JOURNAL OF FINANCIAL AND QUANTITATIVE ANALYSIS VOL. 30, NO. 3, SEPTEMBER 1995

# The Intraday Behavior of Bid-Ask Spreads for NYSE Stocks and CBOE Options

Kalok Chan, Y. Peter Chung, and Herb Johnson*

## Abstract

We study the intraday behavior of bid-ask spreads for actively traded CBOE options and for their NYSE-traded underlying stocks. We confirm previous findings that stocks have a U-shaped spread pattern; however, the options display a very different intraday pattern—one that declines sharply after the open, and then levels off. Our results suggest that both the degree of competition in market making and the extent of informed trading are important for understanding the intraday behavior of spreads.

## I. Introduction

There is extensive evidence that the bid-ask spread in the stock market is not constant, but varies through time, and is affected by a number of variables. For example, the spread is affected by information uncertainty (Hasbrouck (1988)), the inventory risk of the market maker (Ho and Stoll (1983)), and the intensity of trading activity (Lee, Mucklow, and Ready (1993)). Evidence also indicates that the bid-ask spread of New York Stock Exchange (NYSE) stocks follows a U-shaped pattern over the trading day, with spreads widest immediately after the open and prior to the close (McInish and Wood (1992) and Brock and Kleidon (1992)). This pattern seems to be related to the intraday variations of the volume and volatility for NYSE stocks, which also follow a U-shaped pattern (Jain and Joh (1988) and Foster and Viswanathan (1993)).

While there is much work on stock spreads, fewer researchers investigate the variation of spreads for options. Biais and Hillion (1990) and John, Koticha, and Subrahmanyam (1991) develop models that examine the equilibrium bid and ask prices in the stock options markets. There are also a few empirical studies that examine bid-ask spreads for American Stock Exchange (AMEX) options (Ho and Macris (1984)), Chicago Board Options Exchange (CBOE) options (Jameson and

*Chan, College of Business, Arizona State University, Tempe, AZ 85287; Chung and Johnson, Anderson Graduate School of Management, University of California, Riverside, CA 92521. We wish to acknowledge Warren Bailey, Hank Bessembinder, Francis Longstaff, Bob Neal, Andy Schwarz, Rick Smith, and seminar participants at the AMEX Options and Derivatives Colloquium XIV, Arizona State University, Hong Kong University of Science and Technology, and University of California, Riverside, for useful comments and discussions on earlier drafts. We also thank JFQA Managing Editor Paul Malatesta and JFQA Referee Paul Schultz, whose comments significantly improved the paper.

Wilhelm (1992) and Mayhew (1993)), and index options (George and Longstaff (1993)). None of these empirical papers, however, studies stock and option bid-ask spreads together.

In this paper, we look at CBOE puts and calls and their NYSE-traded underlying stocks. We think that examining the spreads both for CBOE options and for their underlying NYSE stocks may allow us to distinguish among several competing hypotheses regarding variations of bid-ask spreads for these two related securities. These hypotheses fall into three general categories: inventory, market maker power, and information asymmetry (adverse selection) hypotheses. In the inventory models, the spread compensates market makers for bearing the risk of holding unwanted inventories. The market maker power hypothesis relates the variation of stock spreads to the behavior of the NYSE specialists, who have a certain degree of market power. The information asymmetry hypothesis states that the bid-ask spread is affected by the adverse selection faced by the market maker. Because the CBOE and NYSE have very different market making systems (competing market makers vs. specialist) and because information, public or private, that affects the stock should also affect a call (put) option on that stock in the same (opposite) direction and at very nearly the same time, we have a case that is nearly a controlled experiment. By comparing the intraday bid-ask spread patterns for CBOE options and NYSE stocks, we can see whether inventory imbalances, market maker power, or information asymmetry contributes to the variations of spreads in these markets.

We find some interesting results. Unlike the stock market, which displays a U-shaped pattern, the options market has a bid-ask spread that narrows sharply after the open, then levels off. In principle, higher uncertainty at the open and the close can account for the U-shaped pattern of stock spreads but, since options and their underlying stocks should be affected by the same information or uncertainty, it is hard to see how such a model alone can account for the sharp difference between the stock and option patterns. One natural interpretation for this difference is that the wide spread for both options and stocks at the open is due to greater uncertainty at the open, whereas the wide stock spread but narrow option spread at the close is due to the difference in market making structure.

In the next section, we discuss the microstructure models for intraday variations in the bid-ask spreads. Section III describes the data. Section IV confirms the results from previous studies on intraday price and volume behavior for NYSE stocks. Section V describes the intraday patterns of CBOE option prices and trading volume, and compares them with the patterns for the NYSE stocks. Section VI provides Generalized Method of Moments (GMM) tests for intraday variations described in the previous two sections. Section VII summarizes and concludes the paper.

## II. The Microstructure Models for Intraday Variations in Bid-Ask Spreads

Microstructure models that deal with order arrival and quote revision can be broadly classified as inventory models, specialist market power models, or asymmetric information models. Inventory models consider a risk-averse market maker's inventory of shares and make predictions about quote revision. Specialist market power models examine the reaction of a monopolistic specialist to the inelastic transaction demand that occurs at the open and close of trading. Information models examine the adverse selection problem faced by the market makers: Trading with informed investors is expected to result in a loss, but an expected gain arises from trading with liquidity investors.

## A. Inventory Models

In the inventory models (Stoll (1978), Amihud and Mendelson (1980), and Ho and Stoll (1981)), the spread exists to compensate market makers for bearing the risk of undesired inventory. When there is an order imbalance that moves the market maker away from his desired inventory position, he adjusts the bid-ask spread to attract orders and move back to his optimal inventory position. Amihud and Mendelson (1980), for example, demonstrate that as long as the market maker attempts to manage his inventory, the spread increases as the inventory imbalance builds up. More recent papers (Lee, Mucklow, and Ready (1993) and, for the long run case, Hasbrouck and Sofianos (1993) and Madhavan and Smidt (1993)) also find some evidence on the relation of bid-ask spreads to dealer inventory control costs. Specifically, Lee, Mucklow, and Ready (1993) find that, for a sample of NYSE stocks, bid-ask spreads become wider in response to higher trading volume. Hasbrouck and Sofianos (1993) find that trades the NYSE specialist participates in tend to have a bigger and more rapid impact on the bid-ask spreads than trades with no specialist participation. Madhavan and Smidt (1993) report that bid-ask quote revisions are positively related to order imbalances. Consequently, during the open and the close of the market when volume tends to be higher, there would be greater order imbalance and, therefore, the bid-ask spreads would be wider than during the rest of the day.[1] Thus, for a specialist system such as the NYSE, this type of model would predict a U-shaped bid-ask spread pattern, as specialists are less likely to be forced into an undesirable inventory position during the lighter trading in the middle of the day. However, this pattern is not predicted for a system using competing market makers, such as the CBOE, as it is easier for any one market maker to avoid accumulating excessive long or short positions during peak trading periods.

