

## AN EMPIRICAL TEST OF HEURISTICS AND BIASES AFFECTING REAL OPTION VALUATION

KENT D. MILLER<sup>1\*</sup> and ZUR SHAPIRA<sup>2</sup>

<sup>1</sup> Krannert Graduate School of Management, Purdue University, West Lafayette, Indiana, U.S.A.

<sup>2</sup> Leonard N. Stern School of Business, New York University, New York, New York, U.S.A.

*This study applies insights from behavioral decision theory to explain how managers value call and put options. Behavioral decision theory points to important deviations from the assumptions of normative option pricing models in finance. We used a questionnaire to collect option pricing data to test our behavioral hypotheses. The evidence indicates specific biases affecting subjective valuations of options: (1) buyers and sellers price options below their expected values; (2) buyers' prices are consistently below sellers' prices; (3) irrelevant outcomes decrease option values; (4) discount rates vary with the option time horizon; and (5) changes in option values do not fully reflect increases in exercise prices. We discuss the implications of these findings for the management of real options and suggest directions for developing descriptive real option theory. Copyright © 2003 John Wiley & Sons, Ltd.*

There is a growing awareness that many of the investment decisions managers face under uncertainty can be characterized as real option problems (e.g., Amram and Kulatilaka, 1999; Buckley, 1998; Copeland and Antikarov, 2001). Finance and management researchers and management consultants are actively involved in developing normative techniques for framing and evaluating real option investments.

Despite the normative work on real option valuation, we know little about how managers actually value real options. A few researchers (Bowman and Hurry, 1993; Kogut and Kulatilaka, 1994; McGrath, 1999) have called for studies on the behavioral aspects of managing real options. Lander and Pinches (1998) indicated that

managers have limited understanding of existing option pricing models and the real option pricing problems they face often violate the assumptions of these models. The limited survey evidence we do have shows managers' assessments of real options deviate from normative models (Howell and Jägle, 1997), organizations lack systematic approaches for assessing real options (Busby and Pitts, 1997), and managers apply real option analyses in only a small minority of their capital investment decisions (Graham and Harvey, 2001).

Past research on decision making under uncertainty provides further reasons to suspect that subjective option values may deviate from prices derived using normative models. For example, people exhibit systematic deviations from the predictions of expected utility theory (see, for example, Kahneman, Slovic, and Tversky, 1982; Schoemaker, 1982). Fox, Rogers, and Tversky (1996) showed that financial option traders' judged probabilities (based on valuations of uncertain prospects) violate expected utility theory in ways similar to

**Key words:** real options; behavioral decision theory; risk preferences; discount rates; prospect theory

\* Correspondence to: Kent D. Miller, Krannert Graduate School of Management, Purdue University, 403 W. State St, West Lafayette, IN 47907-2056, U.S.A.  
E-mail: kmiller@mgmt.purdue.edu

those of other populations. The existence of such biases in the context of simple probabilistic decisions ought to alert us to the potential for biases in the more complex contexts of real option identification, valuation, and exercise decisions.

This study contributes theoretical propositions and empirical evidence regarding managers' subjective perceptions of call and put option values. We find compelling evidence for systematic deviations from expected option values. The next section starts with a presentation of the basics of option theory and then draws on behavioral decision theory to explain subjective option pricing by managers. In contrast with normative option pricing models, we hypothesize systematic deviations from expected risk-neutral values. The latter portion of this article examines data obtained from graduate business school students. Respondents' option values reveal the biases predicted by behavioral decision research. We offer evidence on the effects of specific option characteristics—such as exercise price and option duration—on perceived option values. The latter portion of the study discusses implications for managing real options and developing descriptive real option theory.

## THEORY AND HYPOTHESES

Our theoretical discussion relates the characteristics of real options to the behavior of investors facing risky choices. We begin by defining the two kinds of options (calls and puts) and key parameters affecting option values. We then develop theoretical background and hypotheses on behavior when buying and selling options.

### Option theory basics

There are two types of options: calls and puts. A *call option* provides its holder the possibility (but not the obligation) to purchase a particular asset at a given price (known as the *exercise* or *strike price*). A *put option* confers the prerogative to sell an asset at a specified exercise price. The *option price* is the value of the option at the time of exchange between buyer and seller. Under norms of rationality, option holders will exercise the option only if the price of the underlying asset exceeds the exercise price. Put options will only be exercised if the asset price falls below the exercise price. In such cases, we say that the

option is '*in the money*.' Options with a fixed *exercise date* on which the option can be exercised are known as *European options*. This designation distinguishes them from *American options*, which can be exercised anytime during their *duration* (the time up to their expiration).

The simplest type of option pricing problem can be motivated from the risky choice problems commonly found in microeconomics (von Neumann and Morgenstern, 1944) and behavioral decision theory (Kahneman and Tversky, 1979, 1984). We often use a simple two-branch decision tree to portray the possible outcomes of such a decision, as in Figure 1(a). The simple specification of a risky choice offers payoff  $x_1$  with probability  $p_1$  ( $0 < p_1 < 1$ ) and payoff  $x_2$  with probability  $p_2$  ( $p_1 + p_2 = 1$ ). This simple lottery has an expected value of  $p_1x_1 + p_2x_2$  and its associated expected utility can be represented as  $U(x_1, p_1; x_2, p_2) = p_1u(x_1) + p_2u(x_2)$ .

This standard lottery problem assumes commitment to play a lottery must be made *before* the outcome is known. No allowance is made for the possibility that the decision-maker may choose to wait and view the outcome before deciding whether to obtain the lottery outcome. Allowing for waiting prior to committing to an uncertain outcome is the key difference between option decisions and the standard lottery problem portrayed in microeconomics and behavioral decision theory. If  $x_1$  is a gain and  $x_2$  is a loss, holding a call option truncates the distribution of outcomes relative to holding the lottery. Because option problems reduce the range of possible outcomes while leaving the probabilities unchanged, they are less risky than lottery problems (i.e., they have lower variance). Figure 1(b) depicts the possible outcomes associated with holding a call option on the lottery in Figure 1(a).

The similarities between simple option pricing and lottery problems suggest that behavioral decision theory may help us understand subjective option valuations. In particular, two major aspects studied in behavioral decision theory are relevant for examining perceived option values: risk attitudes and time preferences.<sup>1</sup> Behavioral research

<sup>1</sup> Behavioral decision theory also addresses biases in the assessment of probabilities. Studies on representativeness and availability address deviations in perceived distributions of possible outcomes from actual distributions (see, for example, Kahneman, Slovic, and Tversky, 1982). Such biases may be quite relevant

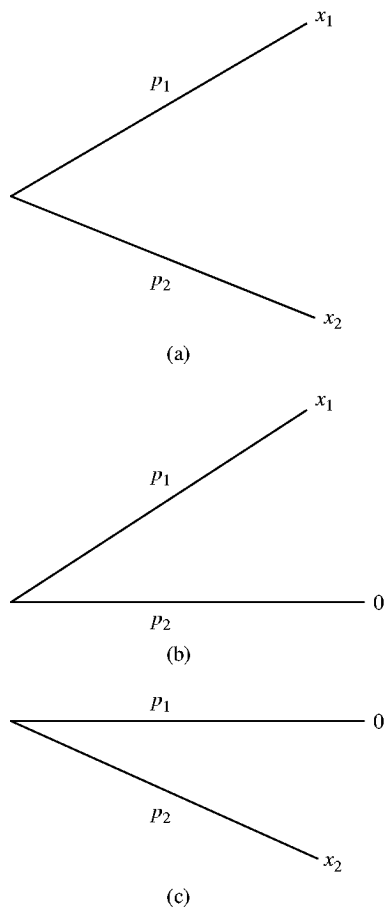


Figure 1. (a) Lottery payoffs. (b) Option holder payoffs. (c) Option seller payoffs

points out the variability in individuals' risk preferences and identifies relevant contextual influences (e.g., Bromiley and Curley, 1992; March and Shapira, 1987). Subjective time preferences arise because the cash flows resulting from buying and selling options are realized in the future. Differences in subjective real option valuations can lead both parties in a transaction to perceive the exchange as advantageous (Chi, 2000; Chi and McGuire, 1996), or can result in divergent valuations that prevent any transaction from occurring. By contrast, normative option pricing models in finance assume investors are uniformly risk neutral and consistently apply the market's risk-neutral discount rate (e.g., Cox, Ross, and Rubinstein, 1979; Trigeorgis and Mason, 1987). The finance

to managers' subjective valuations of real options. However, for this study, we provided respondents with objective distribution data.

assumptions result in common valuations across all investors and prevailing option prices that eliminate arbitrage opportunities.

