Society of Petroleum Engineers

SPE 37948

The Value of Purchasing Information to Reduce Risk in Capital Investment Projects

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This paper was prepared for presentation at the 1997 SPE Hydrocarbon Economics and Evaluation Symposium in Dallas, Texas, U.S.A., 16-18 March 1997.

Abstract

Successful investment management of capital-intensive, long-lived energy projects requires an understanding of the economic uncertainties, or risks, as well as the mechanisms to resolve them. Industry traditionally manages these risks by purchasing information (seismic, well testing, appraisal drilling, reservoir simulation, market capacity and price studies, etc.) about the project and making incremental investments as new information reduces the uncertainties to acceptable levels.

Traditional discounted cash flow analyses cannot readily deal with valuing information. We suggest that the purchase of information about a project has considerable value and can be treated as purchasing an option on the project. As with options on equities, if the information leads to the expectation of a positive investment outcome, the project should be funded. Similarly, options on capital investment projects also have a time factor dictating value and the proper time to undertake the investment.

This article discusses the application of option pricing techniques (OPT) to valuing information. We show how OPT is used to value the information surrounding a production capacity decision for an offshore gas field development. In the example, we value the field development alternatives and the acquisition of incremental information for the alternative selection process. As a further extension of OPT to capital investment projects, we create a dynamic model to identify investment alternatives to capture additional value over the project's lifetime. The dynamic model uses information acquired in development drilling and field operations to maximize the investment outcome.

Introduction

In the last decade, the energy industry has added value creation to its traditional set of performance metrics, i.e., reserve replacement and production volume. Within the same period, the industry's universe of investment opportunities has rapidly grown. However, the trend for many attractive opportunities is towards increasingly complex field and infrastructure developments requiring the expenditure of billions of capital dollars over the project's life; containing extensive uncertainties in timing, technical and financial dimensions; depending on synergies between upstream and downstream activities; and resulting in large positive cash flows distributed over twenty or more years. These uncertainties and project complexities make project financial analysis much more demanding. In particular, the financial analysis must properly reflect the opportunity to create value in a project by resolving the uncertainties and define an investment approach to maximizing the project value.

Traditional financial tools, such as discounted cash flow (DCF), may undervalue the upside associated with these long-lived and uncertain projects relative to what management intuitively senses they are worth[1]. DCF is unable to value management's insight regarding changing technologies, market conditions, and the impact of leveraging. Often these types of projects are defined as strategic and accepted for inclusion into the company portfolio in spite of an unfavorable or marginal valuation.

Why does DCF fail to consider upside value? We believe that traditional approaches do not adequately value the flexibility in investment behavior created by management's use and acquisition of new information. New information about a project allows management to adjust project scope, investment rate, production rates, etc., to accommodate uncertainties related to price, market, cost, as well as reserve size[2].

Mimicking Investment Behavior. Flexibility in investment behavior is the existence of options to adjust the timing and size of the investment profile as new information becomes available. Economists agree that flexibility has value, but it is difficult to quantify flexibility in a manner that can guide management action. A remedy is to identify and value the outcome of an intelligent decision pathway for the project. An intelligent decision pathway maps an optimal sequence of choices through multiple decision points. The choices maximize the return on the investment and are based on the values of key variables at each decision point. So, maximizing the return from an uncertain investment requires building and retaining flexibility, i.e., options, in the investment program. The value of those project options is the difference between the maximized return from a flexible investment program, net of incremental expenditures for reducing uncertainty in key variables, and the return from an inflexible program constructed using only the information available at the project's initiation.

From an applications perspective, economic theories for optimizing investment behavior are problematic if they involve estimating many unknown parameters with little or no guidance. However, Option Pricing techniques (OPT) is a branch of finance theory that has made the most progress towards describing optimal behavior in investments incorporating uncertainty[3]. Financial instruments, shares and options, are claims on uncertain future cash flows as are investments in real assets like gas plants, pipelines, or offshore platforms[4]. The critical questions for buyers and sellers of such claims are: "What are their values?" and, additionally for options, "When should they be exercised?" The value and optimal exercise of a real option can be modeled the same as a financial option. Solutions of these problems depend on the rate at which key variables' uncertainties are resolved, the discount rate, and the time remaining in the option's life. OPT improves the upside valuation for a long-lived, uncertain project. Hence through a different perspective, OPT places a value on the information required to resolve the uncertainties.

Option Pricing Principles. The distinction between the OPT approach and the traditional DCF analysis often boils down to the difference between the expectation of a maximum and the maximum of expectations. For example, an OPT valuation of the option to purchase a stock is valued as the expectation of the maximum:

$$C_0 = E_0 \max\left[0,\ (S_T - K)e^{-rT}\right], \tag{1}$$

where E_0 is the time zero expectation, S_T is the terminal stock value, K is the strike price, r is the discount rate and T is the time to maturity. The expectation is calculated using the risk-adjusted (also called risk-neutral) probability measure. In the now standard analogy to capital budgeting decisions, S_T is treated as the value of the project's cash flows at T and K as the investment required to undertake the project. The maximum is taken over the two possible operating modes: the project is taken if $S_T > K$ (NPV at T_1 is positive), and not taken at T_1 if $S_T \leq K$ (NPV at T_1 is zero or negative.) In this standard analogy, it is assumed that if the project is not taken at T_1, then there is no ability to exercise later (i.e. invest in the project later.) Thus the decision to not take the project at T_1 is tantamount to abandonment.

