A REAL OPTIONS DESIGN FOR PRODUCT OUTSOURCING

HARRIET BLACK NEMBHARD
University of Wisconsin-Madison

LEYUAN SHI
University of Wisconsin-Madison

MEHMET AKTAN
Atatürk University, TURKEY

ABSTRACT

Product outsourcing is recognized as a way to gain flexibility for competitive advantage. We formulate the outsourcing problem using real options. We develop a financial model to assess the option value of product outsourcing. Specifically, we consider a three state-variable problem and use Monte Carlo simulation to estimate the value of the option. This valuation gives decision makers a way to choose the appropriate outsourcing strategy based on an integrated view of the market dynamics. A case example from the apparel manufacturing industry is used to demonstrate the application of real options to value outsourcing flexibility. We show that the inability of classical net present value methods to address dynamics in the market condition leads to an undervaluing of the outsourcing strategy. Numerical results and sensitivity analysis show how the real options approach can be used to give a better view of the long-term value of outsourcing.

INTRODUCTION

Increased competition in the global market has caused organizations to realize that the most competitive way of survival is to be able to respond effectively to a dynamic environment. This can often be achieved through increased flexibility. Then the question becomes: Precisely how valuable is flexibility? The financial arena was the original ground for the application of the options-based framework to the valuation of flexibility. More recently, managerial operating flexibility has been likened to financial options. Triantis and Hodder (1990) examined the pricing of complex options that arise in valuing a flexible production system that allows the firm to switch its output mix over time. Kogut and Kulatilaka (1994) developed a stochastic dynamic programming formulation to determine the value of production switching between two plants located in different countries as the exchange rate fluctuates. Huchzermeier and Cohen (1996) developed a stochastic dynamic programming formulation for the valuation of global manufacturing strategy options with switching costs. Exchange rates are modeled as stochastic diffusion processes that exhibit intercountry correlation. Dasu and Li (1997) studied the structure of optimal policies for a firm operating plants in different countries, where the relative costs of production between the plants vary over time due to exchange rates. Kouvelis (1999) analyzed global sourcing strategies as operational hedging mechanisms for responding to fluctuating exchange rates.

The goal of our research is to model the flexibility surrounding manufacturing operations using financial options. Nembhard, Shi, and Park (2000) develop a framework for the broad scope of this research activity. In Nembhard, Shi, and Aktan (2002), we value the real options associated with applying statistical process control (SPC) charts to monitor quality. Such valuation gives decision makers a way to choose the appropriate quality control strategy based on an integrated view of the market dynamics with the manufacturing aspects. This perspective is increasingly important as competition becomes more intense.

In this paper, we specifically consider the manufacturing decision to increase flexibility through product outsourcing, which is recognized as a source of great competitive advantage (e.g., see Bragg (1998), and Gupta and Zhender (1994)). We use the options approach to find the value of outsourcing during a specified length of time, considering future uncertain market variables. In our outsourcing model, we assume three main sources of uncertainty: unit production cost; unit outsourcing price; and unit delivery cost. Valuing real options for such a model requires an analysis of three state variables. The manufacturer can change the decision about whether to outsource at each time interval. When there is no cost for switching between alternatives, a decision given in one time interval does not affect the succeeding intervals.

In previous work, we have addressed a problem with two variables using a multinomial lattice approach (Nembhard, Shi, and Aktan (2002)). We recognized, however, that when there are more than two state variables, the lattice structure gets quite large with just a few time periods. In addition to the modeling aspects, we expect this paper to contribute to the development of solution methodologies. Specifically, for the present problem with three state variables, we investigate the use of Monte Carlo simulation to value product outsourcing that is based on the relationship between the three variables and a cost comparison. A program code to execute the simulation method was written in JavaScript so that it would be accessible to other users because of its web-enabled feature.

We use a case example from the apparel manufacturing industry to illustrate the application of this method. The case example includes numerical results and a sensitivity analysis for key parameters. We also use the case example to discuss how the proposed design can help company managers answer questions about the long-term value of outsourcing. In general, it is our intention that the combination of modeling methodology, web-based computing, and practical demonstration will contribute to advancements the field of manufacturing decision making.

This paper is organized as follows. Approaches for multivariate option valuation are discussed in Section 2. The financial model that will be used to find the option value of outsourcing is defined in Section 3. Section 4 discusses the Monte Carlo simulation. A case example, numerical results, and a sensitivity analysis are given in Section 5. Some concluding remarks are given in Section 6.

OPTION MODELS AND VALUATION PROCEDURES

Option models have been increasingly used to capture total value in situations where the market dynamics lead to high volatility, growth, risk, or uncertainty. Several authors have discussed the advantages of the options approach over the traditional net present value (NPV) approach in these situations (e.g., see Copeland and Keeney (1998), Luehrman (1998), Boer (2002) and Mun (2002)). Although the NPV approach provides some of the foundation of options theory, it is easy to go astray with NPV analysis alone, leading to serious undervaluation or overvaluation.

