The Effect of Market Opening and Closing on the Volatility of Eurodollar Futures Prices

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INTRODUCTION

Several recent studies in the financial economics literature report evidence of significantly greater volatility in NYSE stock returns at the open and close of trading than at other times during the trading day [Stoll and Whaley (1990); Amihud and Mendelson (1987); Wood, McInish, and Ord (1985)]. Since the release of new information is largely accounted for, this difference in the volatility of returns is primarily attributed to the market structure of the NYSE, to market participants acting on private information, and, to a lesser extent, trading noise. The question naturally arises as to whether these observed patterns in volatility are unique to the equity markets or are common to other financial markets. This study attempts to answer

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that question by examining whether a similar pattern in volatility exists in other financial markets: which have a different market structure than the NYSE; where private information production is unlikely; and, where any private information can be readily exploited in another liquid market prior to market "opening" or after market "closing." In particular, the opening of Eurodollar futures trading on the Chicago Mercantile Exchange (CME) is examined during a period when an active market on a virtually identical Eurodollar futures contract was open on the London International Financial Futures Exchange (LIFFE). In addition, the volatility of CME Eurodollar futures prices is examined at the close of Eurodollar futures trading on LIFFE and on the CME.

INFORMATION, NOISE, AND SECURITY PRICES

In a perfectly informationally efficient capital market security prices change only in response to the release of new information. If new information arrives randomly during the trading day, security prices will also change randomly. When financial markets are less than perfectly efficient, incentives exist for the private production of information and for trading based on that information.[1] Trading based on privately produced information may lead, in turn, to price changes which, in retrospect, are serially correlated as the privately produced information is slowly revealed to other market participants. The behavior of speculative prices may also be influenced by market structure characteristics, such as the way the market is organized [Garman (1976)] or the frequency of trading [Goldman and Sosin (1979)].

In a less than perfectly informationally efficient capital market, speculative prices may react to "noise" as well as information. Black (1986) has characterized deviations of security prices from their informationally efficient or "intrinsic values" as "noise." Black contends that it is the existence of noise in security prices which both motivates trading and makes (reasonably) informationally efficient capital markets possible.

REVIEW OF THE LITERATURE

A number of recent studies in the financial economics literature have reported anomalous patterns in the behavior of stock prices or returns

[1] Indeed, Grossman and Stiglitz (1980) have argued that a perfectly informationally efficient capital market is impossible since there would be no incentive to produce the new information which is necessary to make the market informationally efficient.

on both an intraday and interday basis. French (1980); Gibbons and Hess (1981); Keim and Stambaugh (1984); and Rogalski (1984) have variously reported the existence of a "day-of-the-week," "weekend," "Friday," or "Monday" effect with respect to mean stock returns.[2] Flannery and Protopapadakis (1988) report the presence of a day-of-the-week effect in the returns on selected fixed-income securities. The existence of these anomalous effects is still a matter of controversy, however. For instance, Connolly (1991) argues that there is little evidence to support a day-of-the-week or Monday effect in security returns when more robust tests are employed.[3] Harris (1986) reports evidence of intraday patterns in NYSE stock returns including an observed tendency for higher stock returns at the opening and throughout the first 45 minutes of trading and at the close of trading than elsewhere during the day.[4]

Similarly, as noted earlier, several recent studies have reported evidence of intraday patterns in the volatility of NYSE stock returns. In particular, Wood, McInish, and Ord; Amihud and Mendleson; and Stoll and Whaley all report evidence of greater volatility in NYSE stock returns at the open and close of trading than at other points during the trading day.[5] Their findings are puzzling because by comparing open to open stock returns with close to close stock returns the authors of these studies largely control for possible information differences. Amihud and Mendleson attribute this market opening effect to "the trading mechanism" employed on the NYSE while Stoll and Whaley argue that it may also be attributable to market participants trading on private information. Essentially, both Amihud and Mendleson and Stoll and Whaley argue that the greater volatility in NYSE stock returns simply reflects the combination of the single fixed-price auction at the open with a specialist system used throughout the rest of the day. In

[2] See Keim (1986) for a review of the early literature.

[3] Essentially, Connolly argues that most authors purporting to have evidence of a day-of-the-week or Monday effect in security returns failed to adjust their significance level as they increased their sample size making rejection of the null hypothesis (even when true) more likely. Zellner and Siow (1984) demonstrate the importance of increasing the power of the test (i.e., reducing Type II error) as sample size increases.

[4] Harris states: "In addition to the larger returns at the beginning and end of the trading day, there are other time-series patterns in the 15–minute intradaily returns which are common to all weekdays and, therefore, worthy of note. These patterns appear to include a rise in prices between 12:30 and 1:30 and a fall between 2:30 and 3:15 [New York time]." Harris also notes that: "Trading strategies based only on these weekly and intradaily patterns would not be profitable because of transaction costs."

[5] For instance, Wood, McInish, and Ord, report greater volatility (as measured by the standard deviation) in one-minute stock returns (the log of the price relative) using NYSE data during the first 30 minutes of trading and during the last minute and last 5 minutes of trading.

addition, Stoll and Whaley contend that the bid/ask spread is greater at the opening than at the close of trading. Jain and Joh (1988) provide evidence that the observed greater returns in NYSE stocks during the first and last trading hours are associated with (except for Monday) greater trading volume. Jain and Joh, however, reject the notion that the greater trading volume *causes* (in the Granger-Sims sense) the greater stock returns.

THE STRUCTURE OF FINANCIAL FUTURES MARKETS

Like U.S. equity markets, U.S. financial futures markets are open continuously from the start of trading to the close of each trading day. Unlike U.S. equity markets, however, a specialist system is not used on U.S. futures markets. All trades are made via the open outcry auction system without designated marketmakers.[6] Transaction futures prices result when someone hits a bid or takes an offer. The use of the open outcry auction system means that there is no assurance that transaction futures prices are necessarily equilibrium futures prices at the open or elsewhere during the trading day [Webb (1991)]. Both the CME and LIFFE employ the open outcry auction system.

When markets are open for trading only part of the day, then information released since the previous close must be incorporated into the opening market price. This may result in substantial variation in market prices at the opening when important information arrives "overnight" or, more correctly, after the market's previous close.[7] Even in the absence of the release of new publicly available information, it might be argued that the cessation of trading may result in significant variation in security prices and hence returns at market openings as market participants "hunt" for an appropriate starting price. Obviously, if the market is open elsewhere, then the hunt for a starting price is unnecessary. Similarly, if the market is informationally efficient and markets open and close sequentially but overlap during part of the trading day, then any public information which is released after the close of trad-

[6]The LIFFE allows after hours trading on its APT (Automated Pit Trading) system for selected futures contracts. Eurodollar futures trade on LIFFE's APT system from 4:26 P.M. to 5:56 P.M. London time. On June 25, 1992, the CME and the Chicago Board of Trade launched Globex, an automated after hours trading system on which several financial futures contracts (including Eurodollars) now trade.

[7]Gerety and Mulherin (1991) examine the largest 50 hourly returns on a Dow Jones index from May, 1933 through December, 1989. They observe that 25 of the top 50 hourly returns occur from the close of trading the previous night to the open of trading on the current day.

ing in one market should be currently reflected in the price of the same commodity in another market which is currently open. If not, then arbitrage opportunities may arise. The gradual release of privately produced information could also produce a market opening effect. However, this is unlikely to be a significant source of a market opening effect in most interest rate futures markets where there is limited potential for private information production.[8] Indeed, most of the information, which is likely to affect changes in interest rates, comes from government sources. A potentially significant source of a market opening effect would be increased trading volume at the open, with transaction prices bouncing between bid and ask as futures contracts are sold to or bought from "scalpers" making a market on the floor.[9] Presumably, the excess volatility observed at market opening would simply reflect the pattern of order flows. Although some authors contend that trading volume and price changes are linked, the relationship between the two remains controversial.

If a market opening effect exists for reasons other than the arrival of new information, then it should be observable in markets which open when another market is already open for trading in the same securities. Similarly, if a "market closing effect" exists, (i.e., increased volatility at the close) for reasons other than the arrival of new information, then one should be able to observe increased volatility in markets which close while another market is already open. Such volatility, if it exists, might be attributable to traders "squaring off" their futures positions before going home. Consequently, the null hypothesis is that the volatility of CME Eurodollar futures prices at market opening (or LIFFE closing) is less than or equal to the average volatility during a similar length trading interval during the CME trading day on days when trading in Eurodollar futures on LIFFE overlaps with the CME. The alternative hypothesis is that the volatility of CME Eurodollar futures prices at market opening (or LIFFE closing) exceeds the average volatility of Eurodollar futures prices for similar length trading periods during the CME trading day.