The traditional DCF approach not only ignores the ability to maximize outcomes midstream in a project's life, but also ignores the option to wait and undertake the project later. The flaw is that the evaluation only factors in the value of making the investment decision now, and does not recognize that the investment decision can also be made at a later date. As a result, the value under the traditional approach is a maximum over expectations E_0 using information at time equals T_0:

$$\text{Value} = \max\left[0,\ (E_0 S_T - K)e^{-rT}\right] \tag{2}$$

In words, the traditional DCF approach compares the NPV of the expected project outcome, $(E_0 S_T - K)e^{-rT}$, with zero. If NPV is positive, the project is taken; if NPV is negative, it is abandoned.

In the terminology of option pricing, the difference in value between the call option analogy (1) and the NPV analysis (2) is the time value. Time value reflects the incremental value due to the ability to condition decisions on future acquisition of information about the project's outcome. Time value is never negative. Thus, in the option analogy, the project is taken if $S_T > K$, while in the NPV analysis, the project is taken if $E_0 S_T > K$. If uncertainty is zero, then $S_T = E_0 S_T$ and the two approaches are equivalent, i.e. the time value is zero and incremental information has no value.

Even when the current project NPV is positive, the option analogy suggests that it may still be better to defer the investment decision and acquire information that reduces uncertainty in the cash flow projections, rather than going ahead with the project and extinguishing flexibilities. The value of the additional information can be described as:

$$\text{Value} = E_0 \max\left[0,\ (S_T - K)e^{-rT}\right] - (E_0 S_T - K)e^{-rT}. \tag{3}$$

As long as there is time remaining before investment is required and significant uncertainties can be resolved, it may be better to defer the investment than to accept the positive NPV project immediately. This is only valid if management can actively acquire uncertainty-resolving information. Passive information acquisition, such as waiting for higher certainty in product sales price, will only result in continuous deferrals and project value destruction.

Strictly speaking, the previous discussion applies only to European-style options, i.e. those which can be exercised only at the end of their contract period. In reality, most firms have many highly complex American-style options, which can be exercised at any time during their contract period. When exercising now confers some benefit that exercising later will lose, it makes financial sense to invest in the project immediately. Examples of such benefits include a technological advantage by being first to market in a highly competitive environment, capturing low front-end investment costs, etc. These effects can be valued by

$$\text{Value} = \max\left[C_0(K_T),\ (S_0 e^{-(r-\delta)T} - K_0)\, e^{-rT}\right], \tag{4}$$

where δ may be interpreted as a downward force on value due to competitive pressures and K_0 and K_T are the magnitude of investments required now and at T respectively.

Similarly, immediate investment is also justified if additional information will not change the investment decision or uncertainty-reducing information will not be available before the investment must be taken or abandoned. Since information is acquired in a discontinuous fashion, management should be prepared to regularly revisit the valuation analysis to determine if the uncertainty threshold has been achieved and, if so, the investment should be undertaken (or abandoned) without further delay, i.e. an American-style option.

It is apparent then that OPT is not a substitute for traditional DCF analysis but an enhancement of DCF principles that allows the analyst to properly value managerial flexibility. OPT also provides insight into the existence of project upsides. If a project has limited flexibility, OPT will, as a consequence, reveal limited option value. Further, an OPT model provides guidance in executing the investment program while a traditional DCF analysis cannot. It assumes that there are no decisions remaining once the project begins. The dynamic nature of OPT encourages management to return to the model during the project's life to post-audit prior decisions and prepare for future decisions by valuing the acquisition of new information.

Application to Asset Development

In the following section , we demonstrate the merit of an OPT analysis to identify the highest valued development scenario for an offshore gas field. Production capacity, or facility sizing, applications have been identified by a number of organizations as their principal use of OPT in capital budgeting. We illustrate this application in some detail. However, both gas price and recoverable volumes are uncertainties in this analysis. To our knowledge, this is the first demonstration of an OPT model using more than one variable. Further, the focus on using OPT to value incremental information appears to be a new concept.

The preliminary development program encompassed several distinct fields, zones within fields and numerous nearby exploration opportunities. The project was envisioned as incrementally developing reserves adequate to sustain a base production level, q, of 400 million cubic feet per day of sales gas over a twenty year contract. As the initial development begins to decline in production rate, subsequent volumes will be developed from the remaining proved, undeveloped assets to maintain contract production levels.

The investment, K, required to undertake the project includes:

- drilling and completion costs;
- unmanned platforms for most production facilities;
- one large processing platform with limited separation capability and compression;
- platform-to-shore multiphase pipeline; and
- slug-catcher, separation, and liquids storage facilities on shore.

There are many investment decisions to be made through the life of the project associated with these facilities. This OPT analysis is only concerned with sizing of production capacity. The analysis evaluates the economic merits of q = (400, 600) million cubic feet per day (MMCFD) and a subsequent increase in production capacity of Δq = (0, 200, 400) MMCFD.

