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In This Issue: Real Options and Corporate Strategy

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The Option Value of Acquiring Information in an Oilfield Production Enhancement Project

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Most oil wells produce water in addition to oil and gas. Since the proportion of water generally increases over time, wells benefit from periodic workovers to maintain hydrocarbon production at satisfactory economic levels. The efficacy of workovers can be increased by obtaining information about the reservoir from a production logging tool ("PLT" for short) just before the intervention. (See the box inset for information about the procedure.)

Faced with declining productivity in a well, the operator can choose among three alternatives:

1. No workover (i.e., continue production as is)
2. Workover but with no new information (i.e., designed using existing information)
3. Workover designed using the new PLT information.

If the company decides to carry out a workover on the well, it has to decide whether the additional cost of running a PLT is justified. Before the intervention begins, reservoir engineers have a general sense of the distribution of some of the main technical parameters based on experience and from information garnered from the field. The new PLT data can be used to update their estimates of these distributions.

Our aim was to develop an objective procedure for evaluating the impact and the value of this new information. And since the real options method was developed to evaluate projects with operating flexibility and that are subject to uncertainty, the RO framework is well suited to this kind of project. Having said that, our case is different from most real options applications because there are *two* sources of uncertainty: oil prices and the characteristics of the reservoir (its deliverability). Consequently, we need to be able to incorporate prior knowledge and new data into the real options framework. As described in this article, we accomplished this by combining Bayesian analysis with real options. The appendix shows how Bayesian analysis makes it possible to update prior knowledge using new information.

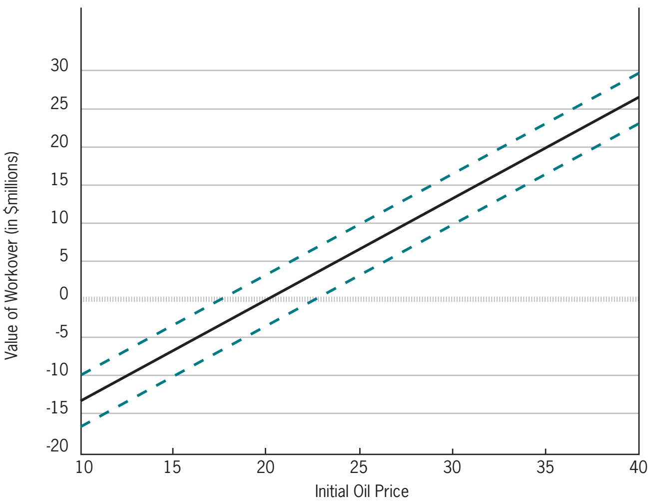
The Economics of the Alternatives

In our example,[1] the well under consideration is located offshore, requiring the commissioning of a suitable rig. We assume that engineering design, planning, and rig mobilization will take six months from the date of the decision to intervene in this well. Also, the economic viability of this work will be based on the production from the well in the six months after the work has been carried out. Thus, the value of the three alternatives listed above was computed over a one-year period. Because alternative #2 (a workover based on no new information) was designed to be in-the-money, we focused on the value of acquiring additional information through the PLT tool—that is, on the incremental value of alternative #3 versus alternative #2.

We refer to these as operating "alternatives" rather than "options" because the decision to perform the workover (regardless of whether we end up using the PLT) has to be made immediately and, once made, is irreversible. There is then no choice or "optionality" of any kind six months later when the workover is just about to be undertaken. Note also that, in contrast to financial options, our alternatives may yield negative returns. When the owners of a financial option have to decide whether to exercise, they know whether it is in-the-money or not. In our case, there is a six-month lead time between the point when the irreversible investment decision is made and the PLT information becomes available. Once the well intervention has been completed, management could decide to stop production if the oil price (or certain technical parameters) turns out to be unfavorable and the well becomes uneconomic. One extreme case would be for the company to turn the valves off (on) as soon as the instantaneous net revenue becomes negative (positive). The other extreme is to continue uninterrupted production until the end of the 12-month period and then evaluate the well's economic state. In the latter case, the incremental value of the PLT information could turn out to be negative for certain outcomes even if its expected value at the outset was positive. Many intermediate rules for stopping production can be imagined. Since it seems more realistic to continue until the end of the trial period, we have used this when evaluating the various options (while keeping in mind the possibility of substituting any other stopping rule by modifying the Monte Carlo simulations used for the computations).