[8]To be sure, Fedwatching is a cottage industry of sorts as market participants try to anticipate Federal Reserve monetary policy actions. Federal Reserve security transactions in the open market (i.e., open market operations) are the principal instrument of monetary policy. Given that the Fed, in recent years, has largely limited its intervention in the security markets to "Fed Time" (11:30–11:45 A.M. Eastern time), it is not immediately clear why the release of privately produced information (about Fed monetary policy actions) would be consistently concentrated about the U.S. opening of the Eurodollar futures market.

[9]Marsh and Rosenfeld (1986) demonstrate that this "market making noise" introduces an upward bias in volatility when marketmakers trade with liquidity based traders and a downward bias in volatility when marketmakers trade with information motivated traders.

Succinctly stated:

$$H_o: \overline{v}_{D,1} \leq \overline{v}_{D,N}$$

$$H_a: \overline{v}_{D,1} > \overline{v}_{D,N}$$

$$\overline{v}_{D,1} = \sum_{d=1}^{D} \overline{v}_{d,1}/D$$

$$\overline{v}_{D,N} = \sum_{t=1}^{N} \left(\sum_{d=1}^{D} \overline{v}_{d,t}/D \right) \Big/ N$$

where:

$\overline{v}_{d,t}$ = average volatility of futures prices during the tth trading interval ($t = 1, \ldots, N$) of day d of the "front month" period ($d = 1, \ldots, D$);

$\overline{v}_{d,1}$ = average volatility of futures prices during the market opening (trading interval = 1) in each day of the "front month" period consisting of D days, $d = 1, \ldots, D$;

$\overline{v}_{D,N}$ = average volatility of a trading interval during the trading day comprised of N trading intervals t, $t = 1, \ldots, N$.

Before the above hypotheses can be tested, the volatility of Eurodollar futures prices and the length of the market opening and closing intervals must be defined. A natural candidate for volatility would be the variance of *changes* in Eurodollar futures prices or its transform, the standard deviation.[10] However, the measure suffers from the drawback that virtually all changes in Eurodollar futures prices are the minimum price move of one tick. Consequently, the standard deviation of Eurodollar futures prices is used as the measure of price volatility instead.[11]

METHODOLOGY

Although the standard deviation of Eurodollar futures prices is used as the measure of *price volatility* in this study, two complementary measures of volatility are also calculated for each trading interval; namely, an indication of *market excitement* (the frequency of price changes) and

[10]As Wasserfallen and Zimmerman (1985) note, the distribution of changes in many speculative price series has been observed to depart from normality over short time intervals, thus calling into question the use of variance as a measure of volatility. The variance also suffers from the drawback that it is sensitive to outliers in small samples. For this reason, the range, interquartile range, and absolute deviations are sometimes advocated as alternative measures of dispersion.

[11]The question naturally arises as to why the volatility of returns on Eurodollar futures positions was not calculated instead. Unfortunately, conventional return measures cannot be calculated for futures positions because futures contracts are zero investment vehicles [Black (1976)].

trading potential (the range of price changes). The principal reason for this is to capture price volatility as it might be perceived by traders on the floor of a futures exchange. In this regard, market excitement provides a measure of the *intensity* of price change behavior while trading potential provides a measure of the *extensiveness* of price change.

Trading potential can be further dichotomized into the: *tick range* (i.e., the difference between the lowest and highest price observed during a trading interval); and *profit likelihood* (i.e., the probability that the tick range of an interval will exceed the apparent bid/offer spread of one tick).[12] The tick range indicates the maximum profit potential for a *single* trade during the interval (under conditions of zero transaction costs and perfect information) while profit likelihood indicates the probability that prices will change enough to make a profitable trade possible.

These complementary volatility measures are useful for comparison of short trading intervals where the number of price changes in an interval on a given day may be small. As is readily apparent, the standard deviation of Eurodollar futures prices is more reliable in a given trading interval the greater the number of observations (i.e., price changes). Similarly, the sensitivity of the standard deviation to extreme prices (i.e., outliers) depends, in part, upon the frequency with which prices are changing.

Figure 1 illustrates the method of calculating volatility measures for the Eurodollar Futures Contract data of the CME, where *all* price changes are recorded. Transactions in the interval will take place at one of the prices shown, beginning with the last price of the preceding period.

Mathematically,

$$
\begin{aligned}
P_{d,t}^{i} &= \text{price } i \text{ in interval } t \text{ of day } d \\
i &= 1, \ldots, N_{d,t} \\
d &= 1, \ldots, D \\
t &= 1, \ldots, \text{defined number of intervals} \\
N_{d,t} &= \text{number of price changes for interval } t \text{ of day } d \\
D &= \text{total number of days for analysis}
\end{aligned}
$$

[12]Price changes in excess of one tick occurr less than four-tenths of one percent of the time in the sample.

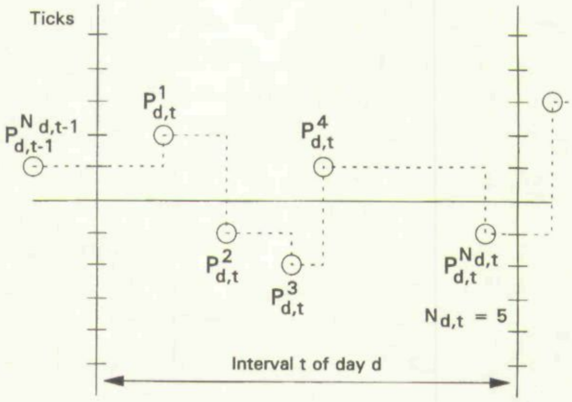

FIGURE 1
Transaction prices used in the calculation of price volatility for a trading interval.

$$\overline{P}_{d,t} = \text{average price over interval } t \text{ of day } d$$

$$= \frac{\left(\sum_{i=1}^{N_{d,t}} P^{i}_{d,t}\right) + P^{N_{d,t-1}}_{d,t-1}}{N_{d,t} + 1}$$

$$V_{d,t} = \text{price volatility over interval } t \text{ of day } d$$

$$= \sqrt{\frac{\sum_{i=1}^{N_{d,t}} (\overline{P}_{d,t} - P^{i}_{d,t})^2 + (\overline{P}_{d,t} - P^{N_{d,t-1}}_{d,t-1})^2}{N_{d,t} + 1}}$$

$$R_{d,t} = \text{tick range over interval } t \text{ of day } d$$

$$= \max_{i}(P^{i}_{d,t}, P^{N_{d,t-1}}_{d,t-1}) - \min_{i}(P^{i}_{d,t}, P^{N_{d,t-1}}_{d,t-1})$$

$$\overline{V}_t = \text{average volatility of interval } t$$

$$= \frac{\sum_{d=1}^{P} V_d, t}{D}$$

$$\overline{R}_t = \text{average tick range of interval } t$$

$$= \frac{\sum_{d=1}^{D} R_d, t}{D}$$

$\overline{L}_t$ = likelihood that $R_{d,t} > 1$, for interval t, or the proportion of days where $R_{d,t} > 1$ over all days $d = 1, \ldots, D$.

DATA

Eurodollar futures contracts are traded on the Chicago Mercantile Exchange (CME), the London International Financial Futures Exchange (LIFFE), and the Singapore International Monetary Exchange (SIMEX).[13] The CME has by far the most active Eurodollar futures market. While minor differences exist between the CME and LIFFE Eurodollar futures contracts, the CME and SIMEX Eurodollar futures contracts are identical and subject to "mutual offset."[14]

Time and sales data on Chicago Mercantile Exchange Eurodollar futures prices for 12 consecutive contract months are examined for the November 25, 1987–October 31, 1990 period (when trading on LIFFE was more active) to test the above hypotheses. The examination is restricted to an analysis of the prices of the nearby or "front" month contract. The front month is invariably the most actively traded contract (except during the short "rollover" period where a new futures contract becomes a new "front" month even through the former "front" month contract has not expired.)

Table I indicates the dates during which each futures contract is the nearby contract. Table I also indicates the number of price changes observed for each futures contract during the period that it is the front month. As is readily apparent, the number of price changes can differ substantially across contract months.[15] The difference in the number of price changes across front months reflects both differences in volatility and trading volume.

Trading in Eurodollar futures contracts on the LIFFE begins at 8:30 A.M. and stops at 4:00 P.M. (London time) on normal trading days.[16]

[13]The Tokyo International Financial Futures Exchange (TIFFE) also trades a Eurodollar futures contract. However, the TIFFE's Eurodollar futures contract is inactively traded. Similarly, an active liquid market in Eurodollar futures on Globex has yet to develop.

[14]Mutual offset allows individuals with open CME (SIMEX) Eurodollar futures positions to treat offsetting futures transactions on the SIMEX (CME) as if they occurred on the CME (SIMEX). From an economic perspective, this effectively extends the CME (SIMEX) Eurodollar trading day and narrows the time period that traders with open futures positions are unable to transact because the market is "closed."

