneration and electricity generation, have employed the portfolio selection approach as an integral part of strategic planning to reduce exposure to fossil fuel price fluctuation (Huanga and Wub, 2008; Zhu and Fan, 2010; Locatelli and Mancini, 2011; Vithayasrichareon and MacGill, 2012; Guerrero-Lemus et al, 2012; Arnesano et al, 2012). Since investments in the exploitation of hydrocarbons involve a high degree of risk as the value of candidate projects can be of very different nature and scope and fluctuate dramatically with the key value drivers, petroleum companies are constantly faced with investment decisions in multiple projects (Park et al, 2009; Zhang, 2010; Jafarizadeh, 2010; Zhang and Wang, 2011; Liu et al, 2012). Although literature has shown that the mean-variance method is the simplest and most effective approach available for asset selection (Quiek, 1982; Quieu and Buek, 1983; Lima et al, 2005; Guo, 2007; Wang and Wang, 2008; Deng and Xu, 2009; Zhao, 2010; Jafarizadeh, 2010; Cartwright, 2011; Willigers et al, 2011; Westner and Madlener, 2011), oil companies in China rarely implement mean-variance portfolio management in practice. The application of modern portfolio theory in petroleum industry stagnates in China, technically due to the lack of reliable and adequate data on comparable candidate projects. Another vital concern in the application of modern portfolio theory in the petroleum industry will be the difference between the oil industry and the securities market, manifesting chiefly in five aspects: type of uncertainties, risk indicators, market characteristics, time periods and the effect of budget constraints (Orman and Duggan, 1999; Walls and Dyer, 1996; Walls, 2004; Ball and Savage, 1999; Hayashib et al, 2010; Egozcue et al, 2011; Sáncheza and Al-Harthy, 2011).

Considering these differences mentioned above, there are two main challenges that call for further theoretical evidence for its practical use: The first notable challenge is that the market of O & G asset merger and acquisition is frictional. We cannot find any risk-free candidate E & P project similar to the risk-free security. Under the premise of no arbitration and a ubiquitously risk-averse policy among oil and gas industry decision-makers, the principle of "Expected Utility-Variance" is more fitted in the petroleum market than the "Expected Return-Variance" principle (Cozzolino, 1977; 1979; Mansoor, 2007; Lasdon et al, 2007; Erdogan and Mudford, 2001; Rahmawatia et al, 2012). Besides, there is no short and long mechanism in oil & gas transaction, and investor's equity share can only be within the range from 0 to 100%.

Therefore, expected return maximization is not a substitute for the goal of expected utility maximization. The second significant challenge is that the participants in petroleum markets have the ability to improve the performance of their portfolios instead of just keeping the portfolios and waiting for their prices to rise, meaning that those investors also act as project operators. As for the first challenge, Cozzolino (1977, 1979) made his contribution by using expected utility criteria to replace expected return criteria. But as for the second challenge, no study is aimed at the effect of international oil companies' dual identity in asset management. To conquer the second challenge, this paper will explore a real asset portfolio optimization model by taking investors' dual identities into consideration.

2 Capital budgeters and operational premium

Oil company executives who make investment and project selection decisions are not like individual investors in the stock market. They are allocating capital to the best projects. Not only do executives care about the assessment and evaluation results given by professional investment advisors, such as Goldman Sachs and Morgan Stanley, but they also want to develop insights into the most operational potential among these candidate E & P projects because projects with operational potential can provide significant growth contribution to the projects' underlying value. To distinguish oil company executives from security investors, we call the latter "professional investors", and the former "capital budgeters", who can create added value by using their own technical skills, production experience, financial strength, risk management and control systems. We name the added value part "operational premium". Based on research into operating behaviors of oil companies, we find that the degree of operational premium is mainly affected by two factors: one is the operating efficiency of a certain investor; and the other is the degree of investor's control ability on the project, namely, ownership interest.

1) Operating efficiency

Measurement of operating efficiency can be considered from many aspects, including the input-output ratio, social status, staff development, social welfare contribution and R&D reserves. The most easily quantifiable factor is input-output ratio—the return on investment ratio a project will get. This paper chooses the input-output ratio to measure the operating efficiency.