In the discussion that follows, we examine some of the findings in behavioral decision theory relevant to option pricing. We believe that several cognitive aspects that characterize the ways people in general assess choices involving risk and time may inform how managers evaluate options. These cognitive patterns differ from what is assumed under the normative approach in finance. We present testable hypotheses based on prior research on risk attitudes and time preferences. Our discussion focuses on the questions: (1) What would someone be willing to pay for an option on a lottery outcome? (2) For what price would someone be willing to sell such an option? In seeking to answer these questions, we need to consider the perspectives of both buyers and sellers in call and put option transactions.

### Risk preferences and option pricing

Our study builds on early 'classic' studies of risky choice and individuals' risk preferences (e.g., Arrow, 1965; Pratt, 1964; von Neumann and Morgenstern, 1944). In these studies, risky choices involve probabilistic outcomes. Classical analyses of risky choice assumed that individual decision-makers' attitudes toward risk could be described in terms of the parameters of their utility functions. Most early writings on risk attitudes assumed risk aversion. When faced with a choice between a sure outcome and a risky alternative with the same expected value, a *risk-averse* individual will choose the sure outcome. For example, Levy and Sarnat (1984) studied 25 years of investments in mutual funds and observed that investors were averse to the variance of returns.

Evidence suggests that the same person may behave as risk averse and risk seeking in different situations (Shapira, 1995; Slovic, 1964). Kahneman and Tversky (1979) observed that when dealing with risky alternatives with gains as the possible outcomes, people appear to be risk averse (i.e., they prefer to reduce the variability of outcomes); but if they are dealing with a risky alternatives with possible loss outcomes, people tend to be risk seeking (i.e., they prefer to increase the variability of outcomes). Hence, whether choices are framed as gains or losses is critical to individuals' risk preferences.

We follow the logic of prospect theory to develop hypotheses regarding the effects of risk preferences for purchasers and sellers of call and put options.<sup>2</sup> Hence, there are four distinct cases to consider: (1) purchasing a call, (2) selling a call, (3) purchasing a put, and (4) selling a put. In developing the hypotheses and questionnaire, we assumed that the call option buyer and put seller have no preexisting risk exposures.<sup>3</sup> The call option buyer seeks exposure to a potential upside outcome. The put seller is willing to be exposed to a potential loss. By contrast, we assumed the call seller and put buyer have preexisting exposures they seek to hedge.<sup>4</sup> The call seller wants to lock in the upside potential rather than remain exposed to an uncertain outcome. The buyer of the put hedges against a potential loss.

We maintain several assumptions throughout our presentation. We assume a common underlying asset that pays a positive sum,  $x_1$ , with probability  $p_1$ , and a negative sum,  $x_2$ , with probability  $p_2$ . The option purchase price is designated  $y$ . The option purchase decision must be made in an initial period and the payoff is determined in a subsequent period. We assume that the utility associated with the initial option transaction and the subsequent option payoff are separable and additive. That is, buyers and sellers engage in a form of mental accounting, as presented by Thaler (1985), that distinguishes the initial option transaction from the subsequent option payoff. For simplicity, we initially assume the exercise price is zero (i.e., there is no subsequent payment required for exercising the option). The arguments made here are based on prospect theory's findings of risk aversion in the domain of gains and risk seeking in the domain of losses.<sup>5</sup> Readers interested in

proofs of each of the hypotheses should see the footnotes.

#### *Purchasing a call*

Consider first the call option purchase. A call option confers the right to wait until the lottery outcome is known before deciding whether to accept or decline its outcome. Once the option purchase price is sunk, the pay-off function becomes  $\max(x_1, 0)$ , and the expected pay-off is  $p_1x_1$ . Hence, the possible outcomes are as given in Figure 1(b).

Call options will only be exercised if they are in the money, so the possible outcomes for their holders are either gains or zero. Because these probabilistic outcomes are in the domain of gains, prospect theory suggests call option purchasers will exhibit risk aversion. Risk aversion is expressed by offering to pay a price that falls short of the expected pay-off of the option ( $p_1x_1$ ). Hence, if call option purchasers are risk averse, we would expect:

*Hypothesis 1: Purchasers price call options at discounts relative to their expected pay-offs.<sup>6</sup>*

#### *Selling a call*

The call option seller's situation is different from that of the call option purchaser. The call option seller is already exposed to the probabilistic outcome associated with holding the lottery (as shown in Figure 1a) and seeks to exchange a possible gain for a sure current call option sale price. The possible gain is  $x_1$  with probability  $p_1$ . A risk-neutral option seller will accept a price of no less than  $p_1x_1$ . A risk-averse option seller would be willing to discount this price. After receiving the option price ( $y$ ), the call option seller faces the residual probabilistic outcomes shown in Figure 1(c). In other words, the seller is still exposed to the possible loss  $x_2$  with probability  $p_2$ .

For lottery holders, call option sales involve exchanging a probabilistic gain for a sure gain in the form of an option price. Because the

<sup>2</sup> To further simplify the hypotheses we do not consider the role of decision weights for very small probabilities, which can operate in contradiction to the value function (see Tversky and Kahneman, 1992).

<sup>3</sup> The unnecessary alternative assumption would be that option buyers and sellers increase already existing exposures.

<sup>4</sup> The alternative would be to assume that call sellers and put buyers take on uncovered positions.

<sup>5</sup> In the proofs, we also assume symmetry of preferences around the origin (i.e.,  $u(x) = -u(-x)$ ). This assumption is not critical to our hypotheses; it merely simplifies the proofs. We also make use of the facts that (1) risk aversion in the domain of gains implies  $u(p_1x_1) > p_1u(x_1)$  and (2) risk seeking in the domain of losses implies  $p_2u(x_2) > u(p_2x_2)$ . These follow from the concavity of the prospect theory value function for gains and convexity for losses.

<sup>6</sup> Using the two-period mental accounting described earlier, the expected utility associated with buying the call option is  $u(-y) + p_1u(x_1)$ . The choice to buy the option turns on whether  $p_1u(x_1) > -u(-y)$ , that is, whether the expected utility exceeds the disutility associated with the option purchase price. Risk aversion implies  $u(p_1x_1) > p_1u(x_1)$ . Assuming the utility function is symmetric and invertible, we have  $p_1x_1 > y$ .

decision is framed in terms of the domain of gains, prospect theory indicates the call option seller should exhibit risk aversion. Thus, the seller should be willing to accept a discount relative to the option's expected value.

*Hypothesis 2: Sellers price call options at discounts relative to their expected pay-offs.<sup>7</sup>*

#### *Purchasing a put*

We now turn our attention to put options. Consider an individual who is exposed to a potential loss, who seeks to hedge the downside portion of this exposure by purchasing a put option. The value of the put option comes from the possibility of avoiding the loss  $x_2$ , which occurs with probability  $p_2$ . A risk-neutral individual would be willing to pay up to the absolute value of the expected loss for the put option, i.e.,  $|p_2x_2|$ . By contrast, a risk seeker, who would actually prefer to hold the risky asset, would offer to pay a price discounted relative to the absolute value of the expected loss.

By purchasing a put option, the individual shifts exposure from the lottery (Figure 1a) to just the gain portion of the possible outcomes (Figure 1b), and eliminates exposure to loss portion of the distribution (Figure 1c).<sup>8</sup> Hence, the put option purchase affects only potential losses, not gains. Prospect theory indicates buyers' valuations should reflect risk seeking in the domain of losses. Buying a put option does not affect potential gain outcomes; it simply shifts from a probabilistic loss to a fixed loss (given by the put option purchase price) and retains the upside gain potential. The convexity of the prospect theory value function for loss outcomes motivates the following hypothesis:

*Hypothesis 3: Purchasers price put options at discounts relative to their expected payoffs.<sup>9</sup>*

<sup>7</sup> For the call option seller to enter into an option transaction, it must be that the expected utility associated with selling the option exceeds the expected utility associated with simply holding the asset. That is,  $u(y) + p_2u(x_2) > p_1u(x_1) + p_2u(x_2)$ , or  $u(y) > p_1u(x_1)$ . By risk aversion,  $u(p_1x_1) > p_1u(x_1)$ . Therefore, the seller is willing to offer a discount as long as  $p_1x_1 > y > u^{-1}[p_1u(x_1)]$ .