[15]The question naturally arises as to whether the criticisms Connolly raises about the need to adjust the power of the test as the sample size increases are applicable to this study. The answer is no because the relevant sample size is the number of trading days rather than the number of price changes.

[16]The CME, the LIFFE, and SIMEX observe different holiday schedules. While they share New Year's Day, Good Friday, and Christmas Day, the LIFFE also observes Easter Monday, May Day (which is observed on the first Monday in May), Whit Monday, the Late Summer Holiday, and Boxing Day. SIMEX observes the Chinese New Year, Hari Raya Puasa, Labour Day (May 1), Vesak Day, Hari Raya Haji, National Day, and Deepavali. There are only 5 days each year where LIFFE is closed when the CME opens.

TABLE I
Time Period That Selected CME Eurodollar Futures Contracts Traded as the Front Month

Contract	*Contract*	*Front Month Period*	*Price Changes*	*LIFE Closed While CMEIs Open*
EDH88	Mar 1988	11/25/87–02/16/88	12,552	12/28/87
EDM88	June 1988	02/17/88–05/10/88	9,334	4/4/88, 5/2/88
EDU88	Sept 1988	05/11/88–08/16/88	12,617	—
EDZ88	Dec 1988	08/17/88–11/08/88	9,805	08/29/88
EDH89	Mar 1989	11/09/88–02/13/89	12,686	12/27/88
EDM89	June 1989	02/14/89–05/09/89	19,637	3/27/89, 5/01/89
EDU89	Sept 1989	05/10/89–07/30/89	20,040	—
EDZ89	Dec 1989	07/31/89–11/10//9	25,866	08/28/89
EDH90	Mar 1990	11/13/89–02/01/90	13,118	12/26/89
EDM90	June 1990	02/02/90–05/01/90	11,573	4/16/90
EDU90	Sept 1990	05/02/90–08/01/90	11,218	5/7/90
EDZ90	Dec 1990	08/20/90–10/31/90	13,026	8/28/90
Total		11/25/87–10/31/90	171,395	12

Sources: CME Yearbook (Series), CME Research Department, CME Time and Sales Data.

Trading in the CME Eurodollar futures contract starts at 7:20 A.M. and usually stops at 2:00 P.M. (Chicago time). With London 6 hours ahead of Chicago, trading on the two Exchanges usually overlaps for 2 hours and 40 minutes. With Singapore 13 to 14 hours ahead of Chicago, trading in Eurodollar futures overlaps with LIFFE but not with Chicago. Trading in SIMEX Eurodollar futures begins at 7:45 A.M. and ends at 6:20 P.M. (Singapore time) on business days.[17] The trading hours for each exchange are indicated in Figure 2. As is readily apparent, Eurodollar futures are traded on exchange floors over 20 hours each business day.

It should be noted that the time and sales data on CME Eurodollar futures prices reflect price changes only. Consequently, it is not possible to ascertain the number or volume of transactions at any given price. Given the limited number of observations on any given day, it is necessary to examine a longer time interval than, say, the first minute of trading. In this study the market opening interval is defined as the first 5 minutes of trading (7:20:00–7:24:59) while the rest of the trading

[17]Both the CME and the LIFFE hold abbreviated trading sessions for the front month contract on the last day of trading (settlement day). On the LIFFE, trading in the contract which is about to expire starts at 8:30 A.M. and concludes at 11:00 A.M. (London time) on settlement day. On the CME, trading in the contract about to expire runs from 7:20 A.M. to 9:30 A.M. (Chicago time) on settlement day.

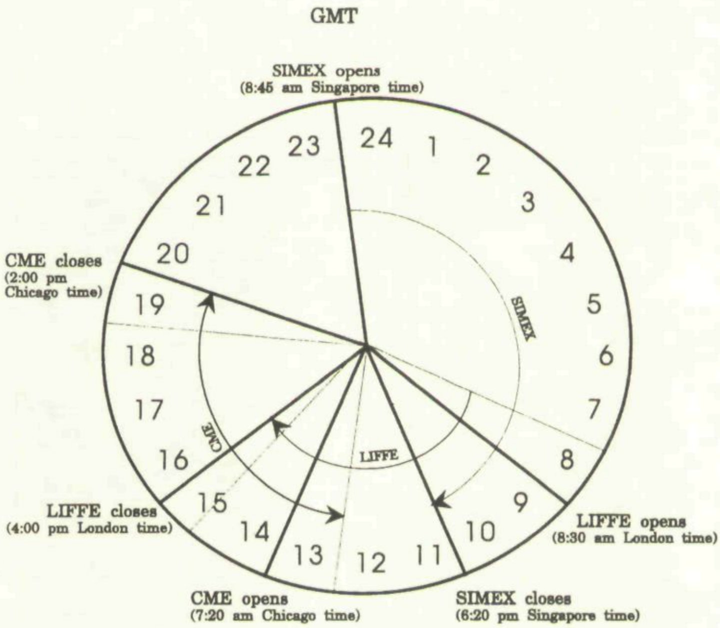

FIGURE 2
The global trading day for Eurodollar Futures Contracts. Note: The time zone differential between Singapore and Chicago varies between 13 and 14 hours depending on the time of year. When Chicago is on Central Standard Time, Singapore is 13 hours ahead of Chicago. When Chicago is on Daylight Savings Time, Singapore is 14 hours ahead of Chicago. In addition, please note that the Eurodollar Futures Contracts entered into on the CME (SIMEX) can be offset on the SIMEX (CME).

day is split up into 79 five-minute trading intervals. This approach results in a total of 80 equal length trading intervals for each full trading day. It should be noted that unlike the stock market, numerous government economic reports are released during the time that CME Eurodollar futures are trading. These reports which are typically released at 7:30 A.M. (Chicago time) often exert a significant impact on interest rate futures prices and are a potentially important source of volatility. Consequently, the 5-minute trading interval beginning at 7:30 A.M. is called the information interval.

EMPIRICAL ANALYSIS

Figures 3–6 provide a graphical depiction of information on Eurodollar futures price volatility, market excitement, and trading potential for each of the 80 five-minute trading intervals across the 742 trading days in

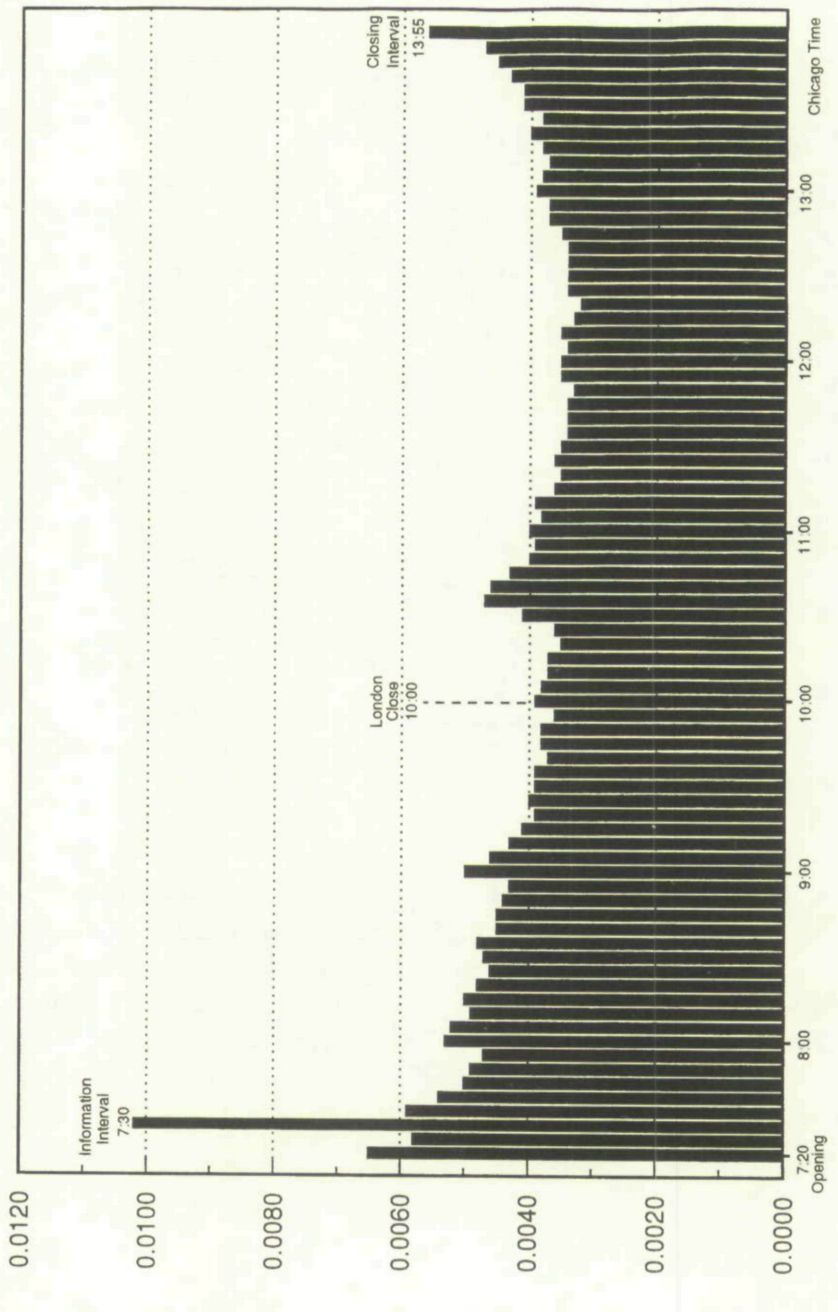

FIGURE 3

Price volatility in five-minute intervals—front month Eurodollar Futures Contracts: 11/25/87–10/31/90.

