Unlocking the Value of Real Options

Management often has flexibility in carrying out projects, capitalizing on new information and new market conditions to improve project economics. Real-options analysis provides a means to determine the value of flexibility in future activities.

William Bailey
Benoît Couët
Ridgefield, Connecticut, USA

Ashish Bhandari
El Paso Corporation
Houston, Texas, USA

Soussan Faiz
Strategic Management Consultant
Walton on Thames, Surrey, England

Sundaram Srinivasan
Sugar Land, Texas

Helen Weeds
University of Essex
Colchester, England

In the early 1990s, Houston-based Anadarko Petroleum Corporation outbid competitors for the Tanzanite block in the Gulf of Mexico. It found oil and gas there in 1998 and was producing within three years. The Tanzanite discovery is significant not so much for an abundance of oil and gas, but that in bidding for it Anadarko broke with industry tradition. Rather than using only conventional discounted cash flow (DCF) to help it decide what the block was worth and how much to bid for the lease, the company opted for a new technique called real-options valuation (ROV). ROV gave Anadarko the confidence to outbid others because it suggested that there was more to Tanzanite than met the eye.[1] Anadarko now routinely uses ROV when making investment decisions.

Options embedded in, or attached to, physical or real assets are real options. These are distinct from options relating to financial assets—securities and other financial claims. ROV is a process by which a real or tangible asset with real uncertainties can be valued in a coherent manner when flexibility—or potential for options—is present.

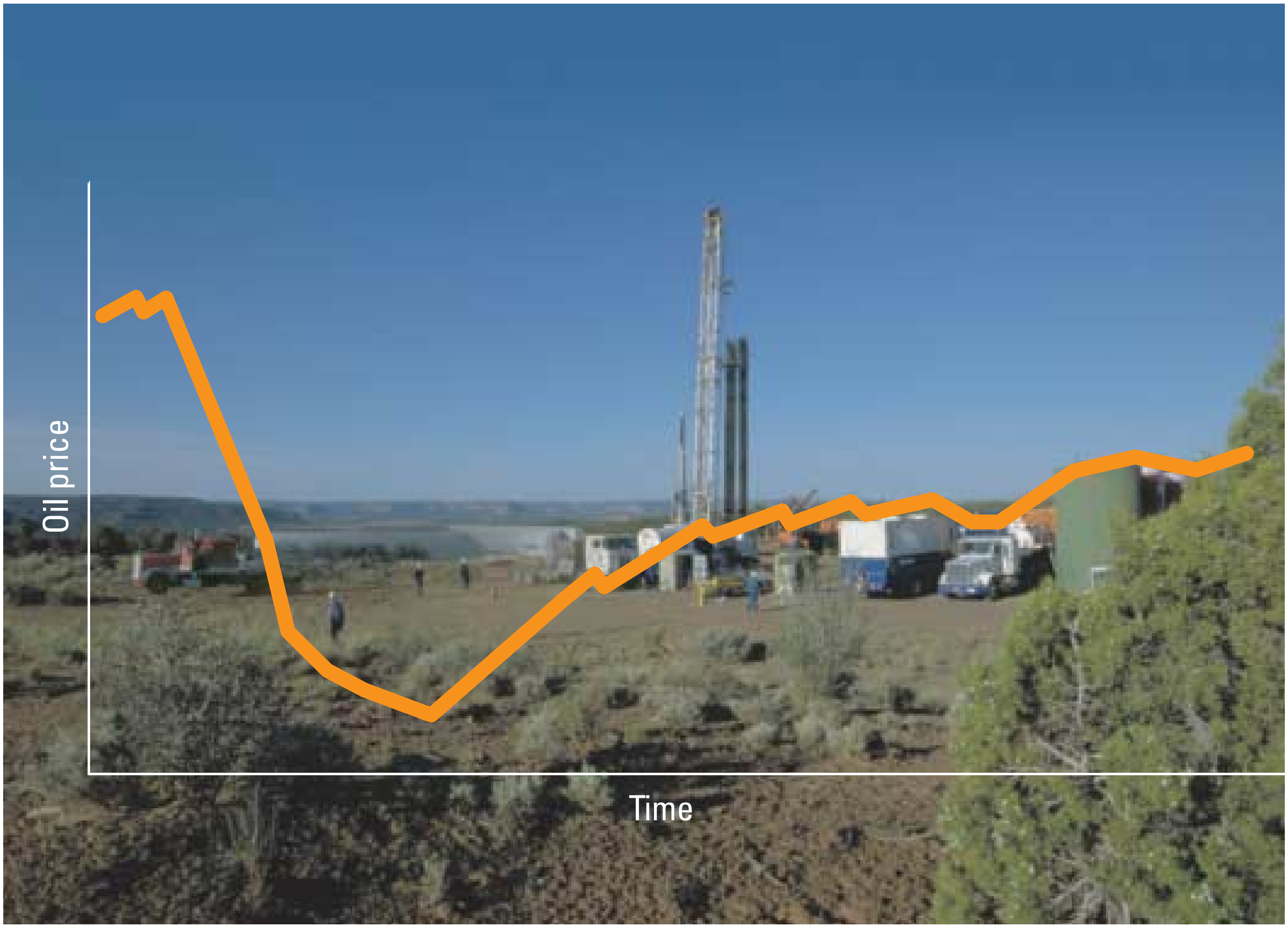
Most oil companies still use DCF to appraise potential investments. This method has served them well. Increasingly, however, companies are asking whether ROV might be used to complement DCF. ROV supporters argue that it gives a truer value than DCF only because the ROV model more closely reflects the variability and uncertainty in the world. ROV often can highlight extra value in projects, value that is possibly hidden or even invisible when DCF is used alone. Some companies that use ROV are reluctant to divulge parameter details of their models because of fears that revealing those details gives away a competitive advantage.

ROV is not on the verge of displacing DCF. In fact, real-options valuation employs DCF as one of its tools. In practice, ROV combines and integrates the best of scenario planning, portfolio management, decision analysis and option pricing.

This article reviews DCF and describes how ROV overcomes some, but not all, of its shortcomings. After explaining the parallels and differences between financial options and real options, it examines two of the many methods of valuing options, the Black-Scholes formula and binomial lattices. ROV is illustrated by a case study of a liquefied natural gas (LNG) transport option. A series of linked, synthetic examples describes several simple forms of binomial lattices.

Discounting Cash Flows

Discounted cash flow analysis is relatively simple. It predicts a stream of cash flows, in and out, over the expected life of a project, then discounts them at a rate—typically the weighted average cost of capital (WACC)—that reflects both the time value of money and the riskiness of those cash flows. The time value of money indicates that money held in the future is worth less than money held now, because money we



have in hand can be invested and earn interest, whereas future money cannot.[2]

The crucial item in any DCF calculation is net present value (NPV), the present value of cash inflows minus the present value of cash outflows, or investments (right). A positive NPV indicates that the investment creates value. A negative NPV indicates that the project as planned destroys value.

A DCF analysis provides clear, consistent decision criteria for all projects (see "Working Out Net Present Value," *page 6*). However, it also has limitations:[3]

- DCF is static. It assumes that a project plan is frozen and unalterable and that management is passive and follows the original plan irrespective of changing circumstances. However, management tends to modify plans as circumstances change and uncertainties are resolved. Management interventions tend to add value to that calculated by DCF analysis.

Time	n	Cash flow	Discount factor	Present value of cash flow
Present	0	–5000	1.0000	–5000
One year	1	+4500	0.9091	+4091
Two years	2	+3000	0.8264	+2479
Undiscounted cash flow		+2500		
Net present value				+1570

Discount factor = $1/(1+\text{Discount rate})^n$.

^ Net present value (NPV) calculation. A discount factor—based on a 10% discount rate—applied to future cash flows indicates the greater value of cash in hand compared with future cash. In this case, the difference between the NPV and undiscounted cash flow is almost a thousand, regardless of the currency used.

For help in preparation of this article, thanks to Steve Brochu, BP, Houston, Texas.

ECLIPSE is a mark of Schlumberger.

1. Coy P: "Exploiting Uncertainty," *Business Week* (US edition) no. 3632 (June 7, 1999): 118–124.
2. Hussey R (ed): *Oxford Dictionary of Accounting.* Oxford, England: Oxford University Press (1999): 131.
   In a deflationary economy, money in the future may not be worth less than money held now.
3. Mun J: *Real Options Analysis: Tools and Techniques for Valuing Strategic Investments and Decisions.* New York, New York, USA: John Wiley & Sons (2002): 59.

A Synthetic-Reservoir Example

Working Out Net Present Value

A series of examples using a fictitious field and simple synthetic models is presented in this article to illustrate some key valuation concepts. This section sets up the case and determines the net present value (NPV).

