ASYMMETRIC PRICE DISTRIBUTION AND BID-ASK QUOTES IN THE STOCK OPTIONS MARKET

Kalok Chan

Department of Finance
Hong Kong University of Science & Technology
ClearWater Bay, Hong Kong
(852) 2358-7680
KACHAN@USTHK.UST.HK

Y. Peter Chung
A. Gary Anderson Graduate School of Management
University of California
Riverside, CA 92521, U.S.A.
Tel: (909) 787-3906
YCHUNG@CITRUS.UCR.EDU

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ABSTRACT

We present a model of the bid and ask quotes in the equity option market when option payoffs are asymmetrically distributed due to the limited liability of the option. We then provide empirical evidence for the actively-traded Chicago Board Options Exchange stock options, which is consistent with the implications of our model. First, the bid and ask quotes are asymmetric around the option value, with the value being closer to the bid quote than to the ask. Second, the degree of the asymmetry increases as the moneyness of the option decreases. Finally, the ask quote of an option changes more than its bid quote. An important implication of the paper is that the bid-ask midpoint is not an unbiased estimator of the option value, especially for out-of-the-money options.

I. Introduction

Researchers in finance are interested in equilibrium values of financial assets. Since market prices reflect the market's expectation of asset values, they allow investors to make inferences regarding market consensus. However, the prices we observe in financial markets are not necessarily equal to equilibrium values. In general, the price at which an investor can sell (buy) is lower (higher) than the value of the asset. The difference between the selling price (bid price) and the buying price (ask price) constitutes a bid-ask spread, which reflects the transaction costs of trading. Bid-ask spreads compensate dealers for providing immediacy service - the convenience of trading without significant delay. Market microstructure theory implies that bid-ask spreads cover three cost components: order-processing costs, inventory-carrying costs, and adverse information costs.

The problem of not observing the asset values could be easily handled if those values lie at the bid-ask midpoints. In this case, if bid and ask quotes are available, one can infer the asset value from the average of the two quotes.[1] However, the bid and ask prices quoted by dealers are not necessarily symmetric around the asset value. Several reasons are provided in the literature. Bossaerts and Hillion (1991) show that in the foreign-exchange markets, the possibility of government intervention causes skewness in the distribution of the future changes in spot exchange rates, so that bid-ask quotes of the currency forward contracts are not symmetric around the forward prices . In the inventory models (Stoll (1978), Ho and Stoll (1981) and Stoll (1989)), dealers tend to change the position of the spread relative to the "true" value in order to

[1] Even when only transaction prices are observable, the transaction price can be an unbiased estimate of the asset vaue if we assume that transactions take place randomly at the bid and ask quotes

induce public orders that would even out the inventory position of the dealer and allow him to go back to his optimal inventory position. Bessembinder (1994) finds that in the foreign-exchange markets, the location of the quotes in relation to the asset value is not constant, but is sensitive to several dealer inventory-control variables. Recently, Anshuman and Kalay (1998) show that the discreteness of stock quotes in multiples of 1/8 th of a dollar can cause asymmetry of the quotes around the true stock value.

In this paper, we demonstrate another important reason why bid and ask quotes are asymmetric around the asset value. In particular, we examine how dealers set the bid-ask quotes in the options markets, and show that there is an asymmetry of bid-ask quotes for stock options, even if there is no asymmetry for their underlying stocks. Our analysis is closely related to Bossaerts and Hillion (1991), who show that bid-ask quotes are symmetric only if the distribution of future price changes is symmetric. One reason the dealer sets a bid-ask spread is that he faces an adverse-selection problem: a customer agreeing to trade at the ask or bid price may know something that the dealer does not. The customer would buy if he knows that the security is undervalued, and sell if it is overvalued. To protect himself from this adverse selection, the dealer will set the bid (ask) price to be lower (higher) than the value of the asset. If the distribution of future price changes is symmetric, adverse-selection costs on buy and sell sides will be the same. In this case, bid and ask commissions are set to be equal[2], resulting in a symmetry of bid and ask quotes around the expected value.

As for stock options, because of limited liability of the option holders, the distribution of

[2]Bid commission equals the difference between the asset value and the bid price, and ask commission equals the difference between the ask price and the asset value.

the option payoffs is not symmetric. Since the loss is limited for buying an option but unlimited for selling, the dealer is more vulnerable to buy orders than to sell orders. As the adverse-selection cost is larger for buy orders than for sell orders, the ask commission charged by the dealer will be higher than the bid commission, so that the value of an option is closer to the bid quote than to the ask.

We examine empirically the location of the asset value relative to bid-ask quotes for stock options and their underlying stocks. Consistent with the prediction of our model, evidence indicates that bid-ask quotes are asymmetric for actively-traded Chicago Board Options Exchange (CBOE) stock options, with the option value closer to the bid quote than to the ask. The asymmetry is more pronounced when the option is out-of-the-money than when it is in-the-money. Furthermore, because of the truncated distribution of option payoffs, the bid-price change is less than the ask-price change.

