AN INTRADAY ANALYSIS OF BID–ASK SPREADS AND PRICE VOLATILITY IN THE S&P 500 INDEX FUTURES MARKET

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INTRODUCTION

Theories of the bid–ask spread suggest that the spread decreases with competition among marketmakers and increases with price volatility

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and trade size.[1] This study estimates the influence of these factors on the realized spread in the S&P 500 futures contract in periods before, during, and after the crash of October 19, 1987. These periods offer a unique opportunity to observe the behavior of the spread and its determinants during a time of large variation. This not only increases the statistical power of the tests, but also reveals changes in the relationships that occur under extreme conditions.

Empirical tests of the theories are hampered by several observational limitations. The bid–ask spread is not directly observable in futures markets but must be estimated. Also, a correct method for the measurement of price risk has not been established. The most commonly used method uses the observed volatility of transaction price changes, which includes the effects of both the bid–ask spread and information which affects the equilibrium price. In other words, a key determinant of the bid–ask spread is usually proxied by a variable which itself includes the spread; and, therefore, the effect of information is not explicitly captured. In addition, there are the usual limitations on the availability of volume and marketmaking data which are even more problematical in an intraday study.

In this study, estimates of the realized bid–ask spread are based on intraday transaction price reversals in a procedure similar to that developed by Bhattacharya (1983). The problem induced by the interdependence of the bid–ask spread and transaction price volatility is mitigated both by the estimation procedure for volatility and by an instrumental variable technique in model estimation. Also, two proxies for information effects are introduced. An important feature of this study is the use of intraday data on volume per transaction, the number of marketmakers trading in the pit, and the number of transactions.

Several researchers have noted a U-shaped pattern in either bid–ask spreads or transaction price volatility or in both.[2] Interpretation of the

[1] Current theory attributes the spread to three cost components (1) Order-Processing [Demsetz (1968); Tinic (1972)]; (2) Inventory [Stoll (1978); Amihud and Mendelson (1980, 1982); Ho and Stoll (1981)] and (3) Adverse Information [Bagehot (1971), Copeland and Galai (1983), and others]. Competition would affect the total size of the spread inversely. The inventory component should be an increasing function of price volatility and trade size. The adverse information component may also be positively correlated with price volatility and trade size.

[2] Wang, Moriarty, Michalski, and Jordan (1988) found U-shaped bid–ask spreads and intraday price volatility in S&P 500 index futures. Jordan, Seale, Dinehart, and Kenyon (1988) found a U-shaped pattern in the volatility of soybean futures contracts. Ma, Peterson, and Sears (1992) found U-shaped patterns for bid–ask spreads in soybean, corn, T-bill, and silver futures contracts. Admati and Pfleiderer (1988) proposed a theory to explain the timing of intraday U-shaped patterns of volume and price volatility. Foster and Viswanathan (1989) proposed a theory to explain interday trading patterns of volume and price volatility.

evidence is obscured by the interdependence of the estimated bid–ask spread and transaction price volatility as well as the possible influence of other variables. The model used here accounts for these factors and so allows better understanding of the U-shaped pattern.

The principal findings are: (i) the number of marketmakers in the futures pit is inversely related to bid–ask spreads, (ii) the October 1987 crash had an important effect on futures bid–ask spread determinants that diminishes over time, and (iii) the observed intraday U-shaped in bid–ask spreads correlates statistically with the volume of trading and number of marketmakers in the pit once all factors are taken into account.

The organization of this article is as follows: First it reviews the literature on determinants of intraday price volatility and bid–ask spreads. The empirical model specification and the data are then described and the results are analyzed. A summary and conclusions are presented in the final section.

INTRADAY PRICE VOLATILITY AND BID–ASK SPREADS

Most of the previous empirical studies have concentrated on explaining the determinants of quoted bid–ask spreads *across* securities. In general, two classes of determinants of spreads have been found. The first class includes (1) activity variables such as volume and trade order size; (2) various measures of risk; (3) competition in marketmaking, such as the number of marketmakers trading in the security; (4) the number of transactions, and (5) institutional ownership. The second class of factors is related to the features of exchanges and the financial characteristics of securities.[3] Most of the previous studies estimate bid–ask spreads from intraday data collected within the closing hour or from data over daily or longer intervals. There are few studies of bid–ask spreads using intraday transactions data.[4]

Although theory and previous empirical work suggest a role for price risk in determining bid–ask spreads, the measurement of price

[3] Thorough literature reviews are provided by Benston and Hagerman (1974), Stoll (1985), Hasbrouck (1988), McInish and Wood (1989), and others.

[4] Intraday data were used in studies of the stock market by Hasbrouck and Ho (1987); Glosten and Harris (1988); and McInish and Wood (1989). Thompson and Waller (1988) studied the determinants of bid–ask spreads for corn and oats futures markets. Wang, Moriarty, Michalski, and Jordan (1988) estimated bid–ask spreads in the S&P 500 future market during the October, 1987 market break period using intraday data. Ma, Peterson, and Sears (1992) studied intraday bid–ask spread patterns, trading noise and private information for soybeans, corn, T-bills, and silver futures contracts.

risk remains problematical. Theory does not clearly indicate whether marketmakers respond to volatility in equilibrium or transaction prices. The sources of intraday transaction price volatility (measured by the standard deviation of transaction price changes) include volatility in the equilibrium price caused by the reaction of market participants to information (the information effect), the deviation of the transaction price from the equilibrium price due to the bid–ask spread (the liquidity effect), and the overreaction of participants (the overreaction effect).

