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Trading Mechanisms and the Price Volatility: Spot versus Futures

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September 1990

Trading Mechanisms and the Price Volatility:
Spot versus Futures

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Trading Mechanisms and the Price Volatility:
Spot versus Futures

ABSTRACT

This paper compares the volatility of spot prices with that of futures prices using two estimators of volatility, natural and temporal in an attempt to compare two different trading mechanisms, dealers market versus clearing auction market. Using the intraday data of the Major Market Index and its futures prices, we show that the well-known volatility patterns during the day are not necessarily due to the different trading mechanisms. We also show that futures prices may be said to be more volatile than spot prices in terms of how quickly the price moves beyond a given unit price level, rather than in terms of how much the price changes during a given unit time interval.

Trading Mechanisms and the Price Volatility:
Spot versus Futures

I. Introduction

It has been fairly well known that opening prices are more volatile than closing prices, and that the intraday volatility pattern is U-shaped in the stock market. The different volatilities during the day have often been attributed to the different trading mechanisms by which the prices are determined.[1] For example, a recent study by Amihud and Mendelson (1987) examines the effects of the mechanism by which securities are traded on their price behavior: the dealership market versus the clearing house. The opening transactions in the New York Stock Exchange represent the outcome of a call auction trading procedure, whereas trading at the close is carried out at prices that are set or affected by the exchange's market-makers. Amihud and Mendelson (1987), acknowledging the difference of trading mechanisms for opening and closing prices, compare the volatility of the opening prices with that of the closing prices, using the 30 NYSE stocks which constituted the Dow Jones Industrial Index for February 8, 1982, to February 18, 1983. The empirical results show that the volatility is much higher at the opening than at the closing. Based upon the results, they argue that the variance is higher in a clearing house compared to the dealership market. Stoll and Whaley (1989), using all stocks on the NYSE for a longer time period, investigate the magnitude of the structurally-induced price volatility at the open. Among others, they confirm that open-to-open variance is higher than close-to-close variance on average. Wood, McInish and Ord (1985), using transaction data of stocks for six months in 1971-1972 and calendar 1982, show not only that opening prices are more volatile than closing prices but that the intraday volatility pattern is U-shaped.

In contrast to the stock market, the futures market is a clearing open outcry auction market from the opening to the closing. Thus, a comparison between the stock market and the futures market will be of particular interest to investigate the effect of the different trading mechanisms on the price volatility. In light of the results in the previous studies, on one hand, one may expect a higher volatility in the futures market than in the spot market since the former is characterized by the clearing open outcry auction while the latter is basically a dealership market, even though there are some factors unique to each market. On the other hand, more importantly, one should not expect different volatilities between opening and closing times and the U-shaped intraday volatility pattern in the futures market.

There are two important factors we should consider when we refer to the price volatility. One is the quantity of price changes over fixed time intervals. This is a conventional estimator of the volatility which is measured by the variance of price changes. The other one, which has been ignored in the previous studies, is the speed of price changes, i.e., how fast the price changes to move beyond a given unit price interval. Theoretically, although the quantity of price changes over fixed time intervals is small (or zero in an extreme case), if the price moves quickly to reach a certain level of price, the price can be perceived as volatile, ceteris paribus.

The purpose of this paper is to compare the volatility of spot prices with that of futures prices using two different estimates of volatility in an attempt to compare the two different trading mechanisms, dealers market versus clearing auction market. Initially, following previous studies, a conventional estimator of the volatility is used, i.e., the variance of the changes in observed prices over fixed time intervals. This conventional measure of volatility will be called hereafter the natural volatility. Using the intraday data of the Major Market Index and its futures prices, we estimate the volatilities of prices from closing to closing, from opening to opening, and for 30 minute intervals during the day. Secondly, we adopt a temporal estimator of volatility, developed by a recent study, Cho and Frees (1988, hereafter CF), which examines the time required for the prices to move beyond a given unit price interval using the concept of the so-called first passage time. This type of volatility will be particularly useful to compare the stock market with the futures market since the latter is acknowledged, in general, to involve less transaction costs than the former. Thus, the temporal estimator of volatility will provide further insights into the price behavior. To the author's best knowledge, this paper represents the first formal study to compare the two markets based on a temporal estimator.

The paper is organized as follows. Section II compares the volatilities of spot and futures prices using the natural estimator. Section III provides the results of the temporal estimator of volatility. Summary and concluding remarks are contained in Section IV.

II. Natural Estimator of Volatility

This paper uses time-stamped intraday spot and futures prices of the Major Market Index (MMI) over the period July 23, 1984 to July 15, 1986, obtained from the Chicago Board of Trade. The MMI is a price-weighted index of 20 blue-chip stocks, including 15 of the 30 Dow Jones industrials. The data base includes only transactions with price changes as reported for the futures contract and the values of the spot index occurring one to four times every minute of the trading day. For futures prices, the most actively traded MMI futures contracts are used. In general, the most actively traded futures contract is the nearby contract except for the delivery month when the next contract becomes most actively traded. Also, following Cornell (1985), all holidays and the days following holidays are excluded from the sample. For the sample period, there are 16 holidays, six on Monday, two on Tuesday, two on Wednesday, three on Thursday and three on Friday. MMI futures contracts were traded between 8:45 a.m. and 3:15 p.m. while the MMI stocks were traded between 9:00 a.m. and 3:00 p.m. Chicago time before October 1, 1985. Since October 1, 1985, both exchanges have opened 30 minutes earlier.