This paper augments the literature on the microstructure of the options market, and, in particular, on the determination of bid-ask quotes in the stock options market. John, Koticha and Subrahmanyam (1991) examine the impact of trading in options markets on the stock's bid-ask spread, and characterize the relation between bid-ask spreads in the markets for the options and their underlying stocks. Biais and Hillion (1994) examine the formation of option transaction prices in an imperfect market, and study how risk-averse dealers adjust bid and ask quotes when facing both liquidity and informed traders. Ho and Macris (1984) test the inventory paradigm of Ho and Stoll (1981) on option prices, and show how the dealer's inventory position affects the bid-ask spreads on the American Stock Exchange (AMEX). Jameson and Wilhelm (1992) demonstrate that the option market maker's inability to rebalance his inventory position continuously and the uncertainty about the return volatility of the underlying stock also contributes to the bid-ask spreads in the option market. George and Longstaff (1993) find that bid-ask spreads in the Standard and Poors 100 index (OEX) options market are related to differences in market-making costs and trading activity across different options. While all these earlier studies examine how the size of the option spread is affected by various explanatory variables, our study focuses on the location of the option spread relative to the value of an option. An importance implication of our results is that the bid-ask midpoint is not an unbiased estimator of the option value, especially for out-of-the-money options. Therefore, one should be cautious, for example, in inferring the trade direction by comparing the trade price with the bid-ask midpoint.

The paper is organized as follows. Section II outlines a model of the bid-ask quote determination in the stock and options markets, followed by some numerical examples. Section III integrates the stock and options markets together, and introduces put-call parity into the analysis. Section IV presents the sample and empirical evidence. Section V concludes the paper.

II. The Model

We assume that there is an individual stock, a call and a put option contract written on one share of the stock. Both option contracts are of European style. Let S_T be the value of the stock at time T, the expiration date of the option contract. At time 0, S_T is uncertain, and is equal to $S_T = S_0 + \delta$, where S_0 is the current stock value, and δ is a random variable with the probability density function $f(\delta)$. We assume that all agents (market makers and traders) are risk neutral, and that the interest rate is zero. To preclude arbitrage, the expected stock return and, therefore, the mean of δ have to be equal to zero. The values of the call and put on the expiration date are Max[0, S_T - X] and Max[0, X - S_T] respectively, where X is the exercise price of the option.

Similar to Admati and Pfleiderer (1989), Bossaerts and Hillion (1994), and Easley, O'Hara and Srinivas (1998), we assume both the stock and option markets to be competitive dealer systems where a large number of risk-neutral dealers commit to take either side of the market. They set the bid and ask quotes, which are valid for one unit of the stock or the option. In both markets, the dealers face two different types of traders, namely, informed and liquidity traders. The informed traders observe the random variable δ, and, therefore, know the true value of the stock and the option at time T.

A. Bid and Ask Prices of the Stock

The stock dealers have to set bid and ask quotes (B_S and A_S) for trading with anonymous investors, who could either be informed or liquidity traders. We assume that the ratio of liquidity traders to informed traders is N_S, and the probability of the liquidity trader buying or selling one unit of stock is 1/2. Each informed trader will buy one unit of stock if the stock value is higher than the ask price ($S_T > A_S$), and will sell one unit of stock if the stock value is lower than the bid price ($S_T < B_S$).

Since dealers are assumed to be risk neutral and face the adverse-selection problem, they will set bid and ask quotes such that their expected profits from liquidity traders offset their expected losses to informed traders. Thus, the ask price (for the buy order) has to satisfy the condition :

$$\frac{1}{2} N_S \int (A_S - S_0) = \int_{S_T > A_S} (S_T - A_S) f(S_T) dS_T \ , \tag{1}$$

where $f(S_T)$ is the probability density function of S_T, and is equal to $f(\delta)$ because $S_T = S_0 + \delta$. The bid price (for the sell order) has to satisfy the condition:

$$\frac{1}{2} N_S (S_0 - B_S) = \int_{S_T < B_S} (B_S - S_T) f(S_T) dS_T \ . \tag{2}$$

We could see that equations (1) and (2) are symmetric. In fact, as suggested by Bossaerts and Hillion (1991), if the distribution of $f(S_T)$ is symmetric, then the stock value (S_o) will be halfway between the bid and ask quotes (B_S, A_S).