Fundamentally, an option is the right, but not the obligation, to take an action in the future (Amram and Kulatilaka (1999)). Some options are associated with investment opportunities that are not financial instruments. These operational options are often termed *real options* to emphasize that they involve real activities or real commodities, as opposed to purely financial commodities, as in the case, for instance, of stock options (Luenberger (1998)).

A European option gives the right to exercise the option on the expiration date. An American option gives the right to exercise the option on *or before* the expiration date. In our model, we formulate the outsourcing problem as a series of n European options, where all options start at time zero, and each option expires at one of the n equally spaced time intervals. In our context, this means that outsourcing can be applied or not applied (which is the option) in any time interval. Different from the classical financial options, manufacturing processes often require exercising sequential decisions. Therefore, we model the problem in such a way that switches are possible at each time step.

One might consider modeling the problem as an American option as an easier alternative, but this would give only one chance to make a decision at a single time point. The manufacturer's need for sequential decisions during the manufacturing process can be better answered by using a model that permits multiple decisions. Therefore, we model the problem as a bundle of *n* European options instead of using a single American option.

We assume a costless switch between different states of production at each time step. When there are no switching costs between the states of production, the option valuation problem simplifies significantly by eliminating any interdependence between decisions at different time points in time. Any switching decision is costlessly reversible and thus can be made without considering the impact on future decisions. The links between time steps in the dynamic programming problem break down, and the problem becomes one of valuing a bundle of European options with different maturities (Hodder and Triantis (1993)).

Black and Scholes (1973) developed a closed form solution for valuing a European option with one variable. In the case of one variable, the binomial lattice approach of Cox, Ross, and Rubinstein (CRR) (1979) is a powerful numerical procedure for valuing options. Boyle (1988) developed an extension of the CRR procedure for option valuation in the case of two state variables. Boyle, Evnine and Gibbs (1989) developed an *n*-dimensional extension of the CRR procedure using multinomial lattices. Kamrad and Ritchken (1991) developed a similar multinomial lattice technique for valuing projects for one or more state variables.

Although in principle, multinomial lattice approaches can be used for multiple state variables, they are not really practical for option valuation involving three or more variables because they generate a large amount of nodes and result complex calculations. In these cases, Monte Carlo simulation is a viable alternative. Hull (1997, 2000, and 2003) gives a method for Monte Carlo simulation that can be used for valuing European options with more than one variable. As discussed in the introduction, we will use the Monte Carlo simulation approach for our outsourcing model which includes the unit production cost; unit outsourcing price; and unit delivery cost. In the next section, we provide a framework for the financial model that will be used.

A FINANCIAL MODEL FOR OUTSOURCING

We consider an item which is a part of the final product. Total production cost for the items sold has three main sources of uncertainty: unit production cost of the item during the time interval beginning at time t, $S_1(t)$; the unit outsourcing price of the item during the time interval beginning at time t, $S_2(t)$; and unit delivery cost of the outsourced item during the time interval beginning at time t, $S_3(t)$. We assume that the demand D is deterministic.

If the item is produced in house, the cost of production $Q_1(t)$ during the time interval that begins at time t is

$$Q_1(t) = S_1(t)D.$$

If the item is outsourced, the cost of outsourcing $Q_2(t)$ during the time interval that begins at time t is

$$Q_2(t) = \left[S_2(t) + S_3(t)\right]D.$$

If the unit outsourcing price of the item is less than the unit production cost of the item, then the total cost reduction $R(t)$ that can be achieved by outsourcing the item during the time interval that begins at time t is

$$\begin{aligned} R(t) &= Q_1(t) - Q_1(t) \\ &= \left[S_1(t) - S_2(t) - S_3(t)\right]D. \end{aligned}$$

If K denotes the fixed cost of outsourcing per time interval (e.g., those costs arising from contracting and handling cost, and other possible costs to make the contract), then the net cost reduction $F(t)$ due to the outsourcing option is

$$\begin{aligned} F(t) &= \max\left\{0, Q_1(t) - Q_2(t) - K\right\} \\ &= \max\left\{0, \left[S_1(t) - S_2(t) - S_3(t)\right]D - K\right\}. \qquad (1) \end{aligned}$$

FIGURE 1 shows the relationship between the variables, total production and outsourcing costs, the option value, and the effect of the option value on decisions. The three variables affect the total costs. Whether we outsource or not also influences the total costs. If the outsourcing price of the item is less than the unit production cost of the item, then we may decide to outsource the item instead of producing it. The option value is found by evaluating the cost reduction that may be possible by outsourcing in the future. Depending on the option value, we may decide whether to outsource now, later, or never.