2) Ownership interest

In Markowitz's portfolio theory, return on investment is an exogenous variable and investors are all price takers, so the ownership proportion of each asset will not impact the underlying yields. This theory is reasonable for most professional investors. But in the case of capital budgeters, like international oil companies, the ownership interest percentage will impact the operating efficiency to different degrees. Generally speaking, the greater proportion the investor's equity account for in an oil & gas asset, the closer the asset's output function will get to that under the investor's full control.

Suppose a capital budgeter has a operating efficiency of e_0 in an existing project when he has 0% ownership interest and an achievable efficiency of e_1 in that project when he has 100% ownership interest. When he changes the ownership interest to w , then the efficiency should be a function of w and the corresponding operating efficiency should be located between e_0 and e_1 . According to real oil companies' management experience, the growth rate of operating efficiency is accelerated with the increase of the working interest, so operating efficiency can be expressed in a nonlinear form of w . Fig. 1 shows the convex property of operating efficiency.

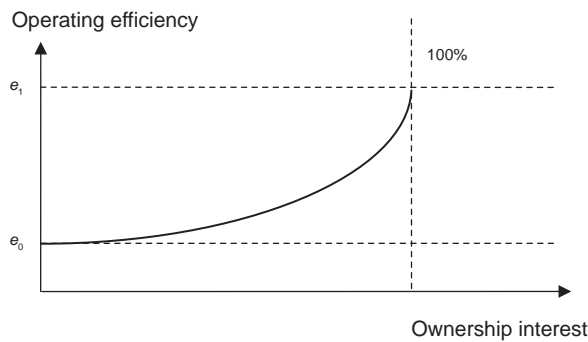


Fig. 1 Influence of ownership interest on operating efficiency

The convex ownership-efficiency line describes the nonlinear relationship between control power and the operating efficiency that a capital budgeter can achieve (Fig. 1). e_0 is the initial operating efficiency when a capital budgeter owns 0% equity share of the candidate asset. The maximum efficiency will be e_1 , realized when the ownership increases to 100%. The convexity between ownership interest and operating efficiency is matched with the underlying assumption that the control power of majority shareholders and minority shareholders on the same candidate project is not in accordance with the proportion of equity allocation respectively. In most cases, the majority shareholders have strong corporate governance, causing the “one share jumbo” phenomenon. Thus, the nonlinear efficiency function can be expressed in the form of w^a for simplicity, where a indicates how much the ownership interest of the underlying asset affect the elasticity of output efficiency. If a is greater than 1, it denotes that the operating efficiency model is closer to the scenario of “one share jumbo”. If a is less than 1, it represents that the minority shareholders may have more control than their equity allocation.

3 Model design

We set expected utility maximization as the goal of portfolio optimization given a specific level of risk and certain budget constraints. The criterion of maximizing expected utility offers a feasible way for asset selection under uncertainty, making it possible to distinguish diversified investment strategies made by different international oil companies at various risk-averse levels. Assume the utility function of a capital budgeter is a negative exponential expression of the total wealth x such that:

$$u(x) = -e^{-x/RT} \tag{1}$$

where x , the total wealth, is given by $(\sum (w \times npv_i))$, namely the anticipated value of a project, and RT is the risk tolerance of the investor. $u(x)$ is a dimensionless variable.

Suppose an original candidate portfolio Φ formed by upstream under-development projects and those projects are initially owned by professional investors. Φ is characterized in a matrix form of:

$$NPV_0 = \begin{bmatrix} npv_{01} \\ npv_{02} \\ \dots \\ npv_{0n} \end{bmatrix} \tag{2}$$

Based on the discussion in the second section, operational premium can be decomposed into the operating efficiency of a company on particular assets and the strength of an enterprise's control over its assets. Hence, we build operating efficiency function (E_i) and nonlinear shareholding-efficiency function ($f(w_i)$) respectively.