Roll (1984), French and Roll (1986), Glosten (1987), and others derived a relationship between the standard deviation of equilibrium price changes and the bid–ask spread for a particular data generating process.[5] Cohen, Maier, Schwartz, and Whitcomb (CMSW) (1986) reviewed previous empirical studies of the relationship between transaction price volatility and bid–ask spreads in securities markets. In general, these studies find a positive relationship between transaction price volatility and the bid–ask spread when price change is measured over short intervals, e.g., daily. The relationship becomes insignificant for price changes over longer intervales, e.g., monthly. Recently, Amihud and Mendelson (1987) demonstrated the existence of a positive relationship at the closing hour of the New York Stock Exchange. None of these empirical studies controlled for the information effect on volatility. In a study of daily volatility of the S&P 500 cash index, Harris (1988) incorporated both liquidity and information effects. However, liquidity was not measured directly by the bid–ask spread but by a set of hypothesized explanatory variables. He found an inverse relationship between transaction price volatility and liquidity. Thus, no previous studies have used direct estimates of the bid–ask spread and controlled for both liquidity and information effects on price volatility.

Several theories of intraday trading predict patterns in the bid–ask spread. Brock and Kleidon (BK) (1992) showed that periodic market closure causes greater (and less elastic) transactions demand at the open and close of trading. In brief, traders have a greater need to revise portfolios at the opening because they could not trade during the night while information continued to develop. Near the close,

[5]French and Roll (1986, p. 20–21) and Glosten (1987, p. 1304) wrote the relationship in terms of variances as

$$\begin{aligned} \mathrm{var}(\Delta P_t) &= \mathrm{var}(\Delta P_t^*) - 2\,\mathrm{cov}(\Delta P_t, \Delta P_{t-1}) \\ &= \mathrm{var}(\Delta P_t^*) + S_t^2/2 \end{aligned}$$

where ΔP_t and ΔP_t^* represent changes in the transaction price and equilibrium price, respectively, and S_t is the realized bid–ask spread.

traders begin revising their portfolios in anticipation of being unable to trade overnight, again while information continues to arrive. This greater transactions demand at open and close increases asks and lowers bids (widens the spread) and increases volume. Price volatility is not addressed explicitly in this theory, but Ma, Peterson and Sears (MPS) (1992) note that the theory implies greater divergence of beliefs during non-trading hours, greater information disparity among traders during the opening period, and higher price volatility in the opening period. In making this interference, MPS appear to be adding asymmetric information to the BK model.

Admati and Pfleiderer (AD) (1988), in an asymmetric information model, predicted periods of high volume and high return volatility due to strategic decisions by informed and discretionary liquidity (uninformed) traders about when to trade. The theory then depends on periodic market closure to make the opening and closing periods the times of high volume and volatility (see AD, p. 34). However, their model appears to imply low bid–ask spreads at the open and close, because discretionary liquidity traders will concentrate their trading only at times when trading costs are low. Lower bid–ask spreads at open and close have not been observed in empirical studies; in fact, the evidence is the reverse (see footnote 2). Extensions of this model by Foster and Viswanathan (1989) and Subrahmanyam (1989) predicted higher bid–ask spreads at open and close because the presence of informed traders increases the adverse information component of the spread.

The model proposed in this study will determine if any pattern in the bid–ask spread is related to patterns in transaction price volatility and other variables.

MODEL SPECIFICATION AND DATA

Model Specification

The following time-series model of determinants of bid–ask spreads and determinants of intraday transaction price volatility incorporates both liquidity and information effects:

$$\text{bid-ask spread}_t = f(\text{transaction price volatility}_t, \text{average volume per trade}_t, \text{number of marketmakers}_t, \text{dummies for each half-hour interval during the day}) \quad (1)$$

$$\text{transaction price volatility}_t = f(\text{bid-ask spread}_t,\ \text{number of transactions}_{t-1},\ \text{Treasury bill futures price volatility}_t,\ \text{dummies for each half-hour interval during the day}) \qquad (2)$$

A simultaneous equation model is proposed for two reasons. First, transaction price volatility is used as a proxy for the price risk perceived by the marketmakers in (1). However, because this proxy is itself a function of the dependent variable, estimates of (1) by ordinary least squares (OLS) would be inconsistent. The two-equation model, estimated by two-stage least squares (2SLS), allows consistent estimates. The second reason is an interest in separating liquidity and information effects on transaction price volatility.

The bid–ask spread in (1) and (2) is measured by the mean of estimated realized bid–ask spreads during half-hour intervals. The realized bid–ask spreads are estimated as follows: (i) create an empirical joint price distribution of ΔP_t and ΔP_{t-1} during a half-hour interval; (ii) discard the subset of price changes which exhibit price continuity (i.e., positive change followed by positive change); (iii) take absolute values of price changes that are price reversals, and (iv) compute the mean of absolute values obtained in step (iii).[6]

Transaction price volatility in (1) and (2), as a proxy for price risk perceived by marketmakers, is expected to have a positive impact on the spread since it implies two types of risk for marketmakers. First, marketmakers may bear non-systematic risk due to under-diversification in the assets they hold. Secondly, large price changes may be correlated with the presence of information traders, and dealers must increase spreads to compensate for expected losses when trading opposite informed traders.[7]

[6]Stoll (1989) suggested that this procedure produces upward biased estimates of realized bid–ask spreads. Therefore, for comparison purposes, two other procedures of estimating realized bid–ask spreads were employed: (1) the Mean of the absolute value of transaction price change procedure and (2) the Bhattacharya (1983) procedure. Bhattacharya's procedure uses only equal-sized price reversals. It was found that the three procedures are very similar empirically.

[7]Thompson and Waller (1988) used the first difference of the standard deviation of transaction price changes as a proxy for the change in equilibrium price volatility. This measure does not alleviate the problem of joint dependence between transaction price volatility and bid–ask spreads.

