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Combining decision analysis and portfolio management to improve project selection in the exploration and production firm

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Abstract

Recent advances in modern finance theory and decision science are being utilized in a more systematic fashion by the upstream petroleum industry. Corporate planning groups as well as business units in oil companies are increasingly applying techniques such as decision analysis, simulation, portfolio management, and real options analysis to improve the overall decision making and capital allocation process.

An important element of improving the practice of risk management in the E&P setting is to ensure the proper integration of these analytical techniques in order to leverage their overall capabilities. The Markowitz optimization approach to portfolio analysis, for example, provides the E&P decision maker an efficient set of portfolios, based on minimizing risk subject to a particular return. However, without some guidance as to what level of risk-taking is appropriate for the E&P firm, the portfolio analysis alone does not provide managerial guidance about which of these efficient portfolios is best for the firm. There are, however, important attributes of the decision analysis paradigm that link directly to choices made by the firm regarding modern portfolio analysis. Preference analysis, an important element of a comprehensive decision analysis, provides us a mechanism for measuring and applying a corporate risk-taking policy. Knowing the firm's attitude about taking financial risk is important in terms of selecting the appropriate portfolio of activities. These linkages between decision analysis and portfolio management can improve the overall decision process, and ultimately, firm performance.

Keywords: Petroleum risk; Portfolio management; Decision analysis; Preference theory

1. Introduction

The capital allocation process, and the quality of its associated decisions, remains a critical factor influencing overall firm performance. This is particularly true for petroleum companies where characteristics of risk and uncertainty are pervasive in this capital investment setting. Today's exploration and production industry is characterized by a highly volatile product price setting, increased pressure to minimize cost structures, diminishing U.S. investment opportunities, a shrinking experienced workforce, and a cautious capital market. The combination of these characteristics provides a compelling motivation for managers to implement the most effective technologies for allocating capital and improving the overall quality of E&P investment decisions.

Relatively recent advances in modern finance theory and decision science are being utilized in a more systematic fashion by the upstream petroleum industry. Corporate planning groups as well as business

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units in oil companies are increasingly applying techniques such as decision analysis, simulation, portfolio management, and real options analysis to improve the overall decision making and capital allocation process.

An important element of improving the practice of risk management and decision making in the E&P firm is to ensure the proper integration of these analytical techniques in order to leverage their overall capabilities. The Markowitz optimization approach to portfolio analysis, for example, provides the E&P decision maker a set of efficient portfolios, based on minimizing risk subject to a particular return. Without some guidance as to what level of risk-taking is appropriate for the E&P firm, the portfolio analysis alone does not provide managerial guidance about which of these efficient portfolios is best for the firm. There are, however, important attributes of the decision analysis paradigm that link directly to choices made by the firm regarding modern portfolio analysis. Preference analysis, an important element of a comprehensive decision analysis, provides us a mechanism for measuring and applying a corporate risk-taking policy. Knowing the firm's attitude about taking financial risk is important in terms of selecting the appropriate portfolio of activities. This integration between decision analysis and portfolio management can improve the overall decision process, and ultimately, firm performance.

This paper is organized as follows: first, we provide an overview of modern portfolio theory and demonstrate an application of Markowitz optimization for a sample of typical E&P projects. We highlight the key insights from the portfolio analysis and how it provides significant guidance to E&P decision makers. In the next section we provide an overview of preference analysis and how this theory is applied in the E&P setting in order to estimate the firm's financial risk tolerance. In the third section we integrate these two approaches and demonstrate how the firm can select the optimal portfolio among an efficient set of portfolios by utilizing their current level of financial risk tolerance. In the last section we discuss the implications of this approach and the intuitions that managers can gain from applying such an approach as part of the capital allocation process.

2. Modern portfolio management

Much of modern portfolio management has been motivated by the seminal work of Harry Markowitz (Markowitz, 1952) and his well known Markowitz optimization approach. Markowitz demonstrated how stock investors could select an efficient set of portfolios that would minimize the standard deviation (risk), subject to a particular portfolio return (expected return). Markowitz (1956) showed through a classic quadratic optimization technique that investors could virtually eliminate their exposure to the unique or unsystematic risk associated with individual securities. This optimization approach is applied in the context of a fixed investment amount for the portfolio. The unsystematic risks are those risks specific to the business or industry. This ability to diversify away the unsystematic risk leaves the stock investor with a portfolio containing only the systematic or market-specific risks, such as inflation, purchasing power, and other market-wide risks. As shown in Fig. 1, Markowitz demonstrated that with only a limited number of properly selected stocks, the investor could virtually eliminate all the unsystematic risk associated with individual stocks, leaving only the generally undiversifiable systematic or market risk.