## B. Specialist Market Power Model

Brock and Kleidon (1992) use a model where the market maker has monopolistic power. They show that transactions demand at the open and close is greater and less elastic than at other times of the trading day. First, accumulation of overnight information may force shifts in optimal portfolio holdings at the open. Second, optimal portfolios at the close can differ, due to the imminent nontrading period, from portfolios that are optimal during the continuous trading period.

[1] This assumes that the specialists reverse inventory within the day. However, the evidence documented in Hasbrouck and Sofianos (1993) and Madhavan and Smidt (1993) suggests that the specialists do not make major reversals of their inventory positions within the day. Therefore, the intraday adjustment of bid-ask spreads may be less pronounced.

Finally, institutional fund managers tend to trade near the close. In response, a monopolist market maker can effectively price discriminate by charging a higher price to transact at these periods of heavy and inelastic demand. On many exchanges, only the specialist has access to the order books at the open. Any opening order imbalance will, therefore, enable him to extract monopolistic profits, and results in high price volatility, as discussed in Stoll and Whaley (1990).

Brock and Kleidon's model, therefore, predicts periodic demand with high volume at the open and close and concurrent wide spreads, which is consistent with observed patterns for the NYSE stocks. It also implies spillover effects, with optimal increases in both transactions demand and spreads in intervals immediately after the open and prior to the close. Brock and Kleidon's analysis assumes a monopolist market maker, which may be appropriate for a specialist but not for competing market makers such as those on the CBOE. Therefore, we would not expect spreads for CBOE options to display a U-shaped intraday pattern if specialist market power is the key for the observed pattern for NYSE stocks.

### C. Information Models

Information models (Copeland and Galai (1983), Glosten and Milgrom (1985), Kyle (1985), Easley and O'Hara (1987), (1992), Admati and Pfleiderer (1992), Hasbrouck (1988), Foster and Viswanathan (1990), (1994), and Madhavan (1992)) focus on the adverse selection faced by the market maker, and assume different types of agents: informed traders, liquidity traders who must trade at a given time during the day regardless of cost, and, in some models, discretionary liquidity traders. In these models, the specialist is at an informational disadvantage, and must keep spreads wide enough so that the gains from trading with the uninformed compensates for the losses to the informed. Trading costs in this type of model arise solely because of the activity of the informed, whose profits are paid by the uninformed liquidity traders. These models predict that higher volume is associated with lower spreads, given the optimal equilibrium behavior of the models' traders.

Foster and Viswanathan (1994) develop a model where strategic trading with two asymmetrically informed traders is analyzed. This model of competition between two informed traders predicts high volume, variances, and spreads at the *start* of trading, a result that is not explained by earlier information models of intraday trading.

Madhavan (1992) develops a model in which information asymmetry is gradually resolved during the trading day by observing trading prices. Hence, the bid-ask spread declines throughout the day.

## III. Data Construction

We use two sources of data. The first is the Berkeley Options Data Base, which contains a complete time-stamped history of quotes and trade prices of the options traded on the CBOE. The second, the Transaction File of the Institute for the Study of Security Markets (ISSM), records all trades and quotes on the NYSE, the AMEX, and most regional exchanges. Both databases contain the time to the nearest second, the price and volume for each trade, and, for each quotation, the time and the bid and ask prices. We obtain the data for the first quarter (61 trading days) of 1986. Since we are interested in comparing the behavior of market makers on the CBOE and NYSE, only options on NYSE-listed stocks are included. Also, the stock trades and quotes that originate outside the NYSE are not included.

Each day, the stock is matched with its most active call (put) option. Since one stock has only one matched option each day, each stock has at most 61 option days (a day for which a matching sample of stock and option data is available), the number of trading days for the three-month period. There are two more criteria for inclusion in the sample. First, the options and underlying stocks that have fewer than 30 trades and quotes for the day are removed from the sample. This is to provide sufficient observations to make intraday inferences. Second, to ensure a sample of actively traded options, we exclude those stocks with fewer than 30 option days. We are left with 32 stocks and 182 matching call options for a total of 1,436 call-option days, and 45 matching put options for a total of 282 put-option days. The sample size for puts is much smaller than that for calls, suggesting that puts are less actively traded than calls. See the Appendix for more details on this sample.

We partition each day into 26 successive 15-minute intervals (and one additional 10-minute interval for the options).[2] Following McInish and Wood (1992), we calculate time-weighted absolute bid-ask spreads for both stocks and options in each time interval.[3] The time weighting is based on the number of seconds the quotation is outstanding during the 15-minute interval. For details, see McInish and Wood (1992). We also calculate bid-ask midpoints at the end of the intervals from which 15-minute stock and option returns are computed. The 15-minute stock and option return volatility are defined as the absolute stock and option returns, respectively.[4] Stock and option trading volume are represented by the number of shares and option contracts traded for the interval. (We also ran our tests using the number of trades to see if block trades affect our empirical results, and found essentially the same results.) The use of 15-minute intervals, rather than, say, five-minute intervals, allows us to obtain estimates of variables even for less actively traded stocks or options without much loss of data synchronicity.

All variables (bid-ask spreads, return volatility, and trading volume) are transformed into standardized deviates. The variables for the stock or option market are standardized by subtracting the mean for the day and dividing by the standard deviation for the day for the respective stock or option. Note that, for our analysis, the actual level of the time-of-day effects is not important, but we need to control for cross-sectional differences across firms.[5]

[2]Since the CBOE closes 10 minutes after the NYSE, there is one additional interval for the options. For brevity, we refer to this as a 15-minute interval.

[3]The spread may vary across stocks, with the higher-priced stocks having higher absolute spreads. But since we are interested in the intraday time-series variation, not the cross-sectional variation, of the spread, the use of the dollar spread (ask−bid) does not bias our results. Also, because option prices are so variable, and often close to zero, their percentage spreads are unstable. As can be seen in Tables 1 and 2, the use of percentage spread does not change the inferences about the intraday patterns.

[4]In calculating the returns, we use the midpoint of the bid and ask prices because transaction returns are quite noisy due to bid-ask bounces and occasional infrequent trades.

[5]Nevertheless, we tried the raw data, and found that the inferences are similar to those using the standardized data.

## IV. Intraday Patterns of Volume, Volatility, and Spreads for NYSE Stocks

We first characterize the intraday patterns of volume, volatility, and bid-ask spreads for the 32 actively traded stocks traded on the NYSE during the first quarter of 1986. Table 1 reports the cross-sectional mean values for each standardized variable of interest for each 15-minute interval of the day. First, stock trading volume shows a distinct U-shaped pattern with significantly higher trading volumes at the open and at the close, confirming Jain and Joh (1988) and Foster and Viswanathan (1993). Second, returns are extremely volatile during the first half-hour of trading and towards the end of the trading day, resulting in the U-shaped pattern of volatility documented in Foster and Viswanathan (1993), Kleidon and Werner (1993), and Wood, McInish, and Ord (1985).