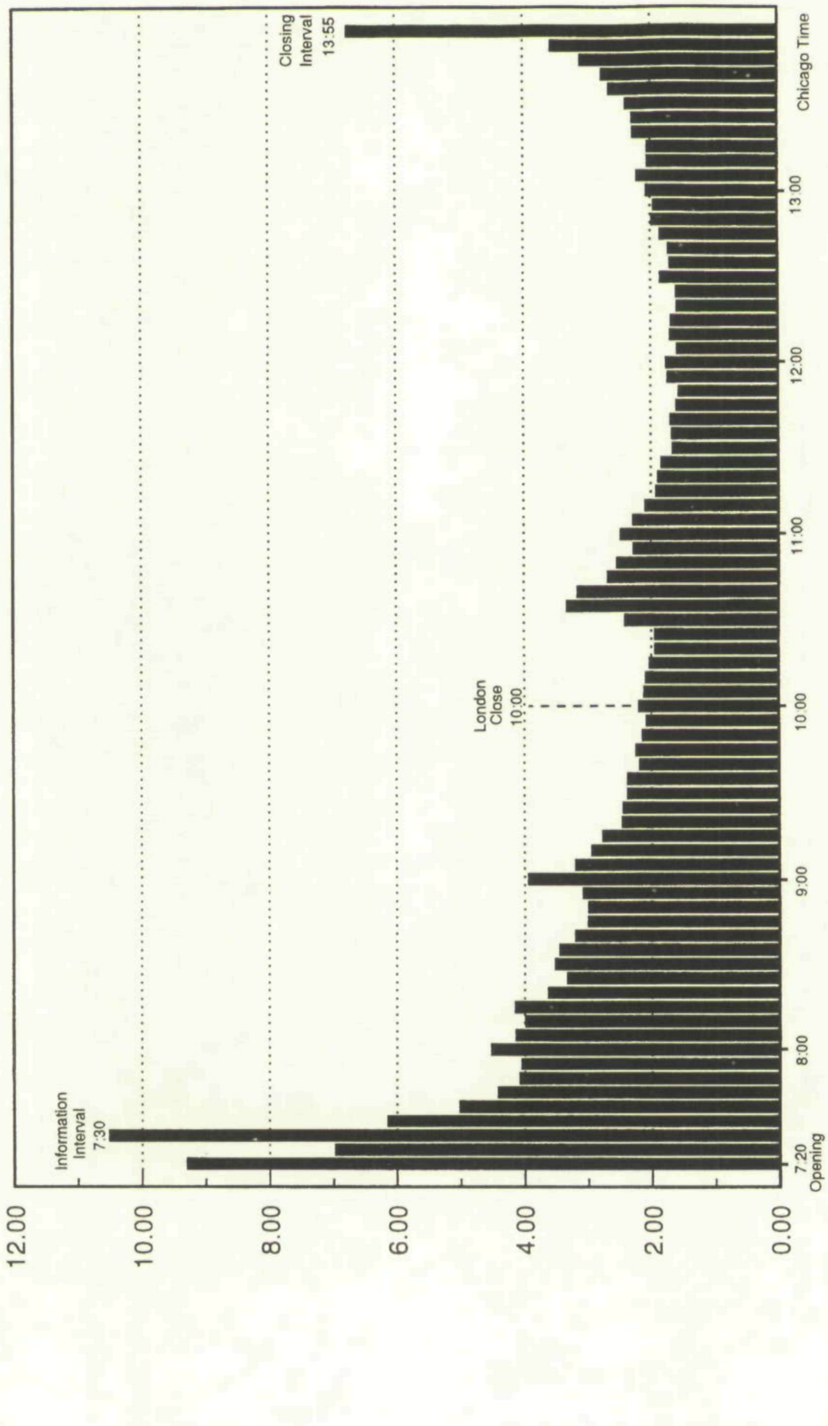

FIGURE 4
Average number of prices in five-minute intervals—front month Eurodollar Futures Contracts: 11/25/87–10/31/90.

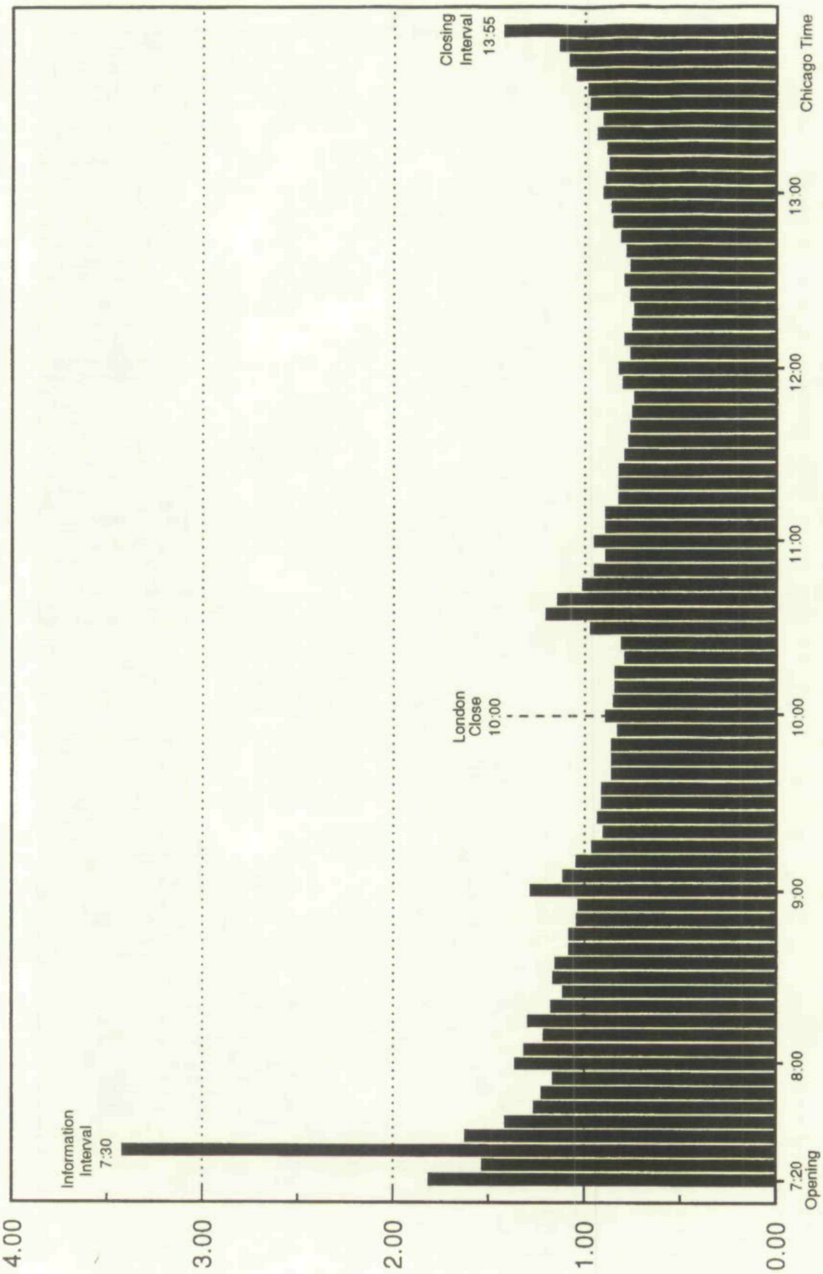

FIGURE 5

Average tick range for five-minute intervals—front month Eurodollar Futures Contracts: 11/25/87–10/31/90.