Using the natural estimator of volatility, we compare spot prices with futures prices. First, we compare them based on open-to-oepn and close-to-close return variances in the spirit of Amihud and Mendelson (1987) and Stoll and Whaley (1989). Table 1 presents the results. The first column shows the ratio of the open-to-open return variance to the close-to-close return variance in the spot and futures markets. The daily returns are measured by $\log(P_t/P_{t-1})$. Since the ratio of the variances follows F-distribution, the results indicate that the open-to-open returns are more volatile than the close-to-close returns in both the futures and spot markets. For the spot market, this result is consistent with Amihud and Mendelson (1987) and Stoll and Whaley (1989), even though the magnitude of the ratio of the variances is different from theirs. The average ratio of $Var(R_0)/Var(R_c)$ for 30 stocks in Amihud and Mendelson (1987) is 1.20 and the average ratio for all stocks on the NYSE in Stoll and Whaley (1989) is about 1.12. The main difference between their results and ours lies in the fact that they deal with individual stocks whereas ours is for a portfolio.[2] Based on these results, one may be tempted to conclude that the different volatility of prices between the opening and closing times in the stock market is due to the different trading procedures, open auction market at the opening versus dealership market at the closing.

Insert Table 1 about here

However, the results on the futures contract suggest that the trading mechanism may not be necessarily the reason for the different volatilities between the opening and closing times. Unlike the spot market, the futures market is essentially an open outcry auction market from the opening to the closing, as pointed out earlier. Nevertheless, the results in Table 1 indicate that the opening prices are more volatile than the closing prices, like the spot market. Note also that the ratio of the variances in the futures market is even larger than that in the spot market. The second and third columns present the comparisons between the spot and futures markets on open-to-open return volatilities, and close-to-close return volatilities, respectively. The spot market is more volatile than the futures market in both opening and closing prices. We also compared the volatilities of spot and futures prices on each day of the week. Since there was no substantial difference of the volatility behavior across days of the week in either the spot or the futures market, the results are not presented.[3]

Note, however, that nonsynchronous trading may cause a problem in observing the opening price of the MMI. To the extent of delayed openings of the MMI component stocks, the opening index is biased.[4] By contrast, the futures opening price reflects traders' current expectations. Also, for the closing prices in both the spot and futures markets, the nonsynchronous trading should not be a problem since the MMI includes only twenty stocks and these are actively traded.

We estimate the volatilities of spot and futures prices for 30 minute intervals during the day to reduce the nonsynchronous problem in the open-to-open returns in the stock market and to examine the intraday volatility patterns, if any. Table 2 and Figure 1 present the results. Although the CBT closes at 3:15 p.m., the last 15 minutes are discarded to match the spot market's closing time. The intraday volatility patterns appear to be U-shaped not only in the spot market but in the futures markets. The results in the spot market are consistent with previous studies (e.g., Wood, McInish and Ord (1985)) and thus are not surprising. However, the results in the futures market give a new insight into the volatility behavior. The intraday volatility patterns of futures prices are very similar to those of spot prices in spite of their different trading mechanisms. The volatility of prices in both the spot and futures markets is very high posterior to the opening time and declines until noon and goes up prior to the closing time. We use the Bartlett statistics to test the hypothesis that the volatilities for all segmented time periods during the day are equal.[5] The results suggest that the hypothesis is rejected at any confidence level in both the spot and futures markets.

Insert Table 2 and Figure 1 about here

Also notable is that futures prices do not appear to be as volatile as spot prices on average throughout the day.[6] In fact, spot prices are more volatile than futures prices before noon (i.e., the ratio of the spot price volatility to the futures price volatility, that follows F-distribution, is greater than one).[7] Also, trading of the MMI stocks are not necessarily synchronous. If some of the stocks are not traded for a short period of time, the volatility of the index is likely to be lower than the case where all of the stocks are traded simultaneously. Thus, the volatility of the index reported here would be a conservative measure. The results in sum suggest that the different volatilities during the day are not necessarily due to the different trading mechanism.

III. Temporal Estimator of Volatility

In the previous section, we have shown that for the MMI the intraday volatility of both spot and futures prices is U-shaped and that unlike the conventional wisdom, futures prices do not appear to be as volatile as spot prices. Then, the question remains why futures prices have been acknowledged, in general, as more volatile than spot prices. We may find one possible reason in the different speed of information adjustment in different markets due to some reasons such as different transaction costs. It is generally perceived that futures contracts involve less transaction costs than stocks so that the futures price may move more quickly than the spot price. However, the lead-lag relation between spot and futures prices is still controversial. Several studies have documented that futures prices lead stock prices (e.g., Kallaller, Koch and Koch (1986), Harris (1989), Finnerty and Park (1987)). On the other hand, a recent study by Chan and Chung (1989) find little evidence that futures price movements lead spot price movements, using the intraday data of the MMI for August 1984 to August 1986. Nevertheless, no study has yet actually estimated the volatility of futures prices based on the speed of price adjustments.

CF propose a <u>temporal</u> estimator of stock price volatility as an alternative to the <u>natural</u> estimator. The temporal estimator comes from the notion of how quickly the price changes rather than how much the price changes. In other words, the more volatile stock price should move quicker, and hence the so-called first passage time should be shorter than the less volatile stock. While the <u>natural</u> estimator focuses on how much the price changes during a given unit time interval, the temporal estimator focuses on how quickly the price moves beyond a given unit price level. CF show that the temporal estimator has desirable asymptotic properties, including consistency and asymptotic normality. The brief outline of the temporal estimator is as follows.[8]

Assume that the true stock prices are log-normally distributed and the observed stock prices are continuously monitored. That is, the true stock price is assumed to be $P(t) = P(0)\exp(\sigma B(t) + \mu t)$, $t \geq 0$. Here $P(0)$ is a known constant, μ and σ are unknown parameters, and $\{B(t);\ t \geq 0\}$ is standard Brownian Motion over $[0,\infty]$. The observed stock price is assumed to be $\hat{P}(t) = [P(t)/d] \cdot d$, where d is a known constant.