1) Operating efficiency function

Given E as the investor's efficiency space defined to be $E=[E_1, E_2, \dots, E_n]$, where E_i implies the investor's operating efficiencies of asset i . The matrix form of E is written in:

$$E = \begin{bmatrix} 1+e_1 & \dots & \dots & \dots \\ & 1+e_2 & \dots & \dots \\ \dots & \dots & \dots & \dots \\ & & & \dots & 1+e_n \end{bmatrix} \tag{3}$$

where e_i indicates the value-added rate of project i that a capital budgeter can achieve under 100% ownership. Meaning, if one E&P project is owned by a professional investor, its value could be npv_{0i} , but if that asset is taken over by a capital budgeter, its value could be increased to $npv_{0i}(1+e_i)$, where e_i is a constant and represents the value-adding capacity that a capital budgeter has because of his professional skills and management experience.

2) Nonlinear shareholding-efficiency function

For a specific investor, his operating efficiency for a certain asset is increasing at an accelerated speed with rising ownership interest. The nonlinear shareholding-efficiency function gauges the change of a capital budgeter's operational premium ratio. It is defined as follows:

$$f = \begin{bmatrix} f(w_1) \\ f(w_2) \\ \dots \\ f(w_n) \end{bmatrix} \tag{4}$$

where w_i indicates investor's ownership interest of asset i in the portfolio space Φ , and $w_i \in [0,100\%]$. $f(w_i) \in [0,1]$, $f(0)=0$, and $f(1)=1$. Besides, $f(w_i)$ is convex in w_i , hence, $\frac{\partial f(w_i)}{\partial w_i} > 0$ and $\frac{\partial^2 f(w_i)}{\partial w_i^2} > 0$.

3) Operational premium function

Assume one investor owns a royalty rate of w_i on project i . When it comes to the professional investor, the value of the investment would be $w_i \times (npv_{0i})$. While when it comes to the capital budgeter, the value of the investment would be:

$$w_i \times npv_{0i} [1 + e_i \times f(w_i)] \tag{5}$$

For the whole asset portfolio Φ , the operational premium vector is described by:

$$\begin{bmatrix} 1 + e_1 \times f(w_1) & & \dots & & \\ & 1 + e_2 \times f(w_2) & & \dots & \\ \dots & & \dots & & \dots \\ & & & \dots & 1 + e_n \times f(w_n) \end{bmatrix} \tag{6}$$

$$\begin{bmatrix} w_1 & w_2 & \dots & w_n \end{bmatrix} \begin{bmatrix} 1 + e_1 \times f(w_1) & & \dots & & \\ & 1 + e_2 \times f(w_2) & & \dots & \\ \dots & & \dots & & \dots \\ & & & \dots & 1 + e_n \times f(w_n) \end{bmatrix} \begin{bmatrix} npv_{01} \\ npv_{02} \\ \dots \\ npv_{0n} \end{bmatrix} \tag{8}$$

The risk constraint is subject to the original risk level δ^2 , and expressed as follows:

$$\text{Var}(\sum w_i \times npv_{0i} \times [1 + e_i \times f(w_i)]) \leq \delta^2 \tag{9}$$

The budget constraint is defined by:

$$\begin{aligned} \text{Max} \{ E[u(\sum w_i \times npv_i)] \} &= -\exp \left\{ - \left[\sum w_i \times npv_{0i} (1 + e_i f(w_i)) \right] / RT \right\} \\ \text{st. } \text{Var}(\sum w_i \times npv_{0i} \times [1 + e_i \times f(w_i)]) &\leq \delta^2 \\ \sum w_i E(npv_i) &\leq \text{Budget} \end{aligned} \tag{11}$$

where δ^2 is the variance of the projects before optimization, and npv_i is the expected value of the repurchased projects for capital budgeter. RT is short for "risk tolerance". w_i , npv_{0i} , e_i , and $f(w_i)$ are defined in Eqs. (3), (4) and (5).

4 Simulation case study

4.1 Simulation assumptions

Company A is a large multinational oil company in China. Taking the company's 19 under-development projects as the original portfolio, we use a Monte Carlo method to simulate the assets packet to find the utility-maximized portfolio. The main parameters of sampling are defined as follows:

- Software: Crystal Ball 11.1
- Stimulation frequency: 100,000 times
- Value-driver variables: oil price, Capex, and Opex.
- Variables described in Table 1.