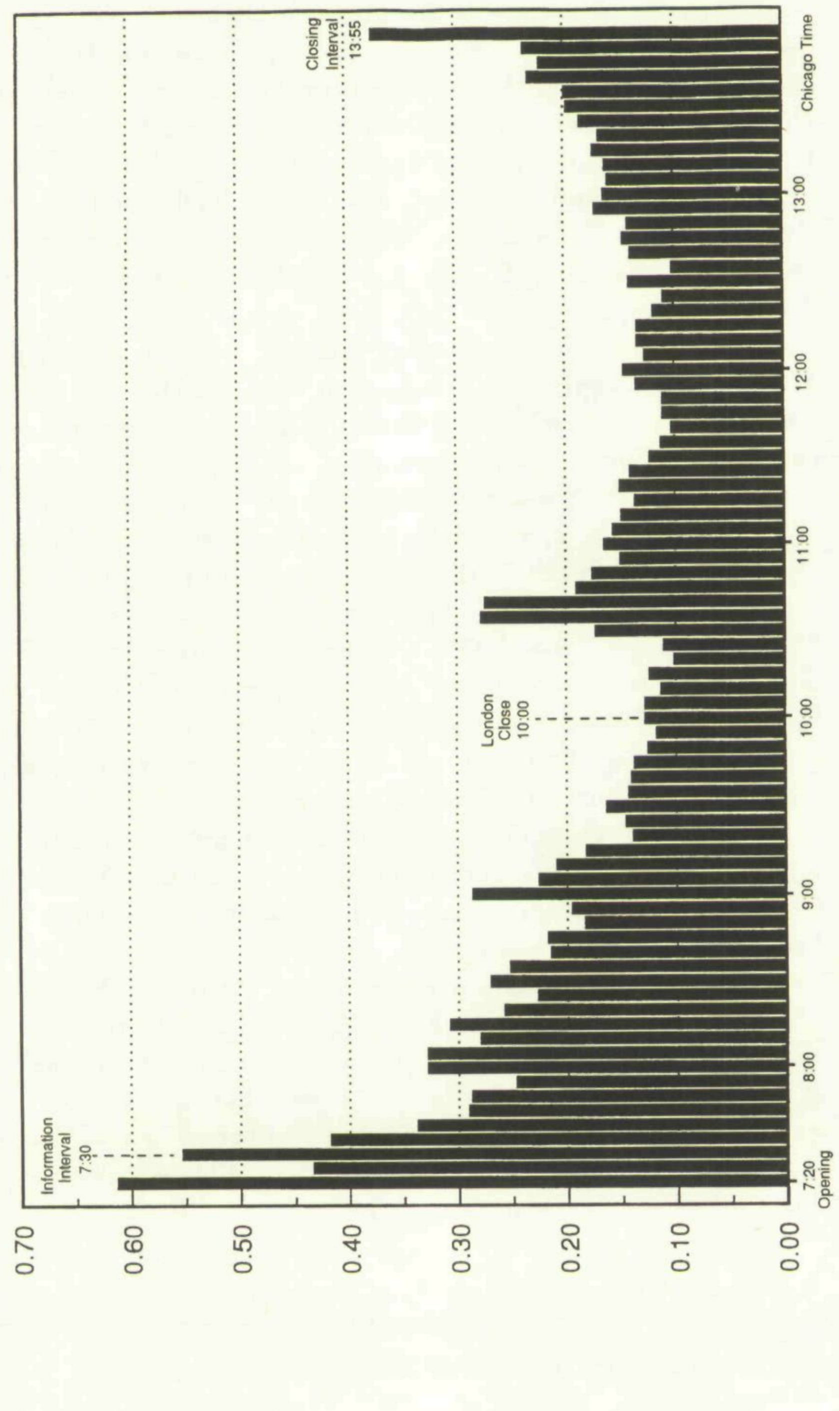

FIGURE 6

Frequency of tick range > 1 for five-minute intervals—front month Eurodollar Futures Contracts: 11/25/87–10/31/90.

the sample. An examination of Figure 3–6 indicates that the information interval has the greatest price volatility, market excitement, and trading potential. However, the market opening trading interval has the second largest amount of price volatility, market excitement, and trading potential while the CME closing trading interval has the fifth largest amount of price volatility and tick range and the fourth largest frequency of price changes. While the information interval has the greatest price volatility, frequency of price changes, and tick range, the market opening interval has the greatest profit likelihood. This is most likely due to the fact that although there is a new market opening each day, government economic reports are only released periodically leading to a lower *average* profit likelihood.

These results are consistent with the findings of other studies which analyze NYSE stock returns. For example, Harris (1986) reports a pattern of greater stock returns during the first 45 minutes of trading than at other times during the trading day. Figures 3–6 also indicate that while the London close is not associated with greater volatility on average, there does seem to be a discernible increase in volatility at the close of trading on the CME. Recall that both the LIFFE and SIMEX are closed at this time as well.[18]

Figures 7–9 report 95% confidence intervals for each of the 80 trading intervals resulting from the parametric test of the null hypothesis. A pattern of significant intraday volatility differences is clearly evident in these figures. Under this parametric method, the dominance of a market opening effect stands out.[19]

In contrast, there does not seem to be a pronouced effect on the volatility of CME Eurodollar futures prices when LIFFE closes. There is, however, a significant increase in volatility at the close of CME Eurodollar futures trading.

The question naturally arises as to what extent the observed greater volatility at the open and close of trading simply reflects market-making noise, especially when the number of price changes is used as the measure of price volatility. For instance, a period of heavy trading activity might result in a large number of price changes even though prices simply bounce from bid to offer as bids are hit and offers are taken. If the market opening effect is due simply to greater

[18]One puzzling phenomenon, however, is the observed tendency for Eurodollar futures prices to increase in volatility on the hour. The regularity of this phenomenon results in a surprising almost "pulse-like" behavior.

[19]These results are confirmed using the non-parametric Wilcoxon-Z test for significance of paired-differences.

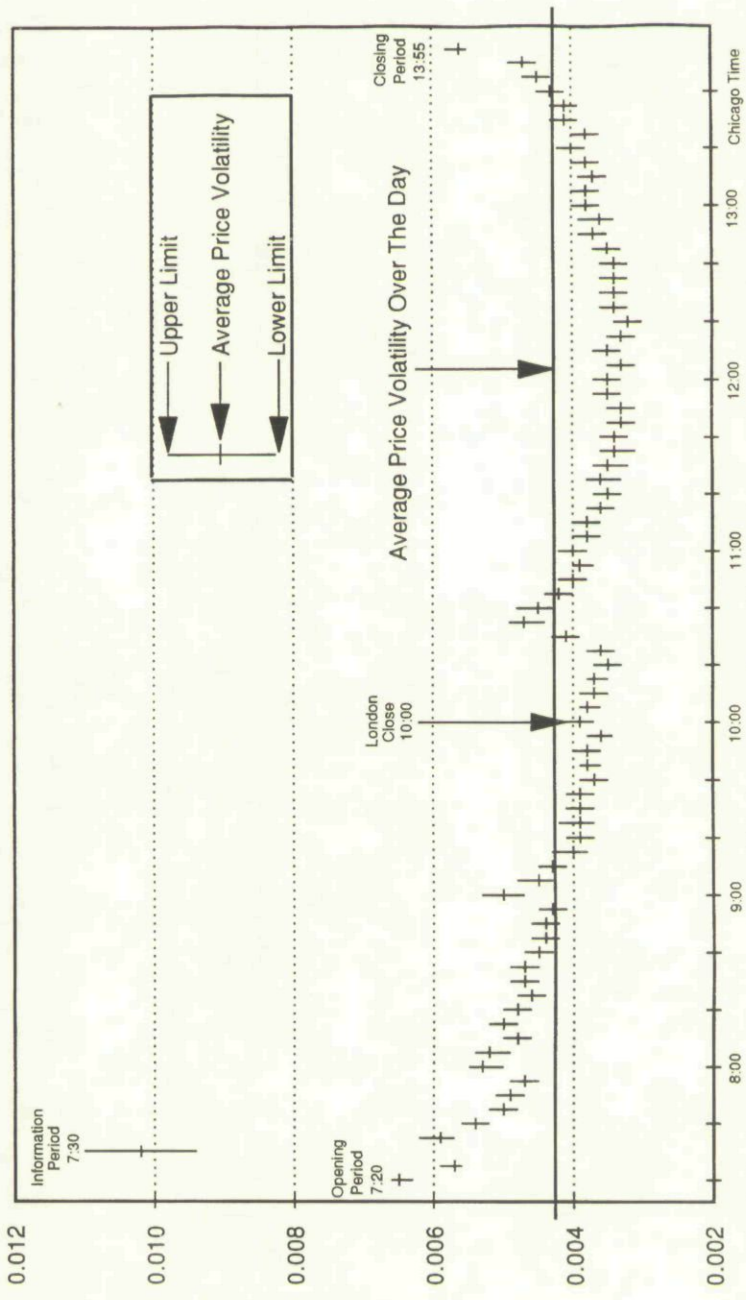

FIGURE 7

Price volatility - 95% confidence intervals around the average price volatility in five-minute intervals—front month Eurodollar Futures Contracts: 11/25/87–10/31/90.