Based on the notion of the first passage time and these assumptions, CF construct a consistent estimator along with its asymptotic sampling distribution. First, they define the sequence of stopping time random variables $\{\tau_n\}_{n=1}^{\infty}$ by $\tau_n = \{$first time $t > \tau_{n-1}$ such that $P(t)/P(\tau_{n-1}) \notin [(1+d)^{-1}, (1+d)]\}$, where $\tau_0 = 0$. Thus, $\{\Delta\tau_n\}$, where $\Delta\tau_n = \tau_{n+1} - \tau_n$, is an i.i.d. sequence of random variables.

Besides, they introduce two functions: $g_1(x) = \{1+(1+d)^{-x-1}\}^{-1}$ and $g_2(x) = \log(1+d)(2g_1(x)-1)$. Applying Theorem 3.6 of Siegmund (1985), they derive some important relationships between the parameters, μ and σ, and the expected time between price changes, $E\tau$. That is, if $\mu \neq 0$, then $\Pr\{P(\tau) = 1 + d\} \equiv p = g_1(2\mu/\sigma^2)$ and $E\tau = \mu^{-1}g_2(2\mu/\sigma^2)$. The temporal estimator is suggested then as

$$\hat{\sigma}^2 = 2\hat{\mu}_2/g_2^{-1}(\hat{\mu}_2\bar{\tau}_n) = 2\hat{\mu}_2/g_2^{-1}[n^{-1}\log P(\tau_n)], \quad (1)$$

where

$$\hat{\mu}_2 = \tau_n^{-1}\log[P(\tau_n)]$$

$$\bar{\tau} = \tau_n/n.$$

Their simulation study shows that measurement errors in the time of price changes are more likely to induce less biases than measurement errors in the magnitude of price changes. It is also shown that the natural estimator does not become better as one adds more observations per day. The temporal estimator is particularly useful in this study since we use intraday transaction data.

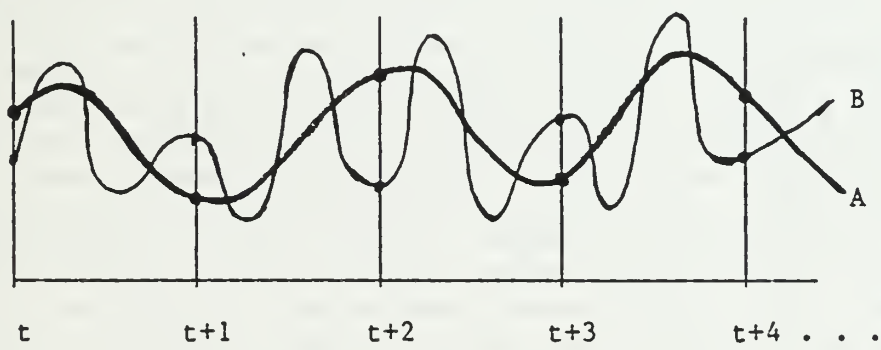
We measure the temporal estimators of volatility for both spot and futures prices using an arbitrary number for d, 1/8, in equation (1).[9] Figures 2, 3, 4, and 5 represent daily temporal volatilities of spot and futures prices, for July 23, 1984 - December, 1984, January, 1985 - June, 1985, July 1985 - December, 1985, January, 1986 - July 15, 1986, respectively.

Insert Figures 2, 3, 4 and 5 about here

Table 3 and Figure 6 show the results on the average temporal estimators of volatility of both spot and futures prices for 30 minute intervals during the day. In contrast to the results based on the natural estimator, futures prices are more volatile than spot prices throughout the day, and the U-shaped patterns of volatility do not exist during the day either in the spot market or in the futures market. However, the results indicate that the hypothesis is rejected that the temporal volatilities for all segmented time periods during the day are equal. It is clear that the futures price moves more quickly than the spot price to reach a given unit price level. Thus, as pointed out earlier, information adjustment in the futures market seems to be faster than in the spot market, which may be due to lower transaction costs in the futures market. This may be able to explain why the futures price has been conceived, in general, by the market participants to be more volatile than the spot price.

Insert Table 3 and Figure 6 about here

Summing up the results of natural and temporal estimates of volatility, we can imagine the following possible patterns of spot and futures prices over time.



It is obvious that if we use the natural estimator of volatility, the series A is more volatile than the series B. On the other hand, if we use the temporal estimator, the series B is more volatile than the series A. Assuming that the unit time is 30 minutes, it is conceivable that the series A and B may correspond to the spot and futures prices, respectively, in the sample, i.e., the futures price is more (less) volatile than the spot price in terms of the temporal (natural) estimator.

IV. Summary and Conclusion

It has been generally well-known that opening prices are more volatile than closing prices, and that the intraday volatility pattern is U-shaped in the stock market. The different volatilities around the opening and closing times have often been attributed to the different trading mechanisms by which the prices are determined: the opening transactions in the NYSE represent the outcome of an auction trading procedure, whereas closing prices are determined by the market-makers.