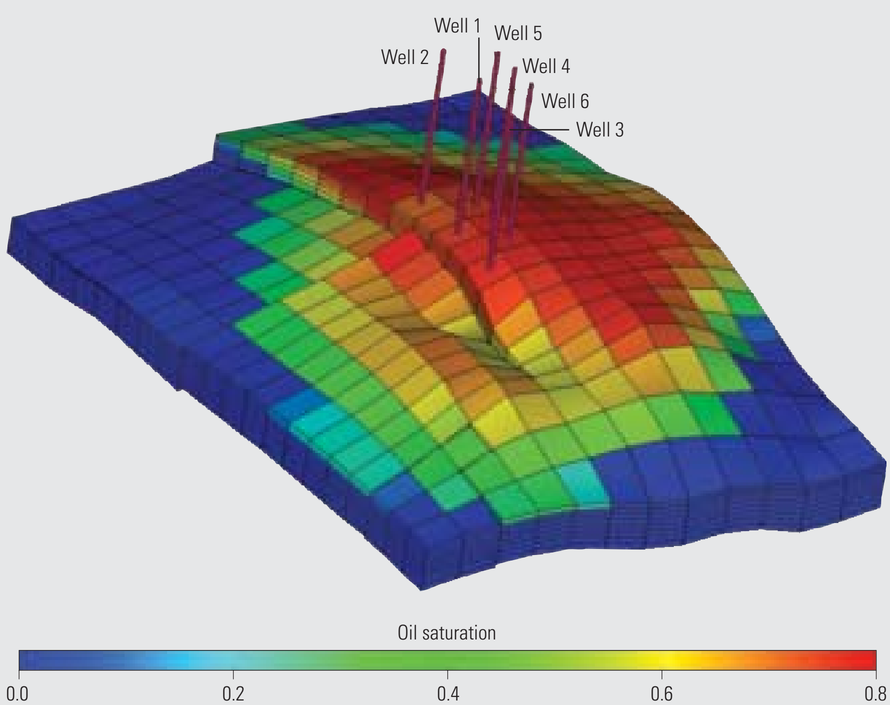
The fictitious Charon field in the Sargasso Sea is an anticline, divided into two blocks by a fault. The reservoir interval consists of shallow marine sediments up to 200-ft [61-m] thick, capped by a sealing shale. The operator, Oberon Oil, has devised a development plan to obtain first oil in three years. The plan calls for drilling six wells tied back to a dedicated production platform that can handle 50 million scf/D [1.4 million m^3/d] of produced gas from the live oil. Expected development costs will be $177.5 million spread over three years (above right).

Company experts assign values to key reservoir properties, such as porosity and permeability, based on probability distributions (below right). The oil/water contact is not known precisely, which impacts the estimate of oil in place. Several geological realizations are constructed and used for simulation models. Hydrocarbon resources are computed for low, median and high estimates—considered representative of the oil in place occurring at the 5%, 50% and 95% values of the probability distribution (next page, top).

Decision-making is based on these three representative scenarios. ECLIPSE oil production predictions are made for each realization (next page, bottom). Oil production decline with time for this fictitious case can reasonably be modeled as a hyperbolic function, making the results easier to use for prediction. A standard discounted cash flow (DCF) model computes project NPV. The oil price is assumed to be $25/bbl at the start of the project and to increase 1% per year, with a tax rate of 33% for net positive revenue and no tax paid for negative net revenue. In this scenario, the median-case NPV for Charon field is $236.3 million.

Period	Time, years	Total development cost, million $
1	0.6	50.0
2	1.2	75.0
3	1.8	107.5
4	2.4	150.0
5	3.0	177.5

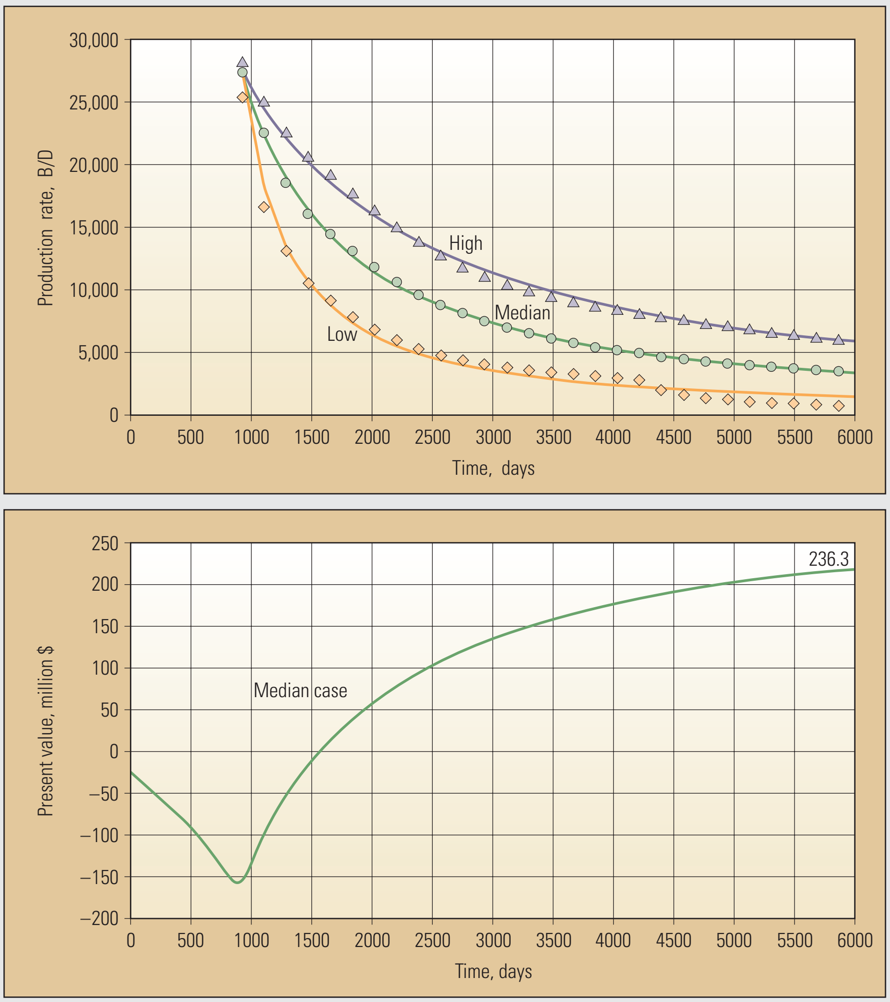
^ Investment schedule for the synthetic Charon field. The three-year construction schedule is broken into five equal-length time periods. These five time steps are used in later examples.



^ Reservoir model of the synthetic Charon field. This ECLIPSE reservoir model provided input for obtaining production predictions, using a large number of simulations with geostatistically derived porosity and permeability values.

	Oil/water contact depth, ft	Field-wide average, ratio of net-to-gross thickness	Average porosity	Original oil in place, million BOE	Initial oil production, B/D
Low	9625	0.65	12.5%	138.6	25,384
Median	9650	0.75	14.4%	228.2	27,930
High	9675	0.85	16.3%	350.4	28,225

^ Results of model realizations. Three models represent the low (5%), median (50%) and high (95%) production predictions in Charon field.



^ Calculation of Charon net present value (NPV). Production begins in the third year of the project and declines (*top*). The low (5%), median (50%) and high (95%) probability model predictions are shown. The project's cumulative cash flow for the median case shows the expenditures in the first three years followed by income over the remainder of the project (*bottom*). The median-case NPV of the project is $236.3 million.

- DCF assumes future cash flows are predictable and deterministic. In practice, it is often difficult to estimate cash flows, and DCF can often overvalue or undervalue certain types of projects.
- Most DCF analyses use a WACC discount factor. But instead of a WACC, companies often use a company-wide hurdle rate that may be unrepresentative of the actual risks inherent in a specific project.

The first two limitations relate to circumstances changing after a project begins. A new DCF analysis can be performed to reflect the new circumstances, but it may be too late to influence basic project decisions, since the project is already under way. The third limitation above results from companies adopting a company-wide hurdle rate for consistency rather than carefully recalculating a WACC for each project.

A sensitivity analysis can enhance information provided by DCF analysis. The consequences of possible changes to key variables—for example, interest rates, cash flows and timing—are evaluated to determine the results of a number of "what if" scenarios. However, the choice of which variables to alter and how much to alter them is subjective.[4] Sensitivity analysis makes assumptions about future contingencies, rather than incorporating those contingencies as they occur.

Embracing Uncertainty and Adding Value

Unlike DCF, ROV assumes that the world is characterized by change, uncertainty and competitive interactions among companies. It also assumes that management has the flexibility to adapt and revise future decisions in response to changing circumstances.[5] Uncertainty becomes another problem component to be managed. The future is regarded as one that is full of alternatives and options, both of which may add value.

The word *option* implies added value. When we speak of keeping our options open, having more than one option, or not foreclosing on our options, the underlying implication is that just holding the option usually has value, whether or not we exercise it. The same is true of real options.

4. Bailey W, Couët B, Lamb F, Simpson G and Rose P: "Taking a Calculated Risk," *Oilfield Review* 12, no. 3 (Autumn 2000): 20–35.
5. Trigeorgis L: "Real Options: A Primer," in Alleman J and Noam E (eds): *The New Investment Theory of Real Options and Its Implications for Telecommunications Economics.* Boston, Massachusetts, USA: Kluwer (1999): 3.

Real-options analysis draws heavily on the theory of financial options.[6] Financial options are derivatives; they derive their value from other underlying assets, such as shares of a company stock. A financial option is the right, but not the obligation, to buy or sell a share on (or sometimes before) a particular date at a particular price. The price at which a share can be bought or sold, if the option holder chooses to exercise the right, is known as the exercise, or strike, price. The two main kinds of options are a *call* option—to buy the share at the exercise price—and a *put* option—to sell the share at the exercise price (below right).

If the share price exceeds the exercise price, a call option is said to be *in the money*. If it exceeds it by a large amount, it is termed *deep in the money*. If the share price fails to reach the exercise price, the option is said to be *out of the money*. An investor would not exercise an out-of-the-money option since doing so would cost more than the market price for the share. This is where the caveat that the option holder has the right but not the obligation to buy the share at the exercise price is important. The investor allows the option to lapse if exercising it would not be beneficial.