<sup>8</sup> Holding the lottery together with the put option creates a position equivalent to holding the call option.

#### *Selling a put*

The fourth situation to consider is that of the put option seller. Put option sellers have no preexisting exposures. Rather, they make discretionary choices to take on avoidable potential losses. After receiving the option price, the put option seller's possible payoffs are depicted in Figure 1(c).

Put sellers' preferences should reflect risk seeking in the domain of losses. Because of convex preferences regarding losses, a risk-seeking put option seller should be willing to accept a price discounted relative to the expected loss. Essentially, they require compensation less than their expected loss to take on the risky put option. As such:

*Hypothesis 4: Sellers price put options at a discount relative to their expected losses.<sup>10</sup>*

#### **Time preferences and option pricing**

Real option theory highlights the potential benefit from waiting (Ingersoll and Ross, 1992; McDonald and Siegel, 1986; Venezia and Brenner, 1979). While waiting, managers can incorporate new information into their decisions. Granted, waiting may have its costs as well, as opportunities pass. The temporal aspect of options introduces discounting into option valuation.

Studies of managerial risk taking (MacCrimmon and Wehrung, 1986; Shapira, 1995) show that managers often delay decisions on risky prospects. In addition, they believe that they can exercise post-decisional control (Langer, 1975; Shapira, 1995). Although managers have been criticized for their 'illusion of control,' their predisposition to make incremental commitments is at the heart of real option thinking.

<sup>9</sup> The put option buyer compares the expected utility with and without entering into the option transaction. To buy the put option, it must be that  $u(-y) + p_1u(x_1) > p_1u(x_1) + p_2u(x_2)$ , or  $u(-y) > p_2u(x_2)$ . By risk seeking,  $p_2u(x_2) > u(p_2x_2)$ . Hence,  $-y > u^{-1}[p_2u(x_2)] > -p_2x_2$ . Thus,  $-p_2x_2 > y$ . The purchase price must be less than the absolute value of the expected loss.

<sup>10</sup> The put option seller must determine whether  $u(y) + p_2u(x_2) > 0$ . We can also write this condition as  $y > u^{-1}[-p_2u(x_2)]$ . Because of risk seeking for losses, we know  $p_2u(x_2) > u(p_2x_2)$ , or  $u(-p_2x_2) > -p_2u(x_2)$ . Thus, the put option seller will sell the option for a price in the range  $-p_2x_2 > y > u^{-1}[-p_2u(x_2)]$ . This indicates a willingness to accept a discount relative to the absolute value of the expected loss.

Both economic considerations of opportunity cost and the psychology of waiting lead to discounting future outcomes. Economic psychologists, following Strotz's (1956) dictum, have examined the preferences of individuals for immediate vs. delayed rewards. Similar to the delayed gratification literature in developmental psychology (Mischel, Shoda, and Rodriguez, 1989), the findings suggest that people have a strong preference for current over delayed payoffs, and future rewards are discounted at very high rates (Loewenstein and Prelec, 1992).

In order to keep our option pricing problems as simple as possible, we examine the discounting of options with zero exercise prices. This avoids confounding exercise price and discounting effects. If option transactions occur prior to the payoff, we should apply the risk-free discount rate to determine the present value of receiving the certainty equivalent payoff. However, the actual discount rate used by managers may deviate from the normative risk-free rate (Benartzi and Thaler, 1995; Loewenstein, 1987). Smith and Nau (1995) reported that managers tend to use the risk-adjusted, rather than the risk-free, discount rate when valuing options.

Behavioral research on discounting has not considered option valuation. Nevertheless, findings from past research point to possible discounting biases associated with the temporal dimension of real options. Ben Zion, Rapoport, and Yagil (1989) examined responses to questionnaire items involving 6-month, 1-year, and 4-year delays. Their data indicated lower discount rates the longer the time horizon, and the rate of decrease in the discount rate decreases with the time horizon. These findings corroborated earlier findings by Thaler (1981). We reexamine these previous research findings in the context of option pricing. Based on previous research on discounting, we expect:

*Hypothesis 5: Discount rates decrease with option duration, and the steepness of decline decreases with time.*

### Exercise prices and option pricing

Up to this point, our analysis of option valuation assumed no cost associated with exercising the option, i.e., a zero exercise price. We now turn our attention to the implications of introducing a positive exercise price.

For a call option with an exercise price of  $e$ , where  $x_1 > e > 0$ , the payoff to the option buyer is  $\max(x_1 - e, 0)$ . The payoff associated with the best possible outcome shifts down by  $e$  relative to the call option with a zero exercise price. The lower bound is zero because the option will not be exercised if it is out of the money.

We have already characterized both buyers' and sellers' call option decisions as risk averse. Each of these decisions reflects concave preferences in the domain of gains. This leads to discounting options relative to their expected values. Following similar reasoning, we anticipate that the acceptable price will decline by less than the shift in expected value ( $p_1 e$ ) when moving from an option with a zero exercise price to a positive exercise price.

*Hypothesis 6: Call option sellers and buyers discount exercise prices.<sup>11</sup>*

Now consider the implications of exercise prices for put option values. We have already characterized put option buyers and sellers as framing their decisions in the domain of losses. The put option buyer—seeking to insure against a loss—pays the purchase price  $y$  and reduces the potential loss to  $-e$  rather than  $x_2$  (where  $-e > x_2$ ). Because of risk seeking, retaining this potential loss will not reduce the offer price by as much as the expected loss. Moving from a zero exercise price to a positive exercise price causes a drop in option value that is less than the expected value of the exercise price ( $p_2 e$ ).

After receiving the option price, the put option seller faces a payoff of zero (if  $x_1$  occurs) with probability  $p_1$  or a loss of  $x_2 + e$  with probability  $p_2$ . This reduction in potential loss (relative to having an exercise price of zero) is underappreciated by the risk-seeking option seller (relative to the risk-neutral valuation). The increase in put option value when going from a zero exercise price to a

<sup>11</sup> The simplest way to demonstrate this contention is to compare risk-neutral and risk-averse valuation of a call option. Consider a call option with probability  $p_1$  of a payoff of  $x_1$  to which both a risk-neutral and risk-averse individual assign the same utility (i.e., the point of intersection of the two utility functions is at  $x_1$ ). Now consider the implications of introducing a positive exercise price. Because of concave preferences, the risk averse certainty equivalent value,  $u^{-1}[p_1 u(x_1 - e)]$ , must exceed the risk-neutral certainty equivalent value,  $p_1 x_1 - p_1 e$ , reflecting linear preferences. Thus, for risk-averse preferences, the reduction in call option value associated with introducing the exercise price is less than  $p_1 e$ .

positive exercise price is less than  $p_2e$ . Thus, under risk seeking in the domain of losses, we expect:

*Hypothesis 7: Put option sellers and buyers discount exercise prices.*<sup>12</sup>

## METHODS

### Sample

In order to gather some initial data to explore our hypotheses, we elicited voluntary responses from 67 part-time students enrolled in an MBA program at New York University. We took several steps to motivate students' interest in the questionnaire. A faculty member distributed and collected the questionnaires. Even though it was optional, most respondents provided their names on their questionnaires in order to receive individual feedback on their responses, in addition to feedback given to the class as a whole. Identifying oneself to the instructor created an incentive to answer the questionnaire carefully. The students were promised (and were indeed provided with) summary statistics about their responses. The feedback session gave the students guidelines for interpreting deviations from the aggregate results as well as a lecture about the role of real options in strategic decisions.

Two questionnaires were unusable because of missing data. One questionnaire was deleted because the respondent provided eight negative valuations. Option prices should always be non-negative so this was taken as an indication that this particular respondent misunderstood the questionnaire items. There were two other instances of isolated negative values in the data set. These were deleted while the remaining data for these two respondents were retained. Hence, the resulting sample size was 64.