The basic assumption of modern portfolio theory is that decisions are made on the basis of a tradeoff between risk and return. Return is measured by the expected value or mean (μ) of the probability distri-

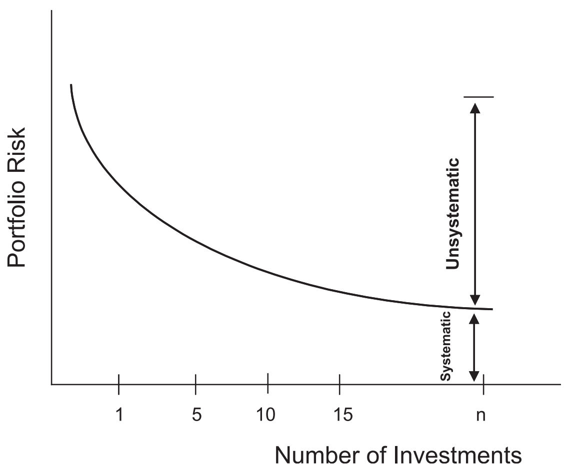


Fig. 1.

bution of payoffs for the stock or asset being considered. Risk is measured by the variance or standard deviation (σ) associated with that payoff distribution. In addition, we make the very reasonable assumption that investors and decision makers prefer less risk to more risk, all other things held constant. In other words, given a certain expected return rational investors will always prefer assets and/or portfolios that have lower risk. Similarly, given a certain level of risk, those same investors will always prefer assets/portfolios with higher expected returns.

In this portfolio optimization approach, risk is defined as the standard deviation of returns (i.e., net present value) of the portfolio of assets. Indeed, standard deviation is a commonly used measure of risk in the financial markets where return distributions are generally normally distributed. Though standard deviation is utilized as a measure of risk in the finance literature, it is important to point out that this measure is more precisely defined as a statistical measure of uncertainty. It is, in essence, of measure of dispersion around the mean value for a distribution of outcomes. Unlike the decision maker who may characterize risk as that portion of the uncertainty that has "downside", the standard deviation measure does not differentiate between "downside" and "upside" uncertainty. In this context, portfolio analysis based on standard deviation (as described by Markowitz) considers extremely high and low returns equally undesirable.

It is important to note that in the case of capital projects, especially in the E&P sector, returns on projects may not be normally distributed. In many cases the distribution of outcomes may have skewed value distributions with high probability of achieving low-value outcomes and small probability of achieving high-value outcomes. In certain cases, it may be more appropriate to utilize an alternative measure of risk such as semi-standard deviation. The semi-standard deviation measure concentrates on reducing losses where the loss point in the semi-standard deviation measure is defined by the decision maker. Markowitz (1991) provides an exposition on this alternative measure of risk and Orman and Duggan (1999) provide an example application in the E&P sector. One should note, however, that there are practical complications associated with the application of the semi-standard deviation measure in portfolio optimization. For example, there are issues associated with selecting an appropriate "loss point" for a distribution of outcomes. Also, in an analysis based on standard deviation, only means, variances and covariances must be supplied as inputs to the analysis. In a semi-standard deviation analysis the entire joint distribution of outcomes is required in order to perform the analysis.

In any case, the notion behind diversification is that it works to reduce risk because returns of different assets do not move exactly together. Even in a two-investment portfolio, a decline in the value of one asset can be offset by an increase in the value of the other asset. The result is that the variability of the portfolio of assets is less than the average variability of the two investments in the portfolio. We utilize the covariance measure as an absolute measure of the extent to which two variables move together over time. Covariance between assets i and j is defined mathematically as follows:

$$\mathrm{Cov}_{i,j} = \sum_{t=1}^{n} h_t[(r_{it} - \mu_i)(r_{jt} - \mu_j)] \tag{1}$$

where, h = probability of state 1 to n; r_{it} = return for asset i in time t; μ_i = mean return for asset i during period t to n.

Positive covariance between two assets suggests that when one asset produces returns above its mean, the other asset tends to also produce above its mean. Negative covariance, on the other hand, tells us that when one asset produces returns above its mean the other tends to be below its mean and vice versa. Zero covariance would suggest that there is no consistent relationship between the movements of returns for the two assets. Diversification effects improve as the covariance measure moves from positive to negative between assets.