4) Optimization model concerning operational premium

We consider operational premium as a key parameter for capital budgeters in contrast to professional investors. Suppose the ownership and variance vector of the original project portfolio before optimization is $[w_{01}, w_{02}, \dots, w_{0n}]$ and δ^2 respectively. Let e_i and $f(w_i)$ be the operational premium function and shareholding efficiency function respectively. Then the objective function is given by:

$$\text{Max} \{ E(\sum w_i \times npv_i) \} \tag{7}$$

where npv_i indicates the anticipated revenue of the i th project repurchased by the capital budgeter who is also the operator of that project, and w_i represents the reallocated ownership interest of project i . The total wealth of reformed portfolio would be:

$$\sum w_i E(npv_i) \leq \text{Budget} \tag{10}$$

Considering utility and efficiency coherently, we build the new objective function as follows:

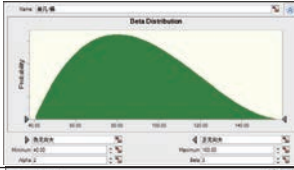
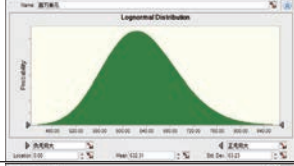
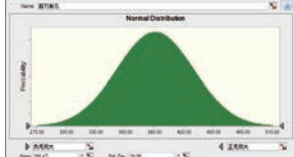
1) Oil price

From the result of fitting Cushing oil future prices from Jan 2001 to December 2011, the oil prices obey the Beta distribution (where $\alpha=1.70$, $\beta=3.32$, $\text{Min}=\$11.54/\text{bbl}$, $\text{Max}=\$152.39/\text{bbl}$); while according to the trend of oil prices in the first half of 2012, the oil prices can be considered to obey a different Beta distribution (where $\alpha=2$, $\beta=3$, $\text{Min}=\$40/\text{bbl}$, $\text{Max}=\$160/\text{bbl}$).

2) Capital expense (Capex)

Assuming that the Capexes obey a lognormal distribution, the mean value is the expected value of the most likely scenario, and the standard deviation is 10% of that mean value. For example, in the basic scenario, the Capex is anticipated to be \$632 million. Capexes are assumed to subordinate to the lognormal distribution. Then, the mean value of that Capex is \$632 million and the standard deviation is 63.2.

Table 1 Proposed distribution of crucial variables

Variables	Assumptions	Correlation with bench oil prices	Diagrammatic presentation
Oil price	Beta distribution Min=\$40/bbl Max=\$160/bbl Alpha=2, Beta=3	0.9	
Capex	Lognormal distribution Mean=Base case value Std. Dev=10% of mean	0.3	
Opex	Normal distribution Mean=Base casevalue Std. Dev=10% of mean	0.7	

3) Operating expense (Opex)

Considering the Opexes to be normally distributed, the mean value is the anticipated value of the most possible scenario, and the standard deviation is 10% of that mean value. For instance, the Opex in the basic scenario is expected to be \$390 million, and Opexes are considered to be normally distributed. Thus, the mean value of that Opex is \$390 million, and the standard deviation is 10% of that mean value.

4) Correlation of variables²

The output of each project is irrelevant to each other, namely those productions are all independent of each other. For economic parameters, it assumes that the correlations are: If the yearly bench oil price is a variable, the correlation between the change of yearly sales price and the change of yearly bench price of each petroleum project is 0.9; the correlation between the change of yearly Capex and the change of yearly bench price of each project is 0.3; the correlation between the change of Opex and the change of bench price is 0.7. Those figures are set according to the different relevant degrees between each economic parameter and bench price.

4.2 Before portfolio optimization

After taking 1×10^5 times of sampling simulation, the mean value of the asset packet without considering operational premium is \$31,893 million, the variance is 32,515,483. Assuming the risk tolerance of investors to be \$3000 million, the anticipated utility of this portfolio bringing to investors calculated by Eq. (1) will be 4.24.

Fig. 2 demonstrates the Mean NPV-variance space without considering operators' premium before optimization.

