INTRADAY FUTURES VOLATILITY AND THEORIES OF MARKET BEHAVIOR

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INTRODUCTION

The existence of intraday U-shaped curves in volatility, volume, and bid–ask spreads is an interesting microstructure discovery that has generated several theories to explain these patterns as well as empirical evidence that investigates various aspects of these U-shaped curves. U-shaped curves are characterized by significantly higher values of the variable in question at the open and the close of trading as compared to periods within the day. This pattern exists in different markets: for example, New York, London, and Tokyo stock exchanges and Chicago futures exchanges. Therefore, the pattern is not associated with one type of market making system or system of determining opening prices. Several theories attempt to explain the U-shaped pattern. Admati and Pfleiderer (1988) provide an elegant explanation of how informed and uninformed traders would execute trades at the same time to create periods of high volatility and trade activity. Brock and Kleidon (1992) derive a market maker power theory to show why bid–ask spreads would be larger at the open and the close. Brock and Kleidon and others also state that "market closure" creates high volatility and high volume at the open and close. However, Brock

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and Kleidon conclude that the empirical evidence lends support to both the information and market closure theories.

This article employs 15-minute and 5-minute time intervals to examine the behavior of the S&P 500, MMI, and T-bond futures contracts. In particular, futures markets that possess unusual timing characteristics of their opening and/or closing periods are examined to provide evidence on the controversy concerning the cause of the U-shaped volatility and trading activity curves. The S&P 500 futures contract closes 15 minutes after the NYSE closes. The MMI stock index futures opens 15 minutes before the NYSE opens and closes 15 minutes after the NYSE closes. The T-bond futures contract possesses a night session as well as the normal day session. In addition, over the period of this study the T-bond contract changed its opening time from 9 AM Eastern to 8:20 AM Eastern time. Most government announcements are made at 8:30 AM Eastern time. To accommodate the effect of the additional futures trading hours into the existing theory, this article extends Brock and Kleidon's market closure theory to an "extended market closure" theory applicable to derivative markets. As part of the analysis, this article compares three different measures of volatility/activity to determine the consistency of the results across these different measures. These measures are the standard deviation, the Garman–Klass measure of volatility (using the open, high, low, and closing prices in an interval), and the number of ticks (price changes). Most studies use the standard deviation (or simply the price change from one interval to the next). The Garman–Klass measure is considered a superior measure of volatility since it includes more information.

The contracts examined here possess the basic U-shape pattern for volatility and trading activity. However, the S&P 500 and MMI futures contracts possess an initial drop in volatility and trading activity after the NYSE closes and then a closing peak when the futures markets close. Moreover, the MMI has lower volatility and activity for the total 15-minute period before the NYSE opens but possesses definite mini-peaks at the futures and the cash openings when the five-minute time intervals are employed. Also of interest is that the peak "closing" values for both the S&P 500 and MMI contracts occur 30 minutes before the NYSE closes. The T-bond futures possess individual U-shaped curves for both the day and night sessions, with the night session having a significantly lower level of volatility and activity. When the T-bond contract opens before the government announcements are made, there is a spike in trading activity and volatility for the announcement period which is higher than the opening values for these variables.

These results show that public information (via the T-bond announcements) does increase volatility and trading activity. This increased volatility and activity at the open is consistent with Admati and Pfleiderer's asymmetric information model. The U-shape pattern also provides evidence to support the market closure theory of Brock and Kleidon. In fact, much of the unique behavior associated with these contracts is only explained by the extended market closure concept discussed in this article. However, several anomalies in the results do suggest that neither theory completely explains the entire intraday pattern of futures prices. These results provide evidence that a theory to explain the intraday behavior of volatility and trading activity needs to consider all of the issues presented in this article, rather than relying on one explanation of market behavior.

INFORMATION TRADING AND THEORIES OF THE U-SHAPED CURVES

French and Roll (1986) were early pioneers of information effects on markets. In particular, they empirically examined the potential role of information on price behavior. French and Roll develop and test formal hypotheses on the nature and timing of information by using daily open and closing prices and by comparing volatility around holidays to non-holiday volatility. They determined that the higher variance during trading hours is caused by differences in the flow of information for trading versus nontrading hours. Moreover, the small variances over exchange holidays suggests that most of the information is private rather than public. Barclay, Litzenberger, and Warner (1990) supported this conclusion by examining the effect of Saturday trading in Japan and the dual trading of stocks. In addition, they determined that private information has its greatest effect when the most liquid market is open.[1]

Admati and Pfleiderer (1988) developed an asymmetric information model to explain the strategic trading behavior of informed and liquidity

[1]Makhija and Nachtmann (1987) examined U.S. companies that have multiple listings on U.K. exchanges to determine the effect of an extension of trading hours. They argued that their evidence is more consistent with trading noise rather than information. Ma, Peterson, and Kao (1991) presented the "Information Dispersal Hypothesis": possessors of private information want to minimize the impact that their trades have on trading noise and bid–ask spreads, therefore they space their trades over several time intervals. A consequence of the Information Dispersal Hypothesis is that the demand for market liquidity will be less intense at the beginning and end of a session when trading hours are extended. Thus, the U-shape pattern would be less pronounced after such an extension of trading hours. Ma, Peterson, and Kao examined the information dispersal hypotheses by comparing pre- and post-night trading in T-bond futures (night trading began in April 1987). They found that the daytime variance decreased significantly after night trading began.

traders and the impact of their trading on volatility and trading volume. Their theory is based on an assumption that liquidity traders want to minimize adverse selection costs, while informed traders want to time their trades to maximize their advantage.[2] The important consequence of Admati and Pfleiderer's model is to show that all strategic traders will choose to trade in the same time periods. While Admati and Pfleiderer could not predict which periods will attract this concentrated trading, they suggested that it will be at the opening and closing of the markets since the nondiscretionary liquidity demand will be highest at these times. During these periods the volume will be high, the price response per unit net order flow will be small, and volatility will be high (due to the influence of the informed traders).[3,4]

Brock and Kleidon (1992) extended Merton's (1971) continuous trading model to show that the liquidity demand from traders rebalancing their portfolios before and after market closures creates larger bid–ask spreads at the open and close and U-shaped patterns in volume and volatility. Brock and Kleidon named their theory a market maker power theory, since the market maker increases the bid–ask spread when liquidity demand is the highest. Others refer to this theory as a market closure

[2]The earlier market microstructure models of Glosten and Milgrom (1985) and Kyle (1984, 1985) assumed three types of market participants: market makers, privately informed traders, and uninformed liquidity traders. In these models only informed traders strategically time their trades, with the trades made so that the market maker cannot infer when the informed are trading. These models associate the variance of returns to the arrival of information. Moreover, variance is associated with trading volume, since variance is a proxy for informed trading volume. Admati and Pfleiderer extended this framework to include uninformed (discretionary) liquidity traders who strategically execute their trades to minimize trading costs.

[3]Foster and Viswanathan (1990, 1993) elaborated on Admati and Pfleiderer by developing a model of interday trading, predicting that Monday's total volume should be the lowest of all days of the week, and informed trading as a proportion of total volume should be the highest. They indirectly tested this hypothesis by examining trading patterns of those likely to be uninformed. Foster and Viswanathan found that the volume of NYSE block trades (discretionary traders) is lower on Monday and block trading volume as a proportion of total volume is also lower on Monday.

Chang and Schachter (1992) complement Foster and Viswanathan by examining the trading of those market participants whom Chang and Schachter assumed are most likely to be informed by using daily large speculator trading behavior in five futures markets. They found that the interday aggregate volume and volatility are similar to other studies, i.e., price volatility increases with aggregate volume. More importantly, they determined that volatility is sensitive to the volume of large speculators. They also claimed that the interday pattern of large speculators volume is inverted, i.e., across weekdays there is an inverted U-shape volume pattern. However, this conclusion is difficult to interpret from their empirical results.