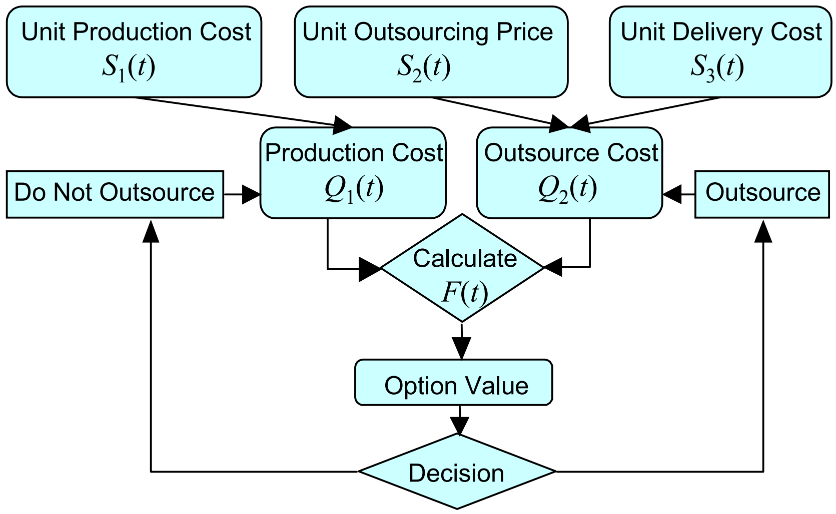

FIGURE 1: Relation between variables and option value.

A MONTE CARLO SIMULATION METHOD FOR PRODUCT OUTSOURCING

In this section, we present a simulation method for the financial model in Section 3. Simulation models may be used to give numerous possible paths of evolution for underlying state variables from the present to the final date of the option. In the Monte Carlo simulation method, the optimal strategy on each path is determined and the payoff is calculated. In this section, we follow Hull (1997) in a discussion of the modeling principles that define this approach. Ross (1999) also gives details on this topic.

Suppose that the process followed by the underlying variable S in a risk-neutral world is

$$\mathrm{d}S = \mu S \mathrm{d}t + \sigma S \mathrm{d}z \tag{2}$$

where z is a Wiener process, μ is the expected return in a risk-neutral world $(\mu = r)$, and σ is the volatility. To simulate the path followed by S, we divide the life of the underlying variable into n short intervals of length Δt and approximate Eq. (2) as

$$S(t+\Delta t) - S(t) = \mu S(t)\Delta t + \sigma S(t)\varepsilon\sqrt{\Delta t} \tag{3}$$

where $S(t)$ denotes the value of S at time t, and ε is a random sample from a normal distribution with a mean zero and unit standard deviation. This enables the value of S at time Δt to be calculated from the initial value of S, the value at time $2\Delta t$ to be calculated from the value at time Δt, and so on. One simulation trial involves constructing a complete path for S using n random samples from a normal distribution.

From Ito's lemma (see Hull (1997) for a discussion of Ito (1951)), the process followed by $\ln S$ is

$$d \ln S = \left(\mu - \frac{\sigma^2}{2} \right) dt + \sigma \, dz$$

so that

$$S(t + \Delta t) = S(t) \exp\left[\left(\mu - \frac{\sigma^2}{2} \right) \Delta t + \sigma \varepsilon \sqrt{\Delta t} \right]. \tag{4}$$

This equation is used to construct a path for S in a similar way to Eq. (3). Whereas Eq. (3) is true only in the limit as Δt tends to zero, Eq. (4) is exactly true for all Δt .

In our model, we use Eq. (4) to generate values for the three cost variables $S_1(t)$, $S_2(t)$, and $S_3(t)$. For each t, we find the average of $F(t) = \max\{0, [S_1(t)–S_2(t)–S_3(t)]*D–K\}$ values (see Eq. (1)) obtained from the simulation runs, and discount that average to the present time. In order to find the estimated option value, we add the discounted averages for all t until T, where T is the expiration time of the option.

Since the three variables in this outsourcing model may be correlated, we need correlated samples ε_i, (i = 1,2,3) from normal distributions (see Eq. (4)) where the coefficient of correlation between sample i and sample j is $\rho_{i,j}$. To achieve this, we first sample three independent variables x_k (k = 1,2,3), from univariate standardized normal distributions. The required samples ε_i are

$$\varepsilon_i = \sum_{k=1}^{i} \alpha_{ik} x_k \, .$$

For ε_i to have the correct variance and the correct correlation with ε_j ($1 \leq j < i$), we must have

$$\sum_{k=1}^{i} \alpha_{ik}^2 = 1$$

and, for all $j < i$,

$$\sum_{k=1}^{j} \alpha_{ik} \alpha_{jk} = \rho_{ij} .$$

The first sample, ε_1, is set equal to x_1. Then, the equations for the α's are solved so that ε_2 is calculated from x_1 and x_2; and ε_3 is calculated from x_1, x_2, and x_3.