The correlation coefficient, ρ, is more commonly used to describe the movement of returns between two assets. The correlation coefficient is a normalized measurement of joint movement between two variables, and is mathematically described as follows:

$$\rho_{i,j} = \frac{\mathrm{Cov}_{i,j}}{\sigma_i \sigma_j} \tag{2}$$

The normalized measure puts bounds on the covariance measure and can range from values of

− 1.0 to + 1.0. In the case of perfect positive (+ 1.0) or negative (− 1.0) correlation, if we know the return on asset *i*, then we know with certainty the outcome on asset *j*, and vice versa. The correlation coefficient is a more commonly used measure to describe the extent to which two variables move together.

We are interested in evaluating the expected return and the risk of a portfolio of assets and so we define those measures at the portfolio level where the expected return on the portfolio, $E(r_p)$, is:

$$E(r_p) = \sum_{k=1}^{n} x_k \mu_k \tag{3}$$

where, k = assets 1 to n in the portfolio; x = percent of total investment in asset k; μ = mean return for asset k, and the variance of the portfolio return, σ^2 for a two-asset portfolio is expressed as:

$$\sigma_p^2 = x_i^2\sigma_i^2 + x_j^2\sigma_j^2 + 2x_i x_j \rho_{i,j}\sigma_i\sigma_j. \tag{4}$$

The standard deviation of the portfolio is the square root of the variance, σ_p. Note that the components of portfolio risk for this two-asset portfolio include the weight-adjusted contribution of variance from each of the assets *i* and *j* in the portfolio (unsystematic risk) and the average covariance between the two assets (systematic risk).

This two-asset measure of portfolio risk can be extended to *n* assets in the form of a portfolio covariance matrix, as shown in Fig. 2. The shaded cells in Fig. 2 represent the contribution of variance (unsystematic risk) by each asset to the portfolio risk (the first two elements on the right side of Eq. (4)) while the unshaded cells represent the covariance contribution (systemic risk) between pairs of assets (the third element on the right side of Eq. (4)). The bold area shown in the top left portion of the matrix represents the matrix for a simple two-stock portfolio as defined in Eq. (4). As we add more and more assets to the portfolio (while holding the total investment amount constant), the unsystematic risk becomes a smaller and smaller portion of the overall risk. Taking *n* assets to the limit, the unsystematic risk is driven to near 0, which is consistent with our earlier discussion regarding the result of diversification. Any time returns on investments are less than perfectly positively correlated (+ 1.0) some risk reduction will be possible by combining the assets in a portfolio. The extent to which we can still get risk reduction from positively correlated assets gives extra meaning to the application of portfolio management in the E&P setting.

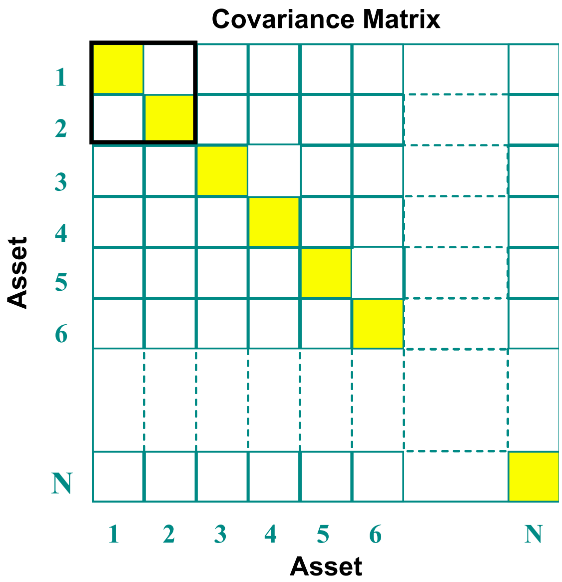


Fig. 2.

3. An application of portfolio management to the E&P setting

Consider the set of eight exploration and development assets summarized in Table 1. Assume for the moment that this is the firm's current mix of opportunities for the next period of drilling activity. Table 1 summarizes the characteristics of each asset including a probability of success, P_s, a net present value of success payoff, a net present value of failure, and the completion costs associated with each asset. Also, for exposition purposes we assume that the correlation coefficient between pairs of assets is equal to + 0.2. In fact, correlations between pairs of assets would in all likelihood be different as there would be various relationships in how these asset returns moved together. In reality these correlations would be influenced by such things as geo-technical dependencies and product types (oil versus gas).