[4]An inconsistency with the Admati and Pfleiderer model is that transactions costs (bid–ask spreads) are predicted to be low at the open and close, while empirically they are large at these times. Subrahmanyam (1991) started with Admati and Pfleiderer's model but assumed that informed traders are risk averse (instead of risk neutral). This change was sufficient to alter the conclusion to "the cost of trading is the highest at the open and close". However, in Subrahmanyam's model, one loses the concentration of trading in equilibrium; therefore, the informed traders do not have anyone to trade with. In addition, there now is no reason for the informed to trade at the close.

theory, as it is based on the impact of nontrading periods on trading preferences. In this theory the opening and closing periods are not arbitrary as in Admati and Pfleiderer, rather these periods are the reason for the concentration of volume and the cause of higher volatility and larger bid–ask spreads. Specifically, exogenous changes in demand for transactions at the open and close drive the trading patterns, rather than the endogenous changes in demand employed by information models. Exogenous demand creates high volume even though costs are high. Endogenous demand occurs when trading costs are low, creating high volume. Brock and Kleidon believe there are good reasons for exogenous trading demand to occur at the open and close, even with higher trading costs. In fact, the NYSE recognizes the demand to trade at the open and close via their "market-at-open" and "market-on-close" orders, which are often used by market participants. Potential reasons for trading at the open and close are:

1. At the close, portfolio traders anticipate price behavior changes overnight in ways that would alter investors' optimal overnight portfolios, creating higher volume and volatility and therefore larger spreads. This is consistent with French and Roll's overnight versus intraday price behavior results. Thus, portfolio based traders are active at the open and close due to the change from a closed market to continuous trading, and vice versa.
2. Trading occurs at the open because information arrives over the closed period (also demand will build up over this period regardless of information). In addition, traders can have greater divergences of opinion at the beginning of the day, creating greater volatility and the potential for larger volume.[5]
3. Trading at the close is initiated by index mutual fund managers who need to make trades at the closing prices for fund purchases, and redemptions.
4. Short sellers frequently close out their positions at the end of the day.
5. Hedgers often hedge their overnight positions; in fact, Jain and Joh (1988) attribute high volume at the end of the day to investors closing or hedging open positions that they cannot monitor or change overnight.

Brock and Kleidon (1992) find that empirical bid–ask spreads are largest at the open and close. Kleidon and Werner (1996) use United

[5]Divergence of opinion is the basis of Shalen's (1993) model. She suggests that the peak volatility and volume occurring at the open may be a consequence of greater dispersion.

Kingdom stocks that are traded both in London and NY to examine the opening and closing in each market for volatility, volume, and bid–ask quote patterns. The key result of their article is that the dual market patterns are incompatible with the information hypothesis, i.e., when the NYSE opens then high volatility exists in NY for London stocks, but in London no increase in volatility occurs. Consequently, information does not seem to be driving the NYSE volatility. Hsieh and Kleidon (1994) examined foreign exchange trading in New York and London. Individually, the two markets both have U-shaped volatility and bid–ask spread shapes. When they are examined simultaneously, New York does not seem to affect London volatility or bid–ask spreads and London does not seem to affect New York. Consequently, information is not the cause of these patterns. Hsieh and Kleidon suggest the potential cause(s) of these patterns: (1) price patterns and market activity could be due to retail customers in the interbank market; and/or (2) these patterns could be an inventory model (dealer) effect.[6]

EXTENDING THE THEORIES TO FUTURES MARKETS

Concepts

Derivative markets, and in particular futures markets, may not have the same factors influencing price patterns as stocks, since futures are more generic in nature and since the futures markets trading mechanism differs. In fact, many researchers claim that no futures traders have specific private information because the trading instrument is so generic and close security exists for government announcements. However, superior analysis of the underlying cash markets can generate superior private information due to beliefs. Whether such private belief information is as important for futures markets as French and Roll claim that it is for the stock market is an unanswered question. On the other hand, public information will affect the price and volume patterns of futures to a greater extent than for individual stocks if these announcements provide important unexpected macroeconomic news.

An important aspect of the trading mechanism for futures markets that differs from the stock market is that futures trades are executed in

[6]Gerety and Mulherin (1994) modeled stock trading at the beginning and end of the day as a function of overnight volatility in the spirit of Brock and Kleidon's market closure. Thus, their model differs from an information model. NYSE data from 1933–1988 indicates that closing volume is positively related to expected overnight volatility, while volume at the open is positively related to both expected and unexpected volatility from the previous night.

pits with a large number of market makers called scalpers. Scalpers affect both the volume and bid–ask spread of these markets. The data in Kuserk and Locke (1993) shows that scalpers are responsible for 40 percent of the futures volume. Since scalpers are not holders of private information, futures volume patterns could differ from the stock market patterns.

Another aspect of futures trading that can differ from the underlying instrument is the time period over which the futures trade. Stock index futures trade 15 minutes after the stock market closes and the MMI trades 15 minutes before the NYSE opens. T-bond futures trade in a night session and (since October 1989) open before the major governmental economic announcements are made public. These characteristics of futures trading have implications for both the theories and empirical testing of price behavior.

Private and public information hypotheses can be examined as they currently exist by using interday and intraday futures prices. However, the market closure theory needs to be amended in order to incorporate the existence of a large number of market makers (scalpers) and the additional uses of derivative markets for hedging and arbitrage purposes. For example, scalpers and day traders close their positions before the market closes for the day. Arbitrageurs need to match their futures trades with trades in the underlying assets, therefore both markets typically must be open when arbitrageurs trade. Cash market dealers often hedge their inventory with futures shortly before the futures markets close. In fact, a large percentage of T-bond futures open interest is cash market dealers hedging their open bond positions. Hedges then can be lifted on the following day. These activities, as interpreted by the market closure theory developed for assets by Brock and Kleidon, imply that the opening and closing time for both the underlying cash and the futures markets will have large volume and a high volatility.[7] However, the volume and volatility should be greater for the dominant market at openings and closings. This study labels these concepts the "extended market closure model" for futures markets. This extension of the market closure theory follows the contagion model of King and Wadhwani (1990), who state that trading in one market affects the price behavior in other related markets because the traders draw inferences from the primary market's observed price behavior. In particular, King and Wadhwani predict a drop in price volatility upon the closing of an associated financial market. This also follows the logic of French and Roll, who show that trading is an important con-

[7]Futures do not record bid–ask spreads. Moreover, models which calculate implicit spreads, such as the Roll (1984) model, create empirical problems which cause difficulties in interpreting the validity of the results.

tributor of short run volatility and that volatility is much larger when the market is open than closed.

Empirical Tests

Empirical tests relating to information for futures markets include Harvey and Huang (1991), Atkins and Basu (1995); Ederington and Lee (1993); Lee, Mathur, and Schwarz (1993); and Webb and Smith (1994). Harvey and Huang use prices to examine foreign exchange futures, finding that home country business hours are an important source of information and therefore volatility. They concluded that increased volatility is most likely driven by macroeconomic news announcements. Harvey and Huang also found that when the European banks are trading, the markets have a different volatility pattern than when the banks are closed, which shows the importance of the spot market for futures trading. Atkins and Basu found a large spike in the number of announcements for individual stocks between 4:00 and 4:15 PM Eastern time, implying that part of the next day's opening volume and the volatility effect are both due to public information, and that stock index futures could be affected after 4 PM by these public announcements. Measuring volatility across days for each time interval, Ederington and Lee (1993) found that macroeconomic announcements are responsible for most of the time-of-day and day-of-the-week volatility patterns for T-bond, Eurodollar, and deutsche mark futures. Lee, Mathur, and Schwarz attempted to disentangle private and public information effects by examining volatility and its determinants in Eurodollar and T-bill futures before and after the change in trading time to accommodate the macroeconomic news announcements. They found a volatility spike larger than the open volatility after 8:30 AM (when pubic information is released). Webb and Smith (1994) did not find a volatility effect for Eurodollar futures due to the close of the London futures markets, but they did find the 8:30 AM public information effect. Overall, these studies show the important effect of macroeconomic public information on futures markets volatility.[8]

U-shape volatility, volume, and/or bid–ask spread patterns were found by Jordan et al. (1988); Lee and Linn (1994); Ekman (1990, 1992); and Ferguson, Mann, and Schneck (1993). Jordan et al. found U-shaped patterns in volatility and number of trades for soybean futures, Lee and Linn found a U-shape volatility pattern for S&P 500 futures, and Ekman found volatility and trading activity U-shaped patterns for S&P 500 and

[8]Ekman's (1990) results also show a volatility increase at this time, but the reason is not discussed in his paper.

Eurodollar futures. Ferguson, Mann, and Schneck used futures audit trail data for foreign exchange futures and found strongly convex U-shaped intraday patterns for volume and spreads. However, volatility declines throughout the day and, in fact, their measure of convexity shows an inverted U-shape for volatility. They also determined that the closure of the European spot market affects volatility. Overall, they found little support for the discretionary liquidity model, while the positive relationship between volume and spreads caused them to give weak support for the market closure model. Chang, Jain, and Locke (1995) found a 20% drop in the S&P 500 futures volatility when the NYSE closes. Overall, despite the common perception of U-shaped curves, empirical results for futures volatility does not show a U-shaped pattern for all research results.