The respondents' ages ranged from 23 to 37 years, with a median age of 29. Sixty-three percent were males and 37 percent were females.

About 40 percent were employed by a financial institution at the time of the study. Fifty-six percent of the respondents indicated they learned about option pricing in a class that covered other finance topics. Eleven percent had taken a class focused on options. Eleven percent of the respondents indicated they had work experience related to options trading, while 8 percent indicated they had traded options for their own accounts. Just over one-third of the respondents (36 percent) indicated no prior background in option theory. We ran a series of single-factor ANOVA models for each of the questionnaire items and found no systematic differences in responses depending on whether the respondents had prior experience with options or not.

### Questionnaire

The questionnaire consisted of 36 option valuation problems. The options described in these problems were expressed in the simplest terms possible. Each involved only two possible outcomes for the values of the underlying assets and, to simplify computation, probabilities were set at 50 percent throughout the questionnaire.<sup>13</sup> Pretesting among 10 graduate students resulted in refinements of the wording of the option pricing problems as well as the instructions. The instructions included brief explanations of call and put options, and related terms such as 'exercise date' and 'exercise price.' Every effort was made to make the questionnaire understandable even to those with little or no previous background on options. Table 1 indicates the kinds of items included in the questionnaire. For each item, respondents were asked to indicate the maximum price they would be willing to pay to buy the option or the minimum they would be willing to receive to sell the option.

Part I of the questionnaire consisted of 12 option pricing problems: three problems each for call buying, call selling, put buying, and put selling. These problems used the values  $(x_1, x_2) = (1000, 500)$ ,  $(1000, 0)$ ,  $(1000, -1000)$ .<sup>14</sup> The  $x_2$  value of  $-1000$

<sup>12</sup> Consider a put option on an asset with probability  $p_2$  of a loss of  $x_2$ . Assume both a risk-neutral and risk-averse individual assign the same utility to  $x_2$ . Now consider the implications of introducing a positive exercise price. Because of convex preferences, the risk-seeking certainty equivalent value,  $u^{-1}[p_2u(x_2 + e)]$ , must be less than the risk-neutral certainty equivalent value,  $p_2x_2 + p_2e$ , reflecting linear preferences. Hence, a risk-averse individual is willing to transact at a higher price than a risk neutral individual. For risk-averse preferences, the reduction in call option value associated with introducing the exercise price is less than  $p_2e$ .

<sup>13</sup> Setting the probabilities at 0.50, we avoid complications associated with extreme probabilities near zero and one. These complications involve subjective interpretations that overweigh low probabilities and underweigh high probabilities, as discussed by Tversky and Fox (1995).

<sup>14</sup> For put options, the wording was changed from 'lose' to 'gain' for the item corresponding to  $x_2 = -1000$ .

Table 1. Option pricing questionnaire items

<b>Buying a call option</b>
You are offered a call option on an investment that has a 50% chance to be worth \$ $x_1$ and a 50% chance to be worth \$ $x_2$ . For this option, I would be willing to pay: \$ _____
<b>Selling a call option</b>
You own an investment that has a 50% chance to be worth \$ $x_1$ and a 50% chance to be worth \$ $x_2$ . I would be willing to sell a call option on this investment to someone else for: \$ _____
<b>Buying a put option</b>
You own an investment that has a 50% chance to lose \$ $x_1$ and a 50% chance to lose \$ $x_2$ . For buying the option to transfer the outcome of this investment to someone else, I would be willing to pay: \$ _____
<b>Selling a put option</b>
You are selling to someone the option to transfer to you the outcome associated with an investment that has a 50% chance to lose \$ $x_1$ and a 50% chance to lose \$ $x_2$ . To sell this option, I would have to receive: \$ _____

is an irrelevant loss outcome for call option valuation and an irrelevant gain outcome for a put option. These outcomes are irrelevant because options remain unexercised if they are out of the money. As shown in Figure 1(b), by not exercising a call option that is out of the money, the lowest possible payoff is zero. From a normative perspective, the magnitude of  $x_2$  below zero should not affect option values. Hence, the values assigned to options using  $x_1$  and  $x_2$  values (1000, -1000) should not differ from those using values (1000, 0). Deviations in values between these two problems indicate biases associated with the size of irrelevant outcomes.

The items in Part II were comparable to those in Part I using  $(x_1, x_2) = (1000, 0)$ . The only difference was that they involved waiting until a specific future time to resolve the value of the investment before the option could be exercised. As such, all of our discounting problems involved European options. The 12 items in Part II considered 6-month, 1-year, and 4-year time horizons.

The 12 items in Part III differed from those in Part I only in that they involved positive exercise prices.<sup>15</sup>

<sup>15</sup> The complete questionnaire is available from the authors.

Analysis

Hypotheses 1–4 indicate that we expect the mean option prices to fall below the risk neutral valuation. The directions of these hypotheses indicate that one-tailed tests are appropriate. If we let  $\mu_0$  and  $\mu$  designate the risk-neutral valuation and the population mean, respectively, these hypotheses indicate that  $\mu \leq \mu_0$ . For the set of reported option values  $V_i (i = 1, \dots, n)$ , let  $S_n^2 = \sum_{i=1}^n (V_i - \bar{V}_n)^2$ . The test statistic  $t = \frac{n^{1/2}(\bar{V}_n - \mu_0)}{[S_n^2/(n - 1)]^{1/2}}$  has a  $t$  distribution with  $n - 1$  degrees of freedom (DeGroot, 1975: 414).

As noted above, the magnitude of the loss outcome is irrelevant when valuing a call option and the magnitude of the gain outcome is irrelevant when valuing a put option. To test for independence from the magnitude of irrelevant outcomes, we considered whether the within-respondent differences of two consecutive items in the questionnaire, one of which introduces an irrelevant outcome, were significantly different from zero using a one-tailed  $t$ -test.

The data from Part II of the questionnaire, in combination with four items from Part I, allowed us to compute the implicit discount rates for the periods ending at 6, 12, and 48 months. Let  $V_t$  represent the reported value of an option with an

outcome realized in period  $t$ . For the first two 6-month periods, the discount rate was computed as  $r_t = (V_t/V_{t+1}) - 1$ . Computation of the discount rate for the period from month 12 ( $t = 2$ ) to 48 ( $t = 8$ ) assumed compounding every 6 months, i.e.,  $r_{t=8} = (V_2/V_8)^{1/6} - 1$ .

For Part III of the questionnaire, we were primarily interested in whether introducing an exercise price resulted in deviations from risk-neutral option values relative to the respondent's values for comparable options with zero exercise prices in Part I. If we designate the probability of exercising the option as  $p_2$ , introducing a positive exercise price ( $e$ ) should shift the option value by  $p_2e$  under risk neutrality. If expressed valuations are consistent with risk neutrality, we ought to observe that the within-respondent differences in option values without and with the exercise price ( $V_1 - V_2$ ) equal  $p_2e$ . Using a one-tailed  $t$ -test allows us to formally test for systematic deviation from risk-neutral valuation when introducing an exercise price.

## RESULTS

Our tests of Hypotheses 1–4 used data from simple option pricing problems that do not raise considerations regarding exercise price or temporal discounting. These simple questionnaire items provide a baseline set of option value data against which to compare subsequent values involving more complex option pricing considerations. Of primary concern in testing Hypotheses 1–4 was whether respondents tend to price options at discounts relative to their expected values.

Table 2 reports descriptive statistics for the 12 simple option pricing items in Part I of the questionnaire. Prices for buying calls (items 1–3), selling calls (items 4–6), and buying puts (items 7–9) reflect consistent—and in some instances, quite substantial—discounting relative to expected values. Two of the three prices for selling put options (items 10–12) reveal discounting. The mean response to item 11 is an anomaly in light of the responses to items 10 and 12. The mean for item 11 was not significantly different from its expected value. The reported  $t$ -statistics are for one-tailed tests of equality of the subjective valuations with their expected values. The  $t$ -statistics are negative and highly significant ( $p < 0.01$ ) for all items except 11. In general, the results indicate discounting of both calls and puts relative to their expected values, irrespective of whether a buyer or seller position is assumed. These findings support Hypotheses 1–4.