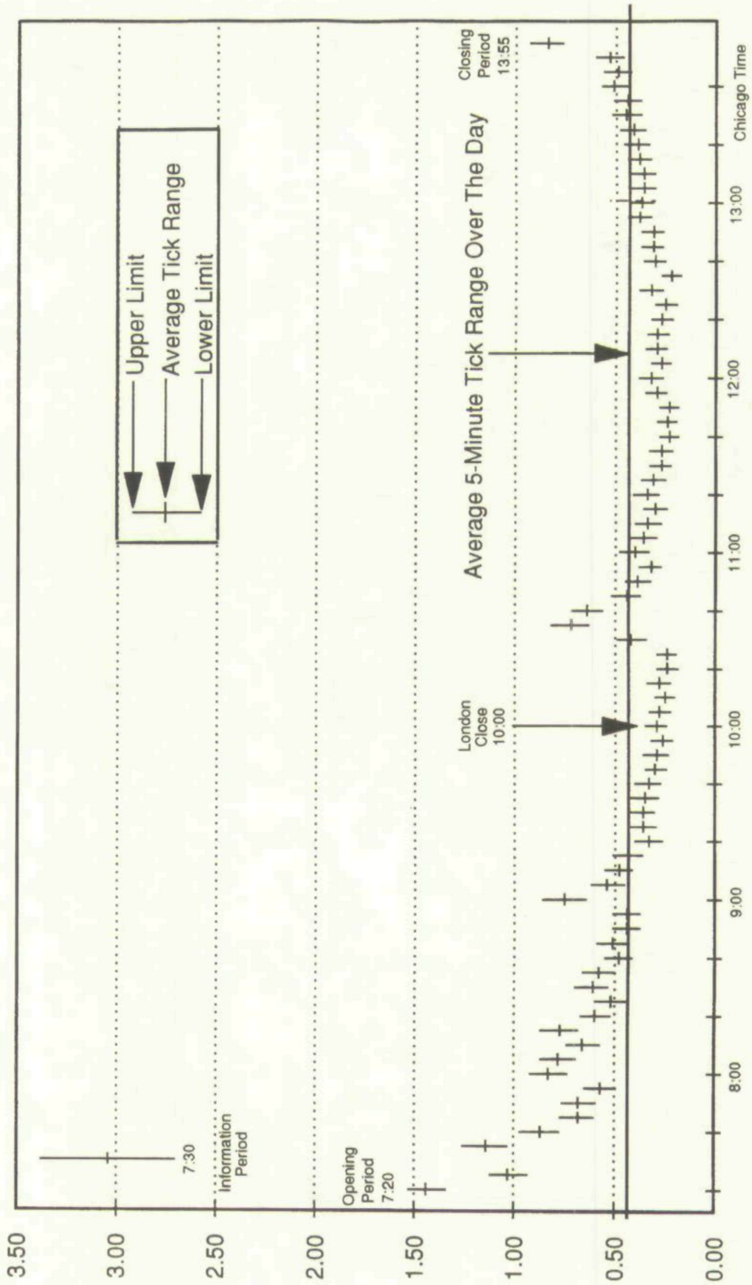

FIGURE 8
Average tick range - 95% confidence intervals around the average tick range in five-minute intervals—front month Eurodollar Futures Contracts: 11/25/87–10/31/90.

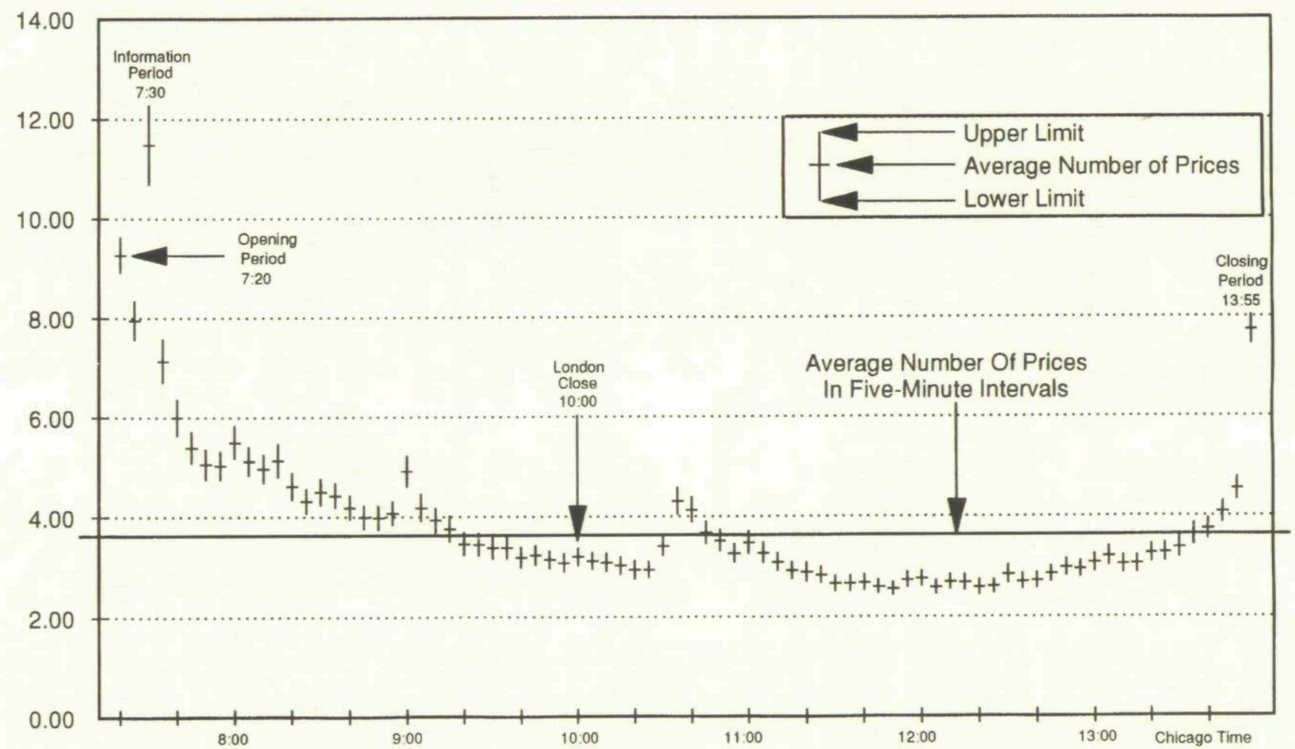

FIGURE 9

Average number of prices - 95% confidence intervals around the average tick range in five-minute intervals—front month Eurodollar Futures Contracts: 11/25/87–10/31/90.

trading volume at the open, then the range in futures prices during the market opening interval should be narrow since there is no new information to disturb prices. That is, the range in futures prices during the market opening interval should be less, on average, than the range in futures prices during other intervals in the trading day. Indeed, other things equal, the more transactions, the narrower the bid/ask spread would be.

Yet, Figures 5–9 show that the average range in prices during CME market opening or closing is greater than all periods save one. To be sure, the greatest range in prices occurs during the information interval. However, the range in prices during the market opening interval ranks second while the range during the CME market closing interval ranks third.

Similarly, if one contends that the appropriate measure of volatility is the variance of Eurodollar futures prices, then the effect of increased market-making activity at the open on volatility depends upon whether the counterparties are information or liquidity motivated traders. As noted earlier, Marsh and Rosenfeld have shown that when marketmakers trade with liquidity motivated traders, an upward bias in variance results. The reverse is true when marketmakers trade with information motivated traders.[20]

When the market opening is decomposed into its constituent one-minute subperiods, it is apparent that there is a negative exponential decline in the number of price changes after the first minute of trading. This is shown in Figures 10 and 11, which depict the average number of price changes observed for each minute of the trading day for a given contract during the front month period. For the sake of brevity, the analysis is limited to two contract months (EDZ88 and EDZ89) although similar results are obtained for the other contract months. The virtual "U" shaped pattern in intraday volatility is immediately apparent. When the time frame is narrowed, more information arises. For instance, Figures 12 and 13 depict the average number of price changes observed from the market opening through 1:59:59 for each contract during the entire front month period. A similar "U" shaped pattern in volatility emerges between the market opening and information periods. (Keep in mind that the information period includes a mix of days when one or more government economic reports are released and many days when none are.) It is also immediately apparent that most of the volatility in

[20]One implication of the Marsh and Rosenfeld article is that if volatility is measured by the variance of futures prices, then the market opening effect is unlikely to be the result of individuals exploiting private information.