FUTURES DATA AND ITS APPLICATIONS

The S&P 500, MMI, and T-bond futures markets are chosen for this study because of their unique opening and closing times. The S&P 500 is the most active stock index futures contract and it closes 15 minutes after the NYSE closes. This allows for an examination of the dual effect of the cash market close and the later futures market close by employing volatility and trading activity data. The MMI stock index futures opens 15 minutes before the NYSE and closes with the S&P 500 futures. Therefore, the MMI contract allows for the examination of the open interval for both the futures and cash markets. The T-bond futures is a very successful long-term debt futures contract that has both a day and a night session. Hence, one can determine the effect of two daily opens and closes, with a relatively short time interval between the day session close and the night session open. Moreover, the night session occurs when the cash bond market is closed in the United States (the night session was instituted for the Japanese market). In addition, over the time period of this study, the T-bond contract moved its starting time from 9 AM Eastern time to 8:20 AM Eastern, allowing one to determine the effect of the macroeconomic public announcements made at 8:30 AM Eastern time.

The time frame for this study is the calendar years of 1988 and 1989. During this time period each price change is used to calculate minute-by-minute open, high, low, and closing prices. Volatility is measured in two ways. First, the closing prices for each one-minute interval are employed to determine one-minute returns, which are then used to calculate standard deviations for each 15 minute interval in the day and selected 5-minute intervals near the open and close. Second, the open, high, low, and closing prices for each one-minute interval are used to calculate each minute's Garman–Klass (1980) volatility measure. The expected value of the 15- (5-) minute Garman–Klass volatility values constitute the Garman–Klass volatility measure for the 15- (5-) minute time interval. This measure is eight times as efficient as using close to close interval values to determine a standard deviation and, hence, is typically considered to be a superior measure of volatility when compared to the standard deviation. The Garman–Klass volatility measure is calculated as:

$$\begin{aligned} \mathrm{Var(GK)} = {} & 1/2\,[\ln(\mathrm{High}) - \ln(\mathrm{Low})]^2 \\ & - [2\ln(2) - 1]\,[\ln(\mathrm{Open}) - \ln(\mathrm{Close})]^2 \end{aligned} \tag{1}$$

The resultant Garman–Klass volatility measure is multiplied by 100 to adjust for scale.

The number of ticks (price changes) for each 15- (5-) minute interval are used to examine the trading activity of the futures contracts. Harris (1987) shows that "tick volume" for stocks is highly correlated with volume for NYSE data. Moreover, Karpoff (1986) and Varian (1989) argue that the tick volume within a given time period is superior to volume as a measure of information arrival.

Before the expiration of the futures contract the futures are rolled over to the first deferred contract. The rollover date is determined by finding the date when the largest total volume switches from the nearby contract to the first deferred contract. For the S&P 500 stock index futures this occurs approximately one week before the expiration of the nearby contract. For the MMI contract the largest volume switches on the last trading day of the month the nearby expires (the MMI expires monthly). T-bond futures are rolled over on the first trading day of the expiration month to avoid potential complications due to delivery (total volume switches to the first deferred contract at approximately this time).[9]

The hypotheses tested in this article involves comparing the volatilities (and trading activity) in one time interval to those in other intervals. Thus, a typical null hypothesis is:

$$H_0\colon \sigma_{9:30} = \sigma_{9:45} \tag{2}$$

which tests if the monthly averages of the daily volatilities for the 9:30 AM time interval are equal to the monthly averages of the daily volatilities

[9]The first time interval for the 15-minute T-bond futures series after the change to the new opening time is 10 minutes. The number of ticks is adjusted by multiplying by 1.5 to make it comparable to the 15-minute intervals. The night session for T-bond futures is Sunday to Thursday night. There is no Friday session. Therefore, there is a two-day interval between the Friday day session and the Sunday night session. Separate tests suggest this does not adversely affect the results.

TABLE I

Volatility Measures for the S&P 500 and MMI Futures: 15-Minute Intervals

	S&P 500 Futures			*MMI Futures*		
Time Interval	*Standard Deviation*	*Garman–Klass*	*Number of Ticks*	*Standard Deviation*	*Garman–Klass*	*Number of Ticks*
9:15				0.0429	0.0679	32.6
9:30	0.0504	0.2121	137.1	0.0487	0.1032	62.9
9:45	0.0432	0.1324	112.0	0.0421	0.0739	53.0
10:00	0.0418	0.1224	107.3	0.0410	0.0714	49.3
10:15	0.0382	0.1116	94.5	0.0381	0.0541	41.2
10:30	0.0377	0.0992	90.6	0.0373	0.0451	38.3
10:45	0.0344	0.0733	80.6	0.0345	0.0308	33.4
11:00	0.0327	0.0681	76.8	0.0333	0.0295	31.0
11:15	0.0323	0.0630	70.8	0.0319	0.0297	28.3
11:30	0.0330	0.0596	71.1	0.0328	0.0259	28.3
11:45	0.0324	0.0599	69.5	0.0318	0.0247	27.0
12:00	0.0317	0.0538	67.0	0.0312	0.0205	25.5
12:15	0.0312	0.0492	62.8	0.0310	0.0203	23.8
12:30	0.0325	0.0533	64.0	0.0314	0.0208	24.5
12:45	0.0311	0.0495	60.2	0.0307	0.0210	23.3
1:00	0.0335	0.0584	66.6	0.0328	0.0267	25.2
1:15	0.0332	0.0590	67.3	0.0332	0.0294	26.7
1:30	0.0348	0.0618	70.7	0.0337	0.0268	27.6
1:45	0.0363	0.0703	74.9	0.0360	0.0336	29.8
2:00	0.0385	0.0798	81.1	0.0375	0.0367	32.6
2:15	0.0400	0.0886	83.1	0.0398	0.0436	35.5
2:30	0.0413	0.0975	87.6	0.0427	0.0527	39.1
2:45	0.0437	0.1044	89.5	0.0435	0.0593	40.8
3:00	0.0457	0.1150	93.1	0.0490	0.0815	45.1
3:15	0.0476	0.1188	92.9	0.0514	0.1186	46.8
3:30	0.0477	0.1434	93.8	0.0521	0.1340	48.5
3:45	0.0455	0.1290	91.2	0.0472	0.0844	43.0
4:00	0.0401	0.1134	93.0	0.0368	0.0479	31.5

for the 9:45 AM interval. With two years of data, most significance tests have 24 observations. The alternative hypothesis is that the standard deviations are not equal for the two time intervals. Equivalent tests and hypotheses are tested for comparisons of different pairs of time intervals and for trading activity (number of ticks).

FIFTEEN-MINUTE RESULTS

Stock Index Futures: Extended Trading Effects

Table I and Figures 1 to 3 show the results from the S&P 500 futures contracts for the 15-minute intervals. Both volatility measures (the stan-

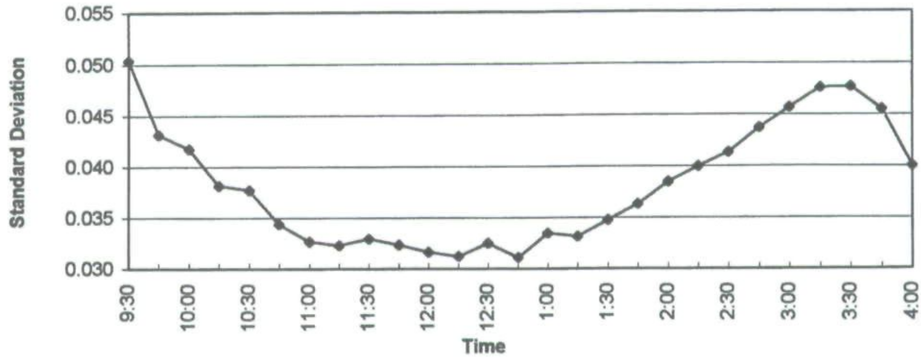

FIGURE 1
S&P 500 Futures: Standard deviation, 15-minute intervals.

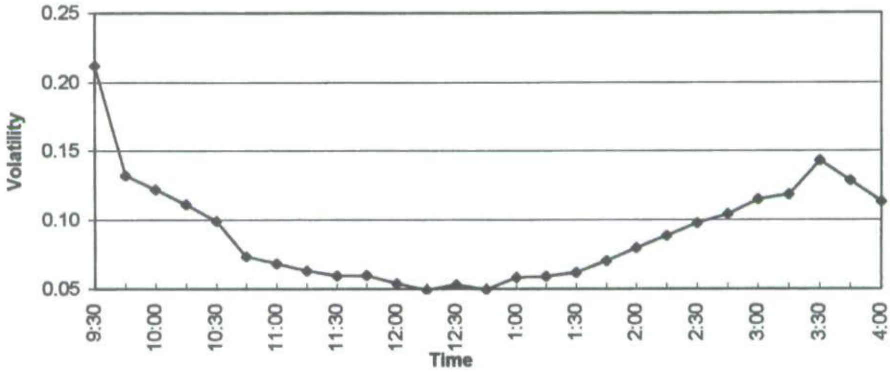

FIGURE 2
S&P 500 Futures: Garman–Klass volatility, 15-minute intervals.