B. Bid and Ask Prices of the Call Option

The model setting is similar to that for the stock. The call option dealers have to set bid and ask quotes (B_C and A_C) for trading with anonymous investors. The ratio of liquidity traders to informed traders is N_C. The probability of each liquidity trader buying or selling one unit of call is 1/2. The profit for the trader from buying a call is $Max[0, S_T - X] - A_C$, while the profit from selling a call is $B_C - Max[0, S_T - X]$. The potential profit (or loss) per contract can be summarized in the following tables:

Profit from buying a call

Scenario	$S_T < X$	$X < S_T < X + A_C$	$X + A_C < S_T$
Profit	$- A_C < 0$	$S_T - X - A_C < 0$	$S_T - X - A_C > 0$

Profit from selling a call

Scenario	$S_T < X$	$X < S_T < X + B_C$	$X + B_C < S_T$
Profit	$B_C > 0$	$X - S_T + B_C > 0$	$X - S_T + B_C < 0$

Informed traders will trade if there is a positive profit from the purchase or the sale. The call option dealers set the bid and ask quotes such that their expected profits from liquidity traders offset their expected losses to informed traders. Thus, the ask price (for the buy order) has to satisfy the condition:

$$\frac{1}{2} N_C \left(A_C - C_0\right) = \int_{S_T > A_C + X} \left(S_T - X - A_C\right) f\left(S_T\right) dS_T \ , \qquad (3)$$

where C_0 is the value of the call, and is equal to $\int_{S_T > X} \left(S_T - X\right) f\left(S_T\right) dS_T$. The bid price (for the sell order) has to satisfy the condition:

$$\frac{1}{2} N_C (C_0 - B_C) = \int_{S_T < X} B_C f\left(S_T\right) dS_T + \int_X^{X+B_C} \left(B_C + X - S_T\right) f\left(S_T\right) dS_T \ . \qquad (4)$$

Unlike the case of the stock, the two equations ((3) and (4)) that determine ask and bid prices of the call option are not symmetric. Therefore, even if the distribution of $f(S_T)$ is symmetric, there is no guarantee that the call value (C_o) will be halfway between the bid and ask quotes (B_C, A_C).

C. Bid and Ask Prices of the Put Option

The model setting is similar. The put option dealers have to set bid and ask quotes (B_P and A_P) for trading with anonymous investors. The ratio of liquidity traders to informed traders is N_P. The probability of each liquidity trader buying or selling one unit of put is 1/2. The profit for the trader from buying a put is $Max[0, X - S_T] - A_P$, whereas the profit from selling a put is $B_P - Max[0, X - S_T]$. The potential profit (or loss) per contract can be summarized in the following tables:

Profit from buying a put

Scenario	$S_T < X - A_P$	$X - A_P < S_T < X$	$X < S_T$
Profit	$X - S_T - A_P > 0$	$X - S_T - A_P < 0$	$- A_P < 0$

Profit from selling a put

Scenario	$S_T < X - B_P$	$X - B_P < S_T < X$	$X < S_T$
Profit	$S_T - X + B_P < 0$	$S_T - X + B_P > 0$	$B_P > 0$

Informed traders will trade if there is a positive profit to make from the purchase or the sale. The put option dealers set bid and ask quotes such that their expected profits from liquidity traders offset their expected losses to informed traders. This implies that the ask price (for the buy order) has to satisfy the condition

$$\frac{1}{2} N_P (A_P - P_0) = \int_{S_T < X - A_P} (X - S_T - A_P) f(S_T) dS_T , \tag{5}$$

where P_0 is the value of the put, and is equal to $\int_{S_T < X} (X - S_T) f(S_T) dS_T$. The bid price (for the sell order) has to satisfy:

$$\frac{1}{2}N_P(P_0 - B_P) = \int_{X-B_P}^{X}(S_T - X + B_P)f(S_T)dS_T + \int_{S_T > X} B_P f(S_T)dS_T \ . \tag{6}$$

Similar to the case of the call option, the two equations ((5) and (6)) that determine ask and bid prices of the put option are not symmetric. We would not expect that the put value (P_o) is halfway between the bid and ask quotes (B_P, A_P).

D. Numerical Analysis

This section provides numerical analysis of bid and ask quotes in the options market, using equations (3) through (6). Our conjecture is that even if the distribution of underlying stock price at expiration is symmetric, the option value will not be located at the midpoint of the quoted spread. In particular, we demonstrate the extent to which bid and ask quotes are asymmetric in the options markets, and how the degree of asymmetry varies with the moneyness of the options.

In the first experiment, we assume that the stock price at expiration is normally distributed, with $S_T \sim N(S_0, S_0\sigma\sqrt{T})$, where σ is the annualized standard deviation of the stock return. A drawback of assuming normal distribution is that it allows for the possibility of a negative stock price. An advantage is that it is a symmetric distribution, and therefore, we can demonstrate that the resulting asymmetry of the option's bid-ask quotes is induced purely by the truncation properties of option prices rather than by the asymmetric distribution of the underlying stock prices. We simulate bid and ask quotes with inputs for model parameters: N_c=N_P=3, X=\$50, σ=25%, and T=0.25.