This paper investigates the volatilities of spot and futures prices using two different estimators of volatility, natural and temporal. The futures market is characterized by the clearing open outcry auction from the opening to the closing while the stock market is basically a dealership market except the opening time. Thus, one might expect higher volatility in futures prices than in spot prices and should not expect the U-shaped intraday volatility pattern and the different volatilities between opening and closing times in the futures market if the different volatility behavior between the opening and the closing in the spot market is solely due to different trading mechanisms. Using the intraday data of the Major Market Index and its futures prices, this paper shows that the volatility of opening prices as measured by the natural estimator is higher than that of closing prices not only in the spot market but in the futures market, and that the intraday volatility patterns are U-shaped in both the markets. Also, futures prices do not appear to be as volatile as spot prices when the natural estimator of volatility is used. Thus, we argue that the different volatility patterns during the day may not be necessarily due to the different trading mechanisms, auction market versus dealership market.

When the temporal estimator is adopted, we are not able to find the U-shaped patterns of volatility during the day in both the spot and futures markets, and futures prices are more volatile than spot prices. Based on these results of natural and temporal estimators of price volatility, we argue that for the MMI, the futures prices may be said to be more volatile than the spot prices in terms of how quickly the price moves beyond a given unit price level, rather than in terms of how much the price changes during a given unit time interval.

Further studies certainly deserve to follow, in particular, on regulation of the futures market, based on the results in this paper. For example, after the market crash in 1987, a number of proposals have been suggested to impose some curbs on trading stock index futures contracts such as circuit breaker system (e.g., Brady's report (1988) and the Joint Task Force Report (1988).[10] The lower natural variance and higher temporal variance of futures prices than spot prices in this paper suggest that information may be more quickly reflected in prices in the futures market than in the spot market but the absolute changes of futures prices during a given unit time interval may be on average lower than those of spot prices. This result is consistent with the view that the futures market can play a positive economic role rather than negative. Besides, the analogy that the various reports use for the justification of circuit breakers may be misleading. They state that if a machine or some other mechanical man made operation is going to get out of control, the best way to keep it under control is to "pull the plug." This may work very well for controlling machines because the machine cannot anticipate the plug being pulled. Financial markets, however, are able to anticipate trading halts or market closure. In fact, the existence of the closing of trading may cause increases in volatility because market participants may want to get their trade complete before the trading is halted, thereby if participants anticipate a trading halt they may increase the level of trading to beat the closure of the market. The increased natural volatility prior to the closing time we observe in this paper may confirm those activities of investors.

FOOTNOTES

[1]For the importance of trading mechanism, see Hasbrouck and Ho (1987), Kyle (1985), Admati and Phleiderer (1988), French and Roll (1986), Hughson (1988), Amihud and Mendelson (1987), Wood, McInish and Ord (1985), MacKinlay and Ramaswamy (1988), and Stoll and Whaley (1989).

[2]Amihud and Mendelson (1987) compute the variances for the whole sample period and take the ratio of the variances for each stock. However, in Stoll and Whaley (1989), return variances are computed for each stock in each month during the sample period, and then the ratio of the variances for each stock in each month is calculated and the ratios are averaged across stocks in each month and then across all months of the sample period. Therefore, the results in this paper may not be directly comparable to Stoll and Whaley (1989).

[3]Detailed results are available from the authors upon request.

[4]Stoll and Whaley (1989) report that the average number of minute between the official opening of the exchange and opening transaction in a stock was 15.48 minutes in 1986. However, as dollar volume increases, the average time until the first transaction declines dramatically to a low 4.15 minutes and does not vary much across high volume stocks. Since the MMI contains only twenty blue chips and these are high dollar volume stocks, the average time to open is likely to be very small.

[5]See Judge, Griffiths, Hill, Lütkepohl and Lee (1985, p. 448) for details of the Bartlett Test.

[6]We also estimated the volatilities for 30 minute intervals for each day of the week. Since the results are not different depending on the day of the week, they are not reported in the paper. However, they are available from the authors upon request.

[7]MacKinlay and Ramaswamy (1988) show that the Standard and Poor 500 futures prices are more volatile than the spot index using the data for April 1982 - June 1987. The different results between this paper and MacKinlay and Ramaswamy (1988) can be due to (1) different time periods, (2) the way of recording prices in the data, (3) different sizes of trading volume, and (4) different components of the index. Both studies use the sample period including the inception of trading of each futures contract. Therefore the first reason may not explain the difference between the two studies. Also, in both studies, the data base includes only transactions with price changes as reported for futures contracts. So, the second reason may not be satisfactory. The MMI futures contract typically has less volume than the S&P 500 futures contract. Thus, the different results between the two studies may have been driven by the third and fourth reasons. Nevertheless, the results in this paper is interesting on its own since this paper focuses more on the intraday pattern of the volatility in each market rather than on just comparison between the two markets for a specific time period.

[8]See Cho and Frees (1988) for details

[9]The temporal estimators of volatility based on two other arbitrary numbers of d, 1/40 and 1/100, were estimated. The general

patterns of the intraday volatility did not vary much. The results are available upon request from the authors.

[10]Other proposals include tightening the price limits of futures prices, increasing margin requirements, and using the opening price as the settlement price.

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Table 1

Comparison of Volatilities: Open-to-Open versus Close-to-Close Returns,* and Spot versus Futures

	$\frac{Var(R_0)}{Var(R_c)}$	$\frac{Var(O-S)}{Var(O-F)}$	$\frac{Var(C-S)}{Var(C-F)}$
MMI (Futures)	1.0967	1.0383	1.0327
MMI (Spot)	1.0384		

*$Var(R_0)$ and $Var(R_c)$ are the variances of the open-to-open returns and the close-to-close returns, respectively. The return is measured by $\log (P_t/P_{t-1})$. Var(O-S) and Var(C-S) represent the variances of open-to-open returns and close-to-close returns in the spot market, respectively. Var(O-F) and Var(C-F) are the counterparts in the futures market.