1. This example was based on work by W. J. Bailey, J. Mun, and B. Couët, "A Stepwise Example of Real Options Analysis of a Production Enhancement Project," paper SPE 78329, presented at the Society of Petroleum Engineers EUROPEC conference, Aberdeen, UK (29-31 October 2002).

Figure 1 **Alternative #2— The value of the carrying out a workover (in $millions) on the well as a function of the oil price at the outset.**



Note: The solid line gives the average value while the dashed lines represent the 10% and 90% quantiles on the value. If the initial oil price was $22, the expected value would be about $2 million but there would be more than a 10% chance of incurring a loss. These values were computed using a mean-reverting model.

Since the values of these alternatives may be negative for some outcomes, it is interesting to know the distributions of values and not just their mean. In the oil industry, it is standard practice to quote the 10% and 90% quantiles as well as the mean, to show the spread of values one could reasonably expect. One advantage of Monte Carlo simulations over other methods of computing option prices (such as binomial or trinomial trees) is that they provide the whole distribution of option values.

The Revenue and the Costs

The revenue from the well depends on the oil price, the quantity of oil produced, and the associated operating costs. Many different models could be envisioned for the oil price, starting with simple models like Black-Scholes and progressing to more complicated models with several factors including convenience yield.[2] Here we chose to compare two models: first, a mean-reverting process with a mean of $22 and a mean reversion time of four years; and second, a standard Black-Scholes model with a volatility of 10% and a risk-free rate of 3%. As we will show, there was little difference between the results for these two models, essentially because of the short time period (12 months) considered. In this example, the results turned out to be much more sensitive to the initial oil price.

Two of the key technical factors are the total flow rate (oil and water) and the proportion of water produced. In the oil industry the latter is called the "water-cut." Engineers have estimated that, in this case, the water-cut would be 50% after a workover based on new PLT information and 65% without the PLT information. The new information also has a marked influence on the total flow rate produced. We further assume that this flow rate would be lower with the PLT information, but that the drop in water production would more than compensate for the ensuing drop in oil production. Based on geological analysis and reservoir simulation, engineers deemed that the initial flow rates of oil would have a triangular distribution. Other factors included in our calculations were:

- lifting cost to pump the liquids to the surface
- processing cost to treat water
- transport cost for the oil, and
- rig costs (both fixed and variable)

Evaluating the Options

The first step was to evaluate alternative #2 (the workover without any new information) using the parameters from Table 1. Figure 1 shows its value for initial oil prices ranging from $10 to $40 using the mean-reverting oil price model. The solid line shows the expected value while the dashed ones correspond to the 10% and 90% quantiles. As expected, the workover generates higher revenues in cases where the oil price is higher. If the initial oil price was $22.50, the expected value of this workover would be about $2 million, but there would still be more than a 10% chance of a loss.

From Figure 1, it is clear that alternative #2 is relatively deep-in-the-money if the initial oil price is above $25 per barrel, but for prices below that it becomes marginal. The ability to acquire more information about the well might be quite attractive for oil prices in the range of $15 to $25 per barrel. This is especially so if we can show that the new PLT information changes a money-losing project into a profitable one. Figure 2, which shows the value of the workover designed using the new PLT information, illus-

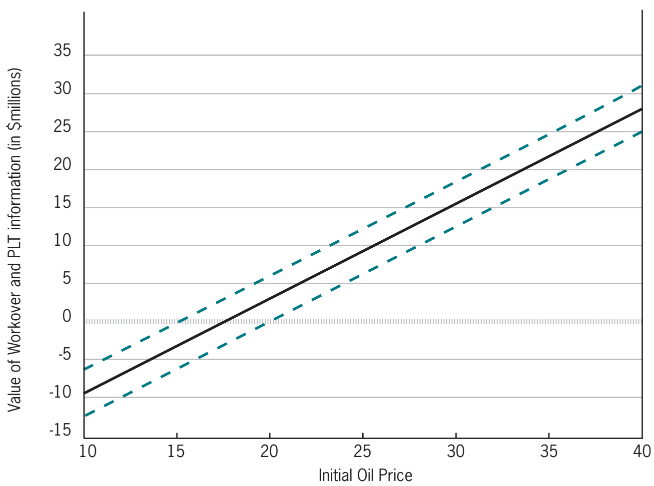
Table 1 **Parameter values for the distribution of the initial oil production rates for alternatives #2 and #3.**

Workover Alternative N°	Minimum oil production (bbls/day)	Maximum oil production (bbls/day)	Modal oil production (bbls/day) produced)	Water-cut (fraction of total fluid produced)
2	3,500	5,100	3,900	0.65
3	3,250	4,000	3,500	0.50

Note: Reservoir engineers have determined that predicted post-workover oil production rates would be best represented by a triangular distribution. The oil production rates given below reflect the fact that use of the PLT information gives engineers greater ability to locate points in the well where there is unwanted water influx (which is reflected in the reduced water-cut).