FIGURE 2 shows our simulation method for the three state variables, i.e., $S_1(t)$, $S_2(t)$, and $S_3(t)$ from $t = 0$ to $t = T$. The value of $Q_1(t)$ is calculated using $S_1(t)$, and $Q_2(t)$ is calculated using $S_2(t)$ and $S_3(t)$. Then, $F(t)$ is found using $Q_1(t)$ and $Q_2(t)$ (see Eq. (1)). In order to make N simulation runs with three state variables, we need to generate a total number of $3 \times T \times N$ values.

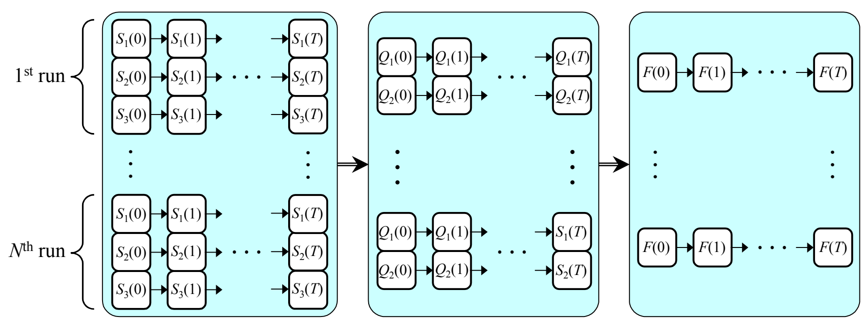

FIGURE 2: N simulation runs of the three state variables from $t = 0$ to $t = T$.

A program code to execute this simulation was written in JavaScript, so that it can be executed with Microsoft Internet Explorer or Netscape Navigator. The user first enters all parameter values into the input window. In order to store the generated values, the program makes an array for each of the three variables. The first array contains the $S_1(t)$ values for all time intervals until the expiration date of the option. Similarly, the second array contains the $S_2(t)$ values, and the third array contains the $S_3(t)$ values. Then, the value of $F(t) = \max\{0, [S_1(t) - S_2(t) - S_3(t)]D - K\}$ at time T is calculated for all simulation runs, and the average of those values is found. Then, this average is discounted to the present time. A discounted average is calculated for each time point (i.e., 1, 2,…, T). The option value estimate is the sum of these discounted averages.

EVALUATING OUTSOURCING FLEXIBILITY: A CASE EXAMPLE

In order to illustrate the application of Monte Carlo Simulation to value the real options associated with outsourcing, we will use the case of BlueJeans, Inc. BlueJeans produces several types of denim jeans. Faced with a decline in profits, managers at BlueJeans need to develop a turnaround plan. As a part of this plan, they wish to consider a move away from owned-and-operated factories to a greater use of contract manufacturing. The thought is that such a move would enable the apparel maker to have a more flexible cost structure, protect its profit margins, and invest more in product development, marketing, and retailing.

USING THE INITIAL PARAMETERS TO EVALUATE THE OPTION

Because managers want to develop and evaluate a one-year turnaround plan, we consider an option structured over one year (i.e., the expiration date of the option is one year from now) with one month time intervals. Previous year's cost data is used to determine the volatility and correlation values that will be used in the analysis. FIGURE 3 shows the input window for the simulation program which contains the specific values of these parameters. Microsoft Internet Explorer version 5.5 was used to make 5,000 simulations runs of the program.

FIGURE 4 gives the output window where the estimated option value, minimum and maximum option values obtained from the 5,000 simulation runs, and the standard deviation of the option value are presented. For each time interval, the proportion of simulation runs where outsourcing resulted in a cost reduction is also given in the output window.

The estimated option value is \$247,692. This means that considering outsourcing as an option for one year has an estimated value of \$247,692. The standard deviation of the estimated option value is \$4,424. Then, a 95% confidence interval for the option value is \$247,692 ± [(1.96).(\$4,424)] which gives (\$239,020, \$256,363).

We see that the maximum option value obtained from the 5,000 simulation runs is \$2,009,403. This means that cost reductions as much as \$2,009,403 may be possible by outsourcing. The minimum option value for the 5,000 simulation runs is \$0. This means that market conditions may be such that outsourcing will not yield a cost reduction in any of the twelve months.

We also see that outsourcing proportion is zero at t = 0. This means that outsourcing will not reduce the cost now. From t = 1 to t = 12, outsourcing proportion is between 46.82% and 49.5%. According to the output of the simulation, the proportion of outsourcing from the first month to the twelfth month is approximately between 47% and 50%. In other words, in 47 to 50 percent of the simulation runs, outsourcing costs less than in-house production. This proportion indicates that creating the option to outsource adds value to the company's strategic plan.