The issue of timing is important in every economic analysis. It is very important in an OPT problem since time can be a variable. This project has two fixed dates with information gathering time frames and decision points preceding them. The project is assumed to begin production at $T_{1.5}$. Construction lead times require a decision point at T_1, at least three years prior to $T_{1.5}$, to fabricate and install facilities and wells. The second fixed date, $T_{2.5}$ occurs five years after

$T_{1.5}$, at which additional production capacity may be added, or not, depending on gas price and remaining reserves. Again a decision point, T_2, at least three years prior to $T_{2.5}$ is required to accommodate construction constraints.

The intelligent decision pathway for the project is shown in Figure 1 for clarity. Decisions can be taken or deferred as indicated. Only $T_{1.5}$ is fixed. The branches on the pathway indicate the possible cases management can select for the development program. Each branch is evaluated independently using OPT modeling principles. The highest NPV branch reflects the optimum approach to developing the gas fields. A base case analysis using traditional DCF analysis techniques is performed to value the preliminary project development program without option considerations, i.e., using only the knowledge of price and recoverable volumes that exists at T_0.

Gas Price as a Variable. Annual gross revenue, $S_i q_i$, from the project is dependent upon spot gas prices over the twenty year life of the known fields and exploration opportunities. As with reserves, gas prices are highly uncertain. However, there is extensive market information available on gas price trend and volatility from which a distribution of future expectations can be constructed. Previous OPT analyses[4,5] have focused exclusively on price, so this paper will only briefly review the standard stochastic process recognized as governing spot prices of natural gas and use that approach to build a future expectation distribution for reserves.

At time T_0, the current spot price of natural gas is known with certainty to be S_0. Given all of the available information at T_0, the spot price at any future date T_1 is unknown. The standard model quantifies the uncertainty surrounding the time T_1 spot price by assuming that the natural logarithm of the price is normally distributed with mean $\ln S_0 + \mu T_1$ and variance $\sigma^2 T_1$. Here, μ is the assumed constant drift rate of the diffusion process for price and σ^2 is the assumed constant variance rate of the process. Table 1 presents the model parameters for spot price. Figure 2 illustrates a discretized gas price distribution as a function of S_0 and time.

As time increases, the variance of $\ln S_T$ increases. The current spot price must reflect expectations of future spot prices. If near-term future prices are expected to be significantly higher than current prices, buyers would rationally increase their present purchases and decrease expected future spot purchases using gas storage. The resulting surge in demand for immediate delivery would push up current spot prices until an equilibrium was reached. Since these economic forces are always present, it is true that spot prices at T_1 also reflect the expectations at T_1 for spot prices at T_2.

Reserve Volume as a Variable. The known fields have a limited production history and therefore retain a residual uncertainty surrounding the recoverable volumes. This uncertainty is represented with a composite probability distribution. Similarly, a probability distribution exists for the composite of the exploration opportunities' speculative potential volumes that may contribute to the gas sales volumes at some time in the life of the project. This probability distribution is shown in Figure 3.

From a modeling perspective, the essential differences between the known fields and the exploration opportunities are:

- there is a 100 percent certainty that there is a positive minimum economic reserve volume in the known fields, whereas there is a significant probability that there are no reserves in the exploration opportunities;
- by expending capital on exploration, the uncertainty surrounding the speculative potential volumes in the exploration opportunities can be reduced, whereas uncertainty regarding the reserves in the known fields can only be further reduced by developing and producing he fields.

Complexity and accuracy may be added to the model by allowing individual variables to represent the reserves in individual fields and exploration opportunities. This additional complexity does not significantly alter the valuation of the overall project but does complicate the investment profile and the timing of commitment to capacity by adding several more decision points to the intelligent decision pathway.

Resolving Reserves Uncertainty. Just as the known current spot price is a standard input for option pricing models, we assume by analogy that the known current expectation of remaining reserves is an input for the valuation model. Formally, the input is $\overline{Q}_0 \equiv E_0\tilde{Q}$, where the subscript 0 on the expectation operator E indicates that expectations are as of T_0 and the tilde over Q recognizes the reserve volumes and speculative potential volumes are uncertain. For simplicity, further use of the term reserves will imply discovered, reserves and speculative potential volumes. This expectation for Q also follows a process over time. Letting $\overline{Q}_t \equiv E_t\tilde{Q}$, we define $\tilde{Q}$ as the remaining reserves at time t. For $t > T_0$, the mean reserves at t, $\overline{Q}_t$, is itself a random variable based on the information that we have at T_0. As a result we can describe the evolution of $\overline{Q}_t$ as a stochastic process.