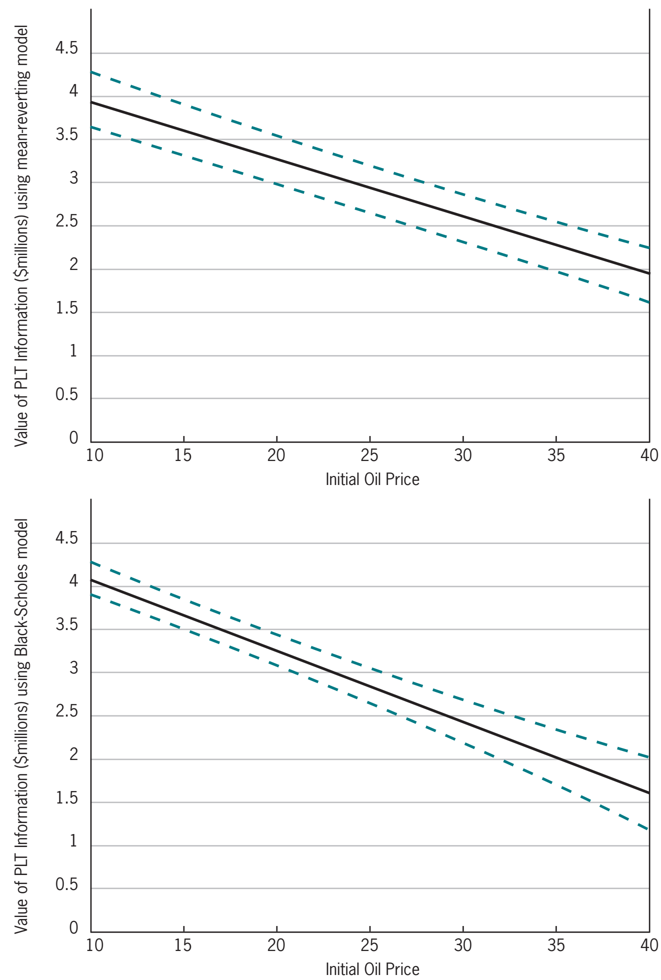
2. For examples of such models, see E. S. Schwartz, "The Stochastic Behaviour of Commodity Prices: Implications for Valuation and Hedging," *Journal of Finance*, Vol. 52 (1997), pp. 923-973; and A. Javaheri, D. Lautier, and A. Galli, "Filtering in Finance," *Wilmott Magazine*, May (2003), pp. 67-83.

Figure 2 **Alternative #3— The value of carrying out a workover (in $millions) on the well after obtaining the new PLT information, plotted as a function of the oil price at the outset.**



Note: As for Figure 1, the solid line gives the average value while the dashed lines represent the 10% and 90% quantiles on the value. Comparing this with Figure 1, we see a marked increase in value for low oil prices. As before, these values were computed using a mean-reverting model for a reservoir of average productivity.

Figure 3 **The incremental value (in $millions) of acquiring the PLT information before carrying out a workover on the well as a function of the oil price at the outset.**



Note: The figures were computed using a mean-reverting model (above) and Black-Scholes geometric Brownian motion (below). The solid line gives the average value while the dotted lines represent the 10% and 90% quantiles on the value. The results are very similar for initial oil prices below $35 because of the short time span considered (12 months).

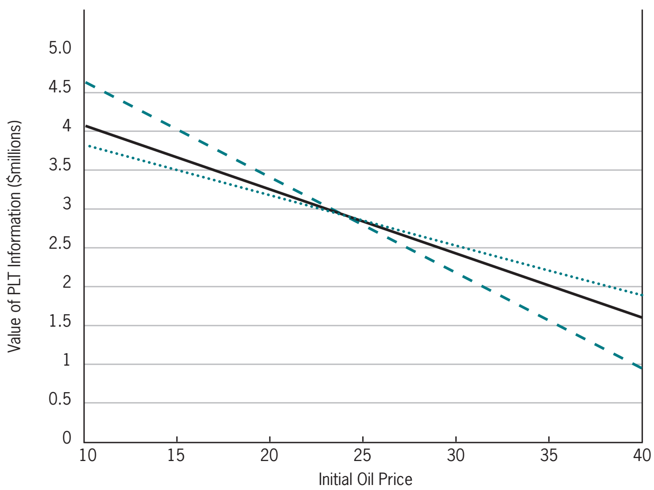
trates this point clearly. The workover can now be profitable in an even lower range of oil prices.