Panel A of Table 1 presents the simulated bid and ask quotes of a call option and a put option at different current stock prices (S_0). The degree of asymmetry is measured by the ratio of the ask commission to the bid-ask spread. If the option value is at the midpoint of the bid-ask spread, the degree of asymmetry should be equal to 0.5 However, Panel A reveals that degree of asymmetry are greater than 0.5 in all cases, indicating that the option value is closer to the bid quote than to the ask. Furthermore, the degree of asymmetry decreases (increases) with the current stock value for the call (put) option, suggesting that the asymmetry is higher when the option is out-of-the-money. We also examine how the bid quote changes relative to the ask quote, conditional on the underlying stock price change. Results indicate that bid quote changes are generally smaller than ask quote changes, and the relative changes are again related to the moneyness of the option. For the call option, the relative bid/ask price change is 0.565 when the stock price moves from $46 to $47 (call is out-of-the-money), but it is 0.804 when the stock price moves from $54 to $55 (call is in-the-money).

In the second experiment, we assume that the stock price at expiration is log-normally distributed, with $\ln S_T \sim N(\ln S_0, \sigma\sqrt{T})$. We then simulate bid and ask quotes with the same model parameters: $N_c=N_P=3$, X=$50, σ=25%, T=0.25. Results are presented in Panel B of Table 1. Again, the asymmetry measures are greater than 0.5 for different current stock prices. In fact, results are very close to the ones reported in Panel A. This suggests that the degree of asymmetry is driven primarily by the truncated price distribution of the options, rather than by the asymmetrical price distribution of the underlying stock.

III. Put-Call Parity

Our analysis has yet to integrate the stock and options markets. As the payoff of a stock can be duplicated through a combination of call, put, and bond, there exists a put-call parity relationship among the bid-ask quotes of the stock, call, and put.

First, since the payoff at the expiration date of the option contract from buying a call plus selling a put is equivalent to the payoff of a portfolio of a long position in the stock and a short position of X dollars in the riskless bond, [3] the initial cash flows setting up the two distinct investments should be the same. This results in the put-call parity relation:

$$- A_c + B_p = - A_s + X . \qquad (7)$$

Likewise, since the payoff at the expiration date of the option contract from selling a call plus buying a put is equivalent to the payoff of a portfolio of a short position in the stock and a long position of X dollars in the riskless bond, we obtain

$$B_c - A_p = B_s - X . \qquad (8)$$

We can compare equations (7) and (8) with the standard put-call parity relation (where there are no bid and ask commissions):

$$C_0 - P_0 = S_0 - X . \qquad (9)$$

We define a_c and b_c as the ask and bid commissions of the call option, where $a_c = A_c - C_o$, $b_c = C_0 - B_C$, and define a_p and b_p as the ask and bid commissions of the put option, where $a_p = A_p - P_o$, $b_p = P_0 - B_p$. One can see that there is a relation among the bid and ask commissions in the stock and options market. If we combine equations (7) and (9), we obtain $a_c + b_p = a_s$. If we combine

[3] Since we assume that the interest rate is zero, the discounted value of the exercise price (X) is equal to X.

equations (8) and (9), we obtain $a_p + b_c = b_{s.}$ Therefore, if the stock bid and ask commissions are symmetric (i.e., $a_{s.} = b_s$), then $a_c + b_p = a_p + b_c$. In other words, while the bid and ask commissions are asymmetric for the call and the put separately, the total commission of the put-call portfolio that replicates the payoff of the underling stock is symmetric.

The existence of the put-call parity in (7) and (8) implies that once the ratio of liquidity traders to informed traders in one market is fixed, the ratio for the other market could be endogenously determined. The intuition is as follows. Suppose informed traders trade only in the option markets. Then, while the option dealers set a positive bid-ask spread to protect themselves from adverse-selection, the stock dealers would set the spread to zero due to the absence of informed trading. However, we can see that this is not in equilibrium. The option dealers could now eliminate the adverse-selection risk simply by hedging the call and put positions with an opposite position in the stock market. In that case, without bearing any risk, the option dealers make a profit from the difference of the spreads in the stock and options market. The profits for option dealers arise from a transfer of the adverse-selection risk to the stock dealers at zero cost. From the viewpoint of stock dealers, this is effectively equivalent to an increase in informed trading in the stock market. If stock dealers are rational, they should increase the bid-ask spread to the point where that the option dealers could not profit from the risk transfer.

We perform a numerical analysis of the equilibrium number of informed traders in the options market. We again assume the stock price at the expiration day follows a normal distribution, with $S_T \sim N(S_0, S_0\sigma\sqrt{T})$, and use the same model parameters: N_S=3, X=\$50, σ=25%, and T=0.25. Note that the ratios of liquidity traders to informed traders in the options market (N_C , N_P) are no longer assumed to be exogenous. Instead, we solve for N_C and N_P, along with six bid-ask quotes (A_S, B_S , A_C, B_C , A_P, B_P), such that equations (1) through (8) are satisfied.