Financial options can be further subdivided into many types.[7] Two of the most common are European and American options. A European option can be exercised only on the expiration date specified in the option contract. An American option may be exercised at any time up to and including the expiration date.

Options have two important features. First, they give an option holder the possibility of a large upside gain while protecting from downside risk. Second, they are more valuable when uncertainty and risks are higher.

Financial and Real Options

Real-options valuation applies the thinking behind financial options to evaluate physical, or real, assets. By analogy with a financial option, a real option is the right, but not the obligation, to take an action affecting a real physical asset at a predetermined cost for a predetermined period of time—the life of the option.[8] While real and financial options have many similarities, the analogy is not exact.

ROV allows managers to evaluate real options to add value to their firms, by giving managers a tool to recognize and act upon opportunities to amplify gain or to mitigate loss.[9] While many managers are not accustomed to evaluating real options, they are familiar with the concept of project intangibles. ROV gives managers a tool to move some of those intangibles into a realm where they can be dealt with in a tangible and coherent fashion.

Petroleum developments and mining operations were among the first examples used by ROV pioneers to demonstrate the parallels between real and financial options (see "How Oil Companies Use Real-Options Valuation," *next page*).[10] The exploration, development and production stages of an oilfield project can be seen as a series of linked options.[11]

At the exploration stage, the company has the option to spend money on exploration and, in return, receive prospective oil and gas resources. This is like a stock option, which gives the holder the right, but not the obligation, to pay the exercise price and receive the stock. Money spent on seismic surveys and exploration drilling is analogous to the exercise price; the resources are analogous to the stock. An exploration option expires the day the lease terminates.

Once the company has exercised its option to explore, it is in a position to decide whether to exercise a second option, the option to develop the field. This gives the company the right, but not the obligation, to develop the resources at any time up to the relinquishment date of the lease for an amount of money given by the cost of development. If the company exercises the development option, it obtains hydrocarbon resources that are ready to be produced.

The final option is the option to produce. The company now has the right, but not the obligation, to spend money on extracting the oil and gas from the ground and sending it to market. It will do so only if a number of uncertainties are resolved, most notably that the oil price is likely to reach a level that makes production profitable.

This series of options is called a sequential or compound option because each option depends on the earlier exercise of another one.[12]

Call option—the right, but not the obligation, to buy shares at the exercise price within a given time period.

Put option—the right, but not the obligation, to sell shares at the exercise price within a given time period.

Widgets, Inc., has a moderately volatile share price with a current price of $100. For a small fee, an investor may buy a call option with an exercise price of $110. If the share price subsequently rises to $120, the option holder would exercise the option to buy the shares for the agreed exercise price of $110 and sell them on the open market for $120, making a profit of $10 per share less the option-purchase fee.

Alternatively, if the investor has a put option with an exercise price of $90 and shares of Widgets, Inc. fall below $90, it will benefit the option holder to buy shares from the open market at the lower price and exercise the option to sell them at $90. Both examples ignore the usual transaction fees paid to a broker.

^ Call and put options.

6. Bishop M: *Pocket Economist*. London, England: Profile Books in association with The Economist Newspaper (2000): 197.
7. Wilmott P: *Paul Wilmott on Quantitative Finance*, vol 1. New York, New York, USA: John Wiley & Sons (2000): 217.
8. An option may be attached to a real asset or to cash flows associated with that asset. Stewart Myers first coined the term "real options" in 1985. For more information: Copeland T and Antikarov V: *Real Options*: *A Practitioner's Guide*. New York, New York, USA: Texere (2001): 5.
9. Brealey R and Myers S: *Principles of Corporate Finance*, 6th Edition. Boston, Massachusetts, USA: Irwin/McGraw-Hill (2000): 619.
10. Paddock J, Siegel R and Smith J: "Option Valuation of Claims on Real Assets: The Case of Offshore Petroleum Leases," *The Quarterly Journal of Economics* 103, no. 3 (August 1988): 479–485.
11. This simple series of linked options ignores any contractual obligations to drill or develop that may accompany a lease.
12. Copeland and Antikarov, reference 8: 12–13.

How Oil Companies Use Real-Options Valuation

Companies as diverse as BP, ChevronTexaco, Statoil, Anadarko and El Paso have shown an interest in real-options valuation (ROV). They usually regard it as complementary to techniques like discounted cash flow (DCF) and decision-tree analysis rather than as a stand-alone method of valuation.

In the mid-1990s, the executive management of Texaco (now ChevronTexaco) was split over what to do with a significant leaseholding in a developing country. The lease included several existing oil discoveries and many other substantial undeveloped discoveries. It was at an early stage of exploitation.[1] Part of the management team wanted to sell the asset, using the proceeds for more capital-efficient projects, while others on the team felt it could lead to other lucrative follow-up opportunities and the development of valuable relationships in the region.

The company management used ROV to decide which action would be better for the company. Results from the ROV substantiated parts of both viewpoints. Even after key options values had been included, the ROV indicated the asset was far less valuable than suggested by DCF. However, there was sufficient value to convince Texaco to retain the asset until some of the uncertainties were resolved, but to be prepared to sell if the price was right. Moreover, ROV enabled a major restructuring of the base plan. Texaco believed that ROV helped its executives reach a better strategic understanding of its holding.[2]

A recent analysis of a transaction that took place in the early 1990s involving Amoco (now BP) and independent oil and gas company Apache Corporation showed how real-options analysis can disclose value that is not apparent when using DCF analysis alone.[3] In 1991, after a strategic review, Amoco decided to dispose of some marginal oil and gas properties in the United States. It formed a new, separate company, MW Petroleum Corporation, to hold its interests in 9500 wells spread across more than 300 fields. Apache indicated interest in obtaining the properties, but Iraq's invasion of Kuwait in the spring of that year had pushed oil prices to historic heights while increasing price uncertainty.

Amoco and Apache agreed on most of the provisions for the MW Petroleum transaction, but disagreed on oil-price projections. The gap was about 10 percent. The two companies found common ground by agreeing to share the risk of future oil-price movements. Amoco gave Apache a guarantee that if oil prices fell below an agreed price-support level in the first two years after the sale, Amoco would make compensating payments to Apache. For its part, Apache would pay Amoco if oil or gas prices exceeded a designated price-sharing level. The MW Petroleum portfolio included 121 million barrels of oil equivalent (BOE) [19.2 million m^3] of proven oil and gas reserves, plus 143 million BOE [22.7 million m^3] of probable and possible reserves.

This transaction was reexamined by independent analysts in 2002. They compared a deterministic DCF valuation of MW Petroleum assets with a real-options valuation. The DCF value of $359.7 million was $80 million less than the ROV result of $440.4 million, indicating additional value in the assets not included in the DCF analysis.[4] In comparison, the purchase price agreed on by Amoco and Apache was $515 million plus 2 million shares of stock. Both methods gave values short of the actual price, but the ROV valuation was much closer than the DCF one.

In a third example, Anadarko, a Houston-based independent, is an enthusiast for ROV.[5] A recent ROV analysis by the company examined the impact of deferring a project until new technologies became available.[6] Anadarko had a deepwater development opportunity that the company approached in two stages. At the end of the first, exploration stage, uncertainties about the amount of oil and gas in place had been resolved. In the development phase, the operator could decide to develop the field using conventional means or wait and develop the field using new subsea completion technology that at that time was still at the research and development stage.

Conventional analysis neglecting the value of flexibility showed that development of the field using current technology would yield a value of $4 million. Including the flexibility associated with being able to wait until new technology was available—using a deferral option and waiting until the new technology was ready—increased the value to $50 million.

1. Faiz S: "Real-Options Application: From Successes in Asset Valuation to Challenges for an Enterprise Wide Approach," paper SPE 68243, *Journal of Petroleum Technology* 53, no. 1 (January 2001): 42–47, 74. This paper was revised for publication from paper SPE 62964, originally presented at the SPE Annual Technical Conference and Exhibition, Dallas, Texas, USA, October 1–4, 2000.
2. Faiz, reference 1.
3. Chorn L and Sharma A: "Project Valuation: Progressing from Certainty through Passive Uncertainty to Active Project Management," paper SPE 77585, presented at the SPE Annual Technical Conference and Exhibition, San Antonio, Texas, USA, September 29–October 2, 2002.
4. Tufano P: "How Financial Engineering Can Advance Corporate Strategy," *Harvard Business Review* 74, no. 1 (January–February 1996): 143–144.
5. In its 2001 annual report, Anadarko says that it "seeks to maximize enterprise value by maintaining a strong balance sheet and applying option theory to assist investment decision-making."
6. Rutherford SR: "Deep Water Real Options Valuation: Waiting for Technology," paper SPE 77584, presented at the SPE Annual Technical Conference and Exhibition, San Antonio, Texas, USA, September 29–October 2, 2002.

The extraction option is contingent on exercising the development option, which is contingent on exercising the exploration option. At each stage, a company obtains information to determine whether the project should be taken to the next stage.

Comparing Financial- and Real-Option Parameters

The variables used to value a financial option can be compared with their analogs in real options. An option to develop oil reserves, for example, is similar to a financial call option (below).