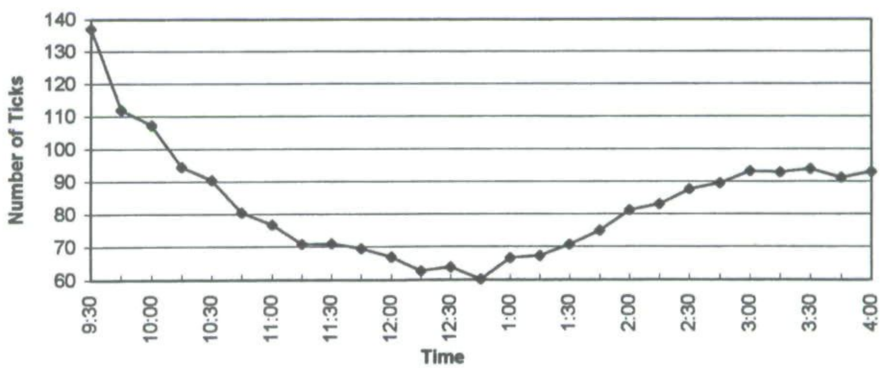

FIGURE 3
S&P 500 Futures: Number of ticks, 15-minute intervals.

dard deviation and the Garman–Klass measure) show the classic U-shaped volatility patterns, which is contrary to the findings of Ederington and Lee (1993) and Ferguson, Mann, and Schneck (1993) for other futures markets, but similar to the results of other studies.[10] In addition, while the last time interval (4:00 to 4:15 PM Eastern, when the stock market is closed but the futures still trade[11]) does have a high volatility, the volatility is less than the volatility of the stock market closing interval of 3:45 to 4:00 PM Both of these results are consistent with the Extended Market Closure theory. A similar, but more pronounced, closing sequence occurs for the MMI futures, as shown in Table I and Figures 4 to 6. The more pronounced change for the MMI futures is feasibly related to the smaller volume in that market. For example, in the MMI pits the scalpers have fewer positions to cover at the end of the day to obtain a net even position, creating lower volatility and fewer trades during the last 15 minutes of trading.

However, two abnormalities occur. First, the 3:45 to 4:00 PM time interval is not the highest closing volatility interval for either the S&P 500 or the MMI futures contracts. Rather, the 3:30 to 3:45 PM interval has higher standard deviations, Garman–Klass values, and number of ticks than any of the afternoon 15-minute time intervals. The second anomaly is that there is no upward spike in any of the measures at either the NYSE close or the futures close. These results suggest that factors other than market closure may be an important component for the closing of these markets. This is particularly interesting for the number of price changes, since other authors claim that this variable is a better measure of information arrival than volume or volatility.

An even more interesting conclusion is the small number of ticks for the MMI futures for the opening time interval of the futures, which is 15 minutes before the stock market opens. Also, while this opening MMI interval has a high volatility, the volatility is less than the 9:30 to 9:45 AM opening stock market interval, thus showing a similar pattern to the number of ticks in Figure 6. This opening sequence does not seem to support the concept that public, or even private, macroeconomic information is the most important force driving the opening volatility and volume of the stock and stock index futures markets, since this type of information should be accounted for in the first rather than the second MMI time

[10]Ederington and Lee calculated their standard deviation across days for each time interval, while the results here obtain a separate volatility measure for each time interval within the day and then average these measures across days. The procedure here concentrates on comparing intervals within the day, while Ederington and Lee concentrated on finding intervals with unusual daily volatility.

[11]All figures and tables show the time for the beginning of the relevant time interval.

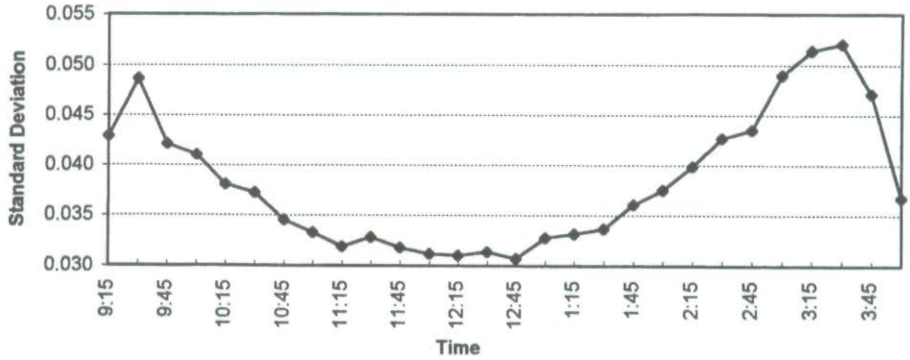

FIGURE 4
MMI Futures: Standard deviation, 15-minute intervals.

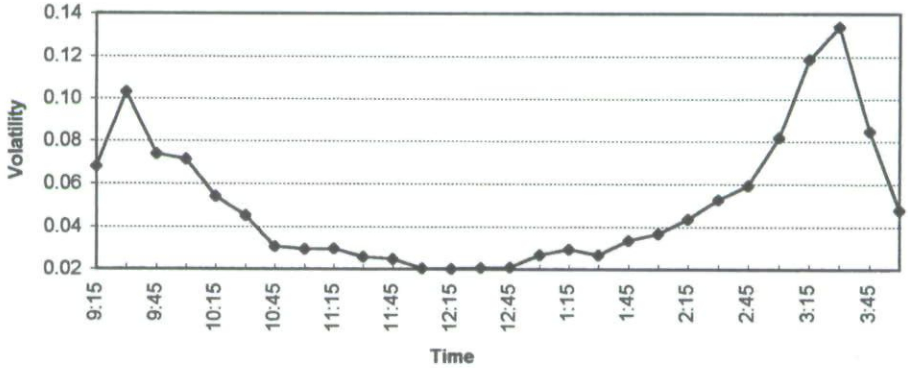

FIGURE 5
MMI Futures: Garman–Klass volatility, 15-minute intervals.

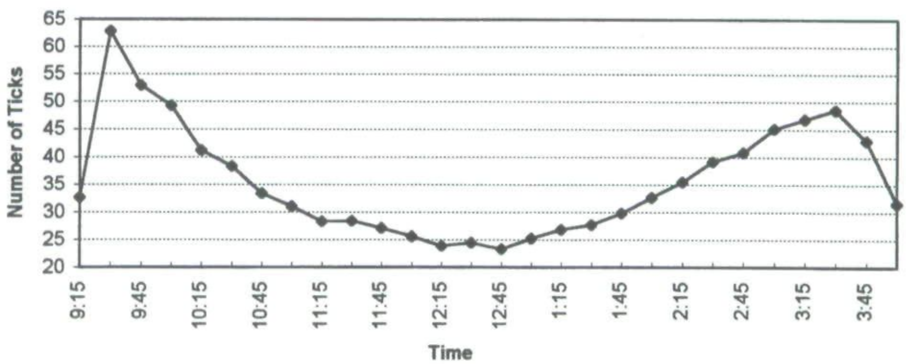

FIGURE 6
MMI Futures: Number of ticks, 15-minute intervals.

interval.[12] On the other hand, this opening sequence does support the Extended Market Closure theory where the cash market is dominant. The article examines this time interval in more detail by examining 5-minute periods.

T-bond Futures: Day and Night Trading and the Morning Information Effect

Table II and Figures 7 to 9 examine the results for the T-bond futures contract. The U-shaped pattern is evident in all three sets of data (although the U-shape may seem less pronounced than for the stock index futures simply because the Y-axis has a wider range of values to accommodate and the 8:20 to 8:45 volatility effects[13]). Notice that the night session is labeled on the right Y-axis in order to distinguish its patterns, given its overall lower volatility and activity compared to the day session. The night session also has larger values of volatility and the number of ticks at both its opening and closing time intervals, although at much lower levels than for the day session.[14] The relative lack of trading activity and volatility for the night session opening suggests that public or private macroeconomic information created between the close of the day session and the opening of the night session is minimal in nature, since a larger effect would be seen at the night session opening if important information was known. Moreover, since the cash T-bond market in the U.S. is not open, the overall level of volatility and activity is minimal for the night session. These results provide additional support for the importance of cash and futures market closure on volatility and trading activity, as well as the importance of the cash market being open to the volatility/activity of the futures market. Furthermore, Figures 7 and 8 clearly show the effect of the information interval on volatility from 8:30 to 8:45 AM, after the government announcements are made. Figure 9 provides weaker sup-

[12]The higher volatility and number of ticks for the 9:30 to 9:45 AM time interval could be associated with private information for individual stocks, with the resultant volatility then transferred to the futures market.