Table 2 presents the results. A couple of interesting results are noted. First, the ratios of liquidity traders to informed traders in the options market (N_C , N_P) are higher than the ratio in the stock market (N_S), which is assumed to be equal to 3. This is consistent with our intuition. Because of the leverage effect, informed traders could exploit the information advantage more in the options market than in the stock market. Therefore, in equilibrium, the option market requires more liquidity traders so that the option dealers could break even. Second, holding exercise price constant at $50, N_C decreases with the current stock price, while N_P increases with the stock price. This is because when the options are out-of-the-money, the leverage effect becomes larger, and that the information advantage for informed traders is greater. Therefore, more liquidity traders are required in the options market when the options are out-of-the-money.

IV Empirical Evidence

A. Econometric Methodology

This section provides empirical evidence of the degree of bid-ask asymmetry and, also, of the relative bid/ask price changes for stock options. Since the equilibrium option value is not observable, we follow Bossaerts and Hillion (1991) and Bessembinder (1994) in estimating the location of bid-ask quotes relative to the option value. We illustrate our method for the call option.

Let θ be a constant ($0 < \theta < 1$) such that

$$_t = \theta B_{c,t} + \quad - \theta) A_{c,t}$$

where C is the call value, A is the ask quote, and B is the bid quote at time t. The coefficient θ a location parameter that measures the proximity of the bid and ask quotes relative to the call value. The call value is closer to θ is less than θ is greater than 1/2. Equation (10) could also be expressed in terms of

$$\Delta C_t = \theta \Delta B_{c,t} + (1 - \theta) \Delta A_{c,t} . \qquad (11)$$

Denoting $\Delta SPD_{c,t} = \Delta A_{c,t} - \Delta B_{c,t}$ as the change in the bid-ask spread for the call, equation (11) can be rewritten as

$$\Delta A_{c,t} = \theta \Delta SPD_{c,t} + \Delta C_t . \qquad (12)$$

Although the change in the call value (ΔC_t) is unobservable, an investor could infer the expected change in the call value from the change in the underlying stock price (ΔS_t), as $\Delta C_t = E(\Delta C_t|\Delta S_t) + \varepsilon_t$, where ε_t is a prediction error that is uncorrelated with ΔS_t. The prediction error could be interpreted as information that affects the option value but not the underlying stock price, and may include changes in stock price volatility, dividend distributions (as stock options are not payout- protected), and decay in the time value of the option through time. Since the conditional expectation $E(\Delta C_t|\Delta S_t)$ is likely to be nonlinear, we estimate the regression for changes in ask prices by including both ΔS_t and $(\Delta S_t)^2$ as independent variables:

$$\Delta A_{c,t} = \alpha_0 + \alpha_1 \Delta SPD_{c,t} + \alpha_2 \Delta S_t + \alpha_3 (\Delta S_t)^2 + \varepsilon_t . \qquad (13)$$

The regression coefficient α_1 provides an estimate of the location parameter (θ), whereas the coefficient α_2 provides an estimate of the hedge ratio. We test whether the coefficient α_1 is equal to 1/2. A value equal to ½ for the parameter α_1, for example, would indicate that the option values are exactly halfway between the bid and the ask quotes.

B. Sample Data and Empirical Results

We collect daily bid-ask quotes from two sources of data: the Berkeley Options Database (for stock options) and the Institute for the Study of Security Markets Data (for underlying stocks). The sample period is from January to March, 1986. For every stock option, we collect the closing bid-ask quotes for the day and match them with the closing bid-ask quotes for its underlying stock. To mitigate the nonsynchronous quotation arising from thin trading, we require the closing bid-ask quotes to occur in the last thirty-minute interval. We then compute daily changes in bid quotes, ask quotes, and spreads for calls and puts. We also compute daily changes in stock prices, using the stock bid-ask midpoints. Since there are missing observations for some options or underlying stocks on some days (i.e., there is no quote in the last thirty-minute interval), price changes could span more than two trading days on relatively rare occasions.

Table 3 presents results for sample regressions of bid quote changes on ask quote changes. Panel A reports results for call options whereas Panel B reports results for put options.   Results are stratified by the moneyness of options, which is defined as the ratio of the stock price to the exercise price for call options, or as the ratio of the exercise price to the stock price for put options.   Consistent with our model, all the slope coefficients are less than unity, indicating that option bid quotes change less than corresponding option ask quotes. Also, the slope coefficients decline as the moneyness of the options declines.   For deep-in-the-money options (quartile 4), for example, the slope coefficients are 0.9906 (for calls) and 0.9804 (for puts). For deep-out-the-money options (quartile 1), the slope coefficients are 0.9593 (for calls) and 0.9172 (for puts). For comparison, we also estimate a similar regression for underlying stocks. The slope coefficient is 0.9892 for stocks underlying call options, and 0.9903 for stocks underlying put options. These coefficients for stocks are higher than those in most of the quintiles for call and puts.