TABLE 1

Mean Values of the Standardized Trading Volume, Volatility, and Bid-Ask Spread of NYSE Stocks for Each Time Interval during the Day[a,b,c]

| Time | SVOLUME | SVOLAT | SSPREAD | S%SPREAD |
|---|---|---|---|---|
| 8:30– 8:45 | 1.3162 | | 0.2962 | 0.3035 |
| 8:45– 9:00 | 0.6657 | 0.5309 | 0.1431 | 0.1459 |
| 9:00– 9:15 | 0.3765 | 0.4935 | 0.0818 | 0.0855 |
| 9:15– 9:30 | 0.2138 | 0.2593 | −0.0628 | −0.0589 |
| 9:30– 9:45 | 0.1082 | 0.1353 | −0.0181 | −0.0147 |
| 9:45–10:00 | 0.0222 | 0.0099 | −0.1096 | −0.1109 |
| 10:00–10:15 | 0.0386 | −0.0117 | −0.0591 | −0.0561 |
| 10:15–10:30 | −0.1048 | −0.1142 | −0.0649 | −0.0670 |
| 10:30–10:45 | −0.1195 | −0.1361 | −0.0914 | −0.0943 |
| 10:45–11:00 | −0.0944 | −0.0720 | −0.0776 | −0.0791 |
| 11:00–11:15 | −0.1028 | −0.0726 | −0.0595 | −0.0624 |
| 11:15–11:30 | −0.1933 | −0.1285 | −0.0797 | −0.0810 |
| 11:30–11:45 | −0.2644 | −0.2174 | −0.0625 | −0.0621 |
| 11:45–12:00 | −0.2628 | −0.1928 | −0.0546 | −0.0559 |
| 12:00–12:15 | −0.3414 | −0.2262 | −0.0966 | −0.0976 |
| 12:15–12:30 | −0.3278 | −0.2233 | −0.1054 | −0.1070 |
| 12:30–12:45 | −0.3075 | −0.1927 | −0.0832 | −0.0861 |
| 12:45–13:00 | −0.3245 | −0.2226 | −0.0789 | −0.0790 |
| 13:00–13:15 | −0.2833 | −0.1562 | −0.0358 | −0.0364 |
| 13:15–13:30 | −0.2478 | −0.1851 | −0.0174 | −0.0149 |
| 13:30–13:45 | −0.2064 | −0.1075 | −0.0083 | −0.0056 |
| 13:45–14:00 | −0.0603 | 0.1059 | 0.0529 | 0.0530 |
| 14:00–14:15 | −0.0007 | 0.0757 | 0.1136 | 0.1137 |
| 14:15–14:30 | 0.0538 | 0.1236 | 0.1548 | 0.1503 |
| 14:30–14:45 | 0.1247 | 0.2391 | 0.1764 | 0.1713 |
| 14:45–15:00 | 0.3219 | 0.3091 | 0.1582 | 0.1576 |

[a]Our sample consists of the 32 actively traded NYSE stocks underlying CBOE call options during the first quarter of 1986. Note that stocks underlying CBOE put options are a subset of stocks underlying CBOE call options.
[b]The standardized variable is defined as $(X_{it} - \mu_i)/S_i$, where $X_{it}$ is the raw variable, $\mu_i$ is the mean for the day, and $S_i$ is the standard deviation for the day.
[c]SVOLUME = the number of underlying shares traded on the NYSE; SVOLAT = the absolute return for the underlying stock with return based on time-weighted bid-ask midpoints; SSPREAD = the time-weighted bid-ask spread for the underlying stock; and S%SPREAD = the time-weighted percentage bid-ask spread for the underlying stock.

The bid-ask spreads are highest at the beginning of the day, gradually declining before they increase during the late afternoon. This confirms the U-shaped pattern in spreads documented in Brock and Kleidon (1992) and McInish and Wood (1992), among others. The intraday pattern of spreads for NYSE stocks mimics that of the volume and volatility.

This evidence appears inconsistent with existing information models, which predict that trading costs are low when volume and return volatility are high.[6] It appears consistent with the specialist market power model of Brock and Kleidon (1992) as well as with the inventory models of specialist market making. However, monopolistic behavior of the NYSE specialist is not the only explanation for the observed intraday patterns in the bid-ask spreads. For example, increased uncertainty (i.e., higher adverse selection costs) at the open can also explain the higher spreads at the open. Therefore, a more confident inference can be made by investigating the intraday variations in volume, volatility, and the spreads in a market that depends on the same information as the NYSE, but whose market making structure is different from that of the NYSE.

## V. Intraday Patterns of Volume, Volatility, and Spreads for CBOE Options

To distinguish among the three explanations for intraday variations in bid-ask spreads, namely, inventory control, the specialists' ability to earn monopolistic rents, and changing levels of asymmetric information, we bring CBOE stock options into our analysis. Since options are derivatives, they should be affected by the same information that affects the underlying stocks. Therefore, if it is the intraday variation of information flow that causes the stock spreads to fluctuate during the day, we should observe a similar intraday pattern for option spreads.

On the other hand, the market making structure of the CBOE differs from that of the NYSE: The CBOE operates as a competitive dealer market with multiple market makers. Thus, option market makers on the CBOE face different inventory control costs and competition. First, order imbalance can be more easily absorbed, since multiple market makers can share the inventory costs or risks. Second, competing option market makers are not able to extract monopolistic rents even in the event of increased and inelastic demands. Third, unlike the NYSE specialists, the market makers on the CBOE do not see the order book. These differences in market making structure suggest that the dealer inventory control and market power would have less effect on the intraday variations of spreads of CBOE options than on NYSE stocks.

We hypothesize that bid-ask spreads of CBOE options will also exhibit a U-shaped intraday pattern if the varying level of information asymmetry is the key reason for the observed U-shaped pattern of NYSE stock spreads. Alternatively, option spreads will not be U-shaped if the market making structure (the inventory cost and/or the specialist market power) of the NYSE causes stock spreads to be U-shaped.

Table 2 reports, for each 15-minute interval of the trading day, the cross-sectional means of the standardized trading volume, volatility, and bid-ask spreads

[6]The evidence for the pattern at the *open* can be reconciled with a recently-developed information model by Foster and Viswanathan (1994), where informed traders are asymmetrically informed.