[13]The data do not permit a definitive analysis of whether the lower overall level of volatility and trading activity for the 8:20 AM series versus the 9:00 AM series is due to the earlier opening of the market or to a change in the fundamental factors that drive prices. However, since the number of price changes is less for each time interval for the 8:20 AM series, it is likely this series has less fundamental volatility.

[14]The Garman–Klass volatility value is biased downward when few trades exist, since at least two prices must occur within a one-minute interval for a non-zero Garman–Klass volatility value. This explains both the low level of night volatility for the Garman–Klass measure and the lack of a large closing interval value.

TABLE II

Volatility Measures for T-bond Futures: 15-Minute Intervals

Time Interval	Standard Deviation			Garman–Klass			Number of Ticks		
	Before[a]	*After*[a]	*Night*	*Before*[a]	*After*[a]	*Night*	*Before*[a]	*After*[a]	*Night*
8:20		0.0352			0.0723			70.9	
8:30		0.0488			0.1942			79.6	
8:45		0.0327			0.0716			63.5	
9:00	0.0420	0.0325		0.1259	0.0686		95.2	63.9	
9:15	0.0369	0.0305		0.0956	0.0607		80.6	58.2	
9:30	0.0358	0.0302		0.0909	0.0524		75.8	53.7	
9:45	0.0355	0.0285		0.0787	0.0443		68.7	49.2	
10:00	0.0343	0.0295		0.0806	0.0577		68.1	52.1	
10:15	0.0324	0.0286		0.0630	0.0465		60.7	47.9	
10:30	0.0320	0.0261		0.0583	0.0411		58.4	43.7	
10:45	0.0309	0.0270		0.0560	0.0354		55.5	41.0	
11:00	0.0307	0.0271		0.0532	0.0361		54.9	41.6	
11:15	0.0309	0.0267		0.0482	0.0332		47.9	37.7	
11:30	0.0312	0.0274		0.0509	0.0346		49.3	37.5	
11:45	0.0307	0.0266		0.0476	0.0327		47.0	37.6	
12:00	0.0302	0.0261		0.0459	0.0325		45.3	37.9	
12:15	0.0310	0.0265		0.0467	0.0311		47.3	36.0	
12:30	0.0301	0.0259		0.0472	0.0317		46.1	35.8	
12:45	0.0314	0.0266		0.0500	0.0278		46.8	35.2	
1:00	0.0318	0.0276		0.0506	0.0350		48.4	38.3	
1:15	0.0319	0.0268		0.0489	0.0323		44.9	36.0	
1:30	0.0329	0.0266		0.0515	0.0315		46.4	35.2	
1:45	0.0340	0.0271		0.0617	0.0339		52.3	37.0	
2:00	0.0345	0.0286		0.0668	0.0397		56.3	41.6	
2:15	0.0344	0.0288		0.0682	0.0444		59.5	44.7	
2:30	0.0369	0.0290		0.0814	0.0449		65.0	47.3	
2:45	0.0382	0.0299		0.0930	0.0592		78.1	68.3	
6:00			0.0239			0.0206			21.3
6:15			0.0184			0.0071			11.5
6:30			0.0189			0.0076			11.3
6:45			0.0190			0.0076			10.8
7:00			0.0188			0.0068			10.3
7:15			0.0175			0.0056			9.0
7:30			0.0169			0.0043			7.9
7:45			0.0159			0.0033			7.0
8:00			0.0155			0.0030			6.6
8:15			0.0151			0.0030			6.4
8:30			0.0149			0.0030			5.9
8:45			0.0152			0.0027			6.1
9:00			0.0156			0.0027			6.4
9:15			0.0193			0.0078			13.2

[a]Before/After the change in opening time from 9:00 am Eastern to 8:20 am Eastern.

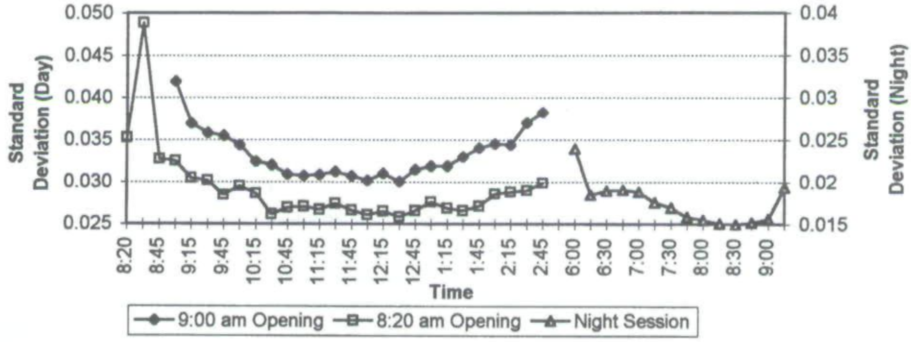

FIGURE 7
T-Bond futures: Standard deviation, 15-minute intervals.

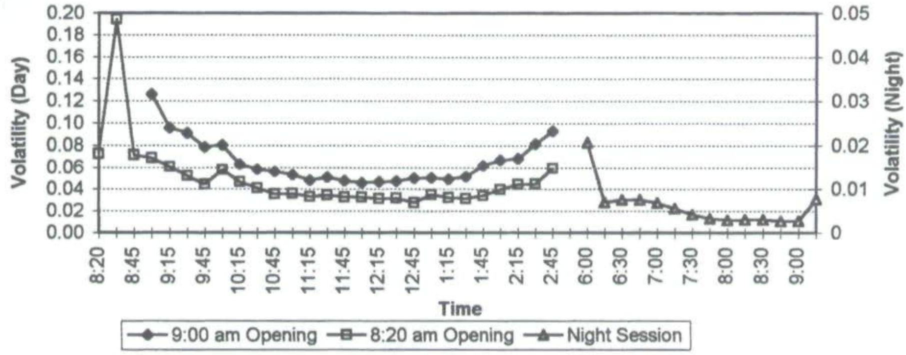

FIGURE 8
T-Bond futures: Garman–Klass volatility, 15-minute intervals.

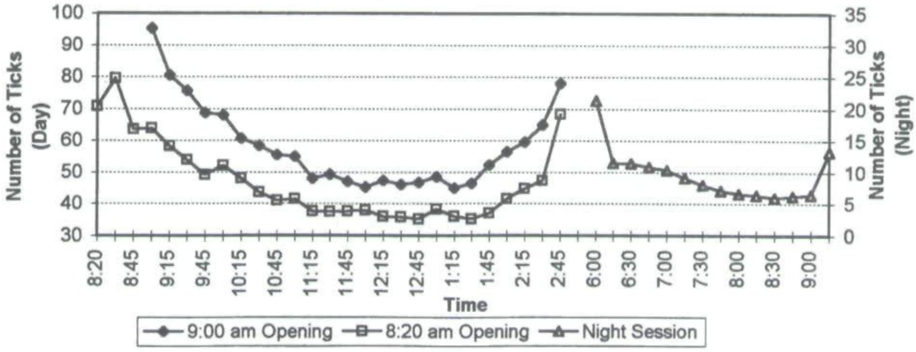

FIGURE 9
T-Bond futures: Number of ticks, 15-minute intervals.

port for this information interval via the number of ticks, which casts some doubt on this measure as a true indicator of information arrival.

Statistical Tests of Significance

Table III provides the statistical tests of significance for all of the futures contracts and volatility/activity measures examined in Tables I and II and Figures 1 to 9. Paired two sample t-test values for the mean are determined for various interesting pairs of time intervals.[15,16] Over 95% of the individual *t*-values are significant at a 10% or better level, with nearly 85% of the individual values being significant at the 1% level. The opening and closing intervals are significantly different from the middle of the day for all observations.[17] More importantly, the opening cash market interval has statistically larger values than the next time interval. In addition, the closing interval for the stock index futures contracts has significantly smaller values in comparison to the time interval when the cash stock market closes. For the MMI futures, the futures opening time interval has significantly lower values than when the cash market opens. The T-bond futures *t*-values are broken into "before" and "after" the change in opening times. The 8:30 AM time interval (the information interval) significantly differs from the two surrounding time intervals for all three measures of volatility/activity. Also, the opening and closing night time intervals for T-bond futures are significantly different than their intervening intervals.

THE FIVE-MINUTE RESULTS

The 15-minute results pointed out possible "anomalies" in the data and additional conclusions concerning the behavior of the markets in question. To examine these possible anomalies and conclusions more closely and to determine if intermediate peaks occur at the NYSE closing, the five-minute intervals of stock index futures closing, MMI and the related NYSE opening, and T-bond futures opening, are examined.

S&P 500 Results

Table IV and Figures 10 to 12 illustrate the 5-minute volatility and activity effects for the S&P 500 contract from 9:30 to 10:00 AM and from 3:15

[15]This test does not assume equal variances. The *t*-values are examined as a one-tail test. Note that the critical *t*-values differ for the T-bonds as compared to the stock index futures since the T-bond futures data are split into "before" and "after" opening time periods.