One alternative explanation for the bid price change to be smaller than the ask price change is that the price is very low for the out-of-the-money option, so that the bid price will not be revised downward on a down-market. If this is indeed the case, the bid price change will be smaller than the ask price change only when the market is going down, but not when it is going up. To examine this possibility, we re-estimate the regressions for the up-market and the down-market separately. The up- (down-) market is defined as the case when the ask price of an option is higher (lower) than that of the previous day. Results are reported in Table 4. We find that for both the call and put options, the bid price change is smaller than the ask price change, regardless of whether the market is going up or down.

Table 5 presents estimates of the location parameter by regressing changes in option ask quotes on changes in option spreads and changes in underlying stock prices. Since the hedge ratio varies with the moneyness of the option, we estimate the regression for subgroups of options stratified by their moneyness. Results for call options are reported in Panel A. The coefficients α_1 are in the range [0.5 , 1]. The estimate of α_1 is inversely related to the moneyness of the options, declining from 0.6942 for quartile 1 to 0.5268 for quartile 4. This suggests that the option value is closer to the bid quote than to the ask quote, and that the asymmetry is more pronounced when the option is further out-of-the-money. Consistent with what we expect, the coefficients associated with stock-price changes (hedge ratios) are all positive and less than unity, but increase with the moneyness of the options.

Results for put options are reported in Panel B. The coefficients α_1 are also larger than 1/2, and are inversely related to the moneyness of options. In fact, the estimate of α_1 is 0.9493 for quartile 1, suggesting that the option value is almost at the bid price. This might reflect the fact that the actively-traded options tend to be deep-out-of-the-money (average moneyness ratio = 0.8840). The hedge-ratio coefficients are all negative and larger than negative unity, but their absolute value decreases with the moneyness of the put.

V. Conclusion

We present a model of the bid and ask quotes in the stock option market when option payoffs are asymmetrically distributed due to the limited liability of the option. We then provide empirical evidence from the actively-traded CBOE stock options, which is consistent with the implications of our model. First, while the bid and ask quotes are symmetric around the stock values, they are asymmetric around option values, with the value closer to the bid quote than to the ask. Second, the degree of the asymmetry decreases as the moneyness of the option increases. The set of empirical evidence appears to be inconsistent with the view that the average of the bid and ask quotes is an unbiased estimator of the option value, especially for out-of-the-money options.

Our results have important implications. The first involves the specification of tests of option pricing model. In their tests of the performance of option pricing models, researchers typically use the midpoint of the bid ask quotes as a proxy for the market price and compare it to various model prices. Our results suggest, however, that the option value is closer to the bid than to the ask. Using the midpoint of bid-ask quotes is likely to overstate the corresponding option value. The second area of concern is on the inferences of trade directions from the option transactions data. Following Lee and Ready's (1991) method for NYSE transactions data, Vijh (1990) and Easley, O'Hara, and Srinivas (1998) try to infer the initiator of the option trade on the CBOE by comparing the trade price with the most recent bid and ask quotes. If the trade price is higher (lower) than the quote midpoint, they infer that it is initiated by the buyer (seller). Our model and empirical results suggest that the algorithm used in Vijh (1990) and Easley, O'Hara, and Srinivas (1998) is biased for the options data, even if it would be acceptable for the stock data.

Certainly, our model focuses only on adverse selection, and it is possible that the phenomenon we document here is due to other factors (e.g. inventory control). This can be determined only by further research. Whatever the cause is, however, our research demonstrates the importance of the issue for subsequent research.

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Table 1
Numerical analysis of bid and ask prices for the call and put options with the following assumptions: (a) the interest rate is zero; (b) the maturity of the options is 3 months; (c) stock price at expiration date is either normally distributed or lognormally distributed; (d) the expected stock return is 0% and the annualized standard deviation of stock returns is 25%; (e) the exercise price is $50; and (f) the ratio of liquidity traders to informed traders is 3. Degree of asymmetry is defined as the ask commission (ask price - option value) divided by the spread (ask price - bid price). Relative bid/ask price change is the bid price change divided by ask price change of the option.

Panel A: Assuming stock price is normally distributed

	Call Option					Put Option				
Current stock value	Value	Ask price	Bid Price	Degree of Asymmetry	Relative bid/ask price change	Value	Ask price	Bid Price	Degree of Asymmetry	Relative bid/ask price change
46.000	1.203	1.727	0.806	0.569		5.203	6.358	4.127	0.518	
47.000	1.563	2.194	1.070	0.561	0.565	4.563	5.679	3.544	0.522	0.859
48.000	1.982	2.721	1.386	0.553	0.599	3.982	5.050	3.027	0.528	0.822
49.000	2.459	3.305	1.756	0.546	0.633	3.459	4.471	2.574	0.533	0.782
50.000	2.992	3.942	2.181	0.540	0.667	2.992	3.942	2.181	0.540	0.744
51.000	3.578	4.628	2.661	0.534	0.700	2.578	3.462	1.842	0.546	0.705
52.000	4.213	5.358	3.193	0.528	0.728	2.213	3.028	1.552	0.552	0.669
53.000	4.895	6.128	3.775	0.524	0.756	1.895	2.640	1.306	0.559	0.635
54.000	5.618	6.934	4.404	0.520	0.780	1.618	2.294	1.097	0.565	0.603
55.000	6.378	7.771	5.077	0.517	0.804	1.378	1.986	0.920	0.571	0.574