TABLE 2

Mean Values of the Standardized Trading Volume, Volatility, and Bid-Ask Spread of CBOE Options Written on NYSE Stocks for Each Time Interval during the Day[a,b,c]

| | CBOE Call Options | | | | CBOE Put Options | | | |
|---|---|---|---|---|---|---|---|---|
| Time[d] | CVOLUME | CVOLAT | CSPREAD | C%SPREAD | PVOLUME | PVOLAT | PSPREAD | P%SPREAD |
| 8:30– 8:45 | −0.2751 | | 0.9325 | 0.9045 | −0.4557 | | 1.0218 | 0.8486 |
| 8:45– 9:00 | 0.2115 | 0.3630 | 0.5920 | 0.5550 | 0.1259 | 0.3183 | 0.6865 | 0.5663 |
| 9:00– 9:15 | 0.4171 | 0.2917 | 0.2902 | 0.2802 | 0.3189 | 0.4123 | 0.3460 | 0.2305 |
| 9:15– 9:30 | 0.3276 | 0.2642 | 0.1227 | 0.1172 | 0.3177 | 0.2503 | 0.1295 | 0.0703 |
| 9:30– 9:45 | 0.2114 | 0.1364 | 0.0032 | 0.0018 | 0.2665 | 0.1032 | 0.0636 | 0.0051 |
| 9:45–10:00 | 0.1151 | 0.0256 | −0.0523 | −0.0515 | 0.0838 | −0.0381 | 0.0755 | 0.0259 |
| 10:00–10:15 | 0.0861 | 0.0655 | −0.0738 | −0.0741 | −0.0024 | 0.0445 | −0.1023 | −0.1257 |
| 10:15–10:30 | 0.0172 | −0.0252 | −0.1110 | −0.1171 | −0.0489 | 0.0279 | −0.1792 | −0.1875 |
| 10:30–10:45 | −0.0160 | −0.0849 | −0.1483 | −0.1647 | −0.1532 | −0.1765 | −0.1813 | −0.1711 |
| 10:45–11:00 | 0.0279 | −0.0230 | −0.1228 | −0.1364 | −0.0380 | −0.0139 | −0.1749 | −0.1819 |
| 11:00–11:15 | −0.0338 | −0.0455 | −0.1035 | −0.1099 | −0.0186 | −0.1193 | −0.1394 | −0.1569 |
| 11:15–11:30 | −0.1053 | −0.1149 | −0.1111 | −0.1071 | −0.1172 | −0.1522 | −0.1263 | −0.1275 |
| 11:30–11:45 | −0.1716 | −0.1920 | −0.0837 | −0.0847 | −0.1611 | −0.2656 | −0.1493 | −0.1468 |
| 11:45–12:00 | −0.1710 | −0.1725 | −0.0465 | −0.0626 | −0.2268 | −0.1835 | −0.1068 | −0.0669 |
| 12:00–12:15 | −0.1973 | −0.2091 | −0.0488 | −0.0676 | −0.2932 | −0.2515 | −0.0860 | −0.0391 |
| 12:15–12:30 | −0.1987 | −0.2041 | −0.0542 | −0.0767 | −0.2692 | −0.1252 | −0.0033 | 0.0195 |
| 12:30–12:45 | −0.2019 | −0.1780 | −0.0452 | −0.0464 | −0.1566 | −0.0846 | −0.0718 | −0.0414 |
| 12:45–13:00 | −0.1909 | −0.1576 | −0.0925 | −0.0857 | −0.1197 | −0.1436 | −0.0498 | −0.0499 |
| 13:00–13:15 | −0.1751 | −0.1085 | −0.0481 | −0.0392 | −0.1129 | −0.0478 | −0.0947 | −0.0989 |
| 13:15–13:30 | −0.1282 | −0.1315 | −0.0511 | −0.0308 | −0.0866 | −0.1355 | −0.1153 | −0.1166 |
| 13:30–13:45 | −0.1221 | −0.1043 | −0.0678 | −0.0486 | −0.0440 | −0.0627 | −0.1224 | −0.0789 |
| 13:45–14:00 | −0.0487 | 0.0233 | −0.0983 | −0.0615 | −0.0026 | 0.1480 | −0.0056 | −0.0462 |
| 14:00–14:15 | 0.0305 | 0.0675 | −0.0869 | −0.0660 | 0.1948 | 0.0948 | −0.0496 | −0.0395 |
| 14:15–14:30 | 0.0667 | 0.0925 | −0.0533 | −0.0706 | 0.1070 | 0.1911 | −0.0251 | 0.0568 |
| 14:30–14:45 | 0.1134 | 0.1924 | −0.0127 | −0.0021 | 0.2322 | 0.0827 | −0.0458 | 0.0037 |
| 14:45–15:00 | 0.2357 | 0.1974 | −0.0332 | −0.0072 | 0.2830 | 0.3165 | −0.0238 | 0.0858 |
| 15:00–15:10 | 0.1759 | 0.0942 | −0.2224 | −0.1804 | 0.3395 | 0.0296 | −0.2815 | −0.0861 |

[a]Our sample consists of the actively traded CBOE calls (182 options for 1,436 option days) and puts (45 options for 282 option days) during the first quarter of 1986.
[b]The standardized variable is defined as $(X_{it} - \mu_i)/S_i$, where $X_{it}$ is the raw variable, $\mu_i$ is the mean for the day, and $S_i$ is the standard deviation for the day.
[c]CVOLUME = the number of call option contracts traded on the CBOE; CVOLAT = the absolute return for the call option with return based on time-weighted bid-ask midpoints; CSPREAD = the time-weighted bid-ask spread for the call option; C%SPREAD = the time-weighted percentage bid-ask spread for the call option; PVOLUME = the number of put option contracts traded on the CBOE; PVOLAT = the absolute return for the put option with return based on time-weighted bid-ask midpoints; PSPREAD = the time-weighted bid-ask spread for the put option; P%SPREAD = the time-weighted percentage bid-ask spread for the put option.
[d]The NYSE closes at 3:00 p.m. C.S.T., whereas the CBOE closes 10 minutes later.

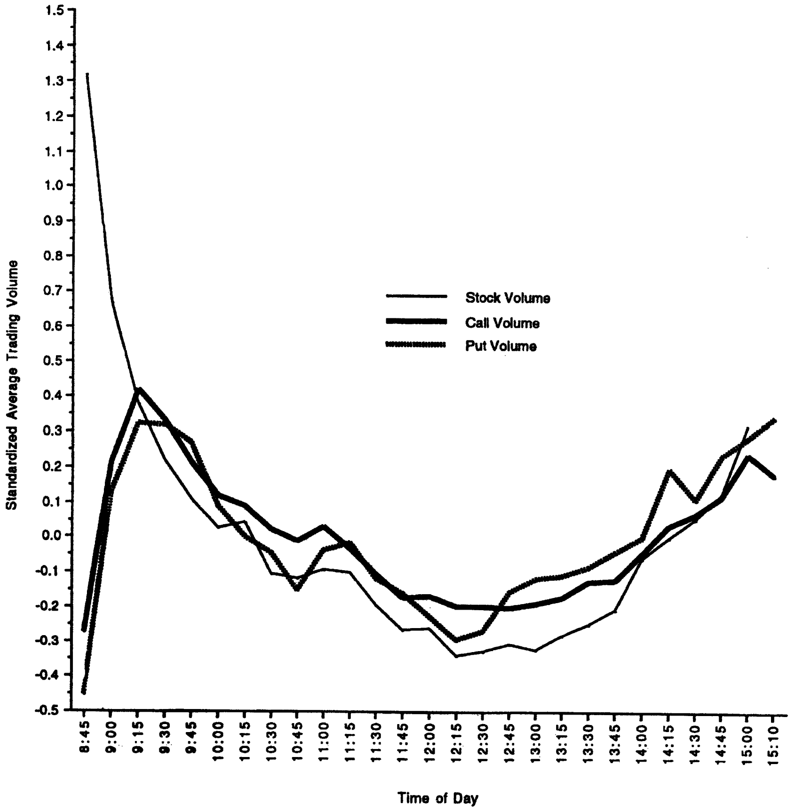
for CBOE call and put options written on our sample of actively traded NYSE stocks. Figures 1 through 3 plot their intraday variations as well as those for their NYSE-traded underlying stocks.