[16]Early and late time intervals are compared to an average of middle-of-the-day intervals for a more logical test of significance.

[17]The 9:30 AM time interval is employed for the MMI contract for the statistical test.

TABLE III

Tests of Significance for the 15-Minute Intervals

Panel A: S&P 500 Futures

Intervals Compared	*Standard Deviation*	*Garman –Klass*	*Number of Ticks*
9:30 vs. av.[a]	7.08	4.28	40.72
3:30 vs. av.[a]	6.67	3.59	9.76
9:30 vs. 9:45	5.08	3.24	19.54
9:30 vs. 3:30	1.31[b]	3.05	15.48
3:30 vs. 3:45	1.56[c]	0.69[b]	1.85[d]
3:45 vs. 4:00	4.05	1.86[d]	−1.32[b]
3:30 vs. 4:00	4.36	1.36[c]	0.40[b]

Panel B: MMI Futures

Intervals Compared	*Standard Deviation*	*Garman –Klass*	*Number of Ticks*
9:30 vs. av.[a]	12.75	5.19	19.62
3:30 vs. av.[a]	7.99	2.49[d]	11.12
9:15 vs. 9:30	−5.23	−5.00	−15.77
9:30 vs. 9:45	7.76	4.80	12.56
9:30 vs. 3:30	−1.68[d]	−0.89[b]	−5.77
3:30 vs. 3:45	3.32	1.32[c]	5.88
3:45 vs. 4:00	9.48	3.43	9.83
3:30 vs. 4:00	7.16	2.06[d]	9.97

Panel C: T-Bond Futures

Before Time Change				*After Time Change*			
Intervals Compared[e]	*Standard Deviation*	*Garman –Klass*	*Number of Ticks*	*Intervals Compared*	*Standard Deviation*	*Garman –Klass*	*Number of Ticks*
9:00 vs. av.[f]	9.36	8.72	15.57	8:20 vs. av.[f]	7.67	11.31	8.27
2:45 vs. av.[f]	7.65	8.58	15.57	2:45 vs. av.[f]	5.95	10.38	13.91
9:00 vs. 9:15	7.53	6.55	11.72	8:20 vs. 8:30	−7.29	−7.14	−14.86
				8:30 vs. 8:45	10.22	7.60	14.42
				8:20 vs. 8:45	2.01[d]	0.49[b]	9.32
9:00 vs. 2:45	3.38	4.97	6.59	8:20 vs. 2:45	4.76	3.98	8.50
2:45 vs. 2:30	2.40[d]	2.74[d]	8.24	2:45 vs. 2:30	2.05[d]	7.91	14.28
2:45 vs. 6:00 pm	9.53	16.02	29.02	2:45 vs. 6:00 pm	9.70	11.97	15.69
6:00 pm vs. av.[f]	11.41	4.89	10.45	6:00 pm vs. av.[f]	11.90	7.35	15.66
9:15 pm vs. av.[f]	7.09	9.64	14.42	9:15 pm vs. av.[f]	4.92	2.43[d]	8.73
6:00 pm vs. 6:15 pm	7.86	9.64	4.76	6:00 pm vs. 6:15 pm	7.83	13.73	5.96
9:15 pm vs. 9:00 pm	8.88	7.71	12.88	9:15 pm vs. 9:00 pm	8.48	12.38	13.09

[a]The average of time intervals 11:00 to 2:30.
[b]Not significant at the 10% level.
[c]Significant at the 10% level.
[d]Significant at the 5% level.
All unstarred t-values are significant at the 1% level.
[e]9:00 is the opening interval before the time change.
[f]The average of time intervals, 10:00 to 1:45, for the day and 6:30 to 8:45 at night.
Critical one tail t-values for S&P 500 and MMI are: 1% = 2.50; 5% = 1.71; 10% = 1.32.
Critical one tail t-values for T-bonds are: before time change: 1% = 2.82; 5% = 1.83; 10% = 1.38; after time change: 1% = 2.65; 5% = 1.77; 10% = 1.35.

TABLE IV

Volatility Measures for the S&P 500 and MMI Futures: 5-Minute Intervals

	S&P 500 Futures			*MMI Futures*		
Time Interval	*Standard Deviation*	*Garman–Klass*	*Number of Ticks*	*Standard Deviation*	*Garman–Klass*	*Number of Ticks*
9:15				0.0484	0.1123	13.1
9:20				0.0381	0.0562	10.5
9:25				0.0350	0.0390	9.7
9:30	0.0523	0.2805	50.7	0.0509	0.1153	21.8
9:35	0.0465	0.1941	45.3	0.0458	0.1103	21.3
9:40	0.0443	0.1655	42.2	0.0414	0.0847	19.9
9:45	0.0425	0.1514	39.6	0.0411	0.0781	18.4
9:50	0.0399	0.1257	37.2	0.0391	0.0711	17.6
9:55	0.0416	0.1217	35.9	0.0408	0.0742	17.4
3:15	0.0444	0.1208	31.2	0.0479	0.0821	15.9
3:20	0.0450	0.1184	31.6	0.0492	0.1201	16.0
3:25	0.0445	0.1195	30.7	0.0478	0.1613	15.9
3:30	0.0466	0.1429	31.9	0.0512	0.1660	16.8
3:35	0.0448	0.1432	31.6	0.0490	0.1356	16.8
3:40	0.0451	0.1453	30.8	0.0477	0.1046	15.7
3:45	0.0459	0.1408	30.9	0.0470	0.1042	15.2
3:50	0.0424	0.1296	30.6	0.0441	0.0758	14.5
3:55	0.0411	0.1175	30.1	0.0438	0.0772	14.1
4:00	0.0377	0.1045	30.0	0.0379	0.0567	11.6
4:05	0.0319	0.0747	26.0	0.0322	0.0240	8.5
4:10	0.0453	0.1614	37.1	0.0394	0.0664	12.4

to 4:15 PM As expected, an opening peak occurs in the first time interval. As with the 15-minute intervals, there is no peak, per se, at the NYSE closing (the 3:55 PM time interval); however, there is a decline in the volatility measures from the 3:55 to 4:00 PM interval to the 4:00 to 4:05 PM interval. Unlike the 15-minute results, the 5-minute data show a substantial increase in both volatility and number of ticks at the close of the futures contract (the 4:10 PM interval).

These figures show two interesting results. First, they substantiate and clarify the earlier "anomaly" that the highest volatility and activity near the NYSE close occur well before 4:00 PM and no peaks occur at the NYSE close (3:55 PM interval). In fact, the largest volatility/activity values occur 20 to 30 minutes before the NYSE close—a fact that does not seem to be consistent with existing theories. Second, the volatility and activity values show a spike for the 5 minute interval at the futures close (4:10–4:15 PM). In fact, the Garman–Klass volatility and number of ticks at the futures close are larger than during any other afternoon time interval. This suggests that scalpers and day traders who close their

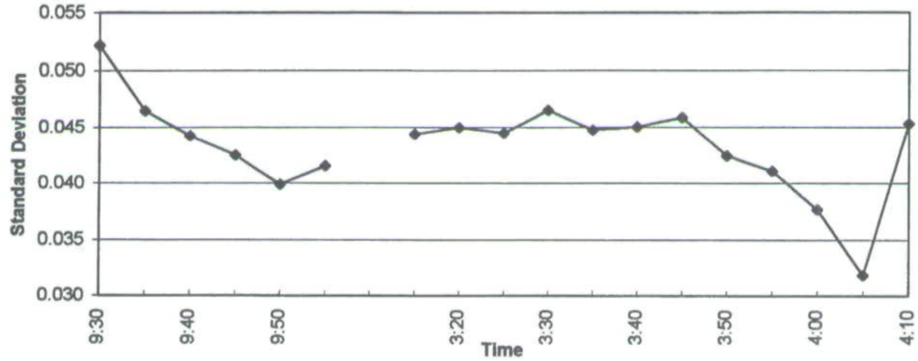

FIGURE 10
S&P 500 Futures: Standard deviation at open and close, 5-minute intervals.