Table 2

Natural Estimator of Intraday Volatility[a]

Time	Observation	$\hat{\sigma}^2$(Spot)	$\hat{\sigma}^2$(Futures)
8:30 - 9:00[b]	198	$1.687E^{-5}$ $(.170E^{-5})$[c]	$0.767E^{-5}$ $(.077E^{-5})$[c]
9:00 - 9:30	495	$1.113E^{-5}$ $(.071E^{-5})$	$0.605E^{-5}$ $(.039E^{-5})$
9:30 - 10:00	496	$0.392E^{-5}$ $(.025E^{-5})$	$0.283E^{-5}$ $(.018E^{-5})$
10:00 - 10:30	496	$0.333E^{-5}$ $(.021E^{-5})$	$0.266E^{-5}$ $(.017E^{-5})$
10:30 - 11:00	496	$0.325E^{-5}$ $(.021E^{-5})$	$0.285E^{-5}$ $(.018E^{-5})$
11:00 - 11:30	496	$0.280E^{-5}$ $(.018E^{-5})$	$0.259E^{-5}$ $(.016E^{-5})$
11:30 - 12:00	496	$0.240E^{-5}$ $(.015E^{-5})$	$0.241E^{-5}$ $(.015E^{-5})$
12:00 - 12:30	496	$0.308E^{-5}$ $(.020E^{-5})$	$0.305E^{-5}$ $(.020E^{-5})$
12:30 - 13:00	496	$0.305E^{-5}$ $(.019E^{-5})$	$0.304E^{-5}$ $(.019E^{-5})$
13:00 - 13:30	496	$0.394E^{-5}$ $(.025E^{-5})$	$0.425E^{-5}$ $(.027E^{-5})$
13:30 - 14:00	496	$0.490E^{-5}$ $(.031E^{-5})$	$0.493E^{-5}$ $(.031E^{-5})$
14:00 - 14:30	496	$0.841E^{-5}$ $(.054E^{-5})$	$0.855E^{-5}$ $(.054E^{-5})$
14:30 - 15:00[b]	496	$0.870E^{-5}$ $(.055E^{-5})$	$0.877E^{-5}$ $(.056E^{-5})$
Bartlett Test Statistic[d]		87.88	61.17

[a]The volatility is measured by the variance of $\log(P_t/P_{t-1})$ and the unit time interval is 30 minutes. If P_t was not available at exact time t, the price closest to t was used.

[b]Since the spot market opened at 9:00 in Chicago time before October 1, 1985, the volatility for 8:30 - 9:00 was estimated using the data only since October 1, 1985. Also, although the futures market closed at 3:15 p.m., the futures prices for the last 15 minutes were discarded to match the spot prices.

[c]The numbers in parentheses represent standard errors of $\hat{\sigma}^2$.

[d]Bartlett Test is for the hypothesis that $\hat{\sigma}_1^2 = \hat{\sigma}_2^2 = \hat{\sigma}_3^2 \ldots = \hat{\sigma}_{13}^2$,

where the subscript represents the segmented time period during the day. The test is based on the statistic

$$M = \frac{(T-m)\ln \hat{\sigma}^2 - \Sigma_{i=1}^{m}(T_i-1)\ln \hat{\sigma}_i^2}{1+[1/3(m-1)][\Sigma_{i-1}^{m} 1/(T_i-1)-1/(T-m)]} \sim \chi^2(m-1),$$

where $(T-m)\ln \hat{\sigma}^2 = \Sigma_{i=1}^{m}(T_i-1)\hat{\sigma}_i^2$, $\Sigma_{i=1}^{m} T_i = T$

and T_i represents the number of observations for the ith time segment.

Table 3

Average Temporal Estimator of Intraday Volatility[a]

Time	Spot Market $\bar{\sigma}^2$	Spot Market Min	Spot Market Max	Futures Market $\bar{\sigma}^2$	Futures Market Min	Futures Market Max
8:30 - 9:00[b]	0.0068 (0.0071)	0.000445	0.342250	0.1490 (0.0431)	0.000797	7.771123
9:00 - 9:30	0.0121 (0.0094)	0.000486	0.542024	0.0194 (0.0107)	0.000668	1.070025
9:30 - 10:00	0.0134 (0.0082)	0.000733	0.257501	0.1441 (0.0680)	0.000842	11.38132
10:00 - 10:30	0.0206 (0.0087)	0.000685	0.524652	0.0774 (0.0384)	0.000773	7.747582
10:30 - 11:00	0.0203 (0.0121)	0.000751	1.070679	0.1371 (0.0925)	0.000902	10.81968
11:00 - 11:30	0.0226 (0.0075)	0.000683	0.521450	0.1479 (0.0938)	0.000811	10.96116
11:30 - 12:00	0.0231 (0.0080)	0.000896	0.785974	0.0641 (0.0260)	0.000995	5.683590
12:00 - 12:30	0.0210 (0.0063)	0.000890	0.295222	0.0587 (0.0213)	0.000807	6.784774
12:30 - 13:00	0.0170 (0.0076)	0.000680	0.299914	0.0568 (0.0245)	0.000728	7.891387
13:00 - 13:30	0.0163 (0.0081)	0.000411	0.416991	0.0478 (0.0187)	0.000803	5.171524
13:30 - 14:00	0.0118 (0.0079)	0.000497	0.228864	0.0647 (0.0512)	0.000653	10.65167
14:00 - 14:30	0.0090 (0.0064)	0.000289	0.166973	0.0201 (0.0086)	0.000393	1.659474
14:30 - 15:00[b]	0.0091 (0.0062)	0.000456	0.170667	0.0338 (0.0107)	0.000426	4.086381
F-statistic[c]	2.01			27.63		

[a]The numbers in parentheses represent the standard deviations of $\bar{\sigma}^2$.