Trading volumes are in general higher at the open and at the close, with two humps during the opening 30 minutes and immediately after 3:00 p.m. C.S.T., when the NYSE closes.[7] Mid-quote return volatility for CBOE options also follows a U-shaped pattern, with a small hump immediately after 3:00 p.m. Returns are extremely volatile early in the morning. Volatility declines subsequently and then increases towards 3:00 p.m.

[7]The delay in the opening trades of the stock options is procedural and seems to affect the trading volume. First, stock options do not trade until the stock has opened. Second, when the first stock price is reported at the option exchange, the stock's options go through an opening rotation. The option volume is extremely low at the open but reaches its highest point in 30 minutes (see Figure 1).

FIGURE 1

Standardized Average Trading Volume of CBOE Options and Their NYSE-Traded Underlying Stocks for Each 15-Minute Interval of the Trading Day

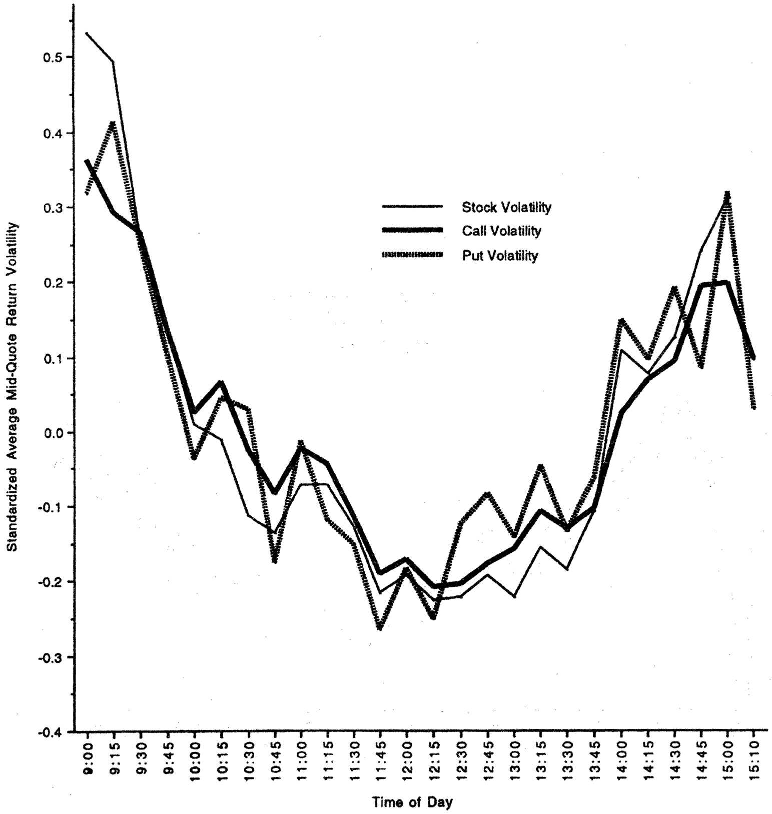



The standardized variable is defined as $(X_{it} - \mu_i)/S_i$, where $X_{it}$ is the raw variable, $\mu_i$ is the mean for the day, and $S_i$ is the standard deviation for the day. Since the CBOE closes at 3:10 p.m. C.S.T., whereas the NYSE closes 10 minutes earlier, there is one additional interval for the options. For brevity, we refer to this as a 15-minute interval. The sample period is the first quarter of 1986.

The intraday pattern in the bid-ask spreads of CBOE options is noteworthy. The spread attains its highest levels immediately after the open without a hump, declines steadily through the first trading hours, remains relatively stable until 3:00 p.m., and then narrows sharply during the last 10 minutes of trading. The spread is at its highest at the open even though volume is at its lowest. The spread does *not* pick up during the late afternoon, even though volume and volatility significantly pick up: The intraday pattern in spreads for CBOE options cannot be attributed to a variation in option volume.

FIGURE 2

Standardized Average Mid-Quote Return Volatility of CBOE Options and Their NYSE-Traded Underlying Stocks for Each 15-Minute Interval of the Trading Day




The standardized variable is defined as $(X_{it} - \mu_i)/S_i$, where $X_{it}$ is the raw variable, $\mu_i$ is the mean for the day, and $S_i$ is the standard deviation for the day. Since the CBOE closes at 3:10 p.m. C.S.T., whereas the NYSE closes 10 minutes earlier, there is one additional interval for the options. For brevity, we refer to this as a 15-minute interval. The sample period is the first quarter of 1986.

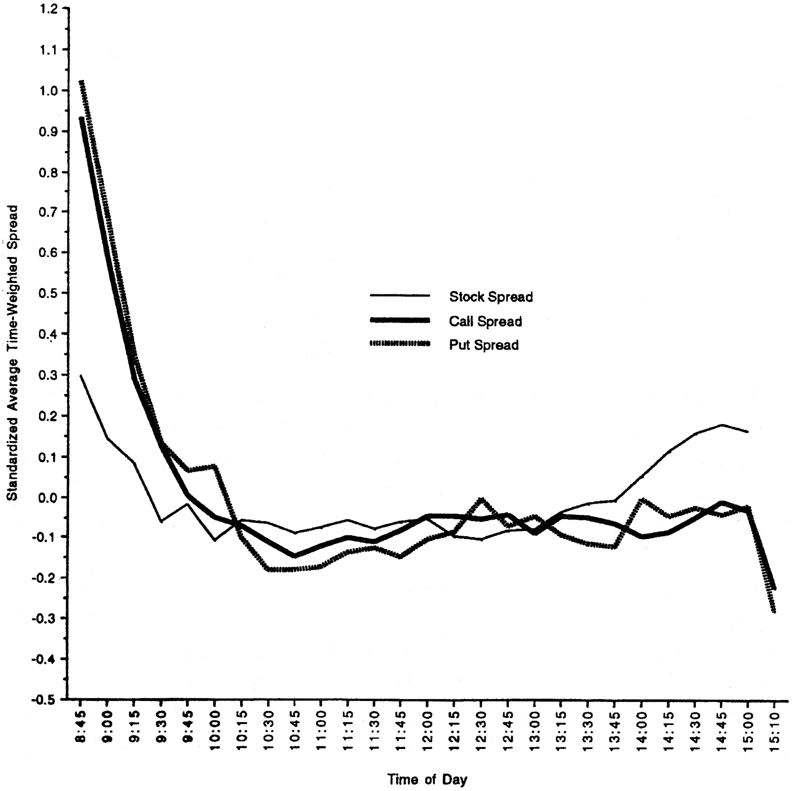
## VI. GMM Tests of Intraday Variations for NYSE Stocks and CBOE Options

We now formally test the null hypotheses that the volume, volatility, and bid-ask spreads of NYSE stocks and CBOE options are constant within a day. Following Foster and Viswanathan (1993) and Chan, Christie, and Schultz (1995), we test for intraday variation by using Hansen's (1982) GMM procedure and adjusting for serial correlation as suggested by Newey and West (1987). GMM estimates are robust in the presence of heteroskedasticity and autocorrelations.

