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Intraday and interday behavior of the TOPIX

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Using minute-by-minute observations of TOPIX, this study examines the behavior of index return and volatility within a trading day. With irregularities detected for the returns at both the morning and the afternoon close, the intraday returns cannot be characterized by a smooth U-shaped curve. Instead, the standard deviations show two distinct U-shaped curves: one in the morning and another in the afternoon trading session. Intraday price reversals are strongly indicated by both correlations and autocorrelations of minute-by-minute returns. The analysis of interday behavior of the TOPIX indicates that the variance ratios are relatively stable and close to unity throughout a trading day. This finding implies that: (i) the variance ratio at the market open is not greater than unity; and (ii) the variance ratio at the afternoon open is not different from the ratio observed at the morning open. These results raise a serious question about the effect of the Itayose clearing house trading method on market volatility.

Keywords: Itayose method; Market volatility; Private information; TOPIX; Variance ratio; Zaraba method

Very little is known about the nature of return-generating processes in the Tokyo Stock Exchange (TSE) market, which is comparable in size to the New York Stock Exchange (NYSE) market.¹ Only a limited number of

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We have benefited from comments on an earlier version of this paper by Warren Bailey, Jeffrey Jarret, Bob Nachtmann and participants of the Fourth Annual PACAP Finance Conference held in Hong Kong in July 1992. Hiroshi Nakamura and Masao Takamori of the Tokyo Stock Exchange for supplying detailed information on trading methods and the TOPIX.

¹The respective 1991 *Fact Books* of the TSE and the NYSE indicate that TSE's market capitalization amounted to \$2,822 billion in 1990 as opposed to NYSE's \$2,820 billion. In 1990, TSE trading volume was \$1,388.9 billion, accounting for 84.4% of the entire trading volume of the Japanese market, whereas NYSE trading volume amounted to \$1,336.2 billion, representing 82.9% of the total volume in the United States. In the same year, the number of listed companies of TSE was 1,627 firms (not including 125 foreign firms), while NYSE had a total listing of 1,774 firms (not including 96 foreign firms).

previous studies has examined intraday behavior of Japanese stock returns and risk. Kato (1990) has used hourly data for the Tokyo Stock Exchange Price Index (TOPIX) to identify weekly patterns. He reports that: (a) hourly returns show a significant weekday effect; and (b) overnight non-trading period returns are positive for all six days of the week, whereas trading period returns on both Mondays and Tuesdays are negative. Kato's study represents a Japanese counterpart of a number of U.S. studies that have focused on the day-of-the-week and intraday effects in stock returns. [See Rogalski (1984), Smirlock and Starks (1986), and Harris (1986).]

Amihud and Mendelson (1991) is the first study with a focus on return volatility rather than return anomalies using Japanese stock price data. Using the opening and closing prices of 50 Japanese stocks of both morning and afternoon trading sessions, Amihud and Mendelson report that the large volatility observed at the morning open is not caused by the periodic clearing house transactions but by the preceding overnight period of non-trading. Amihud and Mendelson's study is in the same line of research as Amihud and Mendelson (1987), Stoll and Whaley (1990), Harris (1990), and Choe and Shin (1993), who have examined the effects of trading method on market volatility. The analysis of trading method is one of two major volatility-related research topics that have gained popularity among academic researchers during recent years. The other major research topic focuses on the role of private information and trading noise on market volatility. Built upon a theoretical model developed by Kyle (1985) and further extended by Admati and Pfleiderer (1988), a series of empirical studies have provided evidence in support of the private information hypothesis and the trading noise hypothesis. [See French and Roll (1986), Barclay et al. (1990), Makhija and Nachtmann (1990), Stoll and Whaley (1990), and Forster and George (1991).]

Using transactions data, Wood et al. (1985) show intraday behavior of return and standard deviation for the U.S. stocks. Their study compiles empirical evidence that the return and the standard deviation curves are U-shaped, with high return and volatility at the market open and close and low return and volatility recorded in the middle of the trading session. Similar results are reported by Lockwood and Scott (1990) when hourly values of the Dow Jones Industrial Average (DJIA) are used to measure intraday return volatility. Gerety and Mulherin (1991) show that interday 24-hour return variance steadily declines during the trading day. Because Amihud and Mendelson's (1991) data are restricted to opening and closing prices in the morning and afternoon trading sessions, only a limited amount of insight can be gained regarding the intraday behavior of return and risk at short time intervals. Using minute-by-minute observations of TOPIX, this study documents the behavior of intraday return and risk. While so doing, empirical evidence is provided to show the manner in which private

information is assimilated into index returns and how price reversals affect index return volatility.