The parameters of the $\overline{Q}_t$ stochastic process depend upon the project's operational status:

$$d\overline{Q}_t = \mu(q_t)dt + v(q_t, l_e)dW_t \; ; \tag{5}$$

where:

$d\overline{Q}_t$ is the change in the mean reserves over a short time interval;

$q_t \geq 0$ is the production rate at time t;

$\mu(q_t) \equiv -q_t$ is the drift rate of the mean reserves;

l_e is an indicator variable, equal to 1 when exploring and to zero otherwise;

$v(q_t, l_e) \equiv \sqrt{v_q^2 q_t + v_{e,t}^2 l_e}$ is the volatility rate of the mean reserves;

$v_q^2 > 0$ is the variance rate per unit of production (assumed constant);

$v_{e,t}^2 > 0$ is the variance rate due to exploration at time t; and

dW_t is the increment of a standard Brownian motion.

As a consequence, we have $E_t d\overline{Q}_t = \mu(q_t)dt$, or equivalently $\mu(q_t) = \dfrac{E_t d\overline{Q}_t}{dt}$, so that the drift rate μ is the expected change at t in the mean reserves per year. We also have $Var_t d\overline{Q}_t = v^2(q_t, l_e)dt$, or rearranging, $v^2(q_t, l_e) = \dfrac{Var_t d\overline{Q}_t}{dt}$, where the variance rate v^2 is the variance at t of changes in the mean reserves per year. In the absence of absorption, the Brownian shock implies that based on the information at any time, the mean reserves at any later time are normally distributed. An absorbing barrier at the origin is imposed on the evolution of $\overline{Q}_t$ to avoid the possibility of creating a probability of negative mean reserves. That is, once the mean reserves fall to zero, they can no longer rise or fall stochastically, since the fields have been fully depleted. The resulting distribution for future mean reserves is no longer normally distributed. There is a strictly positive probability for a realization of zero with the remaining probability smoothly distributed over all positive reserve volumes.

Reducing the uncertainty surrounding the reserves is accomplished through two actions that acquire information: exploration and production. Each action imposes a different variance rate on a different volume, either in exploration opportunities through the conversion from speculative potential volumes to reserves or in known fields through confirmation of a recovery factor through production history. Modeling the uncertainty reduction requires defining the operator's activities relative to their effect on speculative potential or reserves. For this analysis, there are four operational phases which may occur in any of five time periods, $\{T_1 - T_0, T_{1.5} - T_1, T_2 - T_{1.5}, T_{2.5} - T_2, > T_{2.5}\}$. Table 1 also presents the model parameters for mean reserves

Phase I The project's operational state is Phase I when the operator is neither exploring nor producing. At T_0, the operator can decide to lock in the initial capacity now at T_0 or defer the decision until T_1. If the capacity decision is made at T_0, there is no rationale for exploring so the project is in a Phase I state between T_0 and $T_{1.5}$. If the initial capacity decision is postponed until exploration results are available, the project moves into Phase I between T_1 and $T_{1.5}$. Similarly, the project will be in Phase I once all the reserves have been extracted. For Phase I, the parameters in equation 5 become:

$$q_t = 0, l_e = 0, \mu = 0, \text{and } v = 0 .$$

As a result, the mean reserves do not change with time. If the reserves have been extracted, $\overline{Q}_t$ equals zero. If the project is between T_0 and $T_{1.5}$ and there is no exploration underway, $\overline{Q}_t$ equals $\overline{Q}_0$. Note that spot prices continue to evolve in Phase I. Consequently it may be reasonable to defer capacity until T_1, rather than locking in at T_0. But deferral beyond T_1 cannot be justified by claims of improving price knowledge.

Phase II. The project is in Phase II when the operator is exploring but not producing. If the capacity decision is deferred to T_1 so that the operator can explore and optimize the production capacity, the project is in a Phase II state between T_0 and T_1. The parameters for this Phase are:

$$q_t = 0, l_e = 1, \mu = 0, \text{and } v = v_{e,t}^2 .$$

This formulation assumes zero mean reserve drift because exploring does not affect mean reserves, except after the fact. This ex post effect on reserves is captured by the positive variance rate, $v_{e,t}^2$. This rate is fixed by prompting for the reduction in variance of the total reserves due to exploring continuously over the time frame for the exploration program. Estimates of variance reduction magnitudes must be obtained from experienced exploration staff familiar with probabilistic reserve assessments and in resolving uncertainty through the purchase of information, for example, seismic data acquisition and exploratory drilling. The variance rate $v_{e,t}^2$ is computed by dividing this reduction in variance by the time span. If the operator does choose to defer the capacity decision to T_1 and explore over the $T_1 - T_0$ time frame, the project moves into a Phase I state post-T_1, since exploration is concluded and production has not commenced.

Phase III. As the operator begins production, the project progresses into Phase III. This stage of uncertainty reduction in reserves begins at $T_{1.5}$ and continues until the fields are depleted. The parameters of the $\overline{Q}_t$ stochastic process in Phase III are:

$$q_t > 0, l_e = 0, \mu = -q_t, \text{and } v = \sqrt{v_q^2 q_t}.$$

The variance rate per unit of production must be obtained from experienced reservoir engineering staff familiar with probabilistic reserve assessments and resolving recovery factors from reserve estimates and production history. Initially, the reduction in total variance due to production at the base rate of 400 MMCFD over a base case time interval $(T_2 - T_{1.5})$ is determined. This reduction must be annualized and further transformed to the variance rate per unit of production using the annualized production rate. The model assumes that the resulting variance rate per unit of production is a constant. Total variance is reduced in proportion to production capacity, assuming that available production capacity is fully exploited and is equal to the fields' production rate.