For the variable whose intraday variation is being investigated, we pool together 15-minute-interval observations in the whole sample period of all the stocks (options) that meet our inclusion criteria. Thus, the time-series data for individ-

FIGURE 3

**Standardized Average Time-Weighted Bid-Ask Spread of CBOE Options and Their NYSE-Traded Underlying Stocks for Each 15-Minute Interval of the Trading Day**




The standardized variable is defined as $(X_{it} - \mu_i)/S_i$, where $X_{it}$ is the raw variable, $\mu_i$ is the mean for the day, and $S_i$ is the standard deviation for the day. Since the CBOE closes at 3:10 p.m. C.S.T., whereas the NYSE closes 10 minutes earlier, there is one additional interval for the options. For brevity, we refer to this as a 15-minute interval. The sample period is the first quarter of 1986.

ual firms are stacked, and are used in the regression. Standardized variables are used and, similar to Chan, Christie, and Schultz (1995), our GMM estimates use 30-minute intervals instead of finer time intervals. Thus, for each variable, we estimate the following model,

$$(1) \qquad V_i \;=\; \alpha_0 + \alpha_1 D_1 + \alpha_2 D_2 + \alpha_3 D_3 + \alpha_4 D_4 + \alpha_5 D_5 + \alpha_6 D_6 + \epsilon_i,$$

where $V_i$ is the $i$th observation of the standardized variable (volume, volatility, or bid-ask spread) for the stock (or option), and $D_1$ through $D_6$ are dummy variables:

$D_1 = 1$ if the interval is 8:30–9:00 a.m., 0 otherwise;
$D_2 = 1$ if the interval is 9:00–9:30 a.m., 0 otherwise;
$D_3 = 1$ if the interval is 9:30–10:00 a.m., 0 otherwise;
$D_4 = 1$ if the interval is 2:00–2:30 p.m., 0 otherwise;

$D_5 = 1$ if the interval is 2:30–3:00 p.m., 0 otherwise;
$D_6 = 1$ if the interval is 3:00–3:10 p.m., 0 otherwise,

and $\epsilon_i$ is a random error. The coefficients for the dummy variables, $\alpha_1$ through $\alpha_6$, measure the variations of the variable during the intervals immediately after the open and prior to the close relative to the interval between 10:00 a.m. and 2:00 p.m.

GMM estimation involves use of moment restrictions to estimate the coefficients. We impose the following orthogonality conditions,

$$g_T(\hat{\alpha}) \quad = \quad \frac{1}{T}\sum_{i=1}^{T}\begin{bmatrix} \epsilon_i \\ D_1\epsilon_i \\ D_2\epsilon_i \\ D_3\epsilon_i \\ D_4\epsilon_i \\ D_5\epsilon_i \\ D_6\epsilon_i \end{bmatrix},$$

where $T$ is the number of nonmissing time-series observations of all stocks (options) pooled together. Note that there is no missing observation for volume, as a nontrading interval constitutes a valid observation of zero volume. As for the bid-ask quotes, once the first one is observed, there will not be any missing quotes afterwards for that day as the most recent quote, however old, represents the current one.

To estimate $\alpha$ coefficients, we minimize the quadratic form $g'Wg$, where $W$, a symmetric weighting matrix, is a consistent estimator of the inverse of the asymptotic covariance matrix of $\sqrt{T}g_T(\hat{\alpha})$ after adjusting for serial correlation as suggested by Newey and West (1987). We use three lags in the Newey-West correction. The system is just identified, our GMM estimates coincide with ordinary least square estimates, but our standard errors are robust to heteroskedasticity and autocorrelation.

If we define $D_T$ to be the consistent estimator of $\partial g_T(\hat{\alpha})/\partial\hat{\alpha}$, we have

$$\sqrt{T}\,(\hat{\alpha}-\alpha) \quad \sim \quad N\left(0, \left[D_T'WD_T\right]^{-1}\right).$$

We test for the significance of the coefficient estimates using the covariance matrix in the parentheses. Significantly positive (negative) $\alpha_1$ for the stock bid-ask spreads, for example, would suggest that the stock spreads are higher (lower) immediately after the open (8:30 to 9:00 a.m.) than during the rest of the day (10:00 a.m. to 2:00 p.m.).

We also test the hypotheses that the coefficients during the open ($\alpha_1$, $\alpha_2$, and $\alpha_3$) and during the close ($\alpha_4$ and $\alpha_5$) are jointly equal to zero, respectively. Rejecting the hypothesis for the stock bid-ask spreads during the open (8:30 a.m. to 10:00 a.m.), for example, would suggest that stock spreads are significantly different from those during the rest of the day (10:00 a.m. to 2:00 p.m.). For the first hypothesis, let $\Sigma$ be a $3\times 3$ subset of the estimated variance-covariance matrix, $[D_T'WD_T]^{-1}$, where we have dropped terms associated with the coefficients $\alpha_0$, $\alpha_4$, $\alpha_5$, and $\alpha_6$. In addition, let $\hat{\mu}$ be a $3\times 1$ vector of the estimates of $\alpha_1$, $\alpha_2$, and $\alpha_3$. Then under the null hypothesis that $\mu = 0$, we have

$$\sqrt{T}\hat{\mu}'[\Sigma]^{-1}\hat{\mu} \quad \sim \quad \chi^2(3),$$

where the expression $\chi^2(3)$ refers to a $\chi^2$ distribution with three degrees of freedom.

Similarly, for the second hypothesis, let $S$ be a $2 \times 2$ subset of the estimated variance-covariance matrix, $[D_T' W D_T]^{-1}$, where we have dropped terms associated with the coefficients $\alpha_0$, $\alpha_1$, $\alpha_2$, $\alpha_3$, and $\alpha_6$. In addition, let $\hat{\nu}$ be a $2 \times 1$ vector of the estimates of $\alpha_4$ and $\alpha_5$. Then, under the null hypothesis that $\nu = 0$, we have

$$\sqrt{T}\hat{\nu}'[S]^{-1}\hat{\nu} \quad \sim \quad \chi^2(2).$$

The results are presented in Table 3, separately for the early morning and the late afternoon intervals. Panel A reports the results for NYSE stocks. First, coefficients $\alpha_1$ through $\alpha_5$ are positive and significant at the 0.1-percent level, suggesting that stock trading volume, volatility, and bid-ask spreads are higher during the open (8:30 to 10:00 a.m.) and during the close (2:00 to 3:00 p.m.) than during the rest of the day (10:00 a.m. to 2:00 p.m.). For example, $\alpha_1$ is 0.276 for the stock bid-ask spreads, suggesting that the average stock spread immediately after the open (8:30 to 9:00 a.m.) is 0.276 standard deviation to the right of the average stock spread during the rest of the day (10:00 a.m. to 2:00 p.m.). Second, $p$-values from $\chi^2$-tests indicate that the coefficients during the open ($\alpha_1$, $\alpha_2$, and $\alpha_3$) and during the close ($\alpha_4$ and $\alpha_5$) are not jointly equal to zero, respectively, suggesting that stock trading volume, volatility, and bid-ask spreads are different during the open and during the close from those during the rest of the day. Note that the coefficient $\alpha_6$ is missing because the NYSE closes at 3:00 p.m. C.S.T.