Transaction price volatility is measured by the mean of the absolute value of price changes, with transaction price sampled every five minutes in a half-hour. Sampling every five minutes reduces transaction price changes due to bid–ask spreads.[8]

A positive relationship is expected between the bid–ask spread and average volume per transaction in (1). Tinic (1972) suggested that bid–ask spreads will increase when the size of a trade reaches the limit of dealers' financial capacity. Furthermore, the larger the size of a transaction, the lower the likelihood that it can be matched immediately by an offsetting transaction. Hence, the marketmaker may have an undesirable inventory position. In order to compensate for this situation, marketmakers will increase bid–ask spreads. Asymmetric information theory also suggests that large order size may convey adverse information, and hence, marketmakers will protect themselves by raising bid–ask spreads.

Competition among marketmakers is proxied by the number of marketmakers trading in the pit during a half hour in (1). It is expected to be negatively related to the size of the spreads. A large number of marketmakers will tend to keep the spreads at a minimum as they compete for trades.

The half-hour dummies in (1) serve two purposes: (i) to reduce the variance of the error terms and thus provide more sensitive testing results, and (ii) to allow tests for any pattern in the bid–ask spread not accounted for by the primary explanatory variables.

In eq. (2), there are two proxies for information effects. The number of transactions lagged one period is expected to have a positive impact on price volatility, because an increase in the number of transactions may represent the arrival of information. A more direct measure of intraday volatility due to information is the range of price changes of three-month T-bill futures in a half-hour bracket.[9] It is expected to have a positive impact on price volatility. This variable also serves as the exogenous variable necessary for 2SLS estimation. Dummies are also specified in the price volatility equation to increase

[8]Sampling the transaction price at five-minute intervals also reduces the magnitude of biases in the estimation of equilibrium price volatility — biases which are induced by discreteness in transaction prices [see Cho and Frees (1988)]. If a measure of the price risk that is due to the change in the equilibrium price were available, then that measure of price risk would be used in the bid–ask spread equation. In that case, the system would be a block recursive system.

[9]The idea of using the volatility of the short-term rate as a proxy for information effects is motivated by the cost-of-carry model for futures price behavior and is similar to arguments suggested by Anderson (1985, p. 344). Three-month T-bill futures are employed as a proxy for the three-month T-bill because intraday three-month T-bill data are not available.

efficiency and to take account of any U-shaped pattern in intraday price volatility.

The specific model estimated may be written as:

$$Y_{1t} = \beta_{10} + \beta_{12}Y_{2t} + \tau_{11}X_{1t} + \tau_{12}X_{2t} + r_{11}Y_{1t-1} + \sum_{\substack{i=1 \\ i\neq 8}}^{13} \delta_{1i}H_{it} + e_{1t} \tag{1}$$

$$Y_{2t} = \beta_{20} + \beta_{21}Y_{1t} + \tau_{23}X_{3t-1} + \tau_{24}X_{4t} + r_{22}Y_{2t-1} + \sum_{\substack{i=1 \\ i\neq 8}}^{13} \delta_{2i}H_{it} + e_{2t} \tag{2}$$

where

Y_{1t} = the mean of realized bid–ask spreads in period t (a half-hour bracket);
Y_{2t} = intraday transaction price volatility, a measure of price risk during period t;
X_{1t} = the average volume per transaction during t period;
X_{2t} = the total number of marketmakers in the pit trading the nearest contract during period t;
X_{3t-1} = the total number of transactions in period $t-1$;
X_{4t} = volatility of three month T-bill futures at period t;

$$H_{it} = \begin{cases} 1 & \text{if the observation belongs to the } i\text{th half-hour bracket, } i = 1, 2, \ldots, 13,\ i = 1 \text{ represents the half-hour bracket from 9:30 to 10:00 AM. The time brackets from 7 to 9 represent the time periods from 12:30 PM to 2:00 PM} \\ 0 & \text{otherwise} \end{cases}$$

r_{11} and r_{22} are assumed less than one; e_{1t} and e_{2t} are random error terms with zero means and constant variance σ_i^2, $i = 1, 2$.[10]

[10] Y_{1t-1} and Y_{2t-1} are used in the context of a partial adjustment model to accommodate lagged inventory adjustment by marketmakers. Amihud and Mendelson (1987) also used a partial adjustment model.

Data

Transaction prices and times for futures contracts are obtained form "time and sales" data recorded by pit reporters on the Chicago Mercantile Exchange (CME) floor. These are transaction prices and time references to the nearest second for transactions whose prices differ from the previous transaction price. These data are used to calculate realized bid–ask spreads and intraday price volatility. The three-month T-bill futures data are from the CME time and sales tapes. The trading time of three-month T-bill futures is 8:00 AM to 3:00 PM eastern time; an interpolation technique is used to fill the gaps from 3:00 to 4:00 PM. Numbers of marketmakers and volume per trade are obtained from computerized trade reconstruction (CTR) data of the CME.[11]

The data are assembled for the December 1987 contract for a $2\frac{1}{2}$-month period which includes the market crash, September 16, to November 30, 1987. During this period, the December 1987 contract is the nearby (next-maturity) contract. These data are analyzed also for three sub-periods: pre-crash, September 16–October 13; crash, October 14–October 26; and post-crash, October 27–November 30. To examine the longer term effects of the crash, data for three additional contracts and periods are analyzed: the March 1988 contract for December 16, 1987 to February 29, 1988; the June 1988 contract for March 16, 1988, to May 31, 1988; and the September 1988 contract for June 15, 1988, to August 31, 1988. Each contract is the nearby contract for the period examined. The results are so similar for these last three periods, that only the June 1988 contract results are reported.[12]

EMPIRICAL RESULTS

The empirical analysis is composed of two parts: explanatory data analysis and confirmatory analysis. In the explanatory data analysis, the statistical properties of data are examined and the Spearman rank correlation matrix is estimated to examine bivariate relationships between

[11]The information contained in CTR data includes: (1) the trade date and cleared date; (2) broker number; (3) buy or sell code for each transaction; (4) customer type (1= broker/trader trading for own account, 2= broker/trader trading for clearing member house account, 3= broker/trader trading for another present broker/trader, 4= broker/trader trading for any other customer or broker/trader not present); (5) trade price; (6) size of trade (volume data); (7) half-hour time bracket; (8) broker and opposite matched broker and (9) trade type (1= pit trade, 6= spread, 8= transfer, 9= cash for futures) and (10) estimated time of trade. For further information on the procedures used to reconstruct the timing of trades, see Computerized Trade Reconstruction Vols. I and II published by the CME (September 2, 1986.)