For comparison, suppose we undertake a traditional NPV analysis, i.e., *without* considering the dynamics in the market condition with respect to unit production cost, unit outsourcing price and number of sales. TABLE 1 shows the results of a NPV analysis assuming that variables S_1, S_2, and S_3 keep their initial levels for the next twelve months.

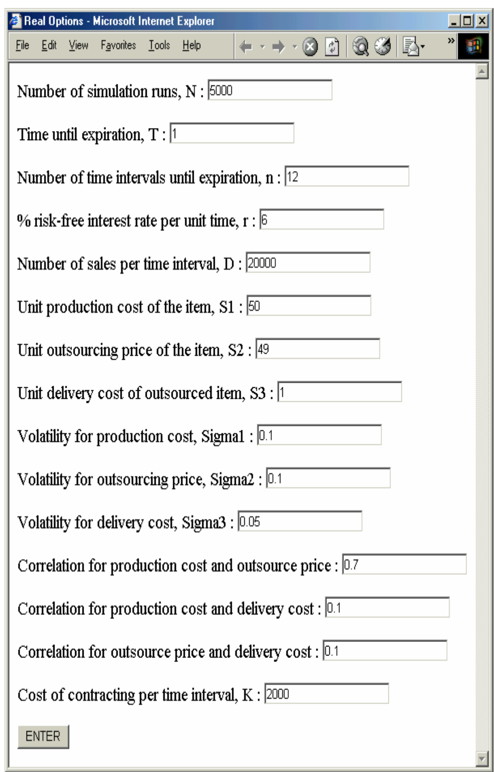

FIGURE 3: Input window for the simulation.

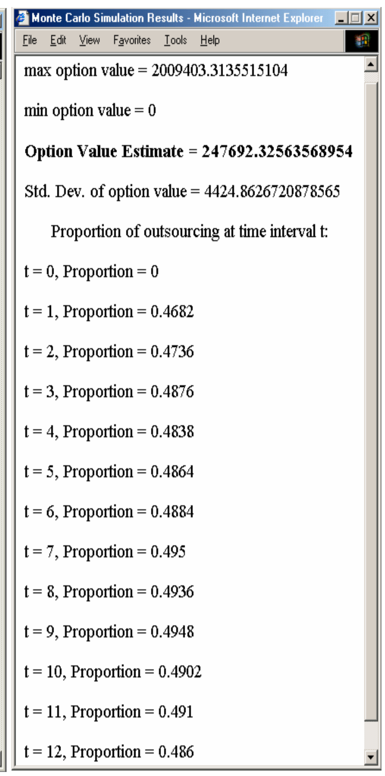

FIGURE 4: Output window of the simulation.

TABLE 1 shows that the cost of outsourcing is larger than the cost of in-house production. Since the NPV analysis did not capture the value of flexibility to switch between in-house production and outsourcing, our decision would be in-house production for all of the next twelve months. By using such an NPV analysis, we miss the additional value of flexibility, which is estimated as \$247,692 by the real options analysis.

Of course, these results are only for the given set of parameter values. In the next subsection, we analyze the effect of the parameters on the option value.

TABLE 1: Results of the NPV Analysis

Month (*t*)	Present value of in-house production cost	Present value of outsourcing cost
0	\$1,000,000	\$1,002,000
1	\$995,012	\$997,003
2	\$990,050	\$992,030
3	\$985,112	\$987,082
4	\$980,199	\$982,159
5	\$975,310	\$977,261
6	\$970,446	\$972,386
7	\$965,605	\$967,537
8	\$960,789	\$962,711
9	\$955,997	\$957,909
10	\$951,229	\$953,132
11	\$946,485	\$948,378
12	\$941,765	\$943,648
Total	\$12,618,000	\$12,643,236

SENSITIVITY ANALYSIS

Analyzing the effect of key parameters gives a broader picture of the problem dynamics. With this view, we can determine which parameters have larger effects on the option value and what levels of those parameters yield larger option values. We present the effects of r (risk-free rate of return), σ_1, σ_2, σ_3 (volatility of each state variable), ρ_{12}, ρ_{13}, ρ_{23} (correlation for the state variables), and K (cost of contracting per time interval) on the option value.