The NPV of the developed hydrocarbon reserves—what they would be worth at today's prices—is similar to the price of the underlying stock, S, in a financial option. The NPV of the expenditure needed to develop the reserves is like a financial option's exercise price, X. The time left on an exploration and production (E&P) lease is equivalent to the time to expiration of a financial option, T. The risk-free rate of return, r_f—the rate of return on a guaranteed asset, such as a government bond—is identical for both financial and real options. The volatility of cash flows from an E&P project, including hydrocarbon price uncertainty, is analogous to the volatility of stock prices, σ. Finally, profits foregone because production has been delayed are like the lost dividends in the financial option, δ. As long as management holds an unexercised option to invest in a project, it foregoes the money that would have flowed from it had the project been producing revenue.

The analogies between real and financial options are not exact. Trying to force real options into a conventional financial-options framework may result in misleading outcomes. One key difference in the two options types is that the exercise price of a financial option is normally fixed. For a real option, this price is associated with development costs, and may be volatile, fluctuating with market conditions, service company prices and rig availability. In the E&P industry, volatility is usually a consolidated value comprising the uncertainty involved in many things, including oil prices and production rates. Determining volatility in real options can be difficult.

Another key difference between financial and real options lies in uncertainties surrounding an option's underlying asset. With a financial option the uncertainty is external. The option is an arrangement between two outsiders—the option writer and the option purchaser—neither of whom can influence the rate of return on the company's shares.[13] In contrast, a company that owns a real option can affect the underlying asset—for example, by developing new technologies for the asset—and the actions of competitors—for example, by developing an adjacent property first, as described later in this article—which in turn can affect the nature of the uncertainty that the company faces.[14]

Black-Scholes Option Valuation

Real options often are valued using financial-option pricing techniques. However, real-option valuation can be extremely complex, so any financial-option technique can provide only a rough valuation. Two approaches are discussed in this article: the Black-Scholes formula (a closed-form solution) and binomial lattices.

Early attempts to use DCF to value options foundered on the appropriate discount rate to use and in calculating the probability distribution of returns from an option. An option is generally riskier than the underlying stock but nobody knows by how much.[15]

The insight of Fischer Black, Myron Scholes and Robert Merton, who derived the Black-Scholes-Merton formula—more commonly referred to as Black-Scholes—was that options could be priced using the arbitrage principle with a portfolio that is constructed to be risk-free, overcoming the need to estimate distributions of returns at all.[16] They showed that it was possible to establish the value of an option by constructing a replicating portfolio, which consists of a number of shares in the underlying asset and a number of risk-free bonds. The portfolio is constructed in such a way that its cash flows exactly replicate those of the option. Prices of bonds and of underlying shares are directly observable in the financial market, so the value of the replicating portfolio is known. If the option were sold for a price that is different from that of the replicating portfolio, there would be two identical assets—the option and the replicating portfolio—selling for different prices at the same time. Any investor would then use the strategy of arbitrage, buying the cheaper of the two and selling the more expensive to profit from the unequal prices.

The existence of the replicating portfolio implies that there is a combination of the option and the underlying asset that is risk-free. In effect, the risk-free rate is used as the discount rate during the option-pricing calculation and is usually taken to be the interest rate on a government-guaranteed financial instrument like a US Treasury Bond.[17]

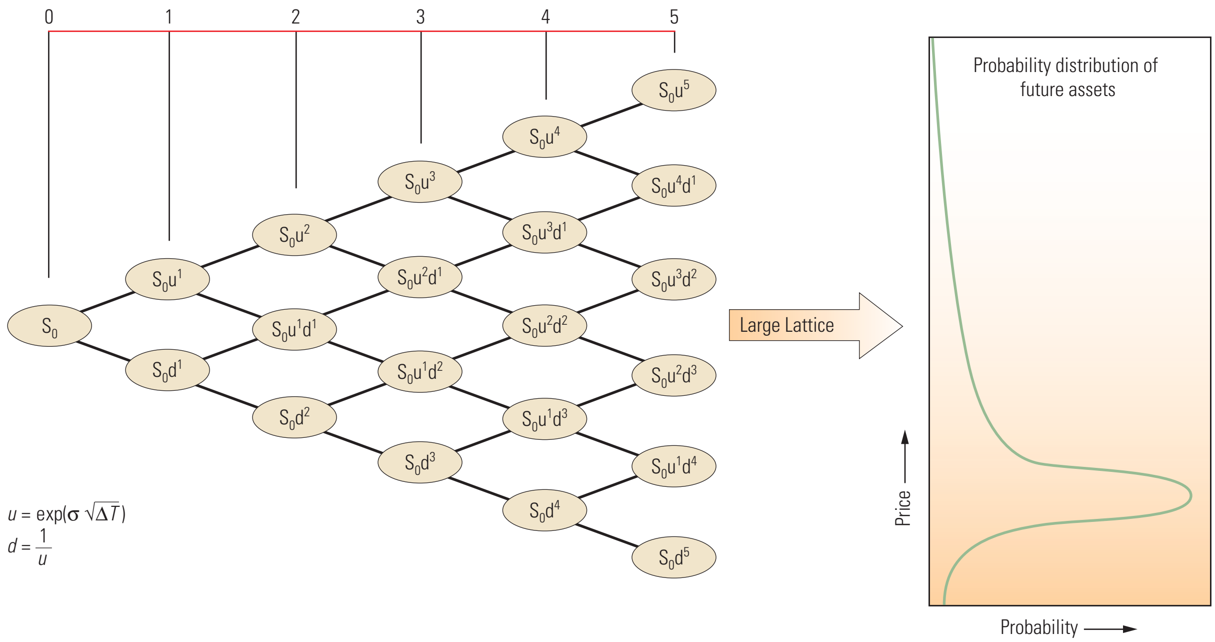
The Black-Scholes formula has fairly limited applicability. The formula is a closed-form solution to a more general expression—the Black-Scholes partial differential equation—for the case of European puts and calls, which can be exercised only on their maturity date. Most real options are not analogs of European options. However, the Black-Scholes partial differential equation itself has far wider applicability. With appropriate boundary conditions, this partial differential equation can be solved—usually numerically—to evaluate many types of options, such as American and compound options.

A numerical method using binomial lattices is applicable across a wide range of options. Since this process of valuation can be visualized in a diagram, lattices are comparatively easy to understand, although actual problems typically are more complex than the simple lattices shown in this article.

Financial and Real Options Compared

Financial call option	Variable	Real option to develop hydrocarbon reserves
Stock price	S	Net present value of developed hydrocarbon reserves
Exercise price	X	Present value of expenditure to develop reserves
Time to expiration	T	For example, time remaining on lease, time to first oil or gas
Risk-free interest rate	r_f	Risk-free interest rate
Volatility of stock price	σ	Volatility of cash flows from hydrocarbon reserves
Dividends foregone	δ	Revenue or profits foregone

^ Comparison of financial and real options. The variables of a financial call option can be related to similar variables for a real option to develop oil reserves.



^ Construction of a lattice of the underlying asset. The deterministic value for the asset today, such as a stock price, goes into the left-most lattice node (*left*). In the first time step, this value can increase by a multiplicative factor, *u*, which is based on the volatility, σ, and length of the time step, ΔT, or it can decrease by the inverse of that factor, *d*. Each node in subsequent time steps can similarly increase or decrease, resulting in an expanding lattice. Results from a five-step lattice are coarse. As the number of steps increases, ΔT becomes smaller and the resolution increases as the lattice becomes larger. A probability distribution of future assets (green curve) can be obtained from the values in the right-hand column of a lattice with thousands of steps (*right*). The assumptions governing the definition of *u* and *d* factors always give rise to a log-normal distribution of asset value at expiration—this is a basic assumption of the Black-Scholes model.

Binomial-Lattice Option Valuation

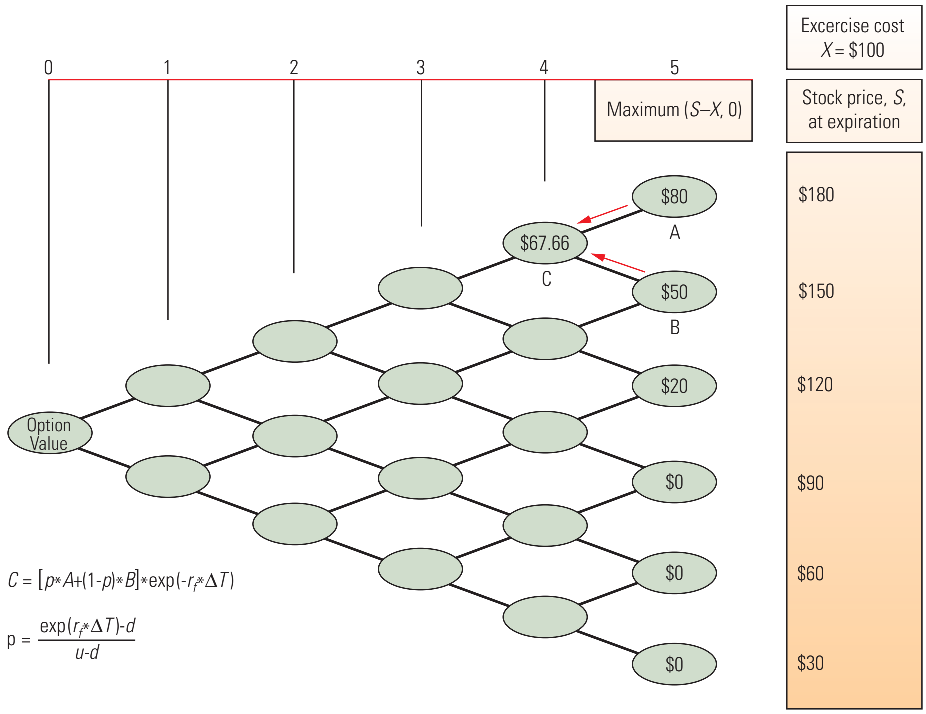
Binomial lattices allow analysts to value both European and American-type options.[18] This section describes how to construct a lattice for a simple European call option.