[12]Interested readers can obtain the empirical results for the March 1988 contract and the September 1988 contract from one of the authors.

variables in a distribution-free manner. In the confirmatory analysis, the simultaneous equation model is estimated.

Exploratory Data Analysis

Statistical properties of each variable are examined and reported in Table 1. These include standard and simple robust estimates of location and scale parameters and coefficients of variation (CV). These data show the effect of the crash on bid–ask spreads and other variables. The crash is clearly apparent when comparing the $2\frac{1}{2}$-month period for the December 1987 contract (column 1) with the period of similar length for the June 1988 contract (column 5). For example, the mean bid–ask spread (Y_1) is almost three times larger for the December 1987 contract than for the June 1988 contract. The data for the three subperiods for the December 1987 contract show that the crash effect is concentrated in the 10/14–10/26 period (column 3) but still lingers in the 10/27–11/30 period (column 4). In general, variables for the June 1988 contract are close to pre-crash (column 2) levels. Note that the results for the Bhattacharya method (Y_1^*) are very similar to the results of this study's method of bid–ask spread estimation.

Spearman rank correlation matrices are estimated. Because of space limitations, these are not reported here. Two major results emerge: (1) most of the relationships between variables have the expected signs and are statistically significant at the 5% level, and (2) in terms of magnitude of correlation, the strongest associations occur during the break period while the weakest are in the more normal market periods, as expected.

Confirmatory Analysis

All data are transformed into natural logarithm form for the estimation of the model.[13] Only 2SLS results are reported in this article.[14] Two diagnostic tests on residuals are performed: (1) tests of independence by

[13]The purpose of the log transformation is to stabilize the variance and to obtain error terms which have approximately symmetric distributions.

[14]Because of space limitations, OLS estimates are not reported. Interested readers may obtain the results from one of the authors. In a comparison between the OLS and 2SLS estimates, the signs of coefficients are consistent in most cases. However, in the bid–ask spread equation, the OLS estimates of the coefficient of $\ln(Y_{2t})$ are approximately half the size of the corresponding 2SLS estimates. Similarly, the OLS estimates of the coefficient of $\ln(Y_{1t})$ in the price volatility equation are smaller than those of the corresponding 2SLS estimates. Both of these results indicate that OLS estimation suffers from simultaneous equation bias. The chi-square test proposed by Hausman (1979) is used, and the results indicate that simultaneous equation bias is present in the OLS estimates at least at the 5% level of significance.

TABLE I

Summary Statistics of Intraday Data Used in the Analysis of S&P 500 Index Futures

Variable	*Dec. 1987 Contract 9/16–11/30* (1)	*Dec 1987 Contract 9/16–10/13* (2)	*Dec 1987 Contract 10/14–10/26* (3)	*Dec 1987 Contract 10/27–11/30* (4)	*June 1988 Contract 3/16–5/31* (5)
1. Y_{1t}					
N - Sample size	648	260	108	280	685
Mean	0.13500	0.0554	0.4307	0.0913	0.0533
Median	0.05980	0.0554	0.4903	0.0653	0.0523
STD. Dev	0.1905	0.0041	0.3111	0.0734	0.0061
Max	1.3148	0.0718	1.3148	0.5644	0.1682
Min	0.0500	0.0500	0.0525	0.0500	0.0500
CV	141.1100	7.4007	72.2300	80.3943	11.4447
2. Y_{2t}					
Mean	0.5690	0.3445	1.3472	0.4774	0.2505
Median	0.3900	0.3000	1.2700	0.4000	0.2200
STD. Dev	0.5447	0.1732	0.8468	0.3087	0.1640
Max	4.000	1.1200	4.000	2.500	2.3400
Min	0.0600	0.0875	0.1500	0.0600	0.0500
CV	95.5729	50.2758	74.2880	64.660	65.4671
3. X_{1t}					
Mean	3.8478	3.4376	5.7475	3.4959	2.8720
Median	3.5105	3.4001	5.5784	3.3622	2.7929
STD. Dev	1.2675	0.4707	1.7670	0.8028	0.4779
Max	10.8339	4.7849	10.8339	5.7725	5.0721
Min	1.9395	2.0941	3.1219	1.9395	1.9801
CV	32.9400	13.6927	30.7438	22.0640	16.6340

continued

TABLE I (Continued)

Variable	*Dec. 1987 Contract 9/16–11/30* (1)	*Dec 1987 Contract 9/16–10/13* (2)	*Dec 1987 Contract 10/14–10/26* (3)	*Dec 1987 Contract 10/27–11/30* (4)	*June 1988 Contract 3/16–5/31* (5)
4. X_{2t}					
Mean	221.5340	251.6808	218.2963	194.7893	210.3679
Median	223.0000	254.0000	213.5000	200.5000	213.0000
STD. Dev	62.4043	56.1479	66.3169	53.3740	43.5385
Max	370.0000	370.0000	353.0000	314.0000	322.0000
Min	42.0000	93.0000	94.0000	42.0000	74.0000
CV	26.1690	22.3092	30.3793	27.4009	20.7003
5. Y_{1t}					
Mean	0.1280	0.0516	0.4189	0.0862	0.0509
Median	0.0533	0.0507	0.4693	0.0584	0.0500
STD. Dev	0.1879	0.0025	0.3086	0.0732	0.0047
Max	1.1220	0.0677	1.1220	0.5174	0.1418
Min	0.0500	0.0500	0.0500	0.0500	0.0500
CV	146.7970	4.8440	73.6691	84.9188	10.2338

Y_{1t} – Average realized bid–ask spread estimated by the Bhattacharya procedure (1983).

autocorrelations and the Q-test and (2) tests for normality by calculating the skewness and kurtosis. Although diagnostic tests alone do not provide guidance on model selection, at the very least they help to avoid major errors.