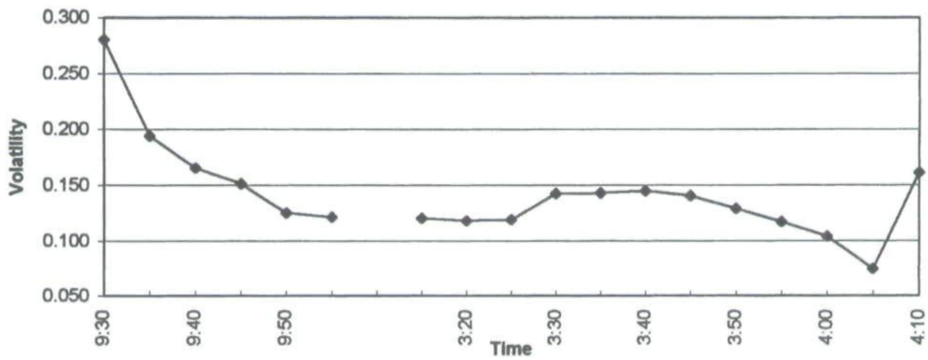

FIGURE 11
S&P 500 Futures: Garman–Klass volatility at open and close, 5-minute intervals.

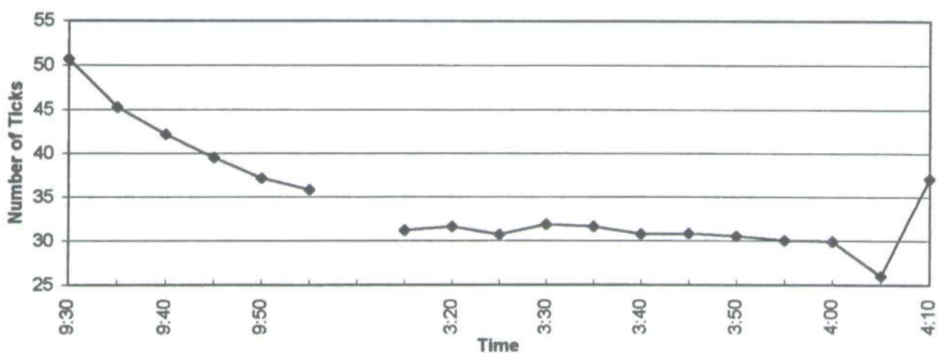

FIGURE 12
S&P 500 Futures: Number of ticks at open and close, 5-minute intervals.

positions at this time have a greater effect on the futures market than the cash market participants.[18] Consequently, this presents another anomaly: since the futures market is more volatile/active when the cash market is closed than when it is open, either the futures market dominates the cash market at the close or a better theory is needed to explain market behavior.[19]

The MMI Results

Table IV and Figures 13 to 15 show the MMI results for the opening and closing periods of the futures and cash markets. Peaks occur at both the opening of the futures market (9:15 AM) and the opening of the cash market (9:30 AM), although the number of ticks at 9:15 AM is substantially less than the number at 9:30 AM. Unlike Figures 4 and 5 (Table I), Figures 13 and 14 (Table IV) show that the 5-minute interval for the opening of the futures market is, in fact, as important as the 5-minute interval when the cash market opens. Hence, the overnight/information effect may still have relevance for the MMI futures opening, although the lower level of activity (number of ticks) mitigates the importance of the initial futures opening. Whether the initial futures pattern is due to overnight information or simply to the market opening can not be discerned from this data.

Like the S&P 500 contract, the MMI futures peak 30 minutes before the cash market closes, further supporting this unexplained anomaly. Moreover, there is no peak at the NYSE close (3:55–4:00 PM). There is a peak at the futures close (4:10–4:15 PM), but (unlike the S&P 500 contract) this peak is far less than the 3:30 PM peaks. This result is consistent with the fact that the MMI futures is a smaller market with far fewer scalpers who need to cover their positions than in the S&P 500 pit.

The T-bond Results

Table V and Figures 16 to 18 illustrate the effects of the T-bond futures opening and the 8:30 AM announcement effect. These results dramati-

[18]While the heightened activity at the futures close may be due to hedgers or others placing "market on close" orders, the scalper/day trader explanation is more likely.

[19]Chang, Jain, and Locke (1995) associate this spike with the private information models of Admati and Pfleiderer (1988) and Foster and Viswanathan (1990, 1993). However, no evidence is provided that this spike is due to such private information. The scalper explanation is more feasible, especially given the results for the MMI contract (given below) that shows a much smaller ending spike (the MMI market has substantially fewer scalpers).

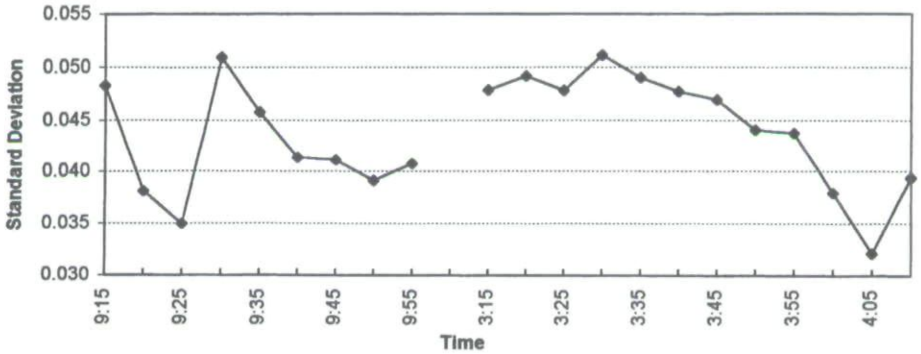

FIGURE 13
MMI Futures: Standard deviation at open and close, 5-minute intervals.

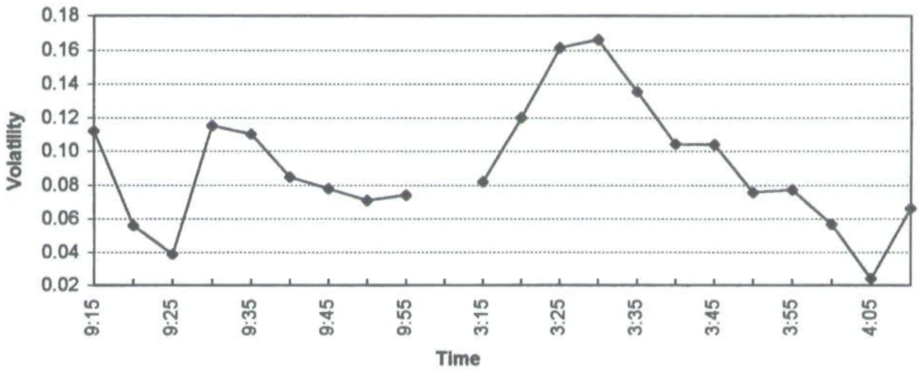

FIGURE 14
MMI Futures: Garman–Klass volatility at open and close, 5-minute intervals.

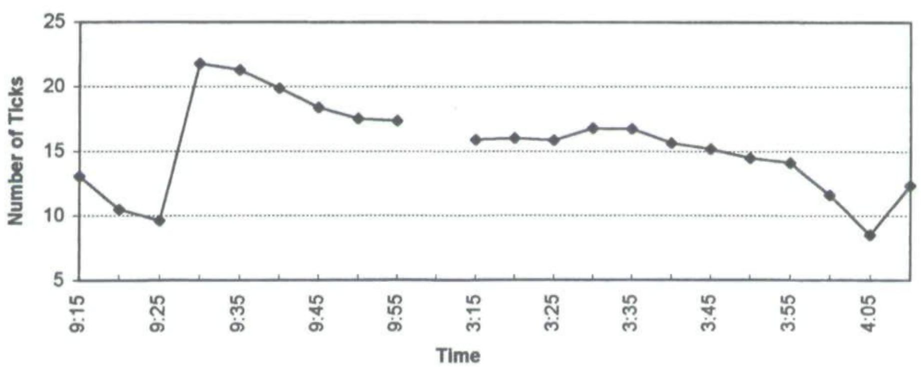

FIGURE 15
MMI Futures: Number of ticks at open and close, 5-minute intervals.

TABLE V

Volatility Measures for T-Bond Futures: 5-Minute Intervals

Time Interval	*Standard Deviation*	*Garman–Klass*	*Number of Ticks*
08:20	0.0321	0.0700	24.3
08:25	0.0329	0.0724	23.5
08:30	0.0670	0.4372	33.5
08:35	0.0356	0.1111	26.3
08:40	0.0332	0.0930	24.1

cally show the large impact of the announcements and trading activity (even more so than the 15-minute results). More interesting is the lack of a peak at the opening of the futures contract. This casts a shadow on the importance of the "opening effect," at least in the T-bond futures market. Thus, little information may be generated overnight (especially given the existence of the night session), and therefore the market waits until the government announcements at 8:30 AM before the volatility and activity increases.

The Statistical Tests of Significance

Table VI provides the tests of significance for the 5-minute intervals. Overall, 80% of the comparisons are significant, most of them at the 1% level. The only comparisons that are not clearly significant for the majority of measures is the 9:30 versus 9:35 AM intervals for the MMI contract, and the 8:20 versus 8:25 AM intervals for the T-bond contract—with the latter's lack of a difference being apparent in the figures.