A lattice is a way to show how an asset's value changes over time, given that the asset has a particular volatility. A binomial lattice has only two possible movements in each time step—up or down. It looks like a fan laid on its side. ROV uses two lattices, the lattice of the underlying asset and the valuation lattice.

Lattice of the underlying asset—The underlying asset pricing lattice, also known simply as the lattice of the underlying, is read from left to right and indicates how possible future asset values could evolve. The value of the left-most node is the NPV of the underlying asset, as calculated from the DCF model. In each time interval, the value of the asset increases by a multiplicative factor u (greater than 1), or decreases by a multiplicative factor d (between 0 and 1), represented as a step up or a step down the lattice (above). The factors u and d, which determine the upward and downward movements at each node, are functions of the volatility of the underlying asset and the length of time between the periods under consideration. The right-hand nodes of the lattice represent the distribution of possible future asset values.

The most difficult issue in constructing the lattice of the underlying asset is estimating volatility. This value must reflect the uncertainties, both economic and technical, in the value of the underlying asset, and the way in which these uncertainties evolve over time.[19] Methods for estimating volatility are nontrivial, and a discussion of these methods is beyond the scope of this article.

13. The case of company executives who are given share options as an incentive to improve company value is an exception.
14. Copeland and Antikarov, reference 8: 111–112.
15. Ross S and Jaffe J: *Corporate Finance*. Boston, Massachusetts, USA: Irwin (1990): 576.
16. The Black-Scholes formula estimates the value of a call option, *C*:
$$C = S * e^{-\delta T} * \{N(d_1)\} - Xe^{-r_f T} * \{N(d_2)\},$$
where $d_1 = \{ln(S/X) + (r_f - \delta + \sigma^2/2)\, T\}/(\sigma * \sqrt{T})$,
$d_2 = d_1 - \sigma * \sqrt{T}$,
and where $N(d)$ = cumulative normal distribution function, ln is the natural logarithm and other terms are defined in the text.
17. Rogers J: *Strategy, Value and Risk—The Real Options Approach*. Basingstoke, England: Palgrave (2002): 61.
18. In a European option, uncertainty is assumed to be fully resolved at expiration. However, valuation of American-type options can be more complex and caution is required. An American option can be exercised at any time prior to expiration, but that does not mean that all uncertainty has been resolved at the time the decision is made. New information about project uncertainties is likely to be streaming in all the time, so the decision is based on incomplete information. Unless all pertinent uncertainty has been resolved, it might be prudent to wait until the last moment to decide on the option.
19. Some ROV specialists argue that it is better to keep technical and market uncertainties separate, especially when managerial decision-making is tied to the resolution of technical uncertainty.



^ Construction of a valuation lattice. Nodes in a valuation lattice are constructed from right to left. The asset value, such as a stock price, *S*, at expiration is taken from the lattice of the underlying asset. The exercise cost, *X*, is known in advance. The nodes in Column 5 contain the difference between stock and exercise price, unless that difference is negative, in which case the node contains zero. The value in the node labelled C comes from the two adjacent Column 5 nodes, A and B, and uses the risk-neutral probability, *p*, as shown in the formula (*bottom left*). Remaining nodes and columns are constructed similarly, from right to left. The single node on the left contains the value of the option.

In summary, the lattice of the underlying illustrates the possible paths that an underlying asset value—like a stock's price, and similarly designated as *S*—will take in time, given that it has a certain volatility.

Valuation lattice—The valuation lattice has exactly the same number of nodes and branches as the lattice of the underlying asset (above). Analysts work backward from the values in the terminal nodes at the right side to the left side of the lattice. The value placed in each terminal node is the maximum of zero and the difference between value S and exercise price *X*, *MAX(S – X, 0)*. Disallowing negative values reflects the holder's right to refuse to exercise an option with negative value.

From these starting values in the terminal nodes, it is possible to work backwards through the lattice—using a process called backward induction—to obtain an option value at the farthest left node of the lattice. Backward induction relies on a factor *p*, the risk-neutral probability of a movement in the price of the underlying asset. This is the probability that would prevail in a world in which investors were indifferent to risk. Applying this to each pair of vertically adjacent nodes in the lattice provides the real-option value at the farthest left node of the lattice.

Binomial lattices are often referred to as binomial trees. However, the two methods operate differently. Trees require an analyst to specify probabilities and appropriate discount rates at each node, which can be highly subjective. ROV, embodying ideas such as risk-neutral probability for financial uncertainty and risk-free rate of interest, is less subjective.[20]

20. Mun, reference 3: 242–245.

Synthetic-Reservoir Development Guarantee

Salvage an Investment

Oberon, operator of the fictitious Charon field, has reservations about the eventual economic viability of the field. To protect itself from a negative result, the company has entered into negotiations with Thalassa Energy, which is eager to add Sargasso Sea assets to its portfolio. Thalassa offers Oberon, for an up-front premium of $45 million, a guarantee to take over the Charon field and reimburse Oberon all development costs incurred up to the exercise date, if Oberon chooses to exercise the option. The salvage value at any time is assumed to be the amount invested at that point. Oberon performs a real-options valuation (ROV) to determine whether the flexibility to recoup development expenses is worth the price asked by Thalassa.

The ROV involves four steps: identifying the underlying asset, determining its volatility, constructing the lattices and interpreting option value.

Oberon identifies the underlying asset as Charon's project NPV. This NPV exhibits a log-normal probability distribution, so the volatility of the underlying asset is based on the logarithm of the future cash flows. Monte Carlo simulation on the DCF model indicates that the implied annual volatility is 66.41%, including both private and public uncertainties.

The engineers construct a lattice of the underlying asset with 0.6-year time steps using a five-step binomial lattice (next page). The asset value, *S*, or Oberon's NPV for the project without any flexibility from salvage potential, is $236.3 million (see "Working Out Net Present Value," *page 6*). The risk-free rate for the three-year period under consideration is 5% per year. The valuation and decision lattices are identical in form to that of the lattice of the underlying asset.

These lattices allow Oberon to interpret option value. The added flexibility provided by the Thalassa contract increases Charon's NPV to $285.5 million. This is the value a rational, frictionless, free market would, given the same information, assign to the project. It is $49.3 million more than the NPV without flexibility—simply because of the presence of the salvage option.

An offer to provide this flexibility for $45 million should be accepted by Oberon management since it appears that Thalassa underpriced the option by $4.3 million, the difference between the option value and the premium price. This apparent underpricing indicates that Thalassa has a different perception of risk and uncertainty than Oberon.

Input Parameters

$\sigma = 66.41\%$

$\Delta T = 0.6$

$u = \exp(\sigma\sqrt{\Delta T})$

$= \exp(0.6641 * \sqrt{0.6})$

$= 1.67265$

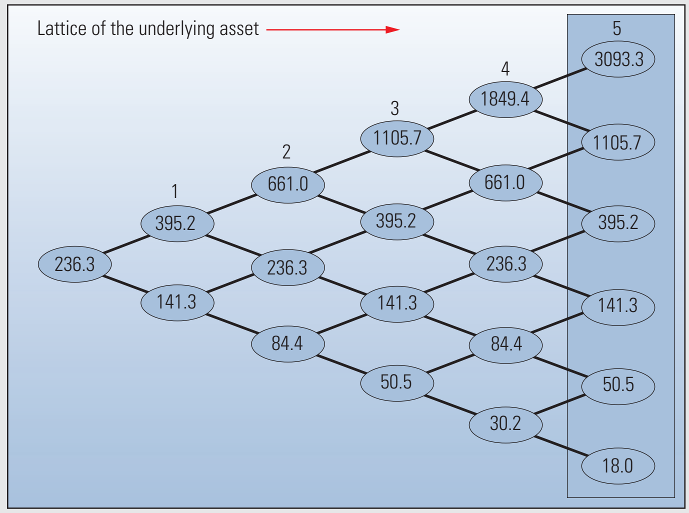
$$d = \frac{1}{u} = \frac{1}{1.67265}$$

$= 0.59785$

$$p = \frac{\exp(r_f * \Delta T) - d}{u - d}$$

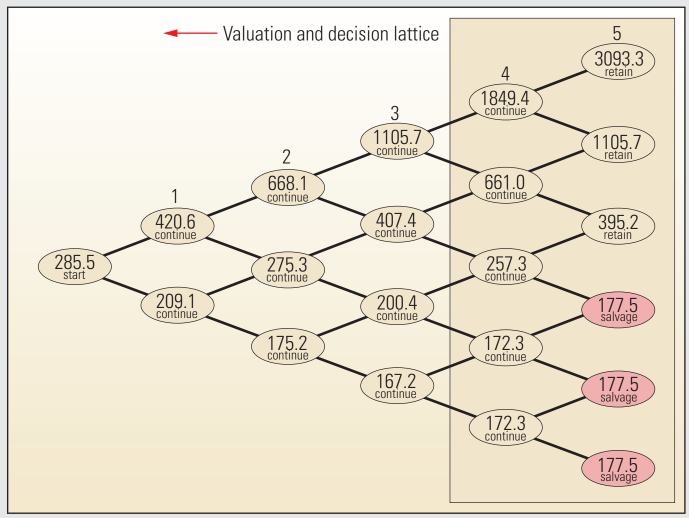
$$= \frac{\exp(0.05*0.6) - 0.59785}{1.67265 - 0.59785}$$