The results for the bid–ask spread equation for the December 1987 contract are shown in Table II. The results for the transaction price volatility equation for the same contract are reported in Table III. Results for both equations for the June 1988 contract are reported in Table IV.

All explanatory variables (ignoring dummy variables for now) for the September 16–November 30 period, December 1987 contract, are consistent with prior expectations and statistically significant at least at the 5% level (Tables II and III). However, the Q value and kurtosis strongly indicate that the model is inadequate for this entire period. On the other hand, based on diagnostic statistics, the equations for the three subperiods are adequate for each period.[15] The remaining discussion of the results is focused on the sub-periods in 1987 and the later period in 1988.

Interpretation of Primary Explanatory Variables

For the bid–ask spread equation, the coefficient of the price risk variable ($\ln Y_{2t}$) is positive and significant for all three subperiods in 1987 (Table II) and for the period in 1988 (Table IV). Note that in the pre-crash period [column (2) of Table II], the

[15] To verify structural change during the crash period, a Wald test statistic is used for testing structural change under two unequal variances in a linear simultaneous equation model. This is suggested by Lo and Newey (1985). The small sample properties of the test were investigated by Park (1991). T_1 and T_2 denote sample size of periods 1 and 2, respectively. As both T_1 and T_2 increase, the distribution of the Wald test statistic W_s asymptotically approaches a chi-square distribution with Q degrees of freedom, where Q refers to the number of parameters in the right-hand side of the equation of interest in the simultaneous equation system. This testing strategy uses the crash period (Oct. 14–Oct. 26) as the base period with which to compare periods before and after. (i.e., the periods in column (2) to (4) in the following table). The test results are as follows:

(1) Oct. 14–Oct. 26, 1987	(2) Sept. 16–Oct. 13, 1987	(3) Oct. 27–Nov. 30, 1987	(4) Mar. 16–May 31, 1988
Bid–Ask Equation (13 d.f.)	36.75	27.45	30.87
Volatility Equation (12 d.f.)	32.13	26.11	28.93

At the 5% level, the theoretical percentile of chi-square with 13 d.f. and 12 d.f. are 22.4 and 21.4, respectively. At the 1% level, the percentiles are 27.7 and 26.2, respectively.

The test results provide additional statistical evidence to justify breaking up the period of Dec. 1987 contract into three sub-periods. The merit of the test is that it allows simultaneous equation estimates and the performance of a Chow test in a linear simultaneous equation framework with unequal variance across two subsample periods.

TABLE II

Empirical Results on Effective Bid–Ask Spreads ($\ln(Y_{1t})$) of S&P Index Futures, December Contract 1987[a]

Variable	(1) *Sept. 16–Nov. 30*	(2) *Sept. 16–Oct. 13*	(3) *Oct. 14–Oct. 26*	(4) *Oct. 27–Nov. 30*
1. Constant	0.2461	−1.8780	0.2106	−0.0017
	(1.25)[c]	(−6.95)	(0.40)	(−0.03)
2. $\ln(Y_{2t})$[b]	0.2363	0.0868	0.2305	0.2307
	(4.76)	(1.84)	(1.93)	(2.12)
3. $\ln(X_{1t})$[b]	0.1437	0.0631	0.3358	0.1812
	(2.08)	(1.19)	(3.21)	(2.04)
4. $\ln(X_{2t})$[b]	0.1494	0.0459	0.2117	−0.1358
	(−4.49)	(−1.58)	(−2.04)	(−1.61)
5. $\ln(Y_{1t-1})$	0.7679	0.2587	0.7459	0.7245
	(22.49)	(3.70)	(10.95)	(12.76)
6. *H1*	0.0182	0.0306	0.1647	0.1427
	(0.51)	(0.97)	(1.96)	(2.32)
7. *H2*	0.1138	0.0086	0.0353	−0.1756
	(−3.76)	(−0.42)	(−0.41)	(−3.37)
8. *H3*	0.0283	0.0100	0.083	−0.0402
	(−0.87)	(0.49)	(−1.04)	(−0.55)
9. *H4*	0.0347	0.0127	0.0181	−0.0354
	(1.16)	(0.55)	(1.28)	(−0.55)
10. *H5*	0.0057	0.0127	−0.0181	0.0354
	(0.207)	(0.55)	(1.28)	(−0.91)
11. *H6*	0.0123	0.0170	0.0069	0.0017
	(−0.51)	(−0.86)	(−0.08)	(−0.03)
12. *H10*	0.007	0.0122	−0.0031	0.0053
	(0.29)	(0.62)	(−0.03)	(−0.03)
13. *H11*	0.0346	0.0012	0.0022	−0.0497
	(−1.32)	(0.05)	(−0.26)	(−0.05)
14. *H12*	0.0238	0.0246	0.0654	0.0103
	(−0.88)	(−1.23)	(−0.74)	(−0.21)
15. *H13*	0.0185	0.0334	0.0666	0.0597
	(−0.67)	(1.78)	(0.79)	(−1.09)
R^2	0.962	0.314	0.970	0.887
Q(26)[d]	65.6	32.4	29.6	31.2
Skewness	1.5	0.21	0.46	0.32
(Kurtosis-3)	11.0	0.95	1.16	0.78

[a]Each equation is estimated by 2SLS.
[b]Definitions of variables:

Y_{1t} = mean of realized bid–ask spreads at tth time unit (half-hour bracket);
Y_{2t} = price volatility measured by means of absolute value of change in price (at five-minute intervals);
X_{1t} = the average volume per transaction at the tth time unit;
X_{2t} = the total number of marketmakers in the pit.