It is also quite interesting to note the differences in valuations assigned to options when the respondents shift from seller to buyer positions. The options described in items 1–3 are identical to those in items 4–6. The only difference is that the former set of items places the respondent in the position of a call option buyer, while the latter places them in the position of a call option seller already exposed to a lottery outcome. Similarly, items 7–9 and 10–12 deal with corresponding put options. Items 7–9 place the respondent in the role of a put option seller already exposed to a lottery outcome, and items 10–12 assume a selling position with no previous exposure.

Table 2 shows a consistent premium when selling an option relative to buying the same option.

Table 2. Descriptive statistics and  $t$ -statistics for simple option items

Type of problem	Item	$N$	Mean	S.D.	Minimum	Maximum	Exp. value	$t$
Buy/Call	01	64	579.77	148.31	200	750	750	−9.18
Buy/Call	02	64	263.25	181.01	0	500	500	−10.46
Buy/Call	03	64	31.58	75.76	0	350	500	−49.46
Sell/Call	04	64	693.02	164.05	200	1001	750	−2.78
Sell/Call	05	64	434.42	177.18	1	999	500	−2.96
Sell/Call	06	64	174.02	222.26	0	1000	500	−11.73
Buy/Put	07	64	485.14	232.58	0	800	750	−9.11
Buy/Put	08	64	300.77	187.03	0	600	500	−8.52
Buy/Put	09	64	110.66	156.31	0	500	500	−19.93
Sell/Put	10	64	618.98	312.30	0	1001	750	−3.36
Sell/Put	11	64	520.25	272.30	0	1001	500	0.59
Sell/Put	12	64	295.70	278.75	0	1000	500	−5.86

Table 3. Selling price minus buying price

Item	<i>N</i>	Mean	S.D.	Mini- mum	Maxi- mum	<i>t</i>
04 vs. 01	64	113.25	186.62	−250	799	4.85
05 vs. 02	64	171.17	221.13	−400	899	6.19
06 vs. 03	64	142.44	199.53	−50	1000	5.71
10 vs. 07	64	133.84	266.76	−500	900	4.01
11 vs. 08	64	219.48	271.64	−299	1000	6.46
12 vs. 09	64	185.05	299.98	−500	1000	4.93

Table 3 reports descriptive statistics for individuals' selling prices minus their buying prices (i.e., premiums relative to the offer prices). The *t*-statistics indicate consistently significant (one-tailed,  $p < 0.01$ ) price premiums when selling relative to buying identical options for both calls and puts. Such price premiums could have important implications. In particular, these findings suggest that markets for real options may fail to clear because asking prices consistently exceed bid prices *even when buyers and sellers share the same understandings of the parameters relevant to valuing the options*. Standard market failure arguments (e.g., Akerlof, 1970) rely upon asymmetric information. Given the idiosyncratic nature of real options and their embeddedness within firms, the standard argument seems both relevant and compelling when applied to real options. Our findings go beyond the standard argument by indicating that differences in subjective valuations may drive a wedge between buyers and sellers *even when information is complete and symmetric*.

Data from this initial set of 12 items also provided a basis for testing whether the magnitude of irrelevant outcomes (i.e., losses for calls and gains for puts) affect perceived option values. There were four pairs of items that involved changing only the magnitude of irrelevant outcomes. For example, one call option purchase problem involved an underlying asset with 50 percent probability of gaining \$1000 and a 50 percent probability of gaining nothing. The only change in the subsequent problem was to substitute a loss of \$1000 as the downside outcome. Such a loss is irrelevant for a call option because it will only be exercised if it is in the money, so the payoff is  $\max(1000, 0)$  in either case.

For each of the four pairs of items that reflected changes in the magnitude of irrelevant outcomes (2 and 3, 5 and 6, 8 and 9, and 11 and 12), significant differences were found. The *t*-statistic for

buying a call was 9.98, for selling a call 9.15, for buying a put 6.40, and for selling a put 7.04. In all instances, these one-tailed *t*-tests are significantly different from zero (d.f. = 63,  $p < 0.01$ ). Changing the magnitude of irrelevant outcomes significantly reduced respondents' option valuations.

Based on previous behavioral research, we expected discount rates would decrease with option duration, and the steepness of decline would diminish with time (Hypothesis 5). For purposes of computing discount rates, we used only option pricing problems that had relevant outcomes (gains for calls and losses for puts) and zero outcomes. This avoids any confusion due to the magnitude of irrelevant outcomes. Discount rate computations involving division by zero were treated as missing data. The data allowed for computation of four values of the discount rates for each of three time periods. We used the within-respondent mean values for each period as the basis for comparing across individuals.

The initial striking feature of the computed implicit discount rates was the large number of negative values. This implies a very counterintuitive approach of valuing future payoffs more highly than current payoffs. For the first 6-month period, the computed discount rate was negative for 30 of the 64 observations. For the second 6-month period, and the 36-month period from year 1 to year 4, the frequency of negative responses was much lower (8 and 4, respectively). Nevertheless, mean values for the discount rate are positive for each of the three periods, as shown in Table 4. The overall pattern exhibits the expected decline in discount rates as we move from proximate to more distant time periods. The diminishing rate of decline is also consistent with Hypothesis 5.<sup>16</sup>

Although the descriptive statistics appear consistent with findings from previous research (e.g.,

Table 4. Descriptive statistics for implicit discount rates

Period	<i>N</i>	Mean	S.D.	Mini- mum	Maxi- mum
0–6 months	64	0.404	1.912	−0.778	14.530
6–12 months	64	0.175	0.292	−0.499	1.125
12–48 months	64	0.065	0.068	−0.084	0.260

<sup>16</sup> The 3-month treasury bill rate, a proxy for the risk-free rate, was about 4.5 percent at the time respondents completed the questionnaire.

Loewenstein, 1987), we must add a word of caution. Analysis of variance indicated that the differences in discount rates across the three time periods were not significant ( $F(2, 189) = 1.53$ ,  $p < 0.22$ ). The overall  $R^2$  for the ANOVA model was just 0.016, indicating that the three periods (0–6 months, 6–12 months, and 12–48 months) do not cause significant differences in the discount rate.

What emerges from our analysis of discounting is evidence that there is a great deal of intra- and interpersonal inconsistency regarding the effect of variations in duration on option values. These within- and across-respondent disparities decrease the longer the time horizon. Both the frequency of negative implicit discount rates and the standard deviations across respondents decline with greater temporal distance. These are

more noteworthy findings than the somewhat weak support for Hypothesis 5, given the insignificant results from our ANOVA model.

We ran three additional single-factor ANOVA models to see whether having prior background in option theory explained differences in 6-month, 12-month, and 48-month discount rates. These analyses showed that respondents with no prior background generally have higher discount rates and greater variability among respondents than do respondents familiar with options. Nevertheless, because of the high variance among inexperienced respondents, none of the three ANOVA model  $F$ -statistics was significant at the 0.05 level.

The items in Part III of the questionnaire served to determine whether introducing a positive exercise price shifted perceived option value by an amount comparable to the actual change in expected value (i.e., risk neutral valuation). Table 5 reports descriptive statistics for the items in Part III along with the expected values for each of the options. Using 60 as the degrees of freedom ( $\approx n - 1$ ) and two-tail tests, the  $t$ -statistics are significant at the 0.01 level if their absolute values are at least 2.66. For a one-tail test, the cut-off value is 2.39. The pattern evident in this table is a tendency to overvalue the options with the higher \$750 exercise price (items 1, 4, 7, and 10) and undervalue the other options with the lower \$500 exercise price.