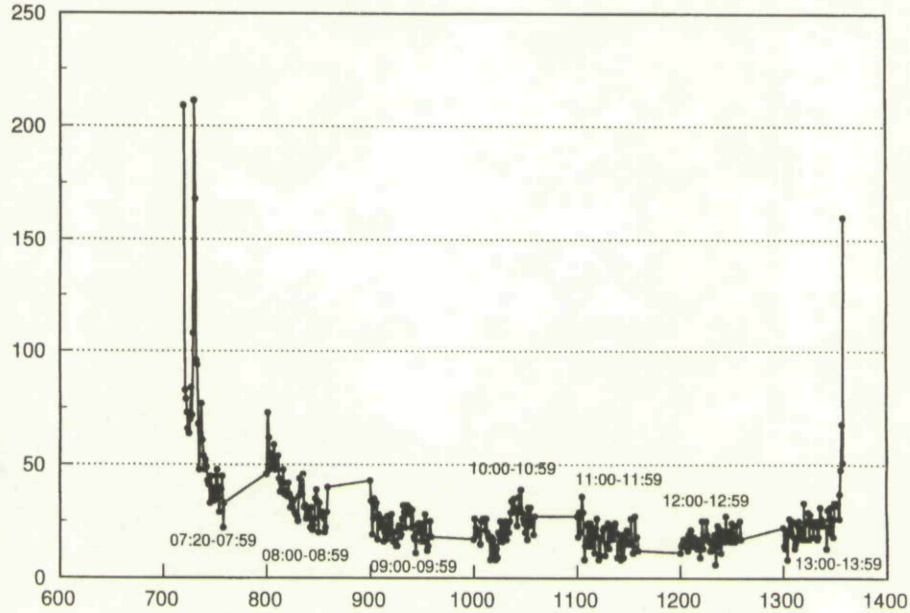

FIGURE 10

Eurodollar Futures Contract EDZ88—total number of price changes in each minute during "front month," 07:20–14:00, Chicago time ("front month" period 08/17/88–11/08/88).

the market opening period occurs during the first minute of trading and seemingly declines exponentially thereafter. This is less true during the information interval.

Figures 14 and 15 narrow the time frame further by depicting the total number of price changes in each second for the first minute of the market opening interval when EDZ88 and EDZ89 are the front month contracts.[21] Figures 16 and 17 show the corresponding total number of price changes for the information interval. In sharp contrast to the information interval, the peak in volatility during the opening interval occurs in the first 10 seconds of trading and then typically declines sharply thereafter. For the information interval, the pattern in volatility during the first minute of trading appears much more random. It is not immediately apparent why there is a seeming lag of a few seconds before a price is reported.[22] There also appears to be a significant decay

[21]Total price changes observed for each second is used because the number of observations in each one-second interval is small, even when taken over the entire front month period. Total price changes, rather than average changes per minute presents a more meaningful picture of the intra-minute pattern.

[22]Alternatively stated, the market opening effect largely occurs within the first minute of trading. Consequently, the use of other measures of volatility such as the range or variance over the *entire* 5-minute trading inteval *understates* the volatility of the market opening effect.

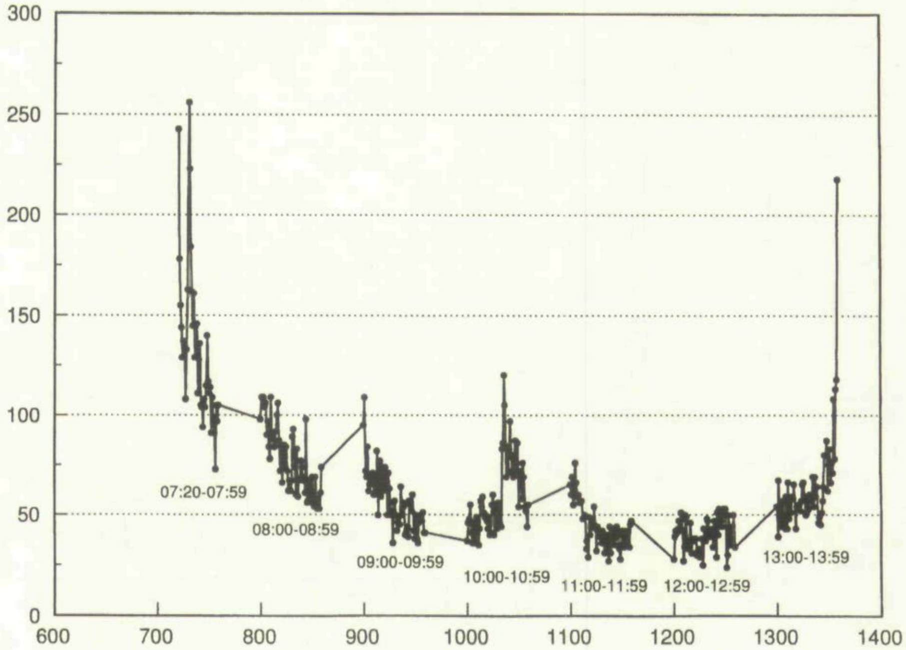

FIGURE 11
Eurodollar Futures Contract EDZ89—total number of price changes in each minute during "front month," 07:20–14:00, Chicago Time ("front month" period 07/31/89–11/10/89).

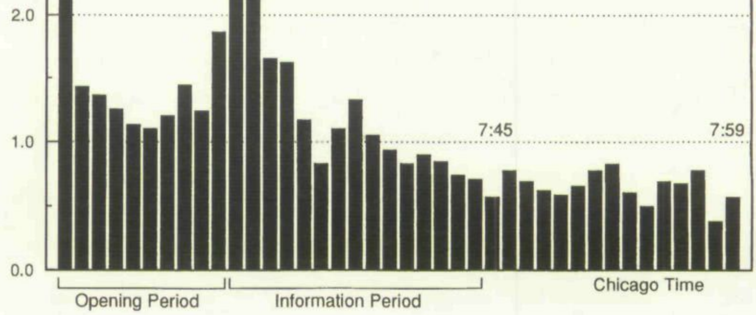

FIGURE 12
Average number of price changes in each minute showing opening and information intervals—front month Eurodollar Futures Contract EDZ88.

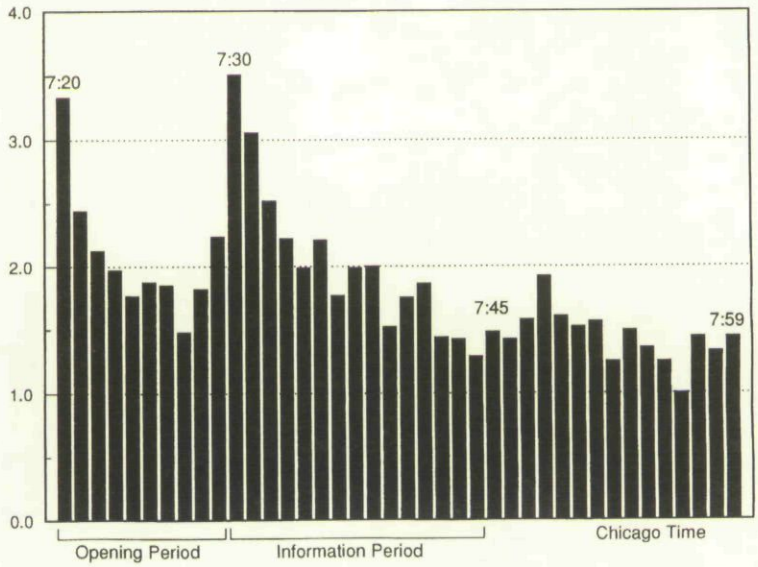

FIGURE 13
Average number of price changes in each minute showing opening and information intervals—front month Eurodollar Futures Contract EDZ89.

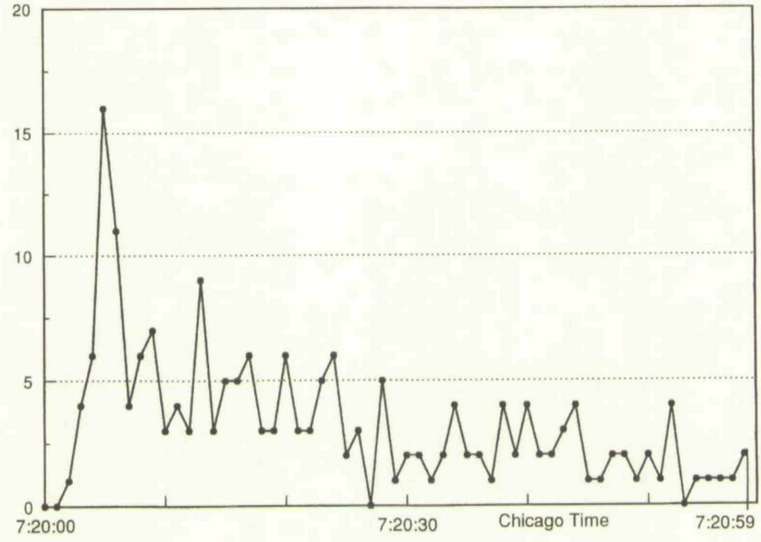

FIGURE 14
Total number of price changes in each second of the first minute of the opening interval—front month Eurodollar Futures Contract EDZ88.