Panel B reports the results for CBOE calls. First, coefficients $\alpha_1$ through $\alpha_6$ for CBOE call volume and volatility are significantly positive, suggesting that call volume and volatility are higher immediately after the open and prior to the close than during the rest of the day. The variations in bid-ask spreads of CBOE calls are, however, very different. While the coefficients for the opening hours ($\alpha_1$ through $\alpha_3$) are significant at the 0.1-percent level, the coefficient for the 2:30 to 3:00 p.m. interval ($\alpha_5$) is positively significant only at the 1-percent level.[8] Thus, the call spreads increase during the late afternoon, but the increase is much smaller than that for the NYSE stock spreads. Also, $p$-values from $\chi^2$-tests indicate that, while we can reject the hypothesis, at the 0.1-percent level of significance, that the coefficients for the opening hours ($\alpha_1$, $\alpha_2$, and $\alpha_3$) are jointly equal to zero, we can reject the hypothesis only at the less significant 1-percent level that the coefficients for intervals immediately prior to the NYSE close ($\alpha_4$ and $\alpha_5$) are jointly equal to zero. Results, therefore, suggest that the option spreads increase far less in the late afternoon than do spreads on the underlying stocks.

Panel C reports the results for CBOE puts. Results are generally similar to those for calls except that the put option volume during the first 30-minute interval (8:30 to 9:00 a.m.) is not significantly higher. The delay in the opening trades of the put options can be an explanation. Also, the put option bid-ask spreads during the late afternoon intervals (2:00 to 2:30 and 2:30 to 3:00 p.m.) are not

[8]One possible reason for a high spread near the open is that early quotes may be artificial, i.e., may not represent prices at which significant quantities of options could be traded. To test for this possibility, we reran our tests omitting all quotes that were posted prior to the first trade for that option. The coefficient ($t$-statistic) for the first entry in Table 3, Panel B, under CSPREAD declined from 0.829 (25.98) to 0.620 (16.76), but remained highly significant. Other coefficients were virtually unaffected. Thus, this explanation for a high spread near the open appears invalid.

TABLE 3

Generalized Method of Moments (GMM) Estimates of Variations in the Standardized Trading Volume, Volatility, and Bid-Ask Spread of CBOE Options and Their NYSE-Traded Underlying Stocks[a,b,c]

$$V_{i,t} = \alpha_0 + \alpha_1 D_1 + \alpha_2 D_2 + \alpha_3 D_3 + \alpha_4 D_4 + \alpha_5 D_5 + \alpha_6 D_6 + \epsilon_{i,t}$$

where $V_{i,t}$ is the standardized volume (volatility, or bid-ask spread) for stock (or option) $i$ during the 15-minute interval $t$; $D_1 = 1$ if the interval is 8:30–9.00 a.m., 0 otherwise; $D_2 = 1$ if the interval is 9:00–9:30 a.m., 0 otherwise; $D_3 = 1$ if the interval is 9:30–10:00 a.m., 0 otherwise; $D_4 = 1$ if the interval is 2:00–2:30 p.m., 0 otherwise; $D_5 = 1$ if the interval is 2:30–3:00 p.m., 0 otherwise; $D_6 = 1$ if the interval is 3:00–3:10 p.m., 0 otherwise; and $\epsilon_{i,t}$ is a random error. The coefficients for the dummy variables, $\alpha_1$ through $\alpha_6$, measure the variations of $\epsilon_{i,t}$ during the intervals immediately after the open and prior to the close relative to the interval between 10:00 a.m. and 2:00 p.m. Asymptotic $t$-statistics are in parentheses.

| | (A) NYSE Stocks | | | (B) CBOE Call Options | | | (C) CBOE Put Options | | |
|---|---|---|---|---|---|---|---|---|---|
| Time[d] | SVOLUME | SVOLAT | SSPREAD | CVOLUME | CVOLAT | CSPREAD | PVOLUME | PVOLAT | PSPREAD |
| 8:30–9:00 | 1.191 | 0.665 | 0.276 | 0.070 | 0.467 | 0.829 | −0.052 | 0.416 | 0.948 |
| ($\alpha_1$) | (49.55) | (19.38) | (12.35) | (3.45) | (13.52) | (25.98) | (−1.24) | (5.07) | (11.91) |
| 9:00–9:30 | 0.495 | 0.511 | 0.067 | 0.474 | 0.431 | 0.288 | 0.432 | 0.425 | 0.345 |
| ($\alpha_2$) | (24.05) | (20.91) | (3.06) | (19.79) | (18.32) | (11.98) | (8.83) | (7.96) | (6.45) |
| 9:30–10:00 | 0.265 | 0.207 | −0.006 | 0.265 | 0.185 | 0.057 | 0.288 | 0.129 | 0.176 |
| ($\alpha_3$) | (14.03) | (9.82) | (−0.28) | (12.06) | (8.81) | (2.64) | (6.15) | (2.74) | (3.50) |
| $p$-value[e] | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
| 14:00–14:30 | 0.227 | 0.234 | 0.192 | 0.150 | 0.184 | 0.012 | 0.264 | 0.239 | 0.069 |
| ($\alpha_4$) | (12.07) | (11.34) | (8.97) | (7.29) | (9.00) | (0.55) | (5.49) | (4.96) | (1.54) |
| 14:30–15:00 | 0.423 | 0.409 | 0.225 | 0.276 | 0.299 | 0.059 | 0.371 | 0.296 | 0.072 |
| ($\alpha_5$) | (18.84) | (16.65) | (9.47) | (12.36) | (13.46) | (2.53) | (7.30) | (5.95) | (1.45) |
| 15:00–15:10 | | | | 0.278 | 0.198 | −0.141 | 0.453 | 0.127 | −0.175 |
| ($\alpha_6$) | | | | (9.65) | (6.54) | (−4.93) | (6.39) | (1.91) | (−2.76) |
| $p$-value[f] | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | 0.01 | <0.001 | <0.001 | 0.06 |

[a] Our stock sample consists of the 32 actively traded NYSE stocks underlying CBOE call options during the first quarter of 1986. Note that stocks underlying CBOE put options are a subset of stocks underlying CBOE call options. Our option sample consists of the actively traded CBOE calls (182 options for 1,436 option days) and puts (45 options for 282 option days) during the first quarter of 1986.

[b] The variables for the stock or option market are standardized by subtracting the mean for the day and dividing by the standard deviation for the day for the respective stock or option.