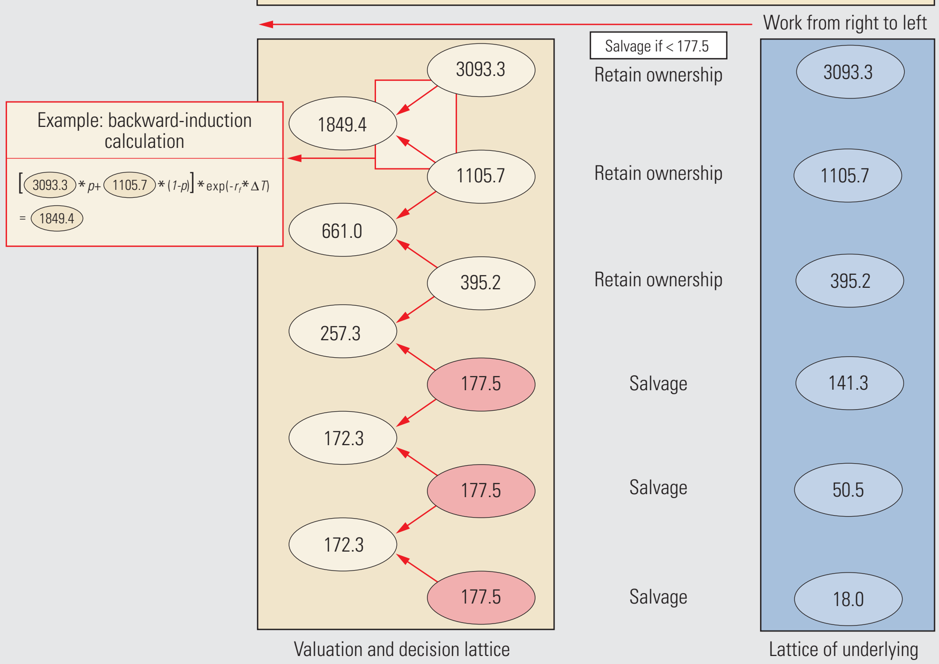
$= 0.40250$



Salvage Value

Period	Years	Value, million $
1	0.6	50.0
2	1.2	75.0
3	1.8	107.5
4	2.4	150.0
5	3.0	177.5





> Real option for salvage. The lattice of the underlying asset begins with the project net present value in the left node and projects potential future values to the right (*top right*). The up and down multiplying parameters, *u* and *d*, are calculated from the inputs of volatility, σ, and the time step size, ΔT (*top left*). The salvage value is based on investment to date (*middle left*). The valuation and decision lattice has the same form as the lattice of the underlying, but it is constructed from right to left (*middle right*). The last column of the valuation lattice is constructed by comparing the equivalent node in the lattice of the underlying with the salvage value at the final time step (*bottom right*). If the salvage value is greater, that amount is entered and the salvage decision is noted. Otherwise, the value from the node in the lattice of the underlying is used for the valuation-lattice node, and the decision is to retain ownership. The value in the node in the next column to the left comes from back-regression from two adjacent nodes, as indicated by the arrows. That value involves the risk-neutral probability, *p*, the risk-free interest rate, r_f, and the time step size, ΔT (*bottom left*).

Types of Real Options

Analysts generally classify real options by the type of flexibility they give the holder.[21] The options may occur naturally, or may be built into a project. Management can defer investment, expand or contract a project, abandon for salvage or switch to another plan. Compound options also can be created.[22]

Option to defer investment—An opportunity to invest at some point in the future may be more valuable than an opportunity to invest immediately. A deferral option gives an investor the chance to wait until conditions become more favorable, or to abandon a project if conditions deteriorate. An E&P lease, for example, may enable an oil company to wait until present uncertainties about oil and gas prices and about development technology have been resolved. The company would invest in exploration and development only if oil price increased enough to ensure that developed acreage on the lease would be profitable. If prices declined, the company would allow the lease to lapse or would sell the remainder of the lease to another company. The exercise price of the option is the money required to develop the acreage.

Option to expand or contract a project—Once a project has been developed, management may have the option to accelerate the production rate or change the scale of production. In an oil or gas field, there might be the option to increase production by investing in an enhanced oil recovery plan or by drilling satellite wells. The original investment opportunity is defined as the initial project plus a call option on a future opportunity.

Option to abandon for salvage—If oil and gas prices go into what seems likely to be a prolonged decline, management may decide to abandon the project and sell any accumulated capital equipment in the open market. Alternatively, it may sell the project, or its share in the project, to another company whose strategic plans make the project more attractive (see "Salvage an Investment," *page 12*). Selling for salvage value would be similar to exercising an American put option. If the value of the project falls below its liquidation value, the company can exercise its put option.

Option to switch to another plan—A switching option can provide a hedge against the likelihood that another technology or project will be more economic sometime in the future (see "Switch Option," *page 16*).

Sequential or compound options—Real options may lead to additional investment opportunities when exercised. The process of exploration, development and production described earlier in this article was a sequential option.

This list of options is not exhaustive. Many other types of options are available. El Paso Corporation, the largest pipeline company in North America and a leading provider of natural gas services, used a location *spread option*—relying on a difference in a price between different locations—to evaluate a new line of business. Various other spread options are possible, for example based on different prices at different times or at different stages of commodity processing.

Real Options for LNG Transport

El Paso owns a liquefied natural gas (LNG) terminal at Elba Island, Georgia, USA, one of only four land-based terminals in the USA. The company investigated purchasing transport vessels and expanding into the LNG transport business. Each tanker, outfitted specifically for use in LNG transport with a regasification capability for downloading at offshore buoys called energy-bridge buoys, costs several hundred million US dollars.

The essence of the problem facing the evaluation team was how to value shipping and diversion flexibility. The company had a variety of potential LNG sources and destinations, and the evaluation was intended to determine how many tanker ships El Paso should purchase.

El Paso felt DCF was deficient for this analysis. The LNG market and its related shipping were relatively new ventures for El Paso, and the company had no history for forecasting the revenues and costs required by DCF. Even if those forecasts had been available, the DCF technique does not have the flexibility necessary to reflect the additional value of a price difference between delivery locations that occurs only for a brief time period. The team tried to model the simple case of a fixed source and destination using DCF, but the model could not correctly value inbuilt options allowing El Paso not to sell if the LNG delivery price did not cover variable expenses.

The base case for this ROV involves transporting LNG from a terminal in Trinidad, West Indies, to the company's Elba Island facility. The LNG producer in Trinidad would pay for infrastructure costs to enable this base-case trade and would in turn receive the netback gas price, which is the gas price at Elba Island less the cost of shipping and regasification and less the margin paid to El Paso. For example, for the analysis presented here this margin was assumed to be $0.20/MMBtu [$0.19/million J]. The NPV of this business over 20 years was $176.7 million.

The first option evaluated included diversion flexibility—adding a second destination terminal offshore New York, New York, USA. El Paso evaluated both intrinsic and extrinsic values for this option. The intrinsic value of this spread option represents the difference in price—the basis spread—between the Georgia and New York markets (next page). The extrinsic value includes the effects of time and reflects the probability that the basis spread will change over the 20-year period of the analysis.

In this spread option, El Paso would buy the LNG on the basis of the Elba Island price and sell it at the New York price, when that choice adds value. Otherwise, El Paso would sell at Elba and receive no incremental value. With an average basis spread of $0.62/MMBtu [$0.59/million J], the total intrinsic value of this spread option is $558.7 million. In this model, El Paso would assume the costs for converting the terminals and purchasing an additional ship to effect this option. The net value of the option after those expenses is $68.5 million. Including the variability over time gives an additional extrinsic value of $101.7 million.

The company then added in the value of having multiple choices of source and destination, termed a rainbow option. The value of a rainbow option increases with increased price volatility at the individual locations, and it also increases when the cross-correlations between prices are low. With two additional destination options, offshore New York and Cove Point, Maryland, USA, there is an additional value of $14.8 million, even though the price correlations between these pairs of locations are high. The rainbow option value increases when there is more flexibility in source and destination locations. In certain scenarios with additional sources in the

21. Rogers, reference 17: 49; and Trigeorgis, reference 5: 5–10.

22. A project with many embedded options can be difficult to evaluate using the simple forms of the Black-Scholes and lattice models presented in this article.

Middle East and Africa and additional destinations in Europe and North America, El Paso found the rainbow option added more than $100 million to the value of each ship.

The evaluation team provided a caveat to the company. Spread options tend to overestimate available flexibility, because contractual obligations would have to be maintained. In addition, the effects of price shifts caused by any reduction in supply were not included in the analysis.

Although real-options analysis indicated a positive value to a business model based on LNG imports to the USA and to diversion flexibility as a value-maximizing technique for shipping, El Paso made a strategic business decision not to enter this market.

^ Liquified natural gas (LNG) transport routes in a spread option. El Paso Corporation evaluated the LNG transport business using a base case between Trinidad, West Indies, and its terminal at Elba Island, Georgia, USA. The company considered purchasing transport ships with regasification capabilities to give it the capability to transport gas to other locations, such as Cove Point, Maryland, USA, or New York, New York, USA. This rainbow option increased the value of the business opportunity.