Table 1

Prospect	Working interest	P_s	NPV success	NPV failure	Completion cost	Expected NPV	Standard deviation
	All values in (US$) million						
1	25%	40%	34.0	−4.5	2.5	2.7	4.7
2	100%	20%	45.0	−6.0	3.0	4.2	20.4
3	100%	50%	40.0	−7.5	1.8	16.3	23.8
4	75%	25%	82.0	−2.6	3.5	13.9	27.5
5	25%	80%	24.0	−8.0	1.0	4.4	3.2
6	40%	60%	33.0	−7.0	1.2	6.8	7.8
7	75%	35%	92.0	−6.5	4.0	21.0	35.2
8	20%	80%	28.0	−9.0	1.3	4.1	3.0
	Current Portfolio E (NPV) 73.4						
	Current Portfolio standard deviation 75.0						

Table 1 also summarizes the mean and standard deviation of each asset as well as the portfolio mean and standard deviation once we have considered the unsystematic and systematic risks associated with this mix of assets. The portfolio metrics shown in Table 1 reflect the individual assets' variances as well as the covariance between assets based on the assumed correlation coefficient of 0.2. The firm's current working interest for each prospect is shown in Table 1 and the total expected budget expenditure based on the firm's current mix of assets is US$33 million. The current budget value is computed by adjusting the gross failure cost (dry hole cost) in column 5 by the firm's working interest and adding to that the probability weighted (expected) completion costs associated with the firm's working interest. The sum of those values for all prospects represents the firm's expected annual capital expenditures for their current portfolio.

At this point we apply the Markowitz optimization approach to construct an "efficient set" of portfolios based on the notion of minimizing risk subject to a certain return. In order to undertake this analysis we must specify how much we can change the mix of assets in order to minimize risk at a specific return. In this example we will assume that the firm can change its working interest in each asset. That change of working interest can range from 0% to 100%. It is important to point out that often firms cannot change their working interest in a given asset because of contractual agreements or other practical constraints. However, the portfolio approach is designed to provide some strategic guidance regarding the types of assets that are most appropriate for the firm to include in its portfolio, given certain constraints. As a result, in the case of projects where the firm may not have the flexibility to increase the working interest in a specific asset, the portfolio analysis provides insight into the general characteristics of assets that may contribute significantly to the firm's portfolio. This can provide important direction to the firm in terms of how they pursue their exploration and development strategy.

Lastly, we apply the linear constraint that the firm cannot spend more on any alternative portfolio than its expected budget for the current portfolio, US$33 million. In general, firms will have a hard capital constraint that limits their ability to pursue additional projects that require more capital. There are any number of additional linear constraints that one could apply to this model including minimum reserve or production targets, finding cost targets, etc. In order to simplify, however, we have only included an expected capital expenditure constraint. We then apply the classic quadratic optimization approach (Markowitz optimization) and solve for the minimum risk portfolio subject to a certain expected NPV and budget constraint.

Table 2 shows the results of this optimization including the expected net present value, the standard deviation, and the expected cost for each of the efficient portfolios that are shown in Fig. 3. In addition, the metrics from the current portfolio are again shown in Table 2 for comparison purposes. Table 3 shows the composition of the optimized portfolios.

The portfolio optimization provides some interesting insights regarding the optimal mix of assets for the firm. Begin by considering a comparison of the

Table 2

	All values in (US$) million		
Portfolio	Expected NPV	Standard deviation	*E* (Expenditure)
Current	**73.4**	75.0	33.0
A	60.0	34.3	31.3
B	65.0	38.0	33.0
C	70.0	43.4	33.0
D	**75.0**	50.4	33.0
E	80.0	58.5	33.0
F	85.0	67.3	33.0
G	90.0	*76.7*	33.0
H	93.0	85.1	33.0

Table 3

	E&P Assets – working interests (%)							
Portfolio	1	2	3	4	5	6	7	8
Current	25	100	100	75	25	40	75	25
A	33	0	29	2	100	68	9	100
B	24	0	33	10	100	77	14	100
C	18	0	18	30	100	80	28	100
D	12	0	3	51	100	82	42	100
E	12	0	3	72	92	73	56	100
F	11	0	3	91	71	83	68	100
G	11	0	3	100	49	91	90	100
H	100	0	0	100	0	100	100	90

current portfolio and Portfolio D. Notice that the expected NPV of these portfolios are essentially equivalent (in Table 2), that is, the NPV of the current portfolio equals US$73.4 million and the NPV of Portfolio D equals US$75 million. However, the risk associated with Portfolio D is significantly less than the current portfolio—the standard deviation is about 33% less than the current portfolio. Similarly, compare the current portfolio to Portfolio G (italic in Table 2). Notice that in terms of standard deviation that the risk of each of these portfolios is very similar, approximately US$75 million. However, the optimized portfolio, Portfolio G, has a significantly higher expected NPV associated with it—US$90 million compared to the current portfolio of US$73 million.