Panel B: Assuming stock price is lognormally distributed

	Call Option					Put Option				
Current stock value	Value	Ask price	Bid Price	Degree of Asymmetry	Relative bid/ask price change	Value	Ask price	Bid Price	Degree of Asymmetry	Relative bid/ask price change
46.000	1.472	2.110	0.989	0.569		4.952	6.031	3.933	0.514	
47.000	1.845	2.591	1.264	0.562	0.573	4.314	5.348	3.356	0.519	0.844
48.000	2.274	3.127	1.589	0.555	0.606	3.731	4.712	2.843	0.525	0.808
49.000	2.758	3.718	1.967	0.548	0.639	3.204	4.125	2.390	0.531	0.770
50.000	3.297	4.361	2.398	0.542	0.671	2.732	3.586	1.996	0.537	0.733
51.000	3.890	5.053	2.885	0.537	0.703	2.313	3.097	1.655	0.544	0.696
52.000	4.532	5.790	3.425	0.532	0.733	1.944	2.655	1.364	0.551	0.658
53.000	5.223	6.569	4.018	0.528	0.762	1.623	2.261	1.118	0.558	0.625
54.000	5.957	7.385	4.660	0.524	0.787	1.346	1.911	0.911	0.565	0.591
55.000	6.731	8.234	5.349	0.521	0.811	1.109	1.603	0.738	0.572	0.561

Table 2
Numerical analysis of bid and ask prices for the call and put options with the following assumptions: (a) the interest rate is zero; (b) the maturity of the options is 3 months; (c) stock price at expiration date is normally distributed; (d) the expected stock return is 0% and the annualized standard deviation of stock returns is 25%; (e) the exercise price is $50; and (f) the ratio of liquidity traders to informed traders in the stock market is 3. Stock price at expiration date is assumed to be normally distributed.

	Ratio of liquidity traders to informed traders		Stock Quotation		Call Option Quotation		Put Option Quotation	
Current stock value	Call Option	Put Option	Ask	Bid	Ask	Bid	Ask	Bid
46	4.31	3.20	47.40	44.60	1.58	0.90	6.30	4.18
47	4.08	3.28	48.44	45.56	2.04	1.17	5.60	3.61
48	3.90	3.36	49.47	46.53	2.57	1.49	4.95	3.10
49	3.73	3.47	50.50	47.50	3.16	1.86	4.36	2.66
50	3.59	3.59	51.53	48.47	3.81	2.28	3.81	2.28
51	3.47	3.73	52.56	49.44	4.51	2.75	3.31	1.95
52	3.38	3.88	53.59	50.41	5.25	3.28	2.87	1.66
53	3.30	4.03	54.62	51.38	6.04	3.85	2.47	1.42
54	3.24	4.18	55.65	52.35	6.85	4.47	2.12	1.21
55	3.19	4.34	56.68	53.32	7.70	5.14	1.81	1.02

Table 3
Regression of daily changes in the bid quotes on corresponding changes in the ask quotes for the actively traded CBOE stock options, stratified by the moneyness of the options. The sample period is from January to March 1986. Moneyness is defined as the ratio of the stock price to the exercise price for call options, or as the ratio of the exercise price to the stock price for put options. Standard errors are in parentheses.

$$\Delta B_{i,t} = \alpha_0 + \alpha_1 \Delta A_{i,t} + \varepsilon_t \quad \text{i=calls, puts, or stocks}$$

Panel A: Call Options and Underlying Stocks

Moneyness Quartile	Mean Moneyness Ratio	Number of observations	α_0	α_1	Adhysted R^2
1	0.9168	6719	0.0040 (0.0017)	0.9593 (0.0021)	0.9688
2	1.0056	7106	0.0016 (0.0018)	0.9691 (0.0015)	0.9829
3	1.0940	7143	-0.0007 (0.0019)	0.9810 (0.0011)	0.9913
4	1.3270	7018	0.0008 (0.0021)	0.9906 (0.0008)	0.9953
Stocks		5225	0.0043 (0.0025)	0.989 (0.0013)	0.9911

Panel B: Put Options and Underlying Stocks

Moneyness Quartile	Mean Moneyness Ratio	Number of observations	α_0	α_1	Adjusted R^2
1	0.8840	3678	-0.0013 (0.0025)	0.9172 (0.0034)	0.9505
2	0.9692	3728	0.0062 (0.0026)	0.9493 (0.0024)	0.9763
3	1.0272	3615	0.0003 (0.0025)	0.9618 (0.0019)	0.9858
4	1.1701	3346	-0.0009 (0.0024)	0.9804 (0.0017)	0.9906
Stocks		3674	0.0019 (0.0031)	0.9903 (0.0015)	0.9913