[b]Since the spot market opened at 9:00 in Chicago time before October 1, 1985, the volatility for 8:30 - 9:00 was estimated using the data only since October 1, 1985. Also, although the futures market closed at 3:15 p.m., the futures prices for the last 15 minutes were discarded to match the spot prices.

[c]The F-statistic is for the hypothesis that all the coefficients are equal in the regression $\sigma_t^2 = \alpha_1 D_1 + \alpha_2 D_2 + \alpha_3 D_3 + \dots + \alpha_{13} D_{13} + e_t$, where σ_t^2 is the temporal volatility for the segmented time period t during the day and D_1 through D_{13} represent the segmented time dummies during the day.

Figure 1

Intraday Natural Variance (E^{-5})
(July 23, 1984 - July 15, 1986)

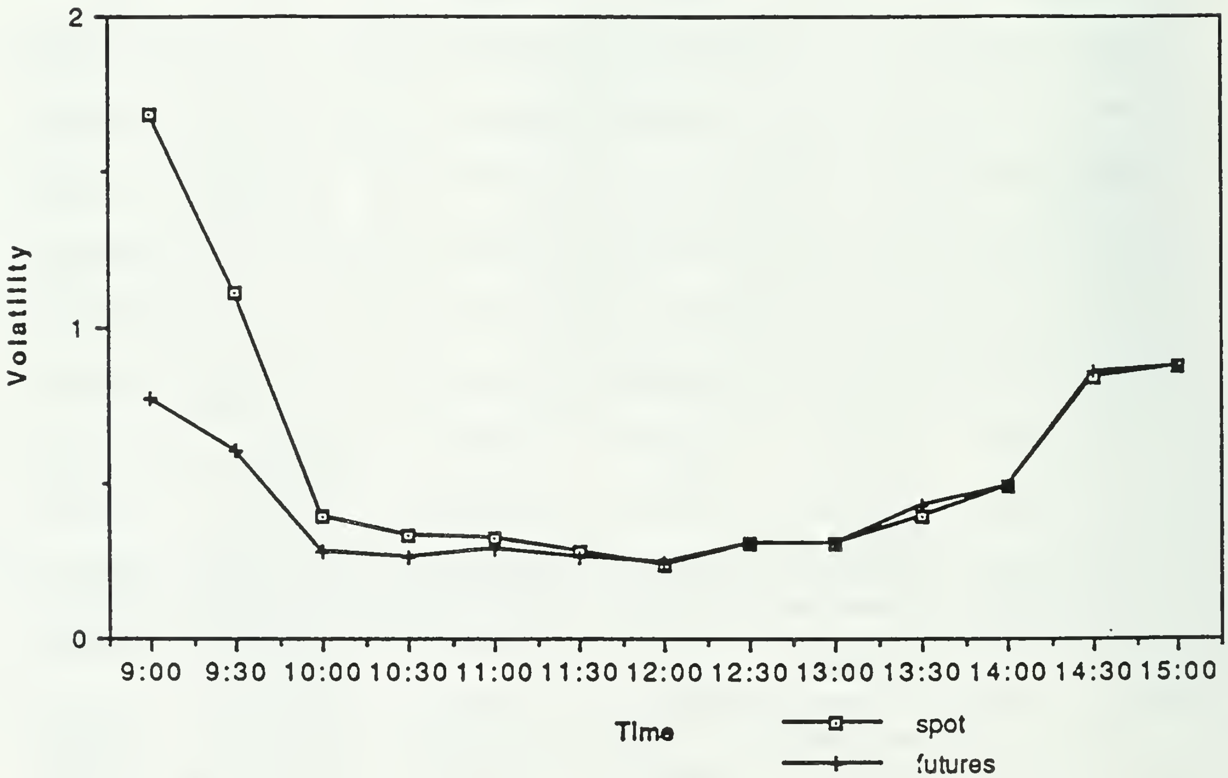

Figure 2

Daily Temporal Volatility of Prices
(July 23, 1984 - December 31, 1984)