As demonstrated graphically in Fig. 3, the firm's current portfolio is sub-optimal in that it lies well off the efficient frontier of portfolios for this set of assets. If the firm is comfortable with the level of value creation, expected NPV, then they should move their current portfolio along the *X* axis to the left until they find an equivalently valued portfolio with significantly less risk, such as Portfolio D. On the other hand, if the firm is comfortable with the level of risk associated with their current portfolio then they should adjust the mix of assets such that they move along the *Y* axis until they reach the efficient frontier (near Portfolio G). In either case, the firm has composed a significantly improved portfolio, one that is Markowitz efficient in terms of portfolio risk and return.

Table 3 summarizes the composition of each of the optimized portfolios. It shows the working interest of each prospect for each of the portfolios on the efficient frontier. The selection of prospect working interests for each portfolio is a function of the risk characteristics of the individual prospects, particularly the tradeoff between risk and return. As a practical

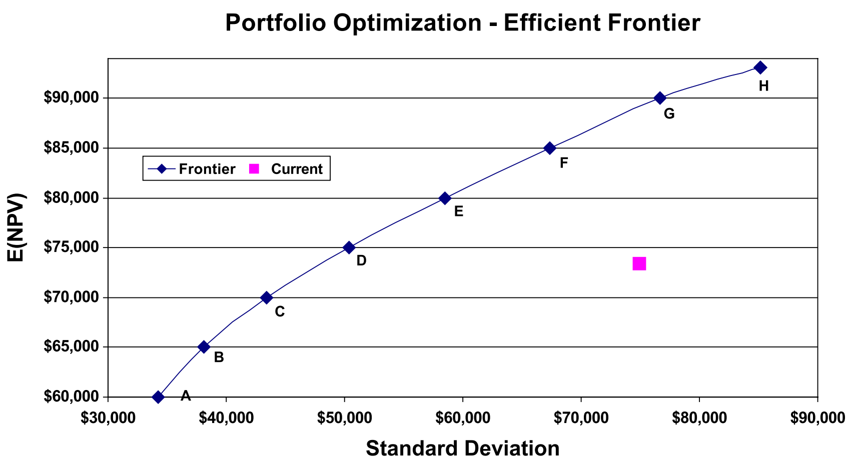


Fig. 3.

matter, prospects with very low working interests (i.e., 3%, 11%) would normally not be a sufficient level of interest for the firm to take on. In these cases one could either impose a constraint which sets a minimum participation interest where the optimizer would simply choose 0% interest if the minimum level was not reached. Nevertheless, this type of optimization provides valuable insights regarding the optimal set of assets included in the portfolios on the efficient frontier.

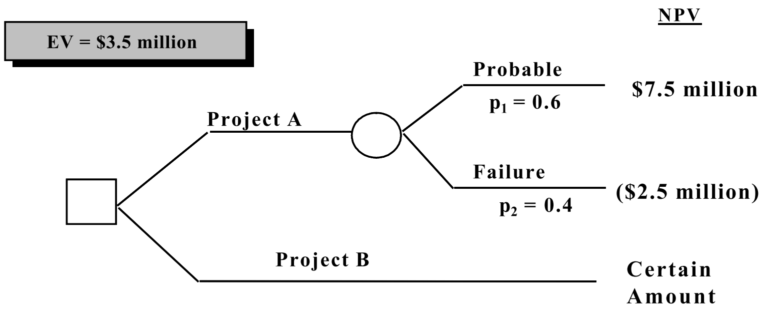
Consider the composition of selected portfolios with respect to the individual prospect characteristics. Note that Prospect #8 increases from its current 25% working interest to nearly 100% working interest in every portfolio along the frontier. Note that even though this prospect has a relatively high failure cost (US$9 million) it also possesses a very high probability of success (80%). We see a similar result with Prospect #5 as all the portfolios but Portfolio H contains a much higher percentage of Prospect #5 than the current portfolio. Note that Prospect #5 goes to a 0% working interest in Portfolio H which is the highest valued portfolio. In this case, the optimizer is selecting a mix for Portfolio H that still minimizes risk but achieves an expected value of US$93 million. It must do this and still honor the budget constraint of US$33 million. Prospects #5 and #8 have the highest dry hole expense so appropriate tradeoffs must be made between value, risk, and budget constraints in order to attain this expected value. In this case, a tradeoff is made and Prospect #5 is not included in Portfolio H. Though Prospect #8 has the same probability of success, one will note that by observing the costs categories it has a slightly higher value to cost ratio than Prospect #5.