Whereas the  $t$ -statistics in Table 5 test for deviations from the expected values of each of the options, our primary interest was in the magnitude of the change in perceived value relative to the same options with zero exercise prices. Table 6

Table 5. Descriptive statistics and  $t$ -statistics for options with exercise prices

Item	$N$	Mean	S.D.	Minimum	Maximum	Exp. value	$t$
01	63	218.51	272.67	0	750	125	2.72
02	63	168.57	169.75	0	500	250	-3.81
03	61	102.97	165.02	0	500	250	-6.96
04	62	290.66	288.73	0	800	125	4.52
05	62	262.35	205.00	0	750	250	0.47
06	62	176.02	182.86	0	600	250	-3.19
07	58	283.64	360.29	0	1500	125	3.35
08	58	204.78	239.30	0	1000	250	-1.44
09	58	152.17	203.57	0	750	250	-3.66
10	57	236.79	260.00	0	800	125	3.25
11	57	244.44	221.52	0	750	250	-0.19
12	57	249.44	238.94	0	1000	250	-0.02

Table 6. Comparison of options without and with exercise prices

Part I				Part II				Comparison		
Item	$N$	Mean	S.D.	Item	$N$	Mean	S.D.	Mean	PE	$t$
01	64	579.77	148.31	01	63	218.51	272.67	363.71	375	-0.27
02	64	263.25	181.01	02	63	168.57	169.75	98.86	250	-4.76
03	64	31.58	75.76	03	61	102.97	165.02	-69.84	250	-14.53
04	64	693.02	164.05	04	62	290.66	288.73	399.71	375	0.52
05	64	434.42	177.18	05	62	262.35	205.00	172.37	250	-2.06
06	64	174.02	222.26	06	62	176.02	182.86	-1.23	250	-7.23
07	64	485.14	232.58	07	58	283.64	360.29	211.16	375	-3.07
08	64	300.77	187.03	08	58	204.78	239.30	105.55	250	-4.28
09	64	110.66	156.31	09	58	152.17	203.57	-39.55	250	-9.34
10	64	618.98	312.30	10	57	236.79	260.00	379.25	375	0.08
11	64	520.25	272.30	11	57	244.44	221.52	257.23	250	0.17
12	64	295.70	278.75	12	57	249.44	238.94	25.56	250	-5.64

reports descriptive statistics for the Part I and Part III questionnaire items that differ only in the exercise price. The 'Comparison' portion of the table reports the mean differences in values for options without and with exercise prices. The column PE is the probability of exercising the option times the exercise price, i.e., the expected change in option value. The reported *t*-statistic is for the test of equality of the shift in valuation equal to PE. For 60 degrees of freedom, one-tailed *t*-values of at least 2.39 are significant at the 0.01 level. Using this criterion, seven of the 12 differences are significant. All of the significant differences indicate underestimation of the shift in option value due to the exercise price.

The results are generally supportive of Hypotheses 6 and 7. Call option buyers and sellers evidence shifts in option values that are less than the shifts in expected values (see items 1–6 in Table 6). This is consistent with risk aversion. Put option buyers and sellers exhibit significant discounting of the exercise price in four of the six cases (see items 7–12), indicating risk seeking in the domain of losses. However, the evidence for discounting the exercise price is least compelling for sellers of put options, where only one of the three items shows significant discounting.

## DISCUSSION

Our analysis of option valuation followed the Kahneman and Tversky (1979) tradition. We assumed that the risk preferences of option buyers and sellers reflect their framing of decisions as either pure gain or pure loss situations, hence the framing notion of prospect theory applies. Hypotheses 1 and 2 could have been derived from classical utility theory, but the focus on risk seeking in Hypotheses 3 and 4 comes uniquely from prospect theory.

Furthermore, we applied Thaler's (1985) notion of mental accounting to separate the option pricing decision from the subsequent option outcome. Shapira and Venezia (1992) used this approach to analyze the behavior of lottery ticket buyers. In their study, the behavior of state lottery buyers could be explained not by calculation of expected values but by considering the cost of the ticket separately from its potential outcome.

Our results indicate that considerations from behavioral decision theory are quite useful in analyzing the responses of individual option buyers

and sellers. Our results supported the contention that call option transactions are framed in the domain of gains and reflect risk aversion (see Table 2). Discounting of put options is consistent with the contention that these transactions are framed in the domain of losses and reflect risk seeking. The results from introducing exercise prices also are consistent with prospect theory expectations (see Table 6). Introducing exercise prices reduces option values by less than the decline in expected values.

The failure to ignore *irrelevant alternatives* has been a major finding in behavioral decision theory (Bell, Raiffa, and Tversky, 1988; Slovic and Tversky, 1974). This study identified a distinct phenomenon: the effects of *irrelevant outcomes*. Irrelevant outcomes arise because the discretion managers have to not exercise out-of-the-money options truncates the distribution of outcomes (relative to lottery problems). Why do the magnitudes of irrelevant outcomes affect option values? Recall that there were no systematic differences in option values between those respondents with previous exposure to option pricing (64 percent of the sample) and those without (36 percent). This rules out inexperience as an explanation for the effects of irrelevant outcomes. We cannot entirely rule out misunderstanding on the part of the respondents, but every effort was made to clearly explain the nature of options and carefully word the items in the questionnaire. A more substantive explanation is the possibility that avoiding irrelevant outcomes may be related to regret avoidance (Bell, 1982; Loomes and Sugden, 1982, 1987). For example, consider a manager who decides to purchase a call option. If the resulting asset price turns out to be grossly out of the money, the outcome may cast greater doubt on the manager's judgment than if the price were only slightly out of the money. Regret avoidance is a speculative explanation at this point, but one that may merit further study.

We also want to highlight the significantly higher prices asked when taking the seller role relative to the prices offered when taking the buyer role (see Table 3). Our results extend previous research on buying–selling price gaps (e.g., Bateman *et al.*, 1997; Hoffman and Spitzer, 1993; Kahneman, Knetsch, and Thaler, 1991; Knetsch and Sinden, 1984) to the realm of real option pricing. This finding is particularly intriguing because we explicitly provided equivalent option pricing parameters in the buyer and seller items. As such,

asymmetric expectations cannot account for the differing valuations of buyers and sellers in this study.

The sellers' price premiums relative to the buyers' offer prices may have important implications for real option markets. The buying–selling price gap points out the difficulties associated with negotiating real option transactions. This gap may restrict the volume of real option trades and, in the extreme, may completely eliminate trading in certain options. As such, the discovered price gap provides a cognitive basis for inefficient and incomplete real option markets. Such inefficiencies in real options markets provide strategic opportunities to capture the rents from unexploited trading opportunities (see Kirzner, 1985; McGrath, 1997; Rumelt, 1987). The key to exploiting these opportunities is to reduce buyer and supplier biases, making new trading opportunities possible.

A manager's ability to incorporate assumptions regarding duration is another key aspect of valuing real options. When volatility per period is constant and the exercise price is fixed, option values increase with duration (e.g., Black and Scholes, 1973). By contrast, our option pricing problems involved constant volatility over the option duration as the time horizon was extended. This created a simple discounting problem; i.e., option values should decrease with the length of time to pay-offs. Our subjects generally recognized the need to discount future option payoffs. For the most part, the subjects' implied discount rates were consistent with other studies demonstrating myopic behavior when valuing future outcomes (cf. Ben Zion *et al.*, 1989; Benartzi and Thaler, 1995; Lowenstein and Prelec, 1992). However, their implicit discount rates indicated much more confusion regarding discounting over short time horizons than longer horizons. Negative implicit discount rates and wide variance across individuals evidenced confusion regarding short-term (6-month) discounting.

Our intention was to develop a *descriptive* model—and not a *normative* model (see Bell *et al.*, 1988)—of managerial tendencies when applying real option analysis to strategic decision making. We believe that this study's findings help us make progress toward such a model. Our findings suggest that managers may benefit from tools supporting their analyses. Such support could include tailored analytical frameworks and computer software for valuing real options. Such steps could help managers reduce investment

valuation errors. Our findings could serve as the starting point for developing tools to make key assumptions explicit and debias managers' option valuations (cf. Fischhoff, 1982).

Nevertheless, we must acknowledge empirical research finding option theory variables explain—at least partially—patterns of strategic investment decisions. This presents an intriguing paradox. On the one hand, we have compelling evidence that managers and organizations are ill equipped to handle real option decisions and often do not explicitly use real option analytical techniques (Busby and Pitts, 1997; Graham and Harvey, 2001; Howell and Jägle, 1997). On the other hand, strategic decisions under uncertainty appear to conform to some general expectations based on real option theory (e.g., Folta, 1998; Folta and Miller, 2002; Kogut, 1991). The resolution of this paradox would seem to be that, despite their biases, managers' strategic investment decisions can loosely conform to normative real option models. Managers' may employ real option reasoning, without getting all the details correct (Triantis and Borison, 2001). Even when quantitative analyses may not be feasible, qualitative assessments employing real option reasoning can guide investment decisions (Miller and Waller, 2003). For example, managers may recognize the value of deferring investments under uncertainty even if they cannot precisely quantify the value-added from doing so or optimally time their investments (Miller and Folta, 2002). Managers' heuristics may be deficient, yet their patterns of strategic decisions may crudely approximate decisions informed by real option valuation techniques (McDonald, 2000). Managers' investment decisions may be 'directionally correct,' even if they are not completely unbiased.