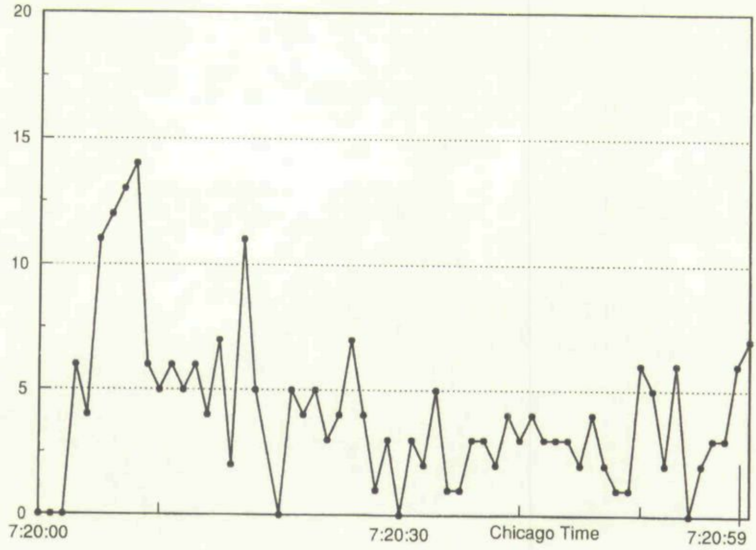

FIGURE 15
Total number of price changes in each second of the first minute of the opening interval—front month Eurodollar Futures Contract EDZ89.

relationship for the opening interval. No such pattern is indicated for the information interval.

The question naturally arises as to whether the greater volatility observed at the open and close of trading simply reflects greater trading

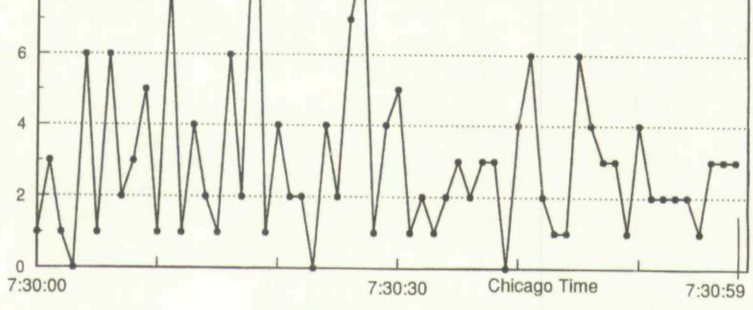

FIGURE 16
Total number of price changes in each second of the first minute of the information interval—front month Eurodollar Futures Contract EDZ88.

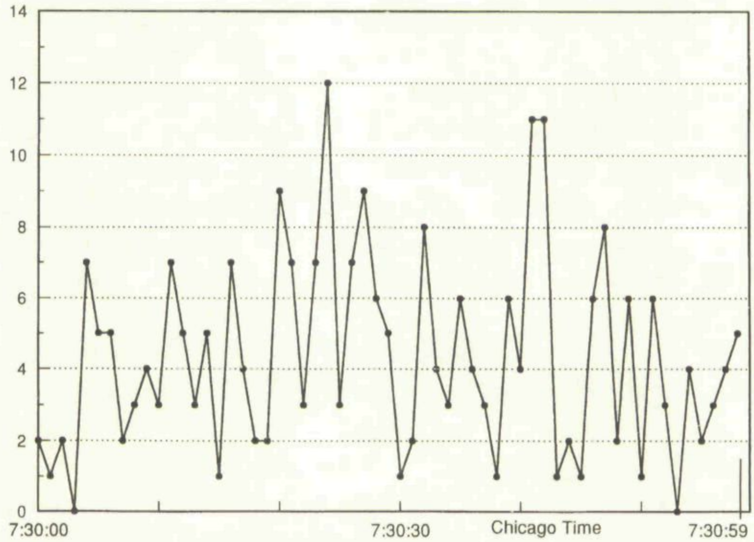

FIGURE 17
Total number of price changes in each second of the first minute of the information interval—front month Eurodollar Futures Contract EDZ89.

volume during these periods. Put differently, to what extent are the volatility measures employed in this study dependent upon volume rather than time? Indeed, some studies suggest an apparent relationship between volume and price changes. Clark (1973), for example, reports a curvilinear relationship between volume and cotton futures prices. However, the driving force in his model and other similar models is the arrival of new information and *not* volume per se.[23] The mere opening of a financial market when another financial market trading the same or virtually identical security is already open is *not* an informational event. Nor would one expect new information to cluster around the opening when another financial market trading the same security is already open elsewhere. Consequently, there are unlikely to be *information*-induced changes in trading volume which would result in changes in prices around the opening of such markets.

Moreover, if financial markets are informationally efficient one would not expect to observe a causal relationship between changes in volume (absent the simultaneous arrival of new information) and

[23]For instance, Clark (1973) states: "The different evolution of price series on different days is due to the fact that information is available to traders at a varying rate. On days when no new information is available, trading is slow, and the price process evolves slowly. On days when new information violates old expectations, trading is brisk, and the price process evolves much faster." (page 137)

changes in speculative prices at all. This is because investors are only concerned with the risk/return characteristics of a security in an efficient market. Different securities with the same risk/return characteristics are effectively perfect substitutes. As a result, the excess demand curve for a security in an informationally efficient capital market is horizontal. Indeed, as Scholes (1972) points out, it is only when the counterparty to a securities transaction is believed to have information not already reflected in market prices would one expect to observe a price volume relationship.

One possible explanation for the market opening and closing effects shown above is that those effects reflect market illiquidity. The presence of large "public" orders requiring immediate execution at the open or close of trading coupled with the reluctance of many marketmakers (in this case, scalpers) to take a position until after an initial price has been determined in the case of market opening or risk holding a position overnight in the case of the market close may combine to create less liquid markets than exist at other points during the trading day. If true, this would suggest that the bid/ask spread is wider on average at the open and close of trading than at other points of time during the trading day. As noted earlier, Stoll and Whaley report evidence that the bid/ask spread is wider at the opening of trading for NYSE common stocks. Unfortunately, this data set, which consists almost entirely of transaction futures prices does not allow a test of the above hypothesis. However, the near-virtual absence at market opening or closing of changes in CME Eurodollar futures prices in excess of the minimum increment of one tick suggests that the apparent bid/ask spread is the same, or smaller, at the open or close than it is during the rest of the day. Whether the effective bid/ask spread widens at the open and close of trading is more difficult to ascertain.

CONCLUSIONS

Several recent studies in the financial economic literature report greater volatility of stock returns at the open and close of trading than at other points during the trading day. This phenomenon has been attributed to traders acting on private information and the market structure of the NYSE. This study examines whether the observed patterns in stock return volatility are also characteristic of other financial markets with different market structures and where private information production is less likely. An examination of the intraday volatility of CME Eurodollar futures prices indicates significantly greater volatility during the opening

5 minutes of trading than during all other trading intervals except the information interval when many government economic reports are released. Moreover, the volatility peaks, on average, during the first 10 seconds after market opening. This is true even on days when a virtually identical Eurodollar futures contract is actively trading on LIFFE. This suggests the presence of a market opening effect. While the close of Eurodollar futures trading on the LIFFE does not appear to exert a discernible effect on the volatility of CME Eurodollar futures prices, there is evidence of a significant market closing effect for the CME.

Differences in market structure do not appear to be a reasonable explanation for the observed greater volatility at market opening since both the CME and LIFFE employ an open outcry auction system, continuously throughout the trading day. That is, unlike the NYSE, the CME does not employ a single fixed-price auction at the market opening coupled with a specialist system for the rest of the trading day. Moreover, unlike individual stocks, it is difficult to conceive of significant private information production for interest rate futures contracts. Thus, differential information across market participants is unlikely to be a cause of a market opening effect. While increased market making activity may explain some of this effect (if there is greater trading at the opening) neither the greater than average range in prices at opening nor the extremely rapid decay in volatility after market opening is consistent with this explanation. If market structure, differential (i.e., private) information, and increased market making activity at the open are rejected as explanations then trading noise becomes a more plausible explanation.

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