Note also that Prospect #2 is never selected as part of a portfolio on the efficient set. This should not be surprising in that it has the lowest probability of success but has a fairly high dry hole cost relative to its net present value of success. Compare Prospect #2 to Prospect #4 which has a similar probability of success (25%). In the case of Prospect #4, the failure cost is significantly lower and the success payoff is almost double. Note that Prospect #4 becomes an increasingly larger portion of the firm's portfolio as we move further out the frontier. Though somewhat risky due to its low probability of success, it has a high potential value if successful.

4. Preference analysis and risk tolerance

Extension of Von Neumann and Morgenstern (1953) and Savage (1954) rational decision making ideas to the level of the firm, where firms make choices among risky alternatives based on preference theory, provides the framework for incorporating the firm's risk attitude into their capital allocation decision process. The basic principles of preference analysis imply that the attractiveness of alternatives should depend on the likelihood of the possible consequences of each alternative and the preferences of the decision maker for those consequences. By utilizing preference analysis, decision makers can incorporate their firm's financial risk propensity into their choices among alternative portfolios of projects. Though managers are evaluating portfolios which are very different in terms of their risk characteristics (as shown in Tables 2 and 3 above), the firm's strength of preference for outcomes and aversion to risk can be consistently applied in the choice process.

The valuation measure we utilize is known in preference theory as the *certainty equivalent*; it is defined as that certain value for an uncertain event which a decision maker is just willing to accept in lieu of the gamble represented by the event (Holloway, 1979). It is, in essence, the "cash value" attributed to a decision alternative which involves uncertain outcomes. The certainty equivalent of a risky investment is a function of the risk characteristics of the investment and the risk preferences of the decision maker. Fig. 4 shows an example of a certainty equivalent analysis. Consider that the firm holds the risky project opportunity shown in Fig. 4. Also, let us assume that the decision makers have a choice of either participating in the risky project or selling the project for some cash value. Consider that this cash value is their minimum selling price for this asset they hold. Manager A indicates that his minimum selling price is US$3.5 million—as a result, he is a risk-neutral decision maker since his minimum selling price is equal to the expected value of the risky investment opportunity. On the other hand, Managers B and C are risk-averse as their minimum selling price (certainty equivalents) are less than the expected value. In this case, Manager B is more risk-averse than Manager C as he is willing to take less cash for this risky project. Another way to think of this is that he is willing to



	Certain Amt.	*Risk Attitude*
Manager A	\$3.5 million	**Risk Neutral**
Manager B	\$1.0 million	**Risk Averse**
Manager C	\$2.0 million	**Less Risk Averse**
Manager D	\$5.0 million	**Risk Seeking**

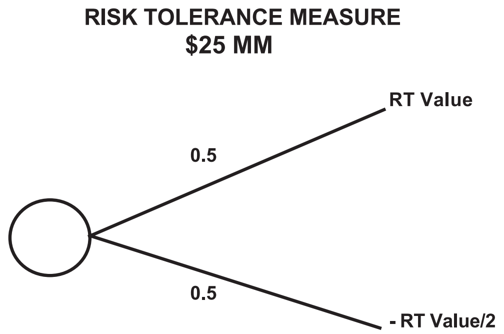
Fig. 4.

forego more of the expectation associated with this project in order to avoid the financial risk—the risk of losing US\$2.5 million. Manager D exhibits risk-seeking behavior as his certainty equivalent is actually larger than the expected value. Risk-seeking behavior is not often observed in the context of firm risk-taking behavior.

Preference analysis is appealing in that it enables the firm's decision makers to utilize a relatively consistent measure of valuation across a broad range of portfolios. In addition, this approach provides a true measure of the financial expectation foregone when firms act in a risk-averse manner. Preference analysis provides a practical way for the firm to formulate and affect a consistent risk policy. This approach provides us a means of mapping the firm's attitude about taking on risky projects in the form of a utility function. One functional form of utility which is dominant in both theoretical and applied work in the areas of decision theory and finance is the exponential utility function, and is of the form $u(x) = -e^{-x/R}$, where R is the risk tolerance level, x is the variable of interest, and e is the exponential constant. A value of $R < \infty$ implies risk-averse behavior; as the R value approaches ∞, risk-neutral behavior is implied (expected value decision making).

In the preference theory approach, the risk tolerance value, R, has a considerable effect on the valuation of a risky project. So at this point it may be useful to provide a definition and some intuition to the term risk tolerance. By definition, the R value represents the sum of money such that the decision makers are indifferent as a company investment to a 50–50 chance of winning that sum and losing half of that sum.