FIGURE 5 shows the effect of r (risk-free rate of return) on the option value, keeping all other factors constant. The estimated option value for 50,000 simulation runs is in the range of \$244,000 and \$252,000 when r is between 0%

and 12%. If we test a hypothesis H_0: $\hat{\mu}_1 - \hat{\mu}_2 = 0$ against an alternative hypothesis H_1: $\mu_1 - \mu_2 \neq 0$ using estimated option values of $\hat{\mu}_1$ and $\hat{\mu}_2$, and $\alpha = 0.05$, H_0 is rejected if the following interval does not include zero:

$$(\hat{\mu}_1 - \hat{\mu}_2) \pm (z_{\alpha/2})(\sigma_{\hat{\mu}_1 - \hat{\mu}_2}) = (\hat{\mu}_1 - \hat{\mu}_2) \pm 1.96 * \cdot 4424.86 * \sqrt{0.2}$$
$$= (\hat{\mu}_1 - \hat{\mu}_2) \pm \$3878.$$

The confidence interval does not include zero for some $\hat{\mu}_1$ and $\hat{\mu}_2$ values when r is between 0% and 12%. Therefore, we conclude that r has an effect on the option value for $\alpha = 0.05$. FIGURE 5 suggests that the option value decreases as r increases from 0% to 12%.

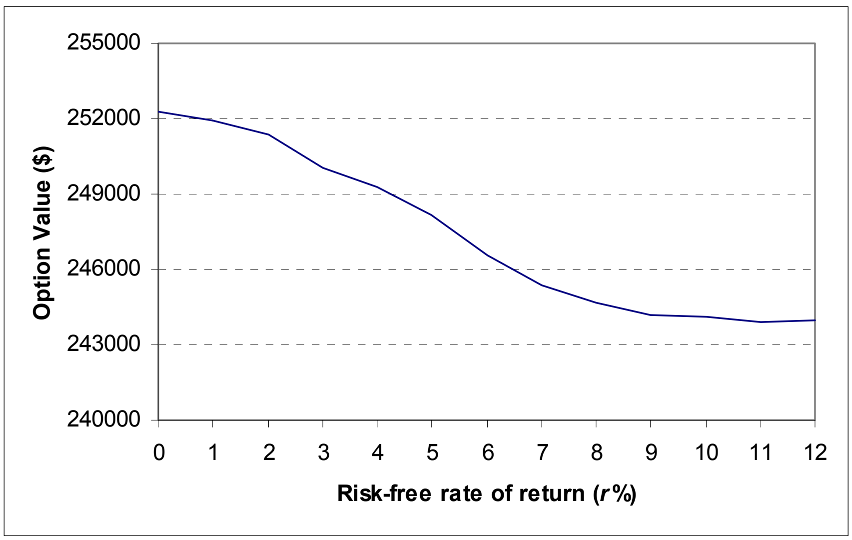

FIGURE 5: Effect of r on the option value.

FIGURE 6 shows the effect of σ_1, σ_2, and σ_3 (volatility for the logarithm of increase rate of each state variable) on the option value, where all other factors are held constant. We see that σ_1 and σ_2 both have large effects on the option value, but σ_3 does not have a large effect on the option value. This is an expected result, because the initial values of S_1 and S_2 are larger than the initial value of S_3 ($50 and $49 vs. $1), and therefore, the amount of change in S_1 and S_2 values will be more than the amount of change in S_3 value with increasing volatility. Since the variables S_1 and S_2 have larger amounts of change due to volatility, their effect on the option value is larger than the effect of S_3. After the volatility value of 0.1, the option value estimate increases with increasing σ_1 and σ_2. When σ_1 and σ_2 goes from 0 to 0.1, the option value estimate slightly decreases.

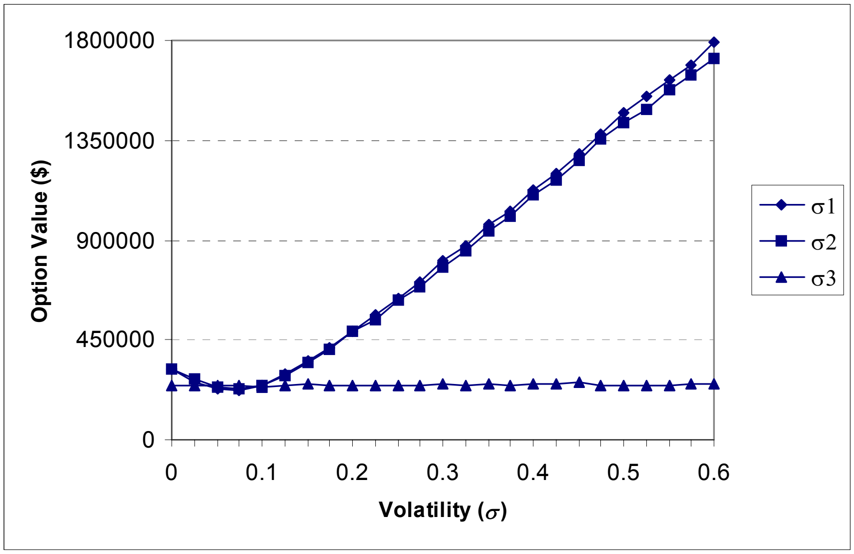

FIGURE 6: Effect of volatility (σ) on the option value.