Phase IV. A fourth phase is possible if the operator chooses to defer exploration until after à production capacity is fixed, facilities and wells are in place, and the known fields are on production. Reserve uncertainties in known fields and exploration opportunities are simultaneously addressed. Phase IV can occur between $T_{1.5}$ and T_2 with these parameters for the stochastic process:

$$q_t > 0, l_e = 1, \mu = -q_t, \text{and } v = \sqrt{v_q^2 q_t + v_{e,2}^2}.$$

The variance rate $v_{e,2}^2$ is calculated assuming the same decrease in reserve variance due to exploration as that used for Phase II, but the rate in Phase IV is computed based on the time interval $(T_2 - T_{1.5})$, rather than $(T_1 - T_0)$ that is used for Phase II. The variance rate, v_q^2 associated with production activities, is the same in Phase IV as in Phase III.

Optimizing the Project Value. Management's principal impact on the value of this offshore gas field is limited to timing the investment and selecting a production capacity to Management's principal impact on the value of this offshore gas field is limited to timing the investment and selecting a production capacity to maximize the present value of cash flows. The production capacity level is selected from a set of several discrete choices which maximizes project value at the decision times T_0, T_1, and T_2. At decision time T_0, if the operator decides to lock-in the initial production capacity, the allowable choices are q_l = 400 MMCFD and q_h = 600 MMCFD. Within the lock-in now alternative, capacity is built at the level chosen at T_0 even if conditions change at T_1 or if the resulting NPV is negative at T_1. Thus, T_1 is a decision date only if the decision is deferred at T_0. If the decision deferral occurs , the allowable choices at T_1 are zero, q_l = 400 MMCFD and q_h = 600 MMCFD. A choice of zero production capacity implies project abandonment. At both T_0 and T_1, the initial capacity level chosen is conditional on the information available then, which includes spot price and mean reserves as well as the optimal decision to be made at T_2. At T_2, two incremental capacity levels of Δq_l = 200 MMCFD and Δq_h = 400 MMCFD are available, as well as maintaining current capacity or abandoning the project. Thus the decision at T_2 chooses from seven discrete production capacity levels available from $T_{2.5}$ until the gas reserves are depleted, namely

$$\{0, q_l, q_l + \Delta q_l, q_l + \Delta q_h, q_h, q_h + \Delta q_l, q_h + \Delta q_h\}.$$

For each potential outcome, i.e. spot price and mean reserves, an optimum choice from this set is taken at T_2, after accounting for any incremental investment. An analytic formula is used to compute the project value for $t \geq T_2$, conditional on the time T_2 spot price, mean reserves, initial capacity, and incremental capacity.

Computational Approach. The simplest method to evolve the mean reserves and spot price into the future and to discount the maximized project value from T_2 back to T_0 is to employ a bivariate binomial lattice. Details regarding binomial lattices for OPT can be found in other articles[6,7]. It is also necessary to value the cash flows associated with the production and sale of reserves between $T_{1.5}$ and T_2. This requires a second analytic formula which utilizes the current spot price, the current mean reserves, and the initial production capacity. "Current" refers to time T_0 if the initial capacity decision is locked-in then, or T_1 if the decision is deferred. The formulas are predicated on the assumption that production at full capacity continues until the reserves are depleted, even if spot prices fall below extraction costs during this time. Since extraction costs are low relative to current spot prices, the option to shut-in gas production is not modeled. Extraction costs are assumed to be a constant percentage of spot price over the project's life.

The binomial lattice is used to discount the cash flows back to prior decision points, retaining evolution of the gas spot price and reserve volumes over time. The maximized project value at T_2 is discounted back from T_2 to T_1 and summed with the analytic value of the cash flows between $T_{1.5}$ and

T_2. The present value of the investment is also subtracted from that sum to form the NPV for each of the two initial capacities. If the initial capacity decision is deferred to T_1, the larger of the two project NPVs is also compared with zero, the abandonment option. The optimum decision at T_1 is chosen and its associated value is discounted back to T_0 again using the binomial lattice. For the lock-in now scenario with the capacity decision made at T_0, the larger of the two project NPVs at T_0 is reported.

The output of the model is the project NPV at T_0 based on the optimal development pathway, the expectation of a maximum. This value is, in essence, the expected value of the discounted cash flows, after adjusting for the gas market price risk (implicitly embedded in the gas spot price) and the risk associated with the recoverable reserves and speculative potential volume estimates). By comparing the OPT NPV values for several pathways with the traditional discounted cash flow analysis for the project, the values of spot price information, information from exploration, and information from production can be computed.

Results

The model was used to investigate two issues and the timing associated with them:

- How should the offshore gathering facilities be sized?
  - initial size
  - incremental capacity additions
- When should the sizing decision be made?
- How much is the exploration information worth?
- When should more exploration be undertaken?

The results reflect the full project size, not partners' share sizes and are computed before taxes, but after royalties.