Consider that the notion of risk involves both uncertainty and the magnitudes of the dollar values involved. The central issue associated with measuring corporate risk tolerance (R) is one of assessing trade-offs between potential upside gains versus downside losses under conditions of uncertainty. The decision maker's attitude about the magnitude of capital being exposed to the chance of loss is an important component of this analysis. Fig. 5 provides some intuition to the risk tolerance measure, in terms of decisions about risky choices. Consider, for example, that the decision maker is presented three lotteries with a 50–50 chance of winning a certain sum and losing half that sum. The decision to reject Lottery #3 which has an even chance of winning US\$30 MM versus losing US\$15 MM implies that the manager would view this investment as too risky. Conversely, the firm's decision to accept Lottery #1 implies that the risk–return tradeoff associated with this lottery is acceptable, given the firm's risk propensity. This iterative procedure is continued until we identify the lottery such that the firm is indifferent between a 50–50 chance of winning a certain sum versus losing half that sum. In our example, that sum is US\$25 MM and represents the risk tolerance of the firm. The risk tolerance value



Lottery	RT Value	- RT Value/2	Decision
#1	$20 MM	- $10 MM	Accept
#2	$25 MM	- $12.5 MM	*Indifferent*
#3	$30 MM	- $15 MM	Reject

Fig. 5.

represents a close approximation to the risk tolerance, R, in the exponential utility function described earlier. In an empirical study of U.S.-based oil companies, Walls and Dyer (1996) have shown that firms are risk-averse and that financial risk tolerance does significantly impact firm performance.

5. Integration of portfolio management and risk tolerance

Application of modern portfolio theory enables the firm to identify the efficient set of portfolios—those portfolios that minimize risk subject to a certain return. In addition we have shown that as a result of very different mixes of projects that these alternative portfolios included in the efficient set are quite different in their risk characteristics. As a result, the selection of the optimal portfolio among those on the efficient frontier is influenced by the decision maker or firm's attitudes about taking financial risk. This provides us an opportunity to integrate portfolio management and preference theory by utilizing the decision maker's risk tolerance to assist in the selection of the optimal portfolio.

In the same way that we can compute certainty equivalents for a risky project we can also compare portfolios on a certainty equivalent basis. This certainty equivalent analysis at the portfolio level is designed to find a cash equivalent for each portfolio that takes into account the firm's tolerance for financial risk. Comparisons between portfolios are easier and more robust because the certainty equivalent approach is consistent in terms of the firm's risk tolerance. Once the equivalencies have been made, the choice is easy, because higher valued portfolios (for desirable consequences) are preferred to lower valued portfolios, which is not always the case with expected value analysis. The certainty equivalent, C_x, is equal to the expected value less a risk discount. The discount, known as the risk premium, is the amount of expectation the firm's management is willing to forego in order to reduce their exposure to financial risk in the portfolio. Using the exponential utility function, the discount is determined by the risk tolerance value, R, for the firm and the risk characteristics (probability distribution on outcomes) of the portfolio. For a mean-variance framework, Raiffa (1968) has shown the expression for certainty equivalent to be:

$$C_x = \mu - \frac{\sigma^2}{2R} \tag{5}$$

where, C_x = certainty equivalent; μ = mean or expected value (NPV) of the portfolio; σ^2 = variance (NPV) of the portfolio; R = risk tolerance of the firm.

Consider again the portfolios that lie on the efficient frontier and that were summarized earlier in Table 2. For each of these portfolios we have a mean and variance as a result of the mix of projects in those portfolios. As discussed earlier, the variance reflects the individual assets' contribution of risk to the portfolio as well as the covariance between projects. We now consider a certainty equivalent valuation of each of the portfolios on the efficient set.

We begin by assuming the firm has a financial risk tolerance, R, of US$30 million. Table 4 summarizes the computed certainty equivalents for each of the portfolios. Note that the "current" portfolio has a certainty equivalent value of − US$20.2 million. This suggests that the risk characteristics of the current portfolio are inconsistent with the firm's willingness to take financial risk, given their R value is US$30 million. More importantly, we can identify the optimal mix of assets by finding the portfolio on the efficient set that maximizes certainty equivalent. In the case of a US$30 million risk tolerance firm, that would be Portfolio B