FIGURE 7 shows the effect of ρ_{12}, ρ_{13}, and ρ_{23} (correlation for the logarithm of increase rates of state variables) on the option value, where all other factors are held constant. FIGURE 7 shows that ρ_{12} has a large effect on the option value. However, ρ_{13} and ρ_{23} do not have large effects on the option value. A strong positive correlation for S_1 and S_2 (unit production cost and unit outsourcing price) results low option values, but a strong negative correlation for these two variables result in large option values. This result is again due to the large initial values of S_1 and S_2, and a small initial value of S_3. If there is a negative correlation between unit production cost and unit outsourcing price, the unit outsourcing price will be low when the unit production cost is large, which gives a better potential for cost reduction by exercising the outsourcing option. On the other hand, if there is a positive correlation between unit production cost and unit outsourcing price, the unit outsourcing price will be large when the unit production cost is large, which gives less chance for cost reduction by exercising the outsourcing option.

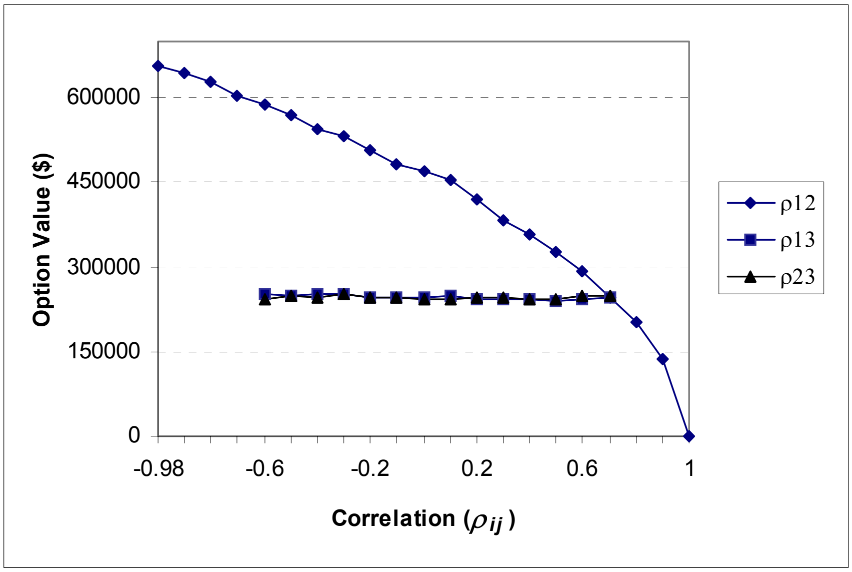

FIGURE 7: Effect of correlation (ρ_{ij}) on the option value.

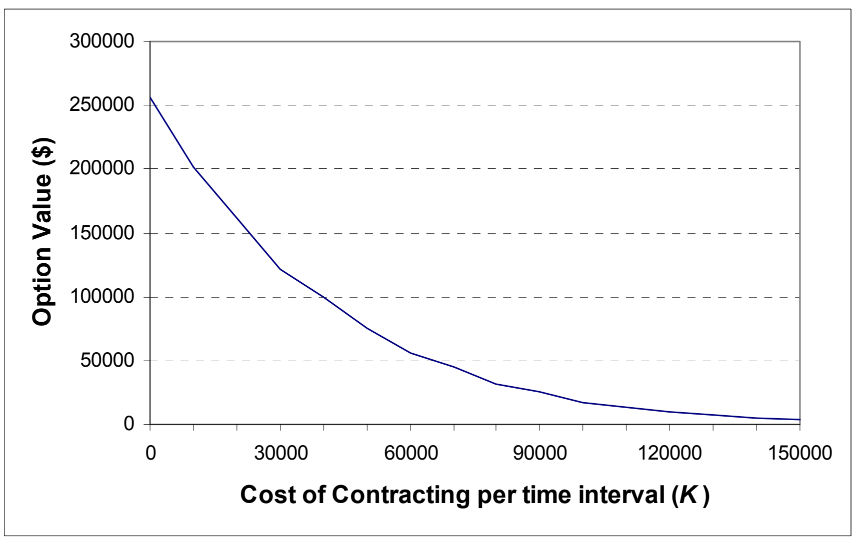

FIGURE 8: Effect of cost of contracting per time interval (K) on option value.

FIGURE 8 shows the effect of K on the option value, where all other factors are held constant. Option value of outsourcing decreases with increasing contracting cost. In other words, outsourcing option becomes less attractive if the contracting cost gets larger.

FIGURE 9 is a tornado diagram that shows the effects of the significant factors on the option value. The diagram presents the estimated option value for the given ranges of factors. Original levels of parameters and the estimated option value from FIGURE 3 and 4 are represented by the vertical axis. We see that the volatility of the first and second variables (σ_1 and σ_2), and their correlation (ρ_{12}), have large effects on the option value. Contracting cost per time interval (K), and risk-free rate of return (r), have relatively smaller effects. Larger σ_1 and σ_2 values have positive effects on the option value. On the other hand, ρ_{12}, K, and r can have positive or negative effects on the option value, depending on their direction and amount of change.