Posing simple option pricing problems in a questionnaire cannot capture all of the complexities associated with managing real options in organizations. We intentionally simplified the problems to make the questionnaire accessible to all respondents and avoid confounding effects. Our problems lack many of the challenging features of the real option problems that managers face. In practice, each real option valuation problem is unique (Bowman and Moskowitz, 2001), and any general representation can, at best, capture just a few of the most salient common features of the problem.

Our respondents were individuals divorced from broader organizational contexts. The usual precautions about generalizing from individuals to groups and organizations apply.<sup>17</sup> Previous research offers no simple answer to whether groups are more or less inclined to exhibit the biases of individuals (Argote, Devadas, and Melone, 1990; Kerr, MacCoun, and Kramer, 1996). Organizations may implement corrective routines to counterbalance individual-level biases (Tetlock, 2000), or they may introduce biases of their own at the collective level. We acknowledge that the collective evaluations of real option decisions made within organizations may differ from our individual-level findings. We encourage research examining real option management processes and investment decisions in organizations.

There are several possibilities for extending this research. In order to limit the length of our questionnaire, this study did not explore the implications of varying the probabilities of alternative outcomes. All probabilities were fixed at 50:50 odds. Future research could vary these probabilities and determine the implications for perceived option values. Of particular interest would be the differences in willingness to pay for options with certain outcomes vs. near-certainty outcomes, and impossible outcomes vs. nearly impossible outcomes (Tversky and Fox, 1995). Kahneman and Tversky (1979) identified a strong preference for sure gains relative to highly probable gains. Their 'certainty effect' may also appear in option valuations.

We also did not take up the issue of subjective estimates of probabilities. When pricing real options, managers may demonstrate the same overoptimism and illusion of control in pricing real options as they have in other risky choice contexts (March and Shapira, 1987) and as evident in the research on the winner's curse (Bazerman and Samuelson, 1983; Kagel and Levin, 1986).

Factoring portfolio considerations into option valuations presents a major challenge to managers. Because of possible correlations in the prices of their underlying assets, the value an option adds to a portfolio may differ from its value on a stand alone-basis. Trigeorgis (1996: ch. 7) calls this the problem of 'nonadditivity' of option values. By isolating each option pricing problem in

the current study, we have left unexplored portfolio effects on perceived option values. In keeping our option problems as simple as possible, we have also not taken up the challenging problem of valuing compound options (i.e., options on options), which is a common type of investment problem managers face when making decisions about R&D and new ventures. Compound option investments may be subject to behavioral phenomena such as myopia (Laverty, 1996; Levinthal and March, 1993; Miller, 2002) and escalation of commitment (Ross and Staw, 1986; Staw, 1981).

In the last decade, we have seen a growing volume of research applying option theory to problems of interest to managers.<sup>18</sup> Although finance research has helped managers frame decisions under uncertainty in option theoretic terms, their normative models for pricing options overlook key aspects of the behavioral and organizational contexts in which investment decisions occur. This study provides encouraging support for applying the insights from behavioral decision theory to understand how managers actually think about real options.

## ACKNOWLEDGEMENTS

Our thanks go to Menachem Brenner, Philip Bromiley, David Budescu, Sari Carp, Diane Lander, Sridhar Seshadri, Itzhak Venezia, Robert Wiseman, George Wu, and the anonymous reviewers for helpful comments on earlier versions.

## REFERENCES

- Akerlof GA. 1970. The market for 'lemons': quality uncertainty and the market mechanism. *Quarterly Journal of Economics* **84**: 488–500.
- Amram M, Kulatilaka N. 1999. *Real Options: Managing Strategic Investment in an Uncertain World*. Harvard Business School Press: Boston, MA.
- Argote L, Devadas R, Melone N. 1990. The base-rate fallacy: contrasting processes and outcomes of group and individual judgment. *Organizational Behavior and Human Decision Processes* **46**: 296–310.
- Arrow KJ. 1965. *Aspects of the Theory of Risk Bearing*. Yrjo Jahnssonis Saatio: Helsinki.
- Bateman I, Munro A, Rhodes B, Starmer C, Sugden R. 1997. A test of the theory of reference-dependent

<sup>17</sup> Kameda and Davis (1990) and Hartman and Nelson (1996) addressed the extension of prospect theory from individuals to groups.

<sup>18</sup> Trigeorgis (1995, 1996), Amram and Kulatilaka (1999), and Brennan and Trigeorgis (2000) provide overviews of this research stream and its applications.

- preferences. *Quarterly Journal of Economics* **112**: 479–505.
- Bazerman MH, Samuelson WF. 1983. I won the auction but don't want the prize. *Journal of Conflict Resolution* **27**: 618–634.
- Bell DE. 1982. Regret in decision making under uncertainty. *Operations Research* **30**: 961–981.
- Bell D, Raiffa H, Tversky A (eds). 1988. *Decision Making: Descriptive, Normative and Prescriptive Interactions*. Cambridge University Press: New York.
- Benartzi S, Thaler RH. 1995. Myopic loss aversion and the equity premium puzzle. *Quarterly Journal of Economics* **73**: 73–92.
- Benzion U, Rapoport A, Yagil J. 1989. Discount rates inferred from decisions: an experimental study. *Management Science* **35**: 270–284.
- Black F, Scholes M. 1973. The pricing of options and corporate liabilities. *Journal of Political Economy* **81**: 637–654.
- Bowman EH, Hurry D. 1993. Strategy through the option lens: an integrated view of resource investments and the incremental-choice process. *Academy of Management Review* **18**: 760–782.
- Bowman EH, Moskowitz GT. 2001. Real options analysis and strategic decision making. *Organization Science* **12**: 772–777.
- Brennan MJ, Trigeorgis L (eds). 2000. *Project Flexibility, Agency, and Competition: New Developments in the Theory and Application of Real Options*. Oxford University Press: New York.
- Bromiley P, Curley SP. 1992. Individual differences in risk taking. In *Risk-Taking Behavior*, Yates JF (ed). Wiley: Chichester; 87–132.
- Buckley A. 1998. *International Investment: Value Creation and Appraisal: A Real Options Approach*. Handelshøjskolens Forlag: Copenhagen.
- Busby JS, Pitts CGC. 1997. Real options in practice: an exploratory survey of how finance officers deal with flexibility in capital appraisal. *Management Accounting Research* **8**: 169–186.
- Chi T. 2000. Option to acquire or divest a joint venture. *Strategic Management Journal* **21**(6): 665–687.
- Chi T, McGuire DJ. 1996. Collaborative ventures and value of learning: integrating the transaction cost and strategic option perspectives on the choice of market entry modes. *Journal of International Business Studies* **27**: 285–307.
- Copeland T, Antikarov V. 2001. *Real Options: A Practitioner's Guide*. Texere: New York.
- Cox JC, Ross SA, Rubinstein M. 1979. Option pricing: a simplified approach. *Journal of Financial Economics* **7**: 229–263.
- DeGroot MH. 1975. *Probability and statistics*. Addison-Wesley: Menlo Park, CA.
- Fischhoff B. 1982. Debiasing. In *Judgment under Uncertainty: Heuristics and Biases*, Kahneman D, Slovic P, Tversky A (eds). Cambridge University Press: Cambridge, U.K.; 422–444.
- Folta TB. 1998. Governance and uncertainty: the trade-off between administrative control and commitment. *Strategic Management Journal* **19**(11): 1007–1028.
- Folta TB, Miller KD. 2002. Real options in equity partnerships. *Strategic Management Journal* **23**(1): 77–88.
- Fox CG, Rogers BA, Tversky A. 1996. Option traders exhibit subadditive decision weights. *Journal of Risk and Uncertainty* **13**: 5–17.
- Graham JR, Harvey CR. 2001. The theory and practice of corporate finance: evidence from the field. *Journal of Financial Economics* **60**: 187–243.
- Hartman SJ, Nelson BH. 1996. Group decision making in the negative domain. *Group & Organization Management* **21**: 146–162.
- Hoffman E, Spitzer ML. 1993. Willingness to pay vs. willingness to accept: legal and economic implications. *Washington University Law Quarterly* **71**: 59–114.
- Howell SD, Jägle AJ. 1997. Laboratory evidence on how managers intuitively value real growth options. *Journal of Business Finance and Accounting* **24**: 915–935.
- Ingersoll JE Jr, Ross SA. 1992. Waiting to invest: investment and uncertainty. *Journal of Business* **65**: 1–29.
- Kagel JH, Levin D. 1986. The winner's curse and public information in common value auctions. *American Economic Review* **76**: 894–920.
- Kahneman D, Knetsch JL, Thaler RH. 1991. Anomalies: the endowment effect, loss aversion, and status quo bias. *Journal of Economic Perspectives* **5**: 193–206.
- Kahneman D, Slovic P, Tversky A (eds). 1982. *Judgment under Uncertainty: Heuristics and Biases*. Cambridge University Press: Cambridge, U.K.
- Kahneman D, Tversky A. 1979. Prospect theory: an analysis of decision under risk. *Econometrica* **47**: 263–291.
- Kahneman D, Tversky A. 1984. Choices, values, and frames. *American Psychologist* **39**: 341–350.
- Kameda T, Davis JH. 1990. The function of the reference point in individual and group risk decision making. *Organizational Behavior and Human Decision Processes* **46**: 55–76.
- Kerr NL, MacCoun RJ, Kramer GP. 1996. When are N heads better (or worse) than one? Biased judgment in individuals versus groups. In *Understanding Group Behavior*. Vol. 1: *Consensual Action by Small Groups*, Witte EH, Davis JH (eds). Erlbaum: Mahwah, NJ; 105–136.
- Kirzner IM. 1985. *Discovery and the Capitalist Process*. University of Chicago Press: Chicago, IL.
- Knetsch JL, Sinden JA. 1984. Willingness to pay and compensation demanded: experimental evidence of an unexpected disparity in measures of value. *Quarterly Journal of Economics* **99**: 507–521.
- Kogut B. 1991. Joint ventures and the option to expand and acquire. *Management Science* **37**: 19–33.
- Kogut B, Kulatilaka N. 1994. Options thinking and platform investments: investing in opportunity. *California Management Review* **36**(2): 52–71.
- Lander DM, Pinches GE. 1998. Challenges to the practical implementation of modeling and valuing real options. *Quarterly Review of Economics and Finance* **38** (Special Issue): 537–567.