[c]The numbers in parentheses under estimated coefficients are t-statistics.
[d]The Q(26) is distributed as Chi-square with 26 degree of freedom. The critical values of Chi-square statistic with 26 d.f. at 5% and 1% level are 38.9 and 45.6, respectively.

TABLE III
Empirical Results on Intraday Price Volatility ($\ln(Y_{2t})$) of S&P Index Futures, December Contract 1987[a]

Variable	(1) Sept. 16–Nov. 30	(2) Sept. 16–Oct. 13	(3) Oct. 14–Oct. 26	(4) Oct. 27–Nov. 30
1. Constant	0.3362	5.1112	−0.5969	−1.6164
	(−1.43)[c]	(1.42)	(1.03)	(−3.80)
2. $\ln(Y_{1t})$[b]	0.5184	2.6805	0.5387	0.6467
	(10.93)	(2.30)	(8.89)	(9.46)
3. $\ln(Y_{2t-1})$[b]	0.1098			
	(2.51)	—		
4. $\ln(X_{3t-1})$[b]	0.2178	0.2695	0.2656	0.4347
	(5.81)	(3.80)	(3.09)	(7.49)
5. $\ln(X_{4t})$[b]	0.1848	0.1241	0.1784	0.1323
	(6.49)	(2.42)	(2.65)	(2.85)
6. $H1$	0.3286	0.4727	0.0173	(0.1680)
	(4.91)	(3.63)	(0.11)	(1.66)
7. $H2$	0.1466	−0.1354	0.2786	−0.2012
	(2.02)	(−0.04)	(−1.68)	(1.86)
8. $H3$	0.2363	0.1369	−0.1718	0.4207
	(3.41)	(−1.15)	(−1.68)	(4.02)
9. $H4$	0.1886	0.2558	−0.1656	−0.1799
	(−2.87)	(−2.28)	(−1.08)	(1.85)
10. $H5$	−0.1037	0.0692	−0.2145	0.0588
	(1.59)	(−0.59)	(−1.41)	(0.61)
11. $H6$	0.169	0.1341	−0.1935	−0.1893
	(2.56)	(1.22)	(−1.29)	(−1.95)
12. $H10$	0.0009	−0.251	−0.1403	0.0530
	(0.013)	(−0.23)	(0.84)	(0.50)
13. $H11$	0.0735	0.1332	0.1972	−0.0463
	(1.03)	(1.19)	(1.19)	(1.19)
14. $H12$	0.0799	0.0935	0.0843	0.0225
	(1.08)	(0.73)	(0.48)	(0.19)
15. $H13$	0.0383	−0.0422	0.0037	0.0648
	(0.52)	(0.31)	(0.02)	(0.51)
R^2	0.683	0.350	0.701	0.548
Q(26)[d]	51.3	27.9	32.4	29.5
Skewness	0.65	0.126	−0.18	−0.16
(Kurtosis-3)	1.2	−0.19	−0.35	0.12

[a]Each equation is estimated by 2SLS.
[b]Definitions of variables

Y_{1t} — mean of realized bid ask spreads at tth time unit (half-hour bracket);
Y_{2t} — price volatility measured by means of absolute value of change in price (at five-min. intervals);
X_{3t-1} — the total number of transactions in period $t-1$;
X_{4t} — volatility of three-month T-bill futures at period t.

[c]The numbers in parentheses under estimated coefficients are t-statistics.
[d]The Q(26) is distributed as Chi-square with 26 degree of freedom. The critical values of Chi-square statistic with 26 d.f. at 5% and 1% level are 38.9 and 45.6, respectively.

TABLE IV

Empirical Results on Effective Bid–Ask Spreads, Intraday Price Volatility of S&P 500 Index Futures, June Contract 1988: Time Period March 16–May 31[a]

Variables	$ln(Y_{1t})$[b]	$ln(Y_{2t})$[b]
1. Constant	1.3895	2.1109
	(6.42)[c]	(1.60)
2. $\ln(Y_{2t})$[b]	0.0819	....
	(2.61)	
3. $\ln(Y_{1t})$[b]		1.8166
		(4.26)
4. $\ln(X_{1t})$[b]	0.0057	
	(1.35)	
5. $\ln(X_{2t})$[b]	−0.0389	
	(1.77)	
6. $\ln(Y_{1t-1})$[b]	0.4325	
	(12.22)	
7. $\ln(X_{3t-1})$[b]		0.3220
		(6.27)
8. $\ln(X_{4t})$[b]	....	0.1276
		(3.62)
9. $H1$	0.0537	0.3948
	(3.84)	(5.25)
10. $H2$	0.0099	0.1739
	(0.74)	(2.11)
11. $H3$	0.0188	0.3035
	(1.14)	(4.00)
12. $H4$	0.0076	−0.0966
	(−0.56)	(−1.27)
13. $H5$	0.0097	0.1029
	(0.82)	(−1.45)
14. $H6$	0.0028	−0.0486
	(0.24)	(−0.69)
15. $H10$	0.0108	0.1442
	(− 0.95)	(2.12)
16. $H11$	0.0094	0.0854
	(0.81)	(1.25)
17. $H12$	0.0026	0.2210
	(0.18)	(2.98)
18. $H13$	0.0007	0.1938
	(−0.05)	(2.52)
R^2	0.387	0.368
$Q(26)$[d]	25.6	32.4
Skewness	0.34	−0.14
(kurtosis-3)	1.12	0.117

[a]Each equation is estimated by 2SLS.
[b]Definitions of variables are defined in Tables II and III.
[c]The numbers in parentheses under estimated coefficients are t-statistics.
[d]The $Q(26)$ is distributed in Chi-square statistic with 26 d.f. at 5% and 1% level are 38.9 and 45.6, respectively.

coefficient is 0.0868. During the crash and post-crash period [columns (3) and (4) of Table II], the influence of price volatility on the bid-ask spread increases markedly. By the spring of 1988 (Table IV), the coefficient has returned to the pre-crash level.