Table 4

Portfolio	All values in (US$) million			
	Expected NPV	Standard deviation	R = US$30 MM	R = US$100 MM
			$C_{x_{30}}$	$C_{x_{100}}$
Current	73.4	75.0	–20.2	45.3
A	60.0	34.3	40.2	54.1
B	65.0	38.0	40.8	57.8
C	70.0	43.4	38.6	60.6
D	75.0	50.4	32.7	62.4
E	80.0	58.5	22.9	62.9
F	85.0	67.3	9.4	62.3
G	90.0	76.7	–7.9	60.6
H	93.0	85.1	–27.7	56.9

with a certainty equivalent value of US$40.8 million. Note that with that level of risk tolerance the firm is willing to give up approximately US$25 million of expectation (US$65 minus US$40.8) in order to avoid the risk associated with this portfolio. Also note that as we move farther out the efficient frontier, Portfolios C through H, the certainty equivalent values decrease. The cash equivalents for these portfolios are less than Portfolio B as they are less preferred by the firm, given its financial risk tolerance. In the case of Portfolios G and H the certainty equivalents are negative implying the firm would actually pay to avoid these risky portfolios.

In the last column of Table 4, we show the certainty equivalents for the same set of portfolios but with a risk tolerance value of US$100 million. This is a less risk-averse firm and therefore we observe higher certainty equivalent values associated with each of the portfolios. In the case of the US$100 million risk tolerance firm, the optimal portfolio is Portfolio E as it has the highest certainty equivalent. Portfolios on either side of Portfolio E along the efficient set decrease in terms of certainty equivalent value. Also, because of the higher level of financial risk tolerance the difference between the certainty equivalent and expected value for each portfolio is less.

6. Discussion and conclusions

To remain competitive, companies must effectively deploy their capital in ways that maximize returns and minimize risks. For oil companies, this deployment of capital (the portfolio of properties in which they invest, and the type, timing, magnitude and share of the investments they make in these properties) is also influenced, among other things, by the firm's tolerance for financial risk. Most companies generally do not have a systematic process in place that evaluates projects outside of their current inventory or, more importantly, alternative mixes of their current project inventory. Without this kind of process, decisions made on the basis of project-by-project analysis and ignoring the diversification effects often yield sub-optimal results. This is particularly true when companies are faced with rapid market changes or when changes in corporate or exploration strategy force significant re-structuring of entire investment portfolios.

A portfolio management system that allows decision makers to see what the marginal contribution of each asset is to their overall portfolio will help the firm identify the optimal portfolio of projects, and the optimal share of or participation in each project. Because of the dependencies between assets, the portfolio approach enables management to see what kind of diversification effect arises as they add and take away projects from the exploration portfolio. Moreover, management will see clearly where their current portfolio position is situated with regard to the risk–return characteristics of alternative portfolios. This analysis is critical in that the decision makers will see how they can significantly improve their expected performance with the same risk exposure and capital budget or, alternatively, preserve their current performance levels with a significant decrease in capital spending.

As a further benefit, integrating portfolio management and the preference analysis approach enables the firm to incorporate their financial risk tolerance into the portfolio selection process. This step is generally intuitive to the decision maker who has an abundance of knowledge about the individual characteristics of the assets in the portfolio—and what financial risks he faces. This integrated approach goes beyond what the decision maker can cognitively process by systematically analyzing the interdependencies among assets, the diversification effects, and the impact of risk aversion on the firm's choice of portfolios along the efficient frontier. This approach enables the manager to evaluate and understand the explicit tradeoffs between risk and return and the impact of the firm's attitudes about those tradeoffs.

References

Holloway, C.A., 1979. Decision Making Under Uncertainty: Models and Choices. Prentice-Hall, Englewood Cliffs, NJ.

Markowitz, H., 1952. Portfolio selection. The Journal of Finance VII (1), 77–91 (March 1952).

Markowitz, H., 1956. The optimization of a quadratic function subject to linear constraints. Naval Research Logistics Quarterly III, 111–133.

Markowitz, H., 1991. Portfolio Selection: Efficient Diversification of Investments, Second edition. Blackwell, Oxford.

Orman, M.M., Duggan, T.E., 1999. Applying Modern Portfolio Theory to Upstream Investment Decision Making. Paper - Society of Petroleum Engineers, vol. 54774.

Raiffa, H., 1968. Decision Analysis: Introductory Lectures on Choices Under Uncertainty. Addison-Wesley, Reading, MA.

Savage, L.J., 1954. The Foundation of Statistics. Wiley, New York.

Von Neumann, J., Morgenstern, O., 1953. Theory of Games and Economic Behavior, 3rd edition. Princeton Univ. Press, Princeton, NJ.

Walls, M.R., Dyer, J.S., 1996. Risk propensity and firm performance: a study of the petroleum exploration industry. Management Science 42 (7), 1004–1021.