The "obvious" way to compute the impact of the PLT information is by computing the value of alternative #3 and subtracting that of alternative #2, but this comparison is not really meaningful; it's comparing apples to oranges. In fact, the PLT provides information on the inherent productivity of the well. So the recommended step is to compare cases with the same inherent productivity characteristics.

Our aim was to compare cases where the only difference is whether the PLT information has been obtained. This was achieved by carrying out the following "thought experiment." Suppose that the well was logged with the PLT but that the results were *not* communicated to the engineering team. A high-productivity reservoir—one where hydrocarbons were plentiful and deliverability was assured—would still be a top quality reservoir even if the engineers did not know this. Re-logging the well does not change the intrinsic productivity of the reservoir; it merely reveals this critical piece of information to the engineers undertaking the production enhancement design. In mathematical terms, we computed the incremental difference between alternatives #2 and #3 for reservoirs of comparable productivity—that is, for equivalent quantiles of the PLT distribution.

In each Monte Carlo simulation, a value of the PLT information was drawn from the appropriate triangular distribution. Then a flow rate value was drawn at random from the posterior distribution (see the appendix for details) and used to value the option. Figure 3 plots the value of acquiring the PLT information as a function of the initial oil price using both the mean-reverting model (above) and the Black-Scholes model (below) for the case of a reservoir with average productivity. Both models give very similar results for initial oil prices below $35 per barrel because of the short time period considered (only 12 months in all). This would not be the case for long-lived projects such as developing major fields, with production lifetimes that can span decades. The difference between the mean-reverting results and those for Black-Scholes is greater for higher

Figure 4 **The incremental value (in $millions) of acquiring the PLT information before carrying out a workover on the well as a function of the oil price at the outset, for three reservoirs of inherently different productivities: average (solid line), below average (dotted line), and above average (dashed line).**



initial oil prices because the mean-reverting model is drawn back toward its long-term average price of $22.

The second important factor is the reservoir quality. The three lines in Figure 4 compare the value of the PLT information for a low-productivity reservoir (dotted line), an average one (solid line), and a better one (dashed line). The productivity of the reservoir has an impact on the slope of the line: the higher the productivity, the sharper the drop-off.

The startling feature of both Figures 3 and 4 is that the incremental value of acquiring PLT information is *lower* for high initial oil prices than for low ones. This counterintuitive finding correctly represents the *incremental value* of using the production logging tool before carrying out the workover, and not the value of the workover alternatives themselves, which increases with the oil price (see Figures 1 and 2), as would be expected. For low initial oil prices (below $22), the option to carry out the workover is out-of-the-money or barely in it (Figure 1). At those prices, it makes good sense to obtain more information from the production logging tool because this generates value (Figure 2). However, for high oil prices when a workover is strongly in-the-money, carrying out a PLT beforehand contributes relatively little extra value. But it is important to note that this finding is not at all general; it is due to the specifics of the situation studied here. Under other circumstances (i.e., with a different well) the option value could well increase with the oil price (almost all hydrocarbon-producing wells have unique response functions).

Even if the financial value of undertaking this additional production logging run is lower at higher oil prices, the usefulness of such information from an operational/engineering point of view remains very high because it provides critical insight into local reservoir characteristics, productivity, and pressure responses and can confirm (or refute) vital geological assumptions and assist the decision-making process for other interventions in neighboring or analogue wells. The evaluation procedure used here does not take this extra dimension of complementary analysis into account.

Conclusions

In many industrial applications, the option to acquire information instead of waiting passively for conditions to improve can add considerable value to projects. This paper presents a case study on oil production enhancement in which Bayesian analysis is incorporated into a real options framework, making it possible to work out whether the additional cost of acquiring the information is justified.

In this particular case, little difference was found between the values of the option using a mean-reverting model of the oil price and the classic Black-Scholes assumption of geometric Brownian motion. The oil price at the outset of the project was the dominant factor. Both of these findings, however, are attributable largely to the short time span of the project (only 12 months). Projects in the petroleum industry often have lifetimes exceeding 10 or 20 years, in which case the initial oil price is not nearly as important as the medium- to long-term behavior implicit in the oil price model.