Table 4
Regression of daily changes in the bid quotes on corresponding changes in the ask quotes for the actively traded CBOE stock options, stratified by the moneyness of the options and by the market condition. The sample period is from January to March 1986. Market condition is "up" ("down") if the ask price of an option is higher (lower) than that of the previous day. Moneyness is defined as the ratio of the stock price to the exercise price for call options, or as the ratio of the exercise price to the stock price for put options. Standard errors are in parentheses.

$$\Delta B_{i,t} = \alpha_0 + \alpha_1 \Delta A_{i,t} + \varepsilon_t \quad \text{i=calls, puts, or stocks}$$

Panel A: Call Options

Moneyness Quartile	Market Condition	Number of Obs.	α_0	α_1	Adjusted R^2
1	up	1557	-0.0220	0.9579	0.8547
			(0.0053)	(0.0100)	
	Down	2153	0.0359	0.9649	0.9697
			(0.0039)	(0.0037)	
2	Up	2076	-0.0133	0.9553	0.9300
			(0.0051)	(0.0058)	
	Down	1613	0.0356	0.9750	0.9831
			(0.0049)	(0.0032)	
3	Up	2373	-0.0275	0.9743	0.9752
			(0.0052)	(0.0032)	
	Down	1339	0.0294	0.9706	0.9732
			(0.0066)	(0.0044)	
4	Up	2485	-0.0317	0.9765	0.9850
			(0.0062)	(0.0024)	
	Down	1219	0.0614	0.9810	0.9494
			(0.0087)	(0.0065)	
all	Up	8491	-0.0271	0.9742	0.9794
			(0.0026)	(0.0015)	
	Down	6324	0.0391	0.9724	0.9722
			(0.0028)	(0.0021)	

Panel B: Put Options

Moneyness Quartile	Market Condition	Number of Obs.	α_0	α_1	Adjusted R^2
1	Up	1069	-0.0434	0.9687	0.9784
			(0.0081)	(0.0044)	
	Down	794	0.0449	0.9505	0.9521
			(0.0106)	(0.0076)	
2	Up	782	-0.0235	0.9358	0.9072
			(0.0083)	(0.0107)	
	Down	1083	0.0540	0.9522	0.9740
			(0.0068)	(0.0047)	
3	Up	675	-0.0116	0.8800	0.7190
			(0.0093)	(0.0212)	
	Down	1190	0.0408	0.9443	0.9620
			(0.0060)	(0.0054)	
4	Up	515	-0.0417	0.8808	0.6650
			(0.0092)	(0.0276)	
	Down	1349	0.0291	0.8996	0.9307
			(0.0054)	(0.0067)	
all	Up	3041	-0.0426	0.9644	0.9659
			(0.0039)	(0.0033)	
	down	4416	0.0442	0.9427	0.9609
			(0.0034)	(0.0029)	

Table 5

Regression of daily changes in option ask quotes on corresponding changes in option spreads and changes in underlying stock prices, stratified by the moneyness of the options. The sample is from January to March 1986 for the actively traed CBOE options and their underlying stocks. Moneyness is defined as the ratio of the stock price to the exercise price for call options, or as the ratio of the exercise price to the stock price for put options. Standard errors are in parentheses.

$$\Delta A_{c,t} = \alpha_0 + \alpha_1 \Delta SPD_{c,t} + \alpha_2 \Delta S_t + \alpha_3 (\Delta S_t)^2 + \varepsilon_t$$

Panel A: Call Options

Moneyness Quartile	Mean Moneyness Ratio	Number of Obs.	α_1	α_2	α_3	Adjusted R^2
1	0.9168	6719	0.6942 (0.0319)	0.3050 (0.0027)	-0.0089 (0.0002)	0.7902
2	1.0056	7106	0.5883 (0.0320)	0.5254 (0.0025)	-0.0094 (0.0002)	0.8781
3	1.0940	7143	0.6277 (0.03121)	0.7291 (0.0023)	-0.0048 (0.00023)	0.9404
4	1.3270	7018	0.5268 (0.0312)	0.8544 (0.0025)	0.0020 (0.0002)	0.9680

Panel B: Put Options

Moneyness Quartile	Mean Moneyness Ratio	Number of Obs.	α_1	α_2	α_3	Adjusted R^2
1	0.8840	3678	0.9493 (0.0445)	-0.1373 (0.0025)	-0.0012 (0.0002)	0.6478
2	0.9692	3728	0.18261 (0.0429)	-0.3130 (0.0027)	-0.0095 (0.0002)	0.8403
3	1.0272	3615	0.8175 (0.0509)	-0.5115 (0.0035)	-0.0078 (0.0003)	0.8696
4	1.1701	3346	0.7208 (0.0675)	-0.6896 (0.0058)	-0.0099 (0.0006)	0.8575