The use of index return series poses an exciting challenge because the behavior of individual firm returns and that of index returns are fundamentally different. As pointed out by Lo and MacKinlay (1990), the index returns will not show negative correlations as individual stocks do, due to the influence of cross-covariances of component securities. The positive correlations at the index return level do not necessarily imply the absence of price reversals. Rather, the intraday pattern of the estimated correlations should be an important indicator of price reversals at the index return level. Negative correlations usually observed at the individual security level as an indication of price reversals will lessen the degree of cross-covariances among the component securities and across the time intervals. Hence, the magnitude of correlations between the adjacent index return series in the first part of a trading session is large, but as the private information is incorporated into the process of price formation and as traders' overreaction becomes less severe, the correlations will begin to decline. However, once private information is fully assimilated into stock prices, the correlations will show an upward trend toward the end of a trading session. Therefore, one may expect a U-shaped correlation curve in a trading session. The same prediction is also applicable to the behavior of standard deviations and autocorrelations of the index returns in a trading day.

This paper is organized as follows. The data are discussed in section 1. Intraday return and volatility are analyzed in section 2. Price reversals are investigated in section 3 based on correlations between adjacent intraday return series and autocorrelations of minute-by-minute returns. Section 4 discusses the impact of the Itayose clearing house transaction method on the index return volatility. Summary and conclusions are presented in section 5.

1. Data

We have obtained the minute-by-minute values of TOPIX during the study period of August 12, 1987 to April 26, 1991. August 12, 1987, is the first day that TSE began to compute and publish minute-by-minute observations in preparation for the launching of TOPIX futures and options. April 26, 1991, is the last trading day before TSE's afternoon session was extended by half an hour with new trading hours between 12:30 p.m. and 3:00 p.m. During the study period, TSE had two daily trading sessions: a morning session between 9:00 a.m. and 11:00 a.m. and an afternoon session between 1:00 p.m. and 3:00 p.m. both from Monday through Friday. During the study period, there were 952 trading days. The TSE market had half-day trading on Saturdays between 9:00 a.m. and 11:00 a.m. except on the second and third Saturdays of each month through January 1989. Beginning in February

1989, TSE stopped trading on all Saturdays. There were 39 Saturday trading days excluded from the study to maintain the identical number of trading hours across all trading days in the sample. After 39 Saturdays were excluded, a total of 912 trading days had daily returns. An additional 94 trading days had to be excluded for the reasons such as: (i) trading days immediately following holidays; (ii) trading days surrounding the October 1987 market crash; (iii) trading days with irregular trading hours; and (iv) trading days with missing indexes and immediately following trading days.² Eventually, the total number of trading days with return data was at 818.

TOPIX is a value-weighted composite index of common stocks listed in the first section, but it is not adjusted for dividend payments. The TSE reports the first TOPIX of each trading day at 9:01 a.m., which represents the opening index. Due to the unavailability of a transactions tape, summary statistics on the timing of opening transactions have not been compiled. However, the TSE communicated to us that it takes an average of five minutes for all listed stocks to open. This compares with the 15.48 minutes

²Shown below are the reasons for the exclusion of some trading days from the study period:

Total number of trading days during the study period	952
Less Saturdays	39
Available trading days	913
The number of days with daily returns	912
Less trading days immediately following holidays	37
Less trading days surrounding the October 1987 market crash	23
Less trading days with irregular trading hours and immediately following trading days	22
Less trading days with missing indexes and immediately following trading days	12
Total number of trading days with returns	818

There were 37 trading days that followed holidays. To avoid holiday-related bias, the trading immediately following holidays had to be discarded. Also, to avoid undue influence of the 1987 global market crash on the analysis, excluded from the study were 23 trading days in the five-week period from October 12, 1987, to November 13, 1987. A total of 22 trading days had to be excluded because they were days with irregular trading hours or trading days immediately following them. For example, nine trading days between June 10, 1988, and June 22, 1988, had shortened afternoon sessions (1:45 p.m. to 3:00 p.m.). These nine days plus the trading day immediately following (June 23, 1988) were excluded. Morning trading started 15 minutes and one hour late on October 12, 1988, and October 3, 1990, respectively. Thus, these two trading days and the two following trading days (October 13, 1988, and October 4, 1990) were discarded. Additionally, the very last trading day and the very first trading day each year had no afternoon sessions, and so four year-end last trading days throughout the study period were excluded. Also, four first trading days each year during the study period plus the trading days immediately following had to be dropped. Since the first trading days of the year were already dropped under the exclusion rule of post-holiday trading days, only the second trading day in each of the four years was dropped. As a result, 22 trading days were discarded because of irregular trading hours. There were 14 trading days with one or two missing index observations. We decided to exclude those days. Altogether, 14 trading days were to be excluded for this reason, but two days were already discarded for other reasons mentioned above. Therefore, an additional 12 trading days were dropped from the sample.