Table 2 shows the model results for the evaluation of two development pathways compared with the "No-options" base case computed using a traditional discounted cash flow analysis. The base case assumes no decision deferral and no additional exploration or incremental capacity additions.

OPT Case 1 evaluates a pathway with no initial capacity decision deferral but with exploration and additional capacity options retained for future exercise. This case 1 pathway reflects a management decision to design the facilities with the option to deliver additional gas, if and only if the information acquired from exploration and production activities are favorable. Exploration results will not be available, in this case, to influence the initial capacity decision. By following the Case 1 pathway, management can potentially add six percent to the project NPV as compared to the base case pathway.

OPT Case 2 evaluates a pathway with an initial capacity decision deferral, while exploration is underway, and an incremental capacity option. This pathway reflects a management decision to retain two options. The first option is to design the initial production facilities to deliver additional gas above the anticipated capacity, if and only if the information acquired from exploration are favorable. The second option is to purchase additional gas production capacity if information from production activities indicate that this decision is value-adding. By following the Case 2 pathway, management can potentially add 28 percent to the project NPV as compared to the base case pathway.

A sensitivity study was performed to measure the impact of variables that are not directly measurable, such as regional gas price volatility, reserve size and speculative potential uncertainty, and gas price at initial production. The results of the sensitivity study are presented in Figure 4 through 7. The OPT results suggest where management should focus attention as well as how to proceed in the field development process. Of particular interest are:

- Near a break-even gas price the options' values are at their peak, and at high gas prices, options' values decrease to zero;
- The degree of uncertainty in reserves and speculative potential has greatest impact on the value of initial capacity deferral option;
- High spot price volatility encourages initial capacity deferral and accelerated exploration;
- Incremental capacity option value is a weak function of both price and volume uncertainty.

A particularly interesting result is shown in Figure 7. This figure illustrates the sensitivity of the analysis to resolution of the uncertainty surrounding the speculative potential in the exploration opportunities. The independent variable is a measure of uncertainty reduction between pre-exploration expectations and post-exploration expectations. The variable is plotted as a percentage change in the standard deviation of the speculative potential volume. The dependent variable is the fractional change in the project NPV relative to a base case analysis in which there was no reduction in the uncertainty. The sensitivity is relatively high at low reductions in the uncertainty but quickly becomes insensitive above about 50 percent. One interpretation of the curve, if the dependent variable is converted to exploration expenditures in dollars, is that it is the upper limit for the present value of the exploration budget. Spending more than the upper limit will gain information that does not improve the project value. In fact, it will likely decrease the NPV.

Conclusions

Option pricing techniques are evolving from their equity origins to become powerful tools in evaluating and managing capital investments. This article illustrates a step in that evolution. In spite of the intuitive nature of an OPT analysis, the complexity of the mathematics and the need for new perspectives of existing economic and technical data have slowed its adoption in most industries.

Investment complexities and ill-defined risks are making asset management increasingly difficult, requiring more sophisticated analysis techniques. OPT offers an approach to quantify the value embedded in large, long-lived opportunities. That value is often perceived, but rarely quantified. As a result, OPT is valuable to management in identifying and quantifying growth opportunities for their organizations. OPT's value is most commonly recognized during the project justification stage, but with a dynamic model, as described here, management can guide the investment project through its early stages where all the major capital expenditure and infnrmation gathering activities occur.

In this article, OPT's application to valuing the purchase of information to improve a project value was introduced. The impact is twofold. Purchase information that will impact the upcoming decisions, if the value increase justifies the cost of the information. Second, adhere rigorously to the converse, i.e., invest now or abandon the project if there is there is no information to be gained (or it's expense is too great) that will significantly change the project's outcome or impact the investment decision process.

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Table 1.
Inputs to the OPT model for a gas field development

Deterministic input variables

- Risk-free rate (% per year)
- Convenience yield (% per year)
- Condensate price (\$/bbl)
- Condensate ratio (bbl/mmcf)

- Time interval (years) between
  - Today and initial capacity decision deadline
  - Deadline for initial and incremental capacity decisions
  - Initial capacity decision and start of production
  - Deadline for incremental capacity decision and start-up of that capacity

- Set of initial production capacities allowed (mmcfd)
- Set of incremental production capacities allowed (mmcfd)
- Investment required for each initial capacity (\$)
- Investment required for each incremental capacity (\$)
- Unit production costs (% of spot price)
- Exploration costs estimates (\$)
  - if exploring at T_0
  - if exploring at $T_{1.5}$

Probabilistic input variables

- Price of natural gas
  - current spot price (\$/mcf)
  - price volatility (% per year)
- Reserves volume in known fields
  - expected recoverable volumes
  - variance around expected volumes
  - variance after 5 years of production
- Speculative potential volume
  - expected recoverable volumes
  - variance around expected volumes, pre-exploration
  - variance around expected volumes, post-exploration
  - variance after 5 years of production

Table 2.
OPT Model Results

Case	Initial Capacity Timing & Decision	Exploration Timing & Decision	Incremental Capacity Timing & Decision	Total Project NPV (normalized to DCF)
DCF (no options)	Today (400 mmcfd)	Today (none within near term)	Today (no planned expansion)	1.00
Capacity "Lock-in"	Today (400 mmcfd)	$T_{1.5}$	T_2	1.06
Defer capacity decision / explore now	T_1	Today (Explore)	T_2	1.28