One unexpected consequence of the characteristics of the particular well studied was that the option to obtain extra information by running a PLT tool turned out to be lower when the initial oil price was high. This is because the additional information adds relatively less value when the oil production after the workover is highly profitable (i.e., when the option to carry out the workover is already strongly in-the-money). Thus, our study suggests that use of the PLT has the greatest potential to add value when this option is just out-of-the-money.

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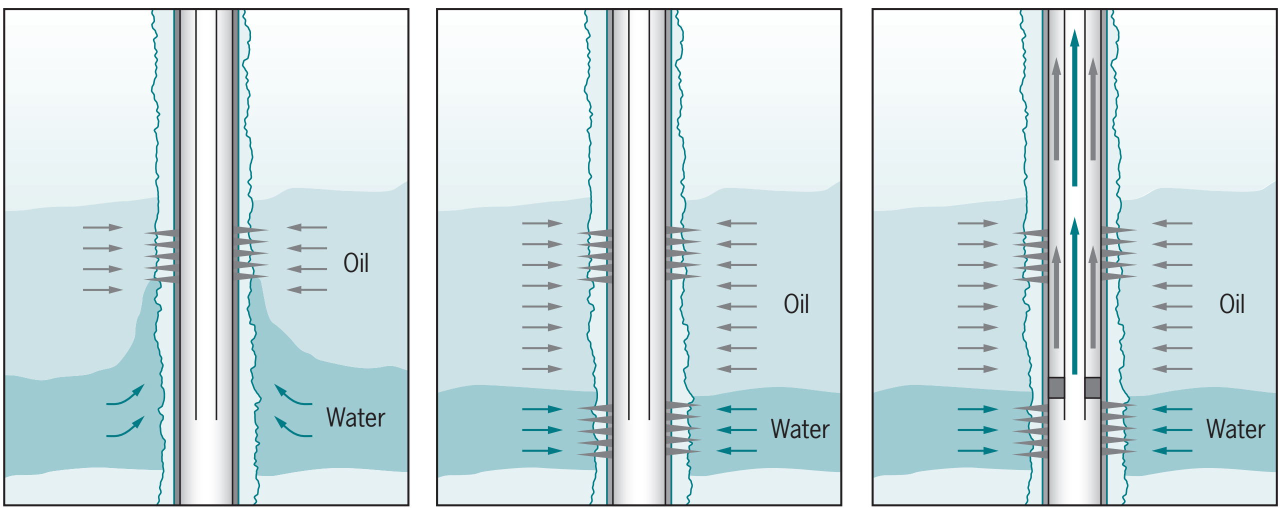
Why Do Oil Wells Need Workovers?

In addition to producing oil and gas, wells often produce unwanted water, which tends to increase in quantity over the years. The diagram on the left shows one possible cause of water influx: "water coning." It can be reduced by re-perforating the well casing (center) then isolating the lower zone with packer. Knowing precisely where the unwanted water is coming from helps when undertaking the engineering design of any workover.

A production logging tool (PLT) is a mechanical device that (among other measurements) records the rate of water influx as it is moved along the perforated interval of a well. Although the primary reason for using a PLT is to learn about the zone immediately around the wellbore, the data gathered can also provide information about the characteristics of a wider region around the well. This is often invaluable to reservoir and petroleum engineers in understanding the reservoir better and refining geological and dynamic reservoir simulation models. Space prevents a more thorough description of the considerable utility and value PLT information provides.



(figure copyright Schlumberger *Oilfield Review*, used with permission).

Appendix: Bayesian Analysis

Most people have come across Bayes theorem in a course on probability and statistics. In its simplest form, it links the conditional probability of an event B given another event A to the joint probability of both events occurring. In this study, B is the event that the oil production rate measured after the workover equals a specified number of barrels per days and A is the event that the initial oil rate predicted from the PLT information has a certain value. If we let P(A) be the probability of event A occurring, and P(B|A) be the probability of B happening given that A has occurred, then the probability of both occurring can be written as:

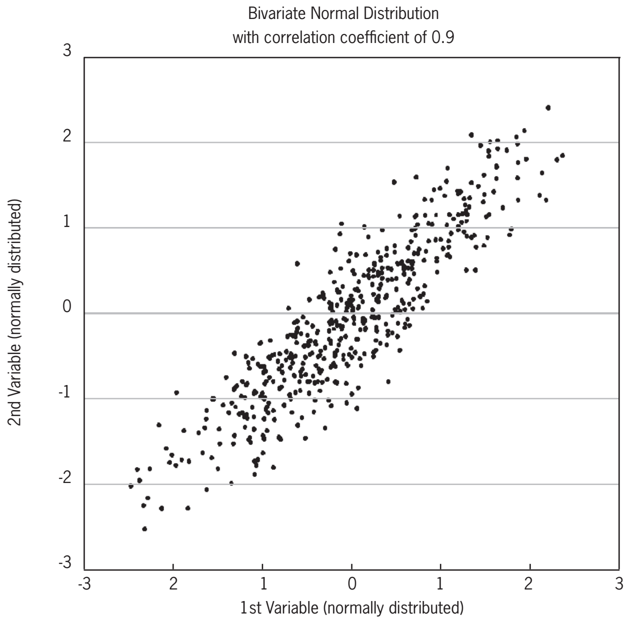
$$P(B|A)P(A) = P(A\&B).$$

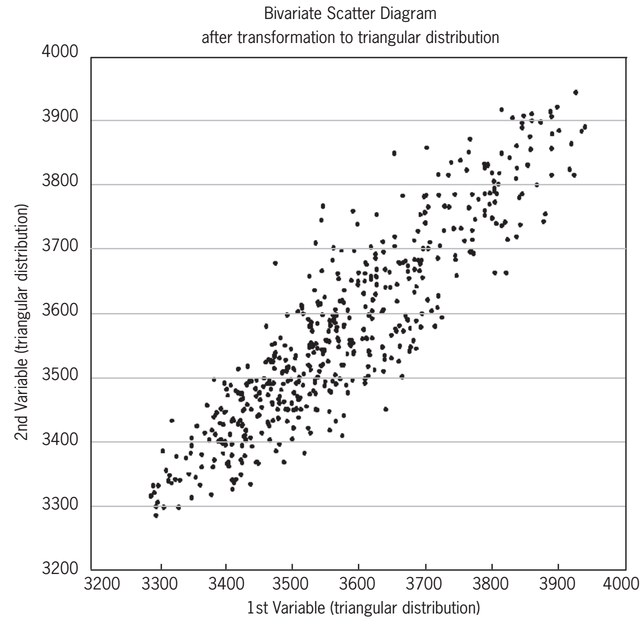
Since we are interested in knowing the conditional distribution of the oil rate after the intervention given the PLT data, we need the joint distribution of both variables. One of the simplest choices often made in Bayesian analysis is the bivariate normal distribution.* To be more precise, we assume that if the marginal distributions of the two variables were transformed to normality, the joint distribution would be bivariate normal. As the PLT information provides good (but not perfect) predictions of the oil flow rate after the workover, we assume that the correlation between the two is high. The figure on the left below shows the bivariate normal distribution with a correlation of 0.9, while the one on the right shows the corresponding bivariate distribution after the individual variables have been back-transformed to have triangular distributions.

These distributions were used in the following way. In each Monte Carlo simulation, a value of the PLT information was drawn from the appropriate triangular distribution. For argument's sake, suppose it was 3,400. The density of

* For more information on Bayesian analysis, see C. P. Robert, *The Bayesian Choice: A Decision-Theoretic Motivation* (Berlin: Springer Verlag, 1994).

Figure 5 **500 pairs of points from a bivariate normal distribution with a correlation coefficient of 0.9 (left) and the corresponding triangular distribution with a minimum value of 3,250, a maximum of 4,000, and a mode of 3,500.**





points in the vertical slice above 3,400 represents the conditional distribution of the initial flow rate given that particular PLT-derived flow rate forecast. We draw a flow rate value at random from this distribution, which is called the posterior distribution, and use it to value the option.

Choosing a bivariate normal distribution for the underlying joint distribution is rather restrictive. For example, it assumes that the same type of dependence exists for high values as for low ones. We are not necessarily convinced that this is true. In credit risk, it is well known that the dependence in the lower tails is much stronger than in the upper ones. As the saying goes, "When things go wrong, they go very wrong." This has led to a surge of interest in asymmetric models, particularly copulas.[**] In our research project we also used Archimedean copulas to model the underlying bivariate distribution.[***]

** For more information on copulas, see R. B. Nelsen, *An Introduction to Copulas* (New York: Springer Verlag, 1999); and H. Joe, *Multivariate Models and Dependence Concepts* (Boca Raton, FL: Chapman & Hall, 1997).

*** The results have been published in M. Armstrong, A. Galli, W. Bailey, and B. Couët, "Incorporating Technical Uncertainty in Real Option Valuation of Oil Projects," *Journal of Petroleum Sciences & Engineering 44* (2004) 67-82.

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