CONCLUSIONS

Transactions data from S&P 500, MMI, and T-bond futures markets are employed to examine the volatility and trading activity patterns within the trading day. The confirmation of the U-shape curve for futures contradicts the recent findings of Ederington and Lee (1993) and Ferguson, Mann, and Schneck (1993), who do not show the U-shape pattern (both articles measure the intraday volatility in a way that differs from the more conventional method). More importantly, the results in this article examine to what extent information and/or futures market closure explain the intraday patterns. The importance of public information is shown via the higher volatility in T-bond futures prices after the governmental announcements at 8:30 AM Eastern time.

Results and conclusions that are more unique:

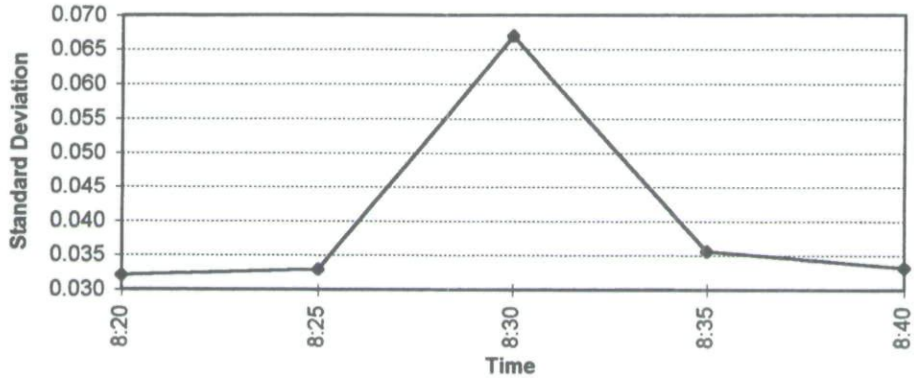

FIGURE 16
T-Bond futures: Standard deviation at the open, 5-minute intervals.

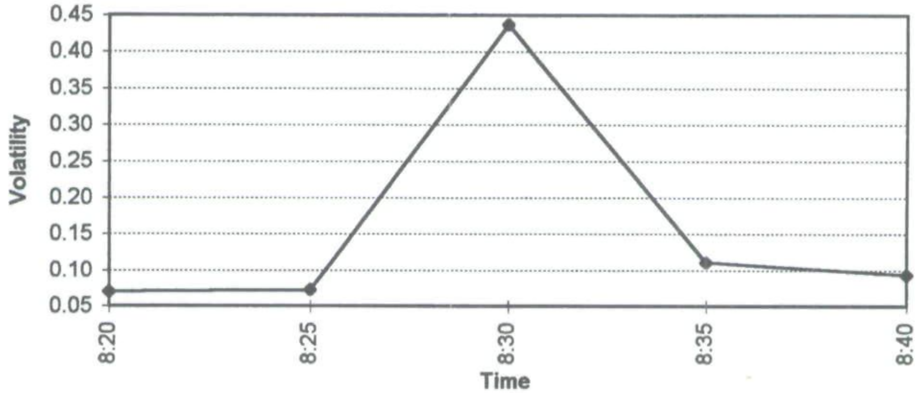

FIGURE 17
T-Bond futures: Garman–Klass volatility at the open, 5-minute intervals.

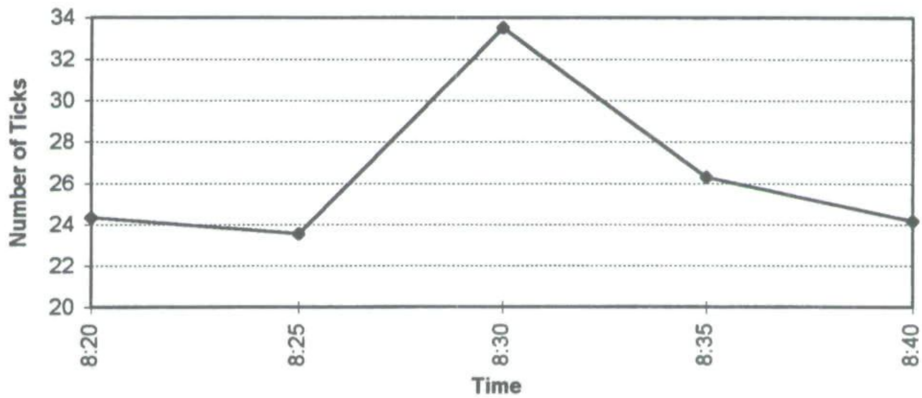

FIGURE 18
T-Bond futures: Number of ticks at the open, 5-minute intervals.

TABLE VI

Tests of Significance for the 5-Minute Intervals

Panel A: S&P 500 Futures

Intervals Compared	*Standard Deviation*	*Garman–Klass*	*Number of Ticks*
9:30 vs. 9:35	3.23	4.00	9.16
3:30 vs. 3:55	3.34	1.25[a]	2.55
3:55 vs. 4:00	2.71	2.27[c]	0.29[a]
4:05 vs. 4:10	−12.17	−7.15	−28.10

Critical one tail t-values are: 1% = 2.50; 5% = 1.71; 10% = 1.32.

Panel B: MMI Futures

Intervals Compared	*Standard Deviation*	*Garman–Klass*	*Number of Ticks*
9:15 vs. 9:20	6.14	3.83	9.38
9:25 vs. 9:30	−9.07	−8.00	−24.03
9:30 vs. 9:35	4.27	0.57[a]	1.02[a]
3:30 vs. 3:55	2.80	1.11[a]	4.46
3:55 vs. 4:00	4.93	3.49	7.43
4:05 vs. 4:10	−4.37	−4.84	−12.39

Critical one tail t-values are: 1% = 2.50; 5% = 1.71; 10% = 1.32.

Panel C: T-Bond Futures

Intervals Compared	*Standard Deviation*	*Garman–Klass*	*Number of Ticks*
8:20 vs. 8:25	−0.61[a]	−0.48[a]	1.46[b]
8:25 vs. 8:30	−7.45	−8.42	−11.88
8:30 vs. 8:35	8.28	8.49	9.42

Critical one tail t-values are: 1% = 2.68; 5% = 1.78; 10% = 1.36.
All unstarred t-values are significant at the 1% level.
[a]Not significant at the 10% level.
[b]Significant at the 10% level.
[c]Significant at the 5% level.

- The results for the opening and the night session for T-bond futures, as well as the 15-minute opening interval results and the number of ticks for the 5-minute opening interval for the MMI contract, show that public and private macroeconomic information play a relatively small role in the opening interval effect found in the futures markets.

- The 15-minute results show the dominance of the cash market over the futures market. Thus, overall, both stock index futures and the T-bond contract are more volatile/active when the cash market is open. Moreover, the 5-minute results show a peak for stock index futures at the NYSE open and the T-bond futures spike at the 8:30 AM government announcements interval.
- Three types of volatility/activity measures are examined to compare their consistency. Theoretically, the Garman–Klass measure is a better method of estimating volatility than the standard deviation, since the former uses the open, high, low, and closing prices in a given time interval. The figures show little difference between the intraday patterns when using the standard deviation versus the Garman–Klass measure. However, the tests of significance tend to provide higher *t*-values for the standard deviation measure and the standard deviation is more likely than the Garman–Klass measure to indicate statistical significance. Hence, the Garman–Klass method provides a more conservative measure of volatility differences.
- The number of ticks (price changes) tends to be less responsive to changing market conditions (information; market openings) than the measures of volatility (see the MMI and T-bond opening intervals and the T-bond announcement interval). It provides different patterns than the two volatility measures at important time intervals in the day.

The results also show three anomalies. First, the closing cash market interval for stock index futures is not the most volatile time interval near the close. In fact, the most volatile time interval is approximately 30 minutes before the NYSE close, which is not consistent with typical explanations of the behavior of markets. A second, perhaps related, anomaly is that there is no upward spike at the cash market close for stock index futures. (Also, there is no spike at the futures market close for the 15-minute intervals, but there is a spike for the 5-minute intervals). The cash market closing result is not consistent with the market closure explanation of price behavior. The third anomaly is that the volatility/activity measures for the 5-minute intervals are greater when the S&P 500 futures close than when the cash market closes, suggesting that the activity of scalpers at the futures close creates this pattern and that the S&P 500 futures market may dominate the cash market at the end of the day.

Overall, information explains the T-bond futures 8:30 AM spike. However, other macroeconomic information tends to have less noticeable effect on futures markets. The market closure theory, or more precisely the extended market closure theory for futures markets, explains most of the other volatility and activity patterns of these futures contracts better than other theories. However, it is unclear whether the cash or futures markets dominates—especially near the close of the stock index futures markets. Thus, the anomalies found here suggest that an integrated theory is needed to explain all of the price patterns exhibited by these contracts.

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