² To simplify the simulation procedures, the correlations between different parameters of different projects are not defined in this paper although those correlations are considered to exist. The correlations among parameters of different projects will be illustrated by using bench price.

The red curve indicates the optimal investment portfolios as demonstrated in Markowitz theory. Compared with the benchmark efficient frontier, at least three projects with variance higher than 1×10^7 can be optimized. These three projects locate in the inner space of the efficient frontier. Apparently, according to the risk-return boundary, the current assets allocation does not meet the optimized risk-return boundary (see Fig. 2), meaning it can be further optimized.

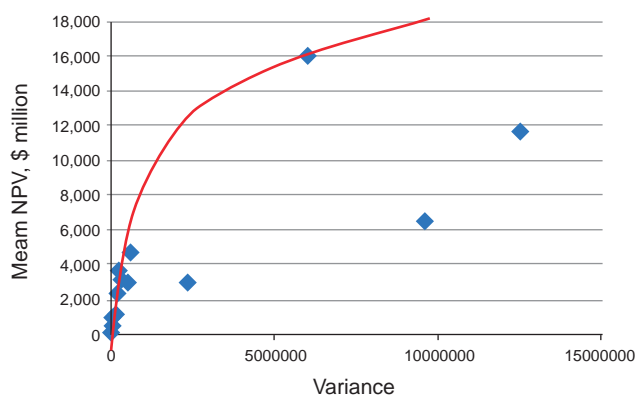


Fig. 2 Mean NPV-Variance space of assets without operational premium before optimization

4.3 After portfolio optimization

Based on the result of “before portfolio optimization” mentioned above, the utility-promotion process can be explained from the perspective of merger and acquisition:

In a simplified market, there are two investors: one is company A, a capital budgeter who specializes in oil and gas project operation, meaning he can put some premium on the asset after the acquisition; the other is a professional investor, who imposes no premium on purpose and whose behavior is completely market-oriented. In the 1st step, company A sells all assets. The professional buyer will only bid for \$31,893 million, which in return becomes the budget ceiling

of company A; in the 2nd step, company A reallocates the \$31,893 million to each of the 19 assets, then a new portfolio would be formed. Then we can reassess investors' new utilities. The target portfolio will be the utility-maximized portfolio under both the budget constraint of \$31,893 million and the risk constraint of 32,515,483, and can be expressed as follows:

$$\text{Budget} \leq W \cdot V \equiv 31893.31$$

$$\bar{W} \cdot \Omega \cdot \bar{W}^T \leq W \cdot \Omega \cdot W \equiv 32515483$$

We perform numerical optimization simulation for a sampling frequency of 800 times to achieve stability (see Fig. 3).

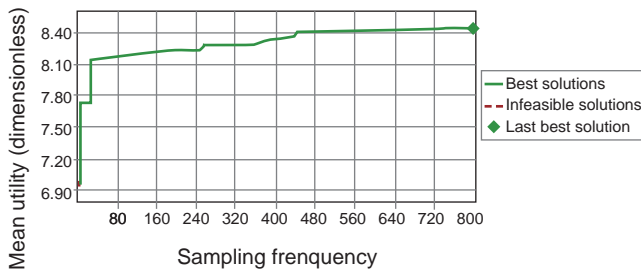


Fig. 3 Curve of numerical optimization simulation (Utility maximization) under a risk tolerance of \$3000 million (RT3000)

Based on the principle of utility maximization under budget constraint and risk constraint, the anticipated utility of the optimized portfolio almost doubled within the budget (\$31,893 million) from 4.24 to 8.45 (see Fig. 4).