Alternatives and Options

In the English language the word option may be used in two technically different senses. In ROV the term option (or real option) is used to denote a decision that may be deferred to some time in the future, and that is accompanied by some uncertainty that can be resolved. On the other hand, in common parlance, an option can simply be an operational alternative, which is a decision that is to be made today and for which there is no future recourse.

For example, a company may decide to drill a well in a certain location. If the well is dry, then the company has lost the cost of drilling. The well location was an operational alternative, a decision that had to be made there and then. However, if there were another party guaranteeing some minimum return on the well, the company drilling the well would have a real option, because it could decide in the future whether to call on that guarantee, thereby minimizing any downside risk and maximizing any upside potential.

A project containing an option is always worth more than one with just a corresponding alternative. This is because deferral allows an owner to eliminate unfavorable outcomes while retaining favorable ones. This is often referred to as optionality. A project having only a set of alternatives has no such cushion. The decision, which must be made today, is effectively irreversible. The estimated NPV must average over all outcomes, both favorable and unfavorable.

Both options and alternatives can be computed using standard lattice-type methodologies (see "True Option and an Alternative Valued under Uncertainty," *page 18*). Alternatives may often be evaluated using simpler methods that automatically average out the possibilities. For example, a forward contract, which obligates the holder of the contract to buy or sell an asset for a predetermined price at a predetermined time in the future, may be valued simply, without the volatility assumption that is required in the Black-Scholes or lattice valuation of a European option.

Within the class of options there are many distinctions. One is the distinction between financial and real options that has been discussed. Another is that between options that are purely internal—residing solely within the company itself—and ones in which an outside party provides flexibility for some agreed up-front payment. Many real options possess just an internal character, while financial derivatives normally exist in the presence of a contracted external party. Fortunately, all these option types can be computed using the same techniques, most notably standard lattice-type methodologies.

Real-World Complications

A real-options methodology attempts to model behaviors of real properties. However, the many possibilities created by human ingenuity limit any such modeling. Actual situations typically have many embedded options, making any analysis complicated. The few examples discussed in this section illustrate a few types of complications that may have to be dealt with in using real options.

The holder of a financial option is guaranteed that the option may be held until the expiration date and, apart from general market movement, its value cannot be undermined by the actions of other individuals. In most real options, there is no such guarantee.

Two oil companies might hold identical leases on adjoining blocks. In effect, they would both have identical options to spend money on exploration and receive undeveloped resources in return.

(continued on page 18)

Synthetic-Reservoir Surface-Separator Decision

Switch Option

At this time, the design criteria for the fictitious Charon field project have been established and a three-year development phase is about to begin. A critical technical issue is the gas-throughput capacity of a surface separator. Economic analysis suggests a maximum separator capacity of 50 million scf/D [1.4 million m^3/d]. A facilities contractor, Proteus Fabrication Inc., has been commissioned to design, fabricate and install it.

Although a 50 million scf/D throughput design—termed Case 50—is deemed adequate, an upside production potential of an extra 10 million scf/D [286,000 m^3/d] is possible. A 60 million scf/D [1.7 million m^3/d] separator—Case 60—would be more expensive, and Charon might not have enough production potential to utilize it fully. The company would like to delay the design-capacity decision for as long as possible.

Proteus can implement this design change within the first year of construction, but cannot make changes after the first year. The implementation cost to switch from a smaller to a larger design, set at $17.72 million, is equivalent to an option exercise price, X.

In addition to this exercise price, Proteus insists on an additional up-front nonrefundable payment. This up-front payment accommodates changing the initial design to allow for later expansion and covers a possible overrun on the agreed exercise price. Oberon initiates a simple switching-option study to determine what the initial payment to Proteus should be.

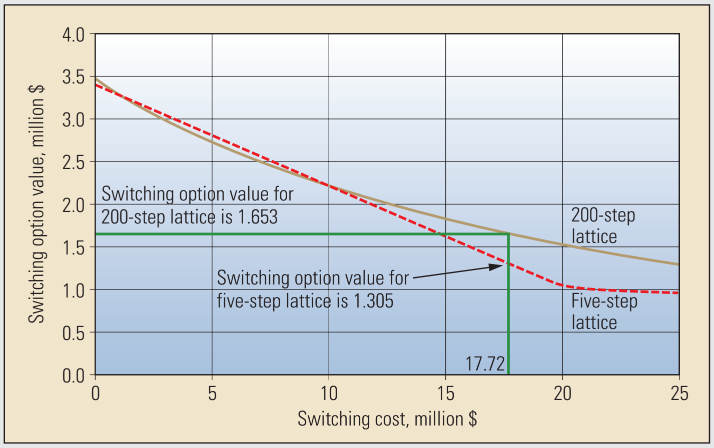
Case 50 and Case 60 are independent cases with different cash-flow NPVs and volatilities. ECLIPSE modeling establishes the static NPV, excluding switching costs, and associated volatility of the two cases (top right). Values for Case 60 are obtained in manner similar to Case 50, the base case used in the previous examples.

A switching option can be analyzed by constructing two lattices, one for each of the two underlying assets (next page). The simplest case assumes these two lattices are completely correlated—each step up or down in one underlying lattice corresponds with the same step in the other. In this way, nodes in the two cases can be directly compared to construct a valuation lattice for the upgrade.

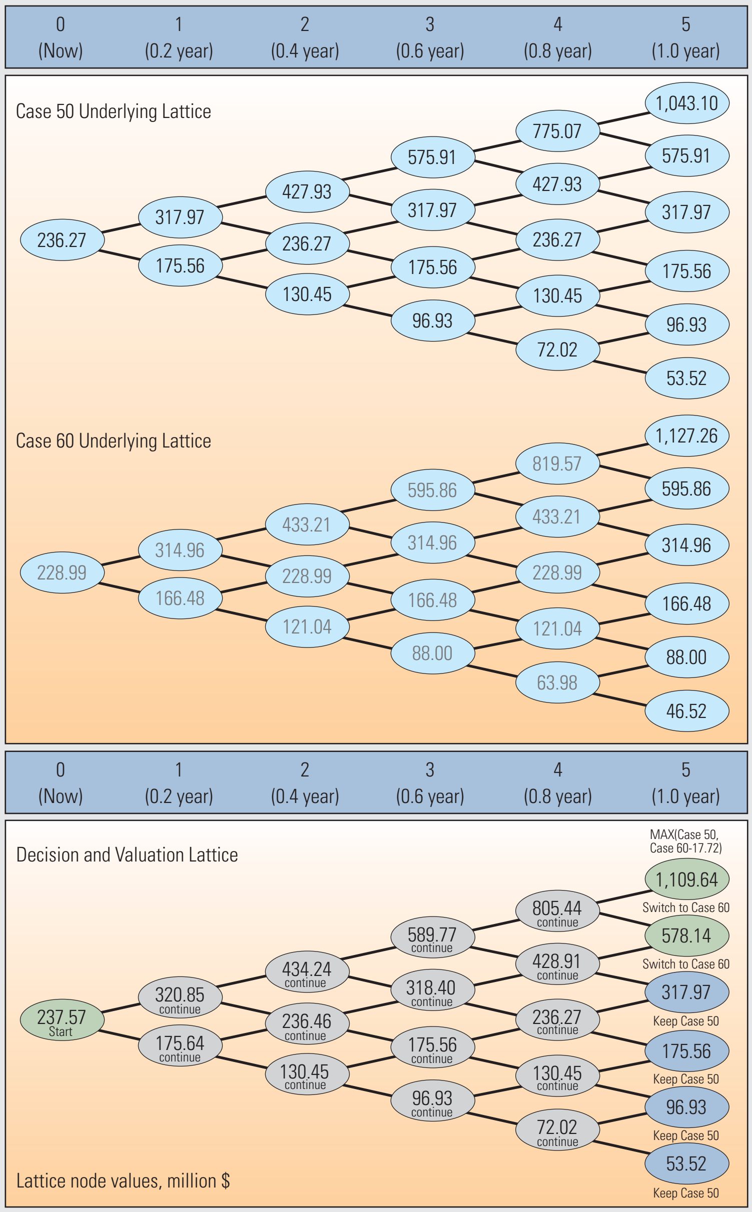
The valuation lattice is obtained by subtracting the upgrade cost, $17.72 million, from the last column of the Case 60 lattice, comparing this to the last column of the Case 50 lattice, and selecting the larger value at each node. This reflects Oberon's right to choose the better of the two cases in any eventuality. The option value is then computed by backward induction using the Case 50 risk-neutral probabilities, p.

	Case 50	Case 60
Throughput, million scf/D	50	60
Volatility	66.41%	71.28%
NPV, million $	236.27	228.99

^ Comparison of volatility and net present value (NPV) for two surface separator cases in the synthetic Charon example.



^ Effect of lattice size on option valuation. The coarse, five-step lattice has been used for illustrative purposes only, yielding a less accurate option value than the more refined 200-step lattice. At the $17.72 million switching cost, that finer lattice indicates the option value is $1.653 million.