The coefficient for average volume per transaction ($\ln X_{1t}$) is positive but insignificant during the pre-crash period, becomes highly significant during and after the crash, then returns to the pre-crash level in 1988. This illustrates the importance of testing the influence of transaction size during periods of large variation in this variable. In normal markets, the small variation of transaction size reduces the power of the test.

The coefficients for number of marketmakers ($\ln X_{2t}$) behave similarly. Again, only the large variation of the variable associated with the crash allows its negative impact on the bid-ask spread to be statistically significant.[16]

For the intraday price volatility equations (Tables III and IV) the coefficients for bid-ask spreads ($\ln Y_{1t}$) are positive and statistically significant at least at the 5% level. The pattern of the coefficients is consistent with the bid-ask spread having a relatively smaller influence on price volatility during the crash because information (changes in the equilibrium price) became a much larger influence. By the spring of 1988, the relatively large role of the bid-ask spread had returned.

The coefficients for the number of transaction lagged one period ($\ln X_{3t-1}$), and volatility of short-term interest rates ($\ln X_{4t}$) are positive and significant at the 5% level. These two variables are intended to reflect the effects of arrival of information in the market, but the patterns of these coefficients suggest that the variables reflect different aspects of information. The behavior of the Treasury bill futures volatility coefficient is consistent with information playing a larger role in price volatility during the crash. The lagged number of transactions coefficient attains its highest value in the post-crash (October 27-November 30, 1987) period, and has still not returned to pre-crash levels by 1988. It has been suggested that an increase in the number of transactions reflects an increase in heterogeneity of opinion not just information arrival. The behavior of this coefficient suggests that differences of opinion were more prevalent following the crash.

[16]An alternative measure of marketmaking competition is the marketmaker participation rate, defined as volume traded by marketmakers for their own account divided by total trade volume. The marketmaker participation rate has the expected signs but is insignificant when the variable $\ln(X_{1t})$, i.e., log of average volume per transactions, is included in the same equation. A possible explanation is multicollinearity due to the construction of the variables (i.e., both variables are functions of volume).

In the volatility equation, all coefficients for the lagged dependent variable ($\ln Y_{2t-1}$) are negative and not statistically different from zero except for the December 1987 contract (September 16 to November 30). For this reason, the variable is deleted in the sub-period tests shown in Tables III and IV.

Interpretation of the Dummy Variables

The dummy variables in the bid–ask spread equation (Tables II and IV) provide little evidence in favor of a U-shaped pattern in bid–ask spreads that is independent of the other variables. Only for the October 27–November 14 period is the first half-hour ($H1$) coefficient clearly significant, although it is nearly so for the crash period. In Table IV, the coefficient is significantly negative. Apparently, transaction price volatility ($\ln Y_{2t}$), average volume per transaction ($\ln X_{1t}$) and number of marketmakers ($\ln X_{2t}$) are the sources of the bid–ask spread pattern or are correlated with the source. Indeed, although not shown in the article, all three of these variables have a U-shaped pattern in these data.[17] To further explore this point, the bid–ask spread equation is re-estimated with different combinations of the variables. Table V reports these results for the period March 16–May 31, 1988. Column (1) repeats the full equation estimation from Table IV. Column (5) is an OLS regression of the spread on only the dummy variables. In column (5) the U-shaped pattern of the bid–asked spread is quite apparent, and consistent with the previous empirical evidence. However, this equation explains very little of the variation in the spread. Column (4) shows the effect of having transaction price volatility in the equation and using 2SLS to achieve consistent estimation. This modification accounts for all of the first half-hour increase in the spread, and most of the last half-hour increase (as well as the two half hours prior to the last). The importance of this variable is also indicated by the large increase in R-square. Column (3) shows the effect of having average transaction volume per trade in the equation estimated by OLS. The effect of having average volume per trade is similar to the effect of having transaction price volatility in the equation.

If transaction price volatility and average volume per trade are indications of more information getting reflected in prices, this result is consistent with information effects being greater at the opening than

[17] Michalski and Wang (1990) reported U-shaped patterns in average volume per trade, the number of marketmakers, and the number of transactions at half-hour intervals for S&P 500 Index futures.