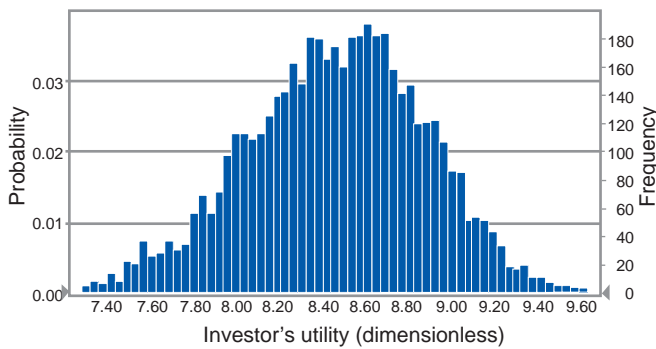


Fig. 4 Distribution of investor's utility after utility maximization under a risk tolerance of \$3000 million (RT3000)

Considering that different capital budgeters exhibit different levels of risk aversion, we recalculate simulations under three different risk tolerance levels, namely \$30, \$300, and \$30,000 million respectively, to improve the robustness. In these three experiments, we keep the optimization target, budget constraint and risk restriction constant. After 1×10^3 times of random simulation, the anticipated utility increases by 148% from 0.58 to 1.44 when risk tolerance rises to \$30,000 million, while 6.32% from 16.76 to 17.82 when risk tolerance declines to \$30 million. The simulation results reached stability are shown in Table 2.

Table 2 Optimization results under different risk tolerances (RT)

Optimization target	Maximize mean of utility			
Budget constraint	\$31,893 million			
Risk constraint	Variance \leq 32,515,483			
RT value (\$ million)	30	300	3,000	30,000
Anticipated utility before optimization	16.76	11.49	4.24	0.58
Anticipated utility after optimization	17.82	16.14	8.45	1.44
Variance of portfolio after optimization	18,962,757	19,807,867	17,887,355	16,539,037

Table 2 shows that the variance of the portfolio under a set budget ceiling and risk constraint decreases sharply, and that the higher the risk tolerance level is, the more the anticipated utility increases. Namely, the utility of investors with higher risk tolerance has more room for improvement than that with lower risk tolerance.

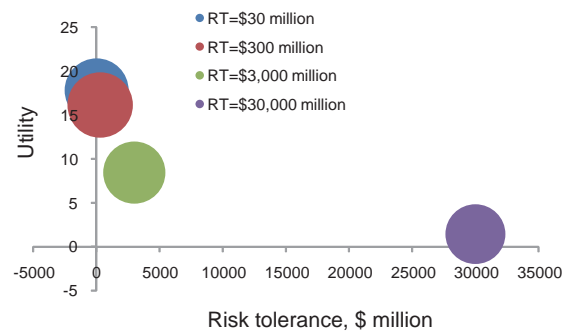


Fig. 5 Results of optimization considering risk appetite and operational premium

Fig. 5 shows the results of optimization considering risk appetite and operational premium, in which the horizontal axis represents risk tolerance level, the vertical axis shows the corresponding utility level (dimensionless) of each investor, and the size of the bubble indicates the variance of the portfolio after optimization. It can be seen that the anticipated utility decreases with increasing risk tolerance. This phenomenon is accordance with the nature of negative exponential utility function. The optimized investment plan is different with changing risk tolerances (See Fig. 6).

Fig. 6 shows the optimized choices for investors with various risk tolerance. At a risk tolerance of \$30 million, the optimal investment presents in a more centralized distribution (Fig. 6(a)), while at a risk tolerance of \$30,000 million, the optimal investment exhibits a more diversified distribution (Fig. 6(d)).

Fig. 6 shows that the allocation of the best portfolio is less centralized with growing risk tolerance, indicating that diversified strategy is positively correlated with investors' risk tolerance. Fig. 6 also shows that enterprise with lower risk tolerance would reduce their holdings of risky projects with high return, such as project 1, project 9, and project 10.