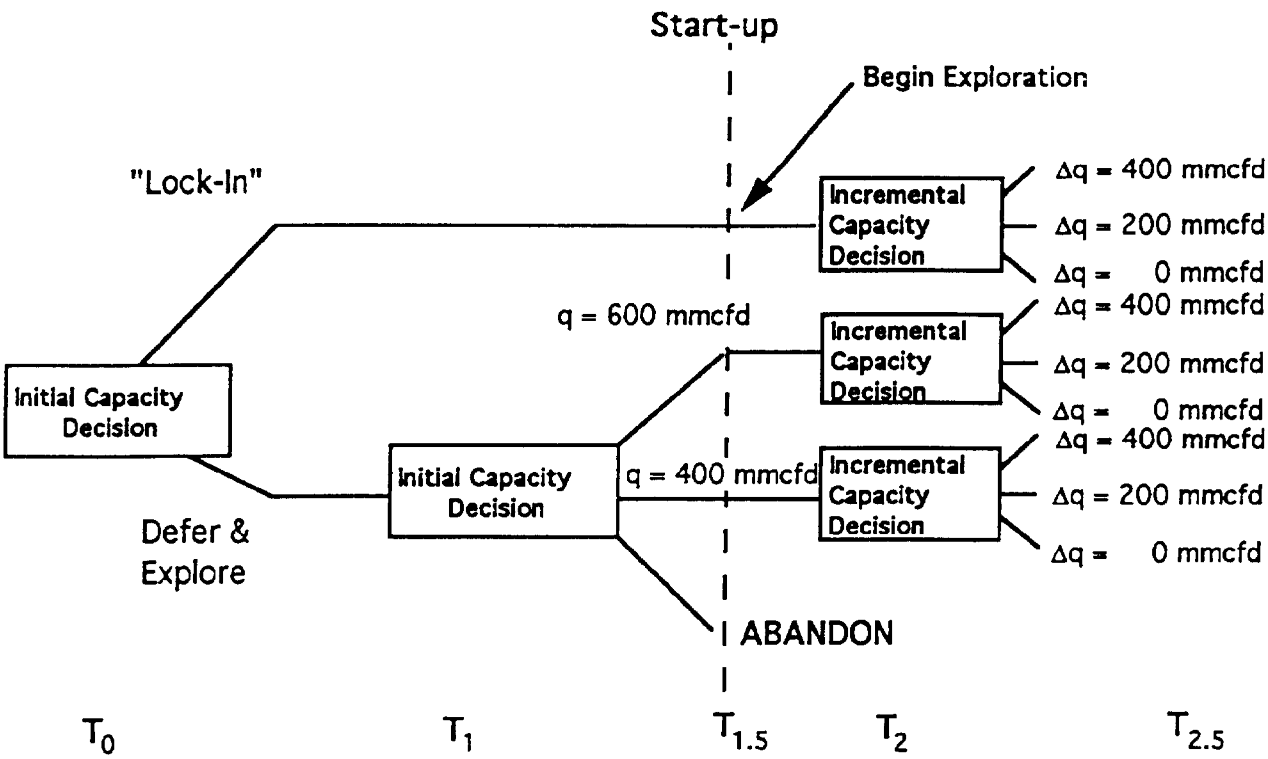

Figure 1. Intelligent Decision Pathway for gas field development

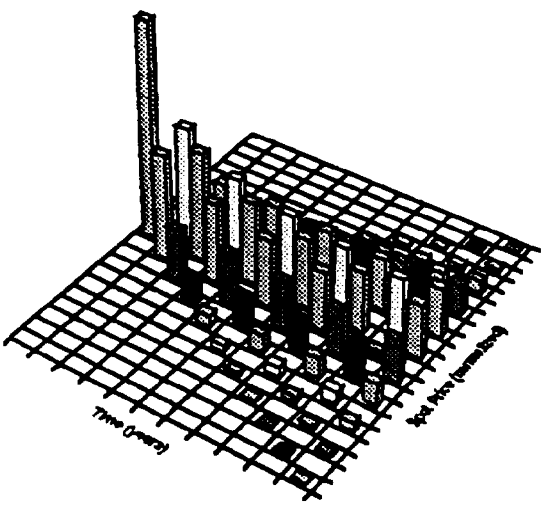

Figure 2. Evolution of Spot Price Distribution over Time

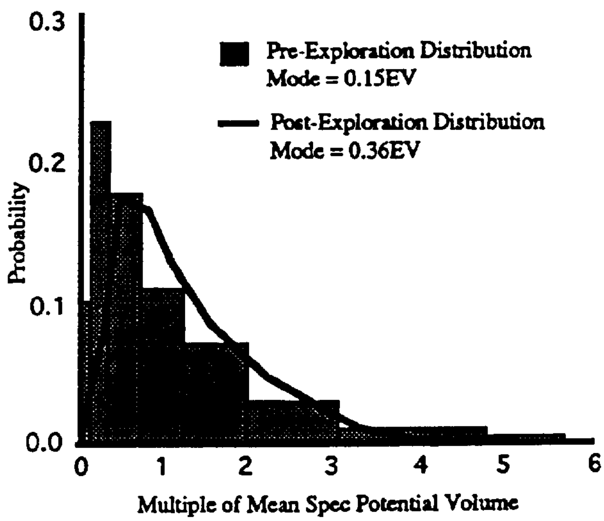

Figure 3. Probabilistic Distribution of Speculative Potential Volumes

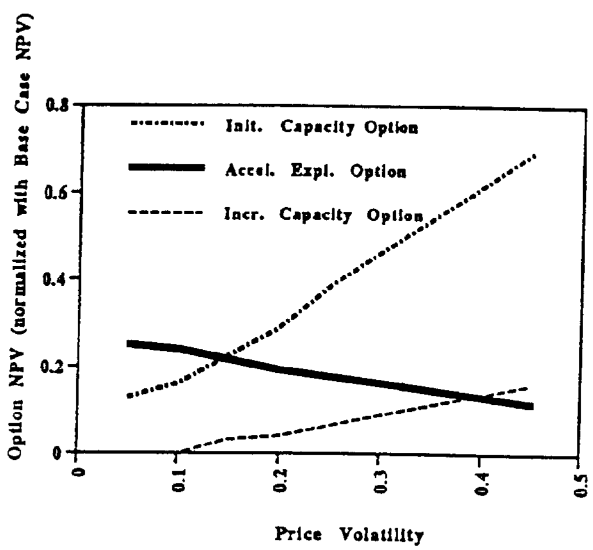

Figure 4. Impact of Spot Price Volatility on Options' NPV