TABLE V

Statistical Analysis on the Sources of U-Shaped Pattern on Bid–Ask Spreads of S&P 500 Index Futures: March 16–May 31, 1988

	(1)	(2)	(3)	(4)	(5)
1. Constant	1.3895	1.0802	−3.1624	2.833	−2.9491
	(6.42)	(−6.08)	(169.59)	(247.3)	(−485.1)
2. $\ln(Y_{2t})^a$	0.0819	0.1683	—	0.068	
	(2.61)	(7.4)		(11.50)	
3. $\ln(X_{1t})^a$	0.0057	—	0.0181	—	
	(1.35)		(11.97)		
4. $\ln(X_{2t})^a$	−0.0389	0.0854			—
	(1.77)	(3.73)			
5. $\ln(Y_{1t-1})^a$	0.4325	0.3874	—		—
	(12.22)	(9.18)			
6. $H1$	0.0537	−0.0906	0.0156	0.018	0.0271
	(−3.84)	(5.24)	(1.32)	(−1.56)	(2.22)
7. $H2$	0.0099	0.0003	−0.0177	0.010	0.0014
	(0.74)	(0.03)	(−1.59)	(0.90)	(0.12)
8. $H3$	0.0188	0.0426	−0.0109	0.005	0.0025
	(1.14)	(2.67)	(−0.98)	(0.44)	(0.12)
9. $H4$	0.0076	0.0029	−0.0249	0.014	−0.0114
	(−0.56)	(0.21)	(2.24)	(−1.27)	(0.93)
10. $H5$	0.0097	0.0211	−0.0083	0.001	−0.0021
	(0.82)	(1.59)	(0.73)	(0.01)	(−0.16)
11. $H6$	−0.0028	0.0047	0.0051	0.003	−0.0075
	(0.24)	(0.37)	(0.46)	(0.35)	(−0.49)
12. $H10$	−0.0108	0.0205	−0.0121	0.009	0.0063
	(0.95)	(1.58)	(−0.19)	(0.82)	(0.52)
13. $H11$	0.0094	0.0077	0.0190	0.008	0.0311
	(0.81)	(0.56)	(1.73)	(0.74)	(2.56)
14. $H12$	0.0026	0.0190	0.0386	0.022	0.0574
	(0.18)	(1.26)	(3.48)	(1.94)	(4.74)
15. $H13$	0.0007	0.0281	0.0346	0.026	0.0631
	(0.05)	(1.83)	(3.08)	(2.22)	(5.22)
R^2	0.387	0.276	0.235	0.238	0.08
F	25.9	20.07	20.05	18.96	6.4

[a]Definitions of variables are defined in Tables II and III.
Equations (1), (2) and (4) are estimated by 2 SLS. Equations (3) and (5) are estimated by OLS.

at the close, since the information-related variable fully accounts for the opening but not the close pattern in the spread. This is consistent with the market-closure theory of the behavior of the spread, since the opening portfolio revisions are based on accumulated information, but the closing revisions are not. The remaining pattern in the spread at the end of the day suggests a greater role for non-information-based trades. Asymmetric information should not be excluded from playing a role, however, since a greater information disparity at the opening suggested by MPS, may also be captured by the transaction price volatility variable.

The result is also broadly consistent with Eckman's (1992) suggestion that informed traders concentrate at the opening and liquidity traders at the close.

Adding the other three variables does not contribute any further explanation of a U-shaped pattern; therefore, one should not attach a great deal of meaning to the relatively small changes that do occur as the variables are added. For example, in Column (1), there is evidence that an unexplained component of the bid–ask spread is smaller in the first half hour. However, this evidence is not repeated in the other periods (Table II), so it may simply be sample dependent.

In the transaction price volatility equation (Table III), the coefficients of the dummy variable in the open and close periods are still positive and some are statistically significant, but the pattern does not emerge clearly until the 1988 period (Table IV) when the sample size is larger. The evidence for a U-shaped pattern in price volatility (after controlling for the effects of explanatory variables) suggests that there is another source of this pattern not captured in this model.

Finally, the power of the empirical model reported here (measured in terms of R^2) fluctuates substantially, ranging from 0.970–0.314 for the bid–ask equation and from 0.701–0.350 for the price volatility equation. This is due to the variation of the data used to estimate the model for different time periods. For example, the CV of both endogenous and exogenous variables is high for the period from October 14–November 30, 1987 (see Table I). The lower explanatory power of the model estimated for the 1988 period (June 1988 contract) is due to the relatively low variability (evidenced by the CV coefficient) of realized bid–ask spreads during the latter part of 1988. This range of explanatory results suggest that the empirical findings of this study, in general, are very reliable (i.e., robust for the sample period used) because the overall time period covers both normal and abnormal market conditions.

SUMMARY AND CONCLUSIONS

This study employs intraday data to examine the major determinants of the bid–ask spread and price volatility of S&P 500 index futures from the period September 1987–May 1988. This time period is extremely informative because it covers the 1987 market crash as well as more normal market situations.

The empirical results indicate that the major factors affecting bid–ask spreads during this period were (1) price risk, (2) volume per transaction, and (3) competition in marketmaking. These results are consistent with previous theories of bid–ask spreads. Furthermore, the investigation reveals a structural change in the market during the 1987 October crash period, evidenced by a change in the parameters of the model.

It is demonstrated also that intraday price volatility is a function of the bid–ask spread and information effects as proxied by the number of transactions lagged one period and the volatility of the short-term interest rate.

Another interesting result is that the U-shaped pattern in bid–ask spreads is not statistically significant after adjusting for the effects of price volatility, volume per transaction, and the number of marketmakers trading in the pit. A U-shaped pattern in intraday price volatility does exist, and it cannot now be attributed to a U-shaped pattern in realized bid–ask spreads.

For empirical research, two important points are demonstrated. First, the price risk variable, measured by the standard deviation of transaction price changes, and realized bid–ask spreads are simultaneously determined. Hence OLS estimates of the bid–ask spread equation are inconsistent if the price risk variable (measured by the standard deviation of transaction price changes) is in the OLS equation.[18] Second, intraday transaction price volatility (measured by the standard deviation of transaction price changes) is a misspecified measure of volatility caused by information effects if the bid–ask variable (or an appropriate proxy) is not considered also.[19]

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[18]For example, Amihud and Mendelson (1987) and Thompson and Waller (1988) employed OLS in this situation.

[19]For example, Jordan et al. (1988) omitted the bid–ask spread or its proxy in their intraday price volatility equation when studying information effects on soybean futures price volatility.

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