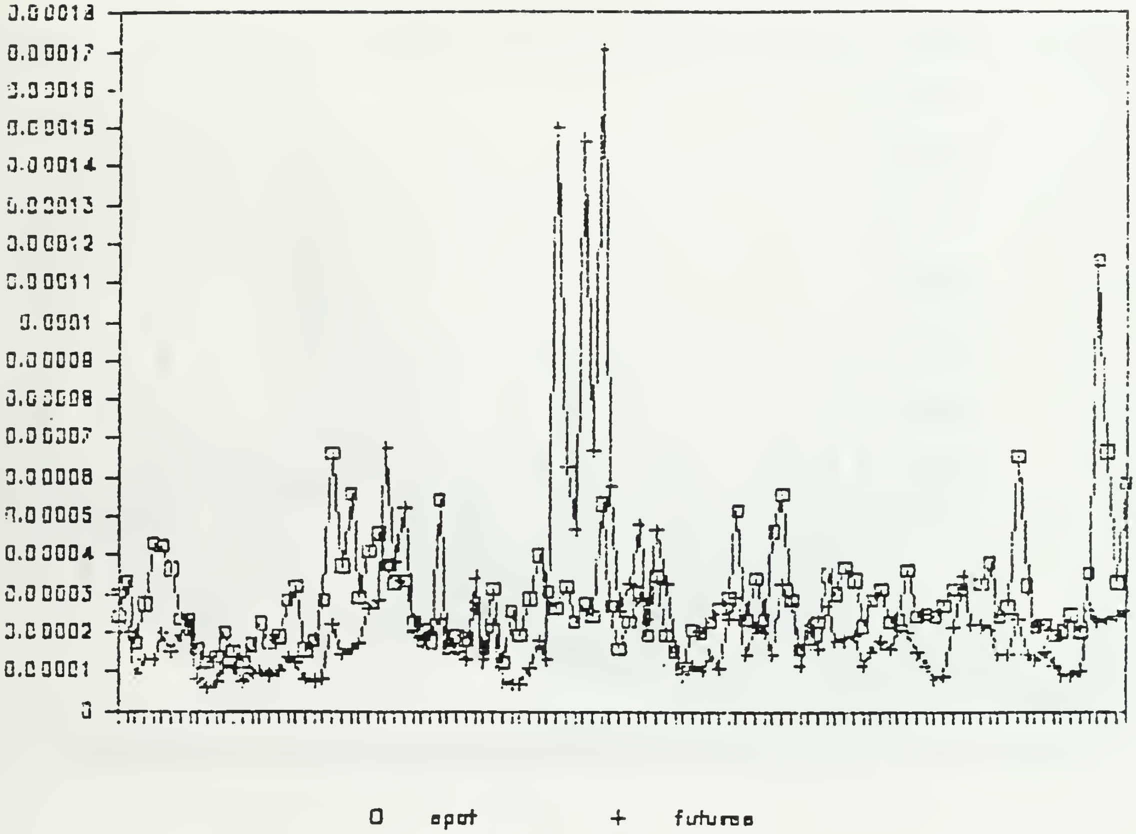

Figure 3

Daily Temporal Volatility of Prices
(January, 1985 - June, 1985)

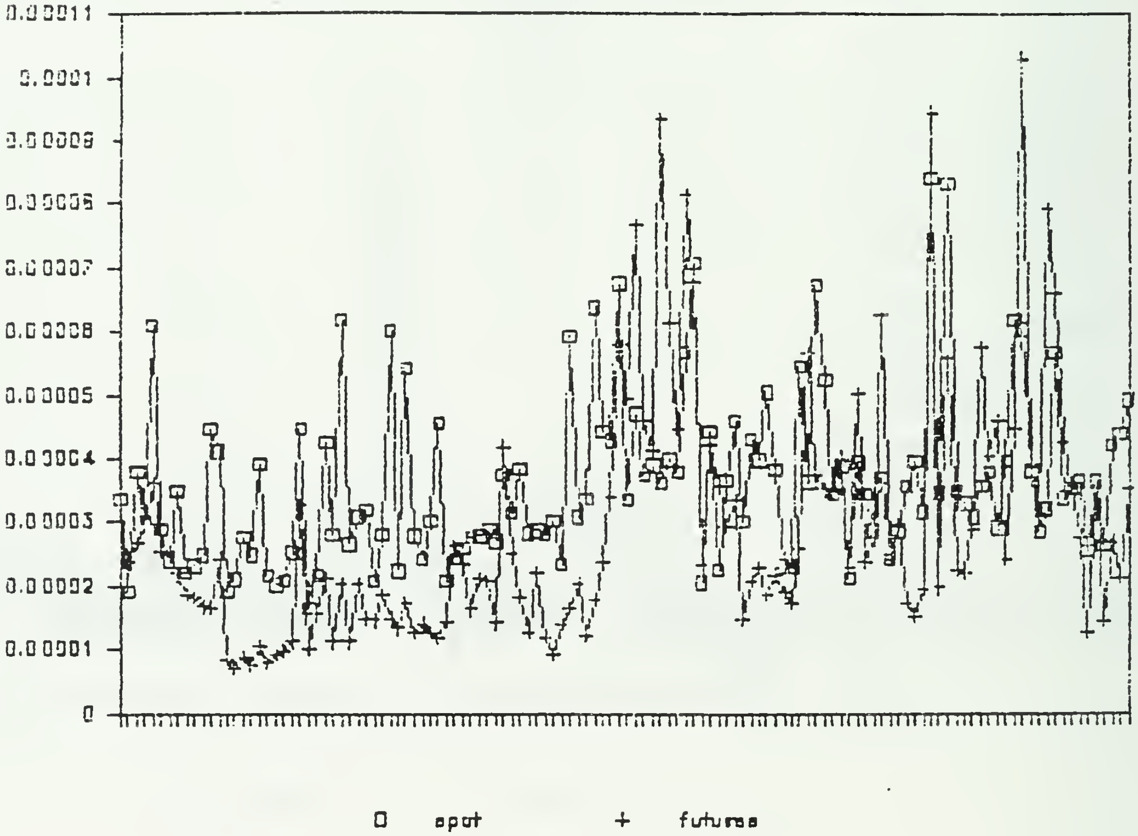

Figure 4

Daily Temporal Volatility of Prices
(July, 1985 - December, 1985)