[c] SVOLUME = the number of underlying shares traded on the NYSE; SVOLAT = the absolute return for the underlying stock with return based on time-weighted bid-ask midpoints; SSPREAD = the time-weighted bid-ask spread for the underlying stock; CVOLUME = the number of call option contracts traded on the CBOE; CVOLAT = the absolute return for the call option with return based on time-weighted bid-ask midpoints; CSPREAD = the time-weighted bid-ask spread for the call option; PVOLUME = the number of put option contracts traded on the CBOE; PVOLAT = the absolute return for the put option with return based on time-weighted bid-ask midpoints; and PSPREAD = the time-weighted bid-ask spread for the put option.

[d] The NYSE closes at 3:00 p.m. C.S.T., whereas the CBOE closes 10 minutes later.

[e] $P$-value of $\chi^2$-statistic from the test whether the coefficients for 8:30–9:00, 9:00–9:30, and 9:30–10.00 a m. intervals ($\alpha_1$, $\alpha_2$, and $\alpha_3$) are jointly equal to zero.

[f] $P$-value of $\chi^2$-statistic from the test whether the coefficients for 2:00–2:30 and 2:30–3:00 p.m. intervals ($\alpha_4$ and $\alpha_5$) are jointly equal to zero.

significantly higher than during the rest of the day. Furthermore, we cannot reject the hypothesis that the coefficients for intervals immediately prior to the NYSE close ($\alpha_4$ and $\alpha_5$) are jointly equal to zero at the conventional level of significance.

In sum, the intraday behavior of bid-ask spreads appears to be fundamentally different for the competitive market maker system on the CBOE relative to the specialist system on the NYSE.[9] None of the existing information models provides a satisfactory explanation for why the spreads are higher at the close on the NYSE but lower at the close on the CBOE. Also, the specialist market power model or

[9] Of course, for many inactively traded options this difference in the degree of competition may be illusory, and recently the CBOE has moved to a system for trading equity options that is more like a specialist system. However, our data are for very actively traded options at a time well before the change in the CBOE's operating procedure. We redid our tests only for the most actively traded CBOE stock options, calls on IBM. Results were virtually identical.

the inventory model alone cannot explain why the spreads are higher at the open on the CBOE. Our results instead suggest that the high spread for both options and stocks at the open reflects market makers' desire to protect themselves from greater uncertainty at the open, whereas the high stock spread but lower option spread at the close reflects the difference in market making structure.[10]

Our results are consistent with a few recent papers that investigate non-NYSE securities. Chan, Christie, and Schultz (1995) find that the bid-ask spread for National Association of Securities Dealers Association (NASDAQ) stocks declines throughout the day. Since NASDAQ stocks are traded on a decentralized competitive market with a large number of dealers, their results suggest that institutional differences between the specialist market (NYSE) and the competing dealer market (NASDAQ) induce differences in the variation of intraday spreads. Kleidon and Werner (1993) also find that bid-ask spreads for cross-listed London Stock Exchange (LSE) stocks decline throughout the day. Since the institutional traders can trade during the LSE trading session after the NYSE closes, spreads for those stocks do not rise at the close: There would be less urgent transaction demand near the NYSE close. However, our study has the advantage of comparing markets with different market making arrangements but presumably the same information arrival.

## VII. Summary and Conclusions

We find that the bid-ask spread for NYSE stocks is higher near the open and close of the trading day than at midday. This confirms the U-shaped pattern documented elsewhere (McInish and Wood (1992)). The spread for actively traded CBOE call options is high only during the opening hour, and is lowest at the CBOE close. This is similar to the findings of Chan, Christie, and Schultz (1995) for NASDAQ stocks and of Kleidon and Werner (1993) for cross-listed London stocks.

Our results suggest a need for a richer model of the bid-ask spread. Considered in isolation, the NYSE bid-ask spread pattern can be explained with the specialist market power model of Brock and Kleidon (1992) or with the inventory model of, for example, Ho and Stoll (1983). Considered in isolation, the CBOE spread can be explained with the model of Madhavan (1992), where information asymmetry is partially resolved as investors become informed by observing trade prices, leading to a decline in the bid-ask spread during the day. We argue that CBOE spreads behave differently from NYSE spreads because of the difference in market making structure. A model that incorporates both information asymmetry and market making structure might show that the high bid-ask spread for both the NYSE and the CBOE at the open is due to greater uncertainty at the open, whereas the high NYSE spread but low CBOE spread at the close is due to the difference in market making structure.

We end on a note of caution. The models we test are inevitably less complex than the phenomena they are trying to describe, and so we must be cautious in

[10]Our data do not permit us to distinguish between the inventory and market power models. We will occasionally refer to those two models together as market making structure models.

drawing conclusions. For example, the Brock and Kleidon model describes a monopolistic market maker, but the NYSE specialist typically only handles about 20 percent of the trades, and so is not a genuine monopolist, but may be more of a monopolist near the open and the close.[11] Similarly, the CBOE and NYSE differ in other ways besides the way markets are made. For example, NYSE trading opens with a call, whereas the CBOE opens with continuous trading. Thus, price discovery may appear to occur more gradually on the CBOE, and this may help explain the high spread-low volume relationship we observe near the open.

## APPENDIX

### Summary of Firms with CBOE Options Contained in Sample

| Firm Name | | Calls | | Puts | |
|---|---|---|---|---|---|
| | | Number of Options | Number of Option Days | Number of Options | Number of Option Days |
| 1 | BA | 4 | 56 | | |
| 2 | BMY | 5 | 49 | | |
| 3 | C | 7 | 56 | 6 | 45 |
| 4 | CBS | 8 | 38 | | |
| 5 | CCI | 5 | 48 | | |
| 6 | CL | 4 | 33 | | |
| 7 | DAL | 5 | 33 | | |
| 8 | DOW | 5 | 40 | | |
| 9 | EK | 6 | 56 | 11 | 38 |
| 10 | F | 8 | 58 | 6 | 43 |
| 11 | GE | 4 | 58 | | |
| 12 | GM | 5 | 56 | 7 | 47 |
| 13 | GW | 3 | 40 | | |
| 14 | HON | 5 | 47 | | |
| 15 | HWP | 4 | 56 | 4 | 50 |
| 16 | IBM | 10 | 58 | 11 | 59 |
| 17 | ITT | 4 | 49 | | |
| 18 | JNJ | 4 | 41 | | |
| 19 | KM | 4 | 33 | | |
| 20 | LIT | 5 | 44 | | |
| 21 | MCD | 7 | 32 | | |
| 22 | MMM | 8 | 33 | | |
| 23 | MOB | 3 | 31 | | |
| 24 | OXY | 3 | 37 | | |
| 25 | PRD | 13 | 43 | | |
| 26 | PWJ | 5 | 50 | | |
| 28 | RJR | 5 | 43 | | |
| 29 | S | 5 | 46 | | |
| 30 | SY | 5 | 53 | | |
| 31 | SYN | 5 | 33 | | |
| 32 | TDY | 11 | 39 | | |
| Total | | 182 | 1,436 | 45 | 282 |

An option day means a day for which a matching sample of stock and option data is available. The sample period is the first quarter of 1986.

[11] See *NYSE Fact Book 1992* (1992), pp. 17–18. The specialist participation was considerably higher in earlier years, such as in our sample period.

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