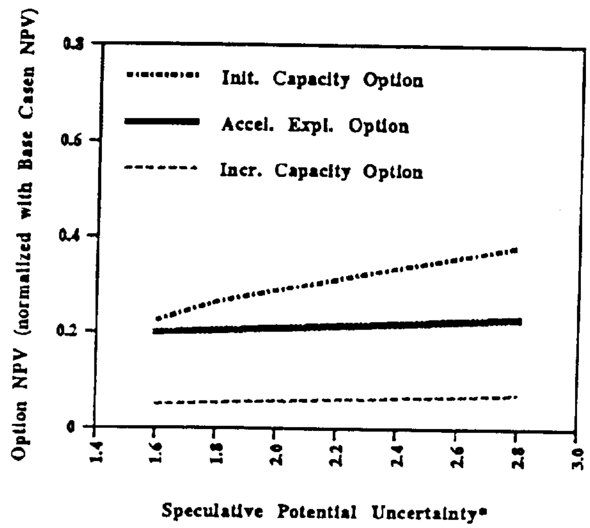

Figure 5. Impact of Speculative Potential Uncertainty on Options' NPV
*Coefficient of variation Pre-Exploration Std. Dev. / Expected Value

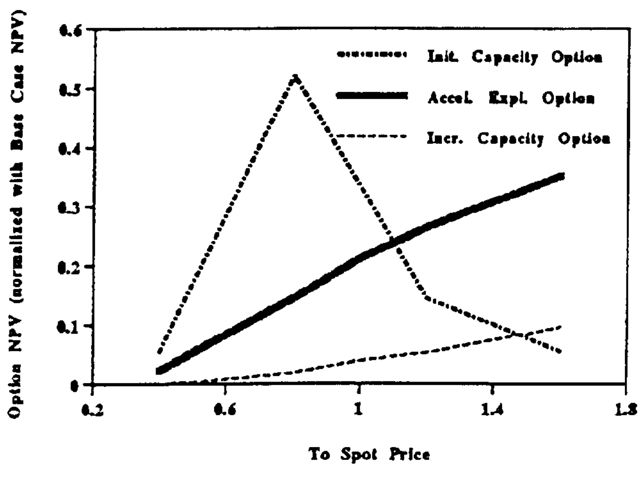

Figure 6. Impact of Time Zero* Spot Price on Options' NPV

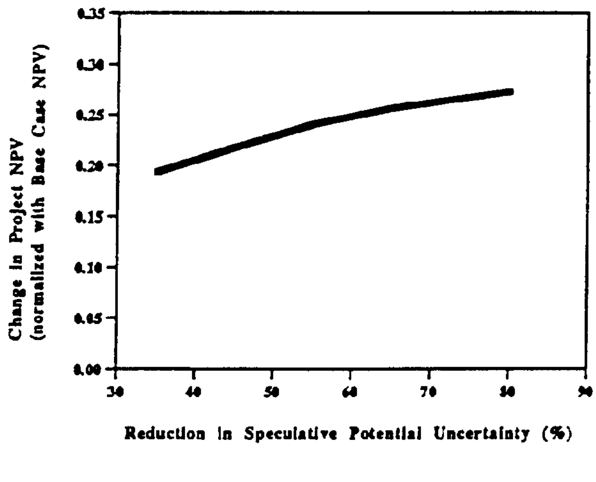

Figure 7. Value of Uncertainty Reduction for Project NPV