- Langer EJ. 1975. The illusion of control. *Journal of Personality and Social Psychology* **32**: 311–328.
- Laverty KJ. 1996. Economic 'short-termism': the debate, the unresolved issues, and the implications for management practice and research. *Academy of Management Review* **21**: 825–860.
- Levinthal D, March JG. 1993. The myopia of learning. *Strategic Management Journal*, Winter Special Issue **14**(2): 95–112.
- Levy H, Sarnat M. 1984. *Portfolio and Investment Selection*. Prentice-Hall: Englewood Cliffs, NJ.
- Loewenstein G. 1987. Anticipation and the valuation of delayed consumption. *Economic Journal* **97**: 666–684.
- Loewenstein G, Prelec D. 1992. Anomalies in intertemporal choice: evidence and interpretation. *Quarterly Journal of Economics* **108**: 573–597.
- Loomes G, Sugden R. 1982. Regret theory: an alternative theory of rational choice under uncertainty. *Economic Journal* **92**: 805–824.
- Loomes G, Sugden R. 1987. Some implications of a more general form of regret theory. *Journal of Economic Theory* **41**: 270–287.
- MacCrimmon KR, Wehrung DA. 1986. *Taking Risks: The Management of Uncertainty*. Free Press: New York.
- March JG, Shapira Z. 1987. Managerial perspectives on risk and risk taking. *Management Science* **33**: 1404–1418.
- McDonald RL. 2000. Real options and rules of thumb in capital budgeting. In *Project Flexibility, Agency, and Competition: New Developments in the Theory and Application of Real Options*, Brennan MJ, Trigeorgis L (eds). Oxford University Press: New York; 13–33.
- McDonald R, Siegel D. 1986. The value of waiting to invest. *Quarterly Journal of Economics* **101**: 707–727.
- McGrath RG. 1997. A real options logic for initiating technology positioning investments. *Academy of Management Review* **22**: 974–996.
- McGrath RG. 1999. Falling forward: real options reasoning and entrepreneurial failure. *Academy of Management Review* **24**: 13–30.
- Miller KD. 2002. Knowledge inventories and managerial myopia. *Strategic Management Journal* **23**(8): 689–706.
- Miller KD, Folta TB. 2002. Option value and entry timing. *Strategic Management Journal* **23**(7): 655–665.
- Miller KD, Waller HG. 2003. Scenarios, real options, and integrated risk management. *Long Range Planning* **36**(1): 93–107.
- Mischel W, Shoda Y, Rodriguez M. 1989. Delay of gratification in children. *Science* **244**: 933–938.
- Pratt JW. 1964. Risk aversion in the small and in the large. *Econometrica* **32**: 122–136.
- Ross J, Staw BM. 1986. Expo 86: an escalation prototype. *Administrative Science Quarterly* **31**: 274–297.
- Rumelt RP. 1987. Theory, strategy, and entrepreneurship. In *The Competitive Challenge: Strategies for Industrial Innovation and Renewal*, Teece DJ (ed). Harper & Row: New York; 137–158.
- Schoemaker PJH. 1982. The expected utility model: its variants, purposes, evidence and limitations. *Journal of Economic Literature* **20**: 529–563.
- Shapira Z. 1995. *Risk Taking: A Managerial Perspective*. Russell Sage Foundation: New York.
- Shapira Z, Venezia I. 1992. Size and frequency of prizes as determinants of the demand for lotteries. *Organizational Behavior and Human Decision Processes* **52**: 307–318.
- Slovic P. 1964. Assessment of risk taking behavior. *Psychological Bulletin* **61**: 220–233.
- Slovic P, Tversky A. 1974. Who accepts Savages' axioms? *Behavioral Science* **19**: 368–373.
- Smith JE, Nau RF. 1995. Valuing risky projects: option pricing theory and decision analysis. *Management Science* **41**: 795–816.
- Staw BM. 1981. The escalation of commitment to a course of action. *Academy of Management Review* **6**: 577–587.
- Strotz R. 1956. Myopia and inconsistency in dynamic utility maximization. *Review of Economic Studies* **23**: 165–180.
- Tetlock P. 2000. Cognitive biases and organizational correctives: do both disease and cure depend on the politics of the beholder? *Administrative Science Quarterly* **45**: 293–329.
- Thaler R. 1981. Some empirical evidence on dynamic inconsistency. *Economic Letters* **8**: 201–207.
- Thaler R. 1985. Mental accounting and consumer choice. *Marketing Science* **4**: 199–214.
- Triantis A, Borison A. 2001. Real options: state of the practice. *Journal of Applied Corporate Finance* **14**(2): 8–24.
- Trigeorgis L (ed). 1995. *Real Options in Capital Investment: Models, Strategies, and Applications*. Praeger: Westport, CT.
- Trigeorgis L. 1996. *Real Options: Managerial Flexibility and Strategy in Resource Allocation*. MIT Press: Cambridge, MA.
- Trigeorgis L, Mason SP. 1987. Valuing managerial flexibility. *Midland Corporate Finance Journal* **5**(1): 14–21.
- Tversky A, Fox CR. 1995. Weighing risk and uncertainty. *Psychological Review* **102**: 269–283.
- Tversky A, Kahneman D. 1992. Advances in prospect theory: cumulative representation of uncertainty. *Journal of Risk and Uncertainty* **5**: 297–323.
- Venezia I, Brenner M. 1979. The optimal duration of growth investments and search. *Journal of Business* **52**: 393–407.
- von Neumann J, Morgenstern O. 1944. *Theory of Games and Economic Behavior*. Princeton University: Princeton, NJ.