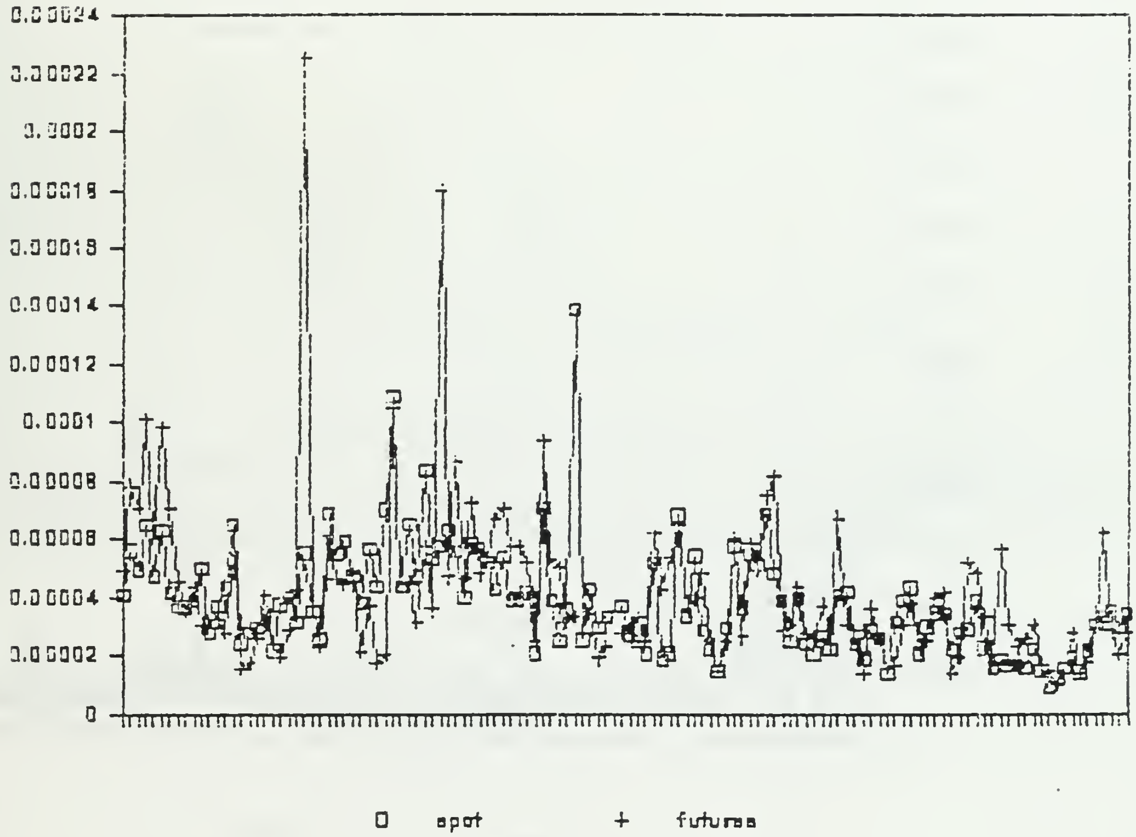

Figure 5

Daily Temporal Volatility of Prices
(January, 1986 - July 15, 1986)

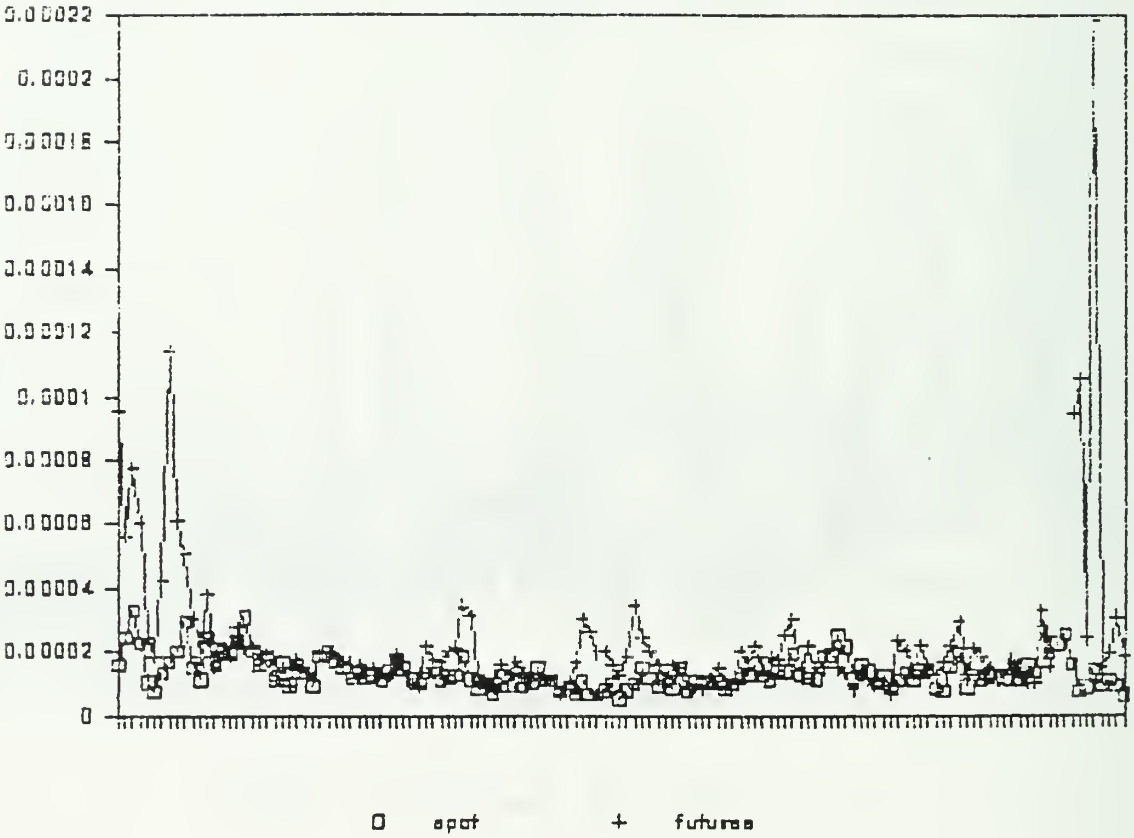

Figure 6

Average Intraday Temporal Variance
(July 23, 1984 - July 15, 1986)