< Lattices for synthetic Charon surface separator cases. Case 50 and Case 60 have different lattices of the underlying asset, but the lattice structure is the same, allowing a node-by-node comparison between them (*top*). Nodes in Case 60 are greyed out, except for the final column, to indicate that no decision is made until the end of one year. The last column of the valuation lattice is constructed by comparing the value of Case 50 to equivalent node value of Case 60 minus the implementation cost of $17.72 million (*bottom*). This also provides the decision to keep Case 50 or switch to Case 60. The other nodes of the valuation lattice are constructed by back-regression, using the risk-neutral probabilities from Case 50, the base case. The value of the project with the switch option is $237.57 million.

Changing the cost to upgrade affects the value of the upgrade option (previous page, bottom). In this case, the five-step lattice is too coarse, resulting in an unrealistic kink in the result. A finer 200-step lattice resolves the kink and indicates that it would be appropriate for Oberon to pay Proteus a $1.653 million premium for the option to switch in the first year at the stated upgrade price. In an actual case, final decisions would be based on finer lattices than the five-step lattices used in these illustrations.

With this arrangement Oberon gains the ability to demand a design change resulting in accelerated cash and throughput from reservoir production, if conditions warrant. Proteus gets an up-front premium of $1.653 million and a locked-in payment of $17.72 million if Oberon chooses to upgrade the facility. Proteus has a cash incentive to explore more cost-effective and efficient design solutions for the upgrade.

Actions of one company can affect the business results of the other. Most governments now insist on unitization, an arrangement that requires parties on both sides to jointly develop reserves located on more than one lease or auctioned tract. Each party pays a share of the costs and receives a proportionate amount of the revenues. In a sense, when governments do this, they are ensuring the purity of the real options involved.

It is possible to conceive of circumstances—such as constructing a pipeline to an area where only one is needed—in which if Company A took up the option to invest, it would preempt Company B from doing so, rendering B's option worthless, or certainly worth less. The real-options approach attaches a positive value to delay, but in instances such as this one, delay can undermine value.[23]

Finally, the parameters used in real-options calculations can be difficult to determine. There is no simple road map to computing volatility and there is still debate over the correct approach to finding this value. Obtaining an estimate often entails performing a Monte Carlo simulation on the existing DCF model and examining the standard deviation of the natural logarithm of the cash-flow returns. The cost of deferment requires knowledge of the profits foregone during the period prior to exercising an option, but the value of the missed cash flows may be poorly known.

Financial-option pricing relies on an assumption that the underlying asset can be traded, meaning there is a large liquid market for the asset. This is often not true for real options. Factors affecting the prices of financial options are also easier to determine—that is, more transparent—than those for real options.

The simplified discussion in this article is intended only to introduce the concept of real options. It uses simple examples that correlate with financial options. Use for an actual case is typically more complicated, with an expanding array of possible options available, as demonstrated in the El Paso LNG case. Ultimately, real options are not financial options. The techniques of financial options provide a basis for

23. For a discussion of such investment behavior: Weeds H: "Strategic Delay in a Real Options Model of R&D Competition," *Review of Economic Studies* 69 (2002): 729–747.

24. Trigeorgis, reference 5: 3.

Synthetic-Reservoir Intervention

True Option and an Alternative Valued under Uncertainty

The fictitious Charon field, operated by Oberon Oil, has been producing for a few years. Production is declining and water cut is increasing in some of the wells. Engineers propose a production-enhancement operation involving water shutoff on one of the wells. Their analysis has determined what incremental production is likely to be from this intervention.

With DCF, the expected NPV of the incremental cash flow, which is the option asset value S, is $1,280,000, excluding the actual intervention cost. The cost of the intervention, or exercise price X, is $750,000. The resulting NPV is $530,000.

Analysts estimate a 40% volatility of the incremental cash flow subject to oil price and technical uncertainties, and use a 5% risk-free rate of interest.

The service provider offers Oberon two choices:

1. Pay the $750,000 job cost up-front and accept whatever may happen.
2. Pay an additional up-front premium to the service provider for the right to claim back some or all the job cost if the incremental net revenue generated from this intervention is negative after one year.

The second choice provides Oberon with protection from downside risk, up to the cost of the job, but the intervention would still have an unlimited upside potential. For example, if after one year the net incremental cash flow (after job cost) were negative $100,000, then the service provider would reimburse Oberon that sum. Oberon's net incremental cash flow from this operation would be zero. In effect, this option offered by the service provider provides a cost-reimbursement guarantee for an agreed up-front premium. Oberon wants to calculate what a reasonable value for this up-front premium should be.

The first choice is a pure operational alternative—to intervene or not to intervene. If Oberon takes this choice, then any job cost is sunk; the decision to spend money on the job is irreversible. This arrangement is an alternative, not an option in the sense discussed in this article. A valuation lattice for this alternative differs from an ROV lattice in that the right-hand terminal nodes of the valuation lattice contain the simple term, $S\text{-}X$, rather than the conventional terms used in those nodes, that is, the maximum of zero and $S\text{-}X$—$MAX(S\text{-}X,0)$ (next page).

The difference between the alternative and real-option lattices—$8,198—represents the premium the service provider should theoretically demand in order to agree to a contracted cost-reimbursement provision. It is small in this case because there is a small likelihood that the provision would be required and the option would be exercised.

The NPV of $530,000 undervalues this project. Even with no reimbursement provision, the value added to the asset from the intervention is $36,578 more than the NPV. This additional value emerges solely because of the presence of volatility in the underlying asset. Adding the revenue reimbursement provision increases this net value by $44,776 beyond the NPV calculation.

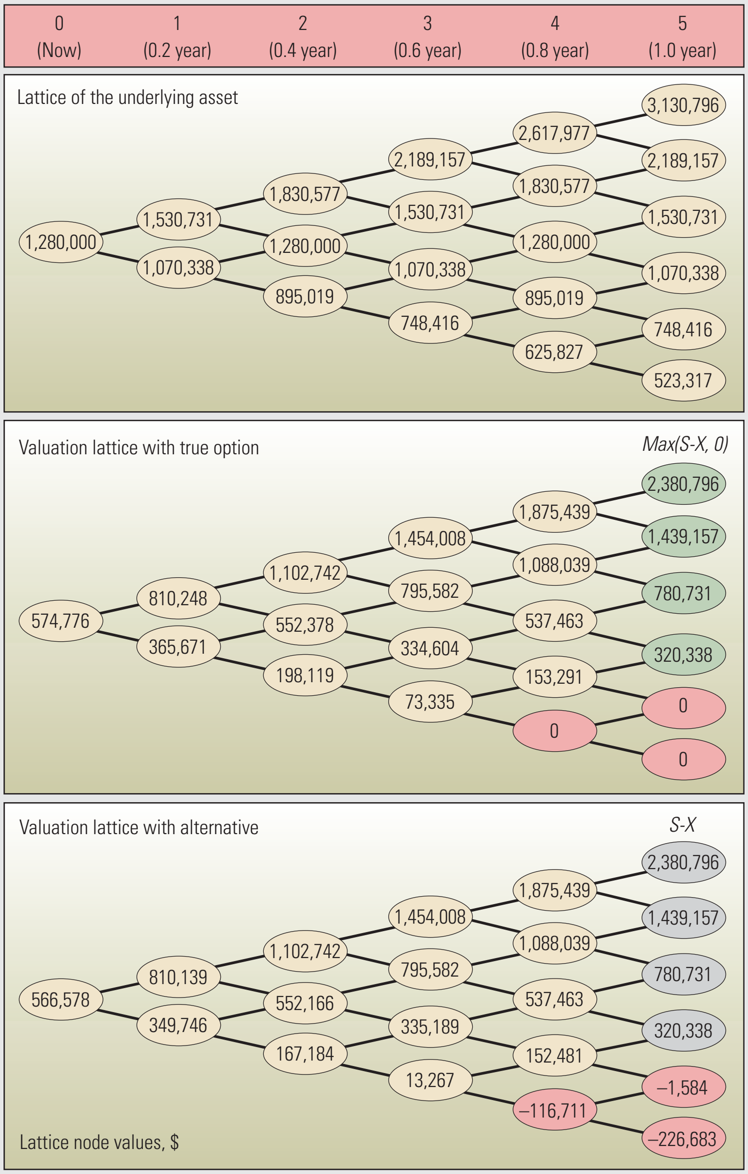
evaluating real options, but an expert in ROV should be consulted to assure the techniques are properly applied.

These complications should not dissuade a company from using real options. Valuation experts can determine when ROV should be used, and when other methods, such as decision trees incorporating Monte Carlo simulation, are more appropriate. Working with managers and experts in other disciplines, valuation experts can help place a value on the options inherent in many projects.

The Real-Options Mindset

Actually recognizing options that are embedded in a project takes practice. Managers often learn to discern options simply by brainstorming with one another about the project.

In many ways, having a real-options mindset is as important as using the mathematics. Real-options thinking emphasizes and values management flexibility. It recognizes that in a world characterized by change, uncertainty and competitive interactions, management can be active. It can alter and modify plans as new information becomes available or as new possibilities arise.[24] It can be reactive to changing circumstances or proactive—intervening to take advantage of possibilities that may improve the value of the project. If management understands that flexibility is valuable, it will look for that flexibility in its projects and capitalize on it to increase shareholder value. —MB, MAA



^ Comparison of an option and an alternative. The lattice method can be used to value an alternative. Both use the same lattice of the underlying (*top*). For an option, the right-hand column is the maximum value of zero and the difference between the underlying value and the $750,000 implementation cost (*middle*). The values for an alternative can be negative, because the function is simply the difference between the value and the implementation cost (*bottom*). This leads to an $8,198 difference in value between the option, valued at $574,776, and the alternative, valued at $566,578.