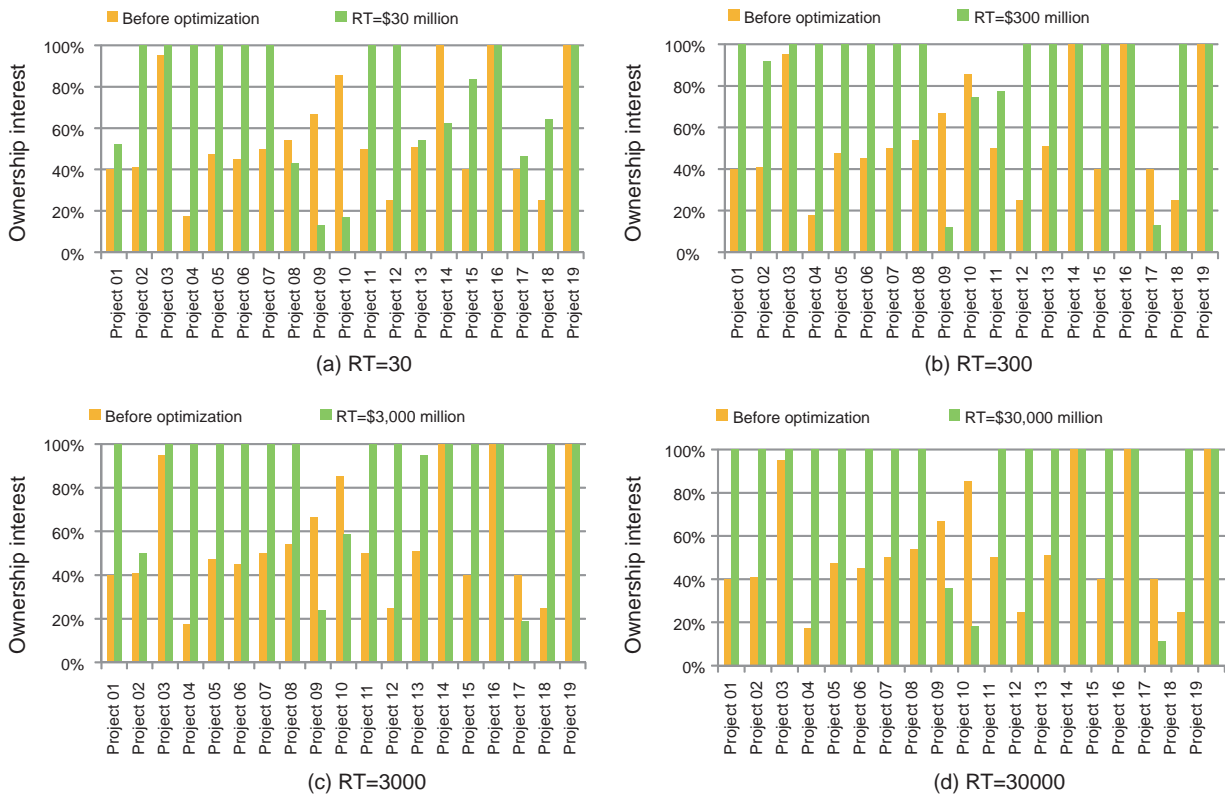


Fig. 6 Optimized choices for investors with various risk tolerance

5 Conclusions

Although NPV is a deterministic indicator in most engineering dominant cultures, portfolio management is pushing it forward by considering investment opportunities from the view of capital budgeting. Based on Markowitz portfolio theory, this article built an improved portfolio selection model by introducing operational premium as a factor to distinguish the double identities of petroleum enterprises as both operators and investors. The concept of “operational premium” is borrowed from the concept of “acquisition premium”. Since petroleum companies are not investors who gain profits by merely buying and selling those equities, they also act as project operators who should accomplish the production targets, improve the petroleum production and recover the investment. Therefore, those companies can generate a “operational premium” by using techniques, production and management experience and inner capital markets to save costs and increase returns. According to actual production experiences, the size of operational premium can be influenced by the control ability of one petroleum company on its projects or assets: if the equity ratio of one petroleum company in one project rises, the operational premium would increase gradually at a growing speed.

We used numerical simulation of real data from 19 under-development projects to further analyze the effect of operational premium and risk tolerance on the optimization results. The numerical simulation results shows operational premium has significant impact on asset selection:

- 1) After a Monte Carlo simulation of the improved

portfolio selection model, the expected utility of the company’s present portfolio increased dramatically, and the risk represented by portfolio variance has been decreased sharply;

- 2) Concerning operational premium, the optimization result suggests holding high ratio of assets with high operational premium and low ratio of assets with low operational premium;

- 3) The utility of investors with higher risk tolerance has more room for improvement than the utility with lower risk tolerance;

- 4) Diversification strategy is positively correlated with investors’ risk tolerance. Investors with a higher degree of risk aversion would choose intensively centralized portfolios.

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