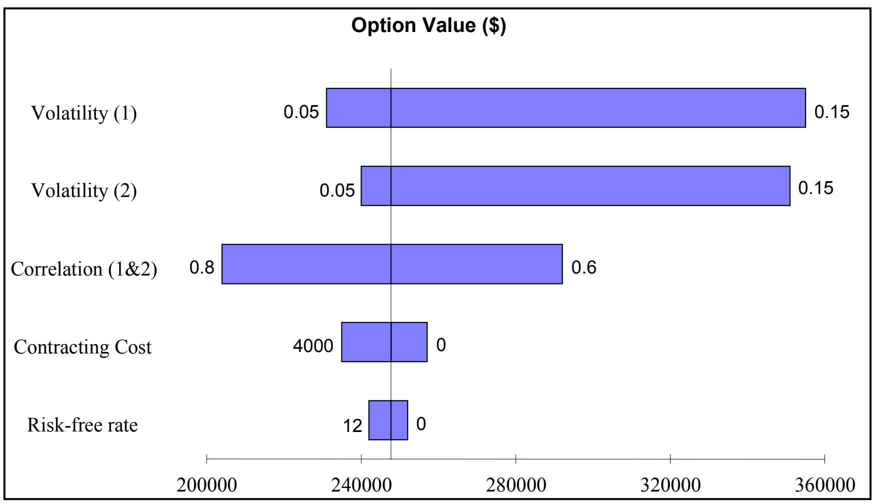

FIGURE 9: Tornado diagram of the factors affecting the option value.

In general, by using the simulation method presented here and performing a sensitivity analysis, a company will be able to answer questions about the long-term value of outsourcing: Does outsourcing give additional value? If so, what is the estimated additional value? Should we outsource now? Should we get ready for the possibility of outsourcing in the future? What is the possibility that outsourcing will be favorable in the future? Answering such questions gives the manufacturer an advantage in market competition through assessing the value of outsourcing.

In this section, we have answered these questions for the case example. Using the parameters given in FIGURE 3, we have found that outsourcing gives additional value, and it is estimated as $247,692 for a time span of one year. According to the initial levels of state variables, outsourcing is not favorable to in-house production, but the possibility that outsourcing will be favorable during the next twelve months varies between 47% and 50%. Therefore, outsourcing should be considered as an option for the next twelve months.

SUMMARY

In this paper, we have shown how the value of outsourcing can be determined using a real options framework. We formulated the outsourcing problem as a series of European options. A financial model was defined in order to be able to make a cost analysis. A Monte Carlo simulation model was defined to address the dynamics in the market conditions. Monte Carlo simulation was key in this study because, for three sources of uncertainty, it was more practical to use than other methods. Monte Carlo simulation also provided the maximum and minimum option values obtained during the simulation, which represent the best and the worst scenarios for the decision.

In a case example, the output of the simulation model was used in the financial model to find the option value estimate. We saw that the inability of classical net present value methods to address dynamics in the market condition led to an undervaluing of the outsourcing strategy. By connecting the dynamic aspects with the manufacturing operational aspects, we now have a way to address a key issue: the bottom-line cost associated with an outsourcing decision.

In this study, switching between in-house production and outsourcing was assumed to be costless. Introduction of switching costs makes the problem more complex, and the solution requires the application of dynamic programming. In our future work, we plan to address the problem with switching costs.

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BIOGRAPHICAL SKETCHES

HARRIET BLACK NEMBHARD is an associate professor of Industrial Engineering at the University of Wisconsin-Madison. She received her Ph.D. from the University of Michigan. She is a member of INFORMS, IIE, and ASQ. Her interests include quality engineering, manufacturing systems, and discrete-event simulation. Her email and web addresses are (hbnem@engr.wisc.edu) and (www.engr.wisc.edu/ie/faculty/nembhard_harriet.html).

LEYUAN SHI is an associate professor of Industrial Engineering at the University of Wisconsin-Madison. She received her Ph.D. from Harvard University. She is a member of INFORMS, IIE, IEEE, and IAFE. Her research interests include modeling and analysis of discrete dynamic systems, discrete-event simulation, and large-scale optimization. Her email and web addresses are (leyuan@engr.wisc.edu) and (www.engr.wisc. edu/ie/faculty/shi_leyuan.html).

MEHMET AKTAN is a research assistant at Atatürk University, Industrial Engineering Department. He received his Ph.D. from the University of Wisconsin-Madison. His B.S. is in industrial engineering from Boğaziçi University. He received his M.S. in industrial engineering from the University of Iowa. His email address is (maktan@wisc.edu).