Table 1
Summary of the frequency distribution of market closing minutes
toward the end of the morning and afternoon trading sessions.

Morning session		Afternoon session	
Closing minutes	The number of observations	Closing minutes	The number of observations
11:01	0	3:01	0
11:02	13	3:02	0
11:03	171	3:03	21
11:04	131	3:04	111
11:05	104	3:05	128
11:06	95	3:06	156
11:07	69	3:07	107
11:08	60	3:08	70
11:09	48	3:09	76
11:10	30	3:10	46
11:11–11:15	85	3:11–3:15	69
11:16–11:20	10	3:16–3:20	9
11:21–11:26	2	3:21–3:24	2
Total	818	Total	818

reported by Stoll and Whaley (1990) for NYSE stocks. Thus, one may expect noise-induced mispricing as well as the impact of an overnight non-trading period at the beginning of the morning trading session.

Since January 1982 the TSE has been implementing a Computer Assisted Order Routing and Execution System (CORES) to enhance the automation of its trading system. At present, all listed stocks are traded through the CORES with the exception of 150 of the most active stocks, which are subject to the traditional face-to-face method of trading on the trading floor.³ This traditional method of floor trading causes delays in reporting trades; thus, the TSE continues to compute and report TOPIX as late trade reports arrive after 11:00 a.m. and 3:00 p.m. Table 1 summarizes the frequency distribution of market closing minutes toward the end of the morning and afternoon trading sessions. None of the TOPIX values reported at 11:01 a.m. and 3:02 p.m. represents closing indexes in each of the sessions. Closing index values appear at 11:02 a.m. on 13 trading days in the morning session and at 3:03 p.m. on 21 trading days in the afternoon session. During the next ten-minute period, closing TOPIX values are reported on the majority of trading days for both trading sessions. The last closing indexes are reported at 11:26 a.m. and 3:24 p.m., respectively.

Considering these delays in reporting closing TOPIX values after 11:00

³To enhance the operational capacity of the trading floor where the 150 active stocks are traded, the TSE adopted an electronic system called the Floor Order Routing and Execution System (FORES) in March 1991.

a.m. and 3:00 p.m., we have synchronized all morning and afternoon closing by lining up all morning and afternoon closing index values at 11:02 a.m. and 3:03 p.m. This synchronization is warranted for three major reasons. First, correlations can be computed between two adjacent intraday minute-by-minute return series with identical observation numbers. Otherwise, some correlations would be estimated using a different number of observations after 11:00 a.m. and 3:00 p.m. Second, it eliminates the serious distortion in estimated autocorrelation coefficients caused by the declining number of observations after 11:00 a.m. and 3:00 p.m. on each of the trading days. Third, it keeps the length of non-trading periods (i.e., lunch break and overnight market closing time) the same on each trading day.

The study period was further divided into two subperiods: (a) August 12, 1987 to December 28, 1989; and (b) January 4, 1990 to April 26, 1991. The decision to partition the study period was made because of the lack of trading volume data on a minute-to-minute basis. During the first subperiod, the TSE market enjoyed a unprecedented bull market trend, whereas the second subperiod may be characterized as a bear market. The daily average trading volume in the first subperiod amounted to 934 million shares, whereas the second subperiod recorded an average volume of 506 million shares. Given the asymmetric price-volume relationship proposed by Karpoff (1987) and documented by Jain and Joh (1988), the comparison of risk and return behavior in the two subperiods will provide additional insight not achievable with the combined data. The difference in trading volume in the two subperiods will have important implications for market volatility, serial correlations, price reversals, etc. Throughout this study, therefore, we present the results for the whole period as well as for the two subperiods.

2. Intraday returns and volatility

2.1. Behavior of intraday returns

Intraday returns, r_i , are defined as the natural logarithm of the index relative multiplied by 100:

$$r_i = \log(I_i/I_{i-1}) \times 100, \quad (1)$$

where I_i signifies the TOPIX observed at minute i , and I_{i-1} is the TOPIX observed at the prior minute. For example, r_{902} is a one-minute return between 9:01 a.m. and 9:02 a.m., while r_{901} represents an overnight non-trading period return computed using the morning opening index value and the afternoon closing index value on the preceding day. r_{101} also represents a non-trading period (lunch break) return between the morning close at 11:02 a.m. and the afternoon open at 1:01 p.m.

Fig. 1 presents the minute-by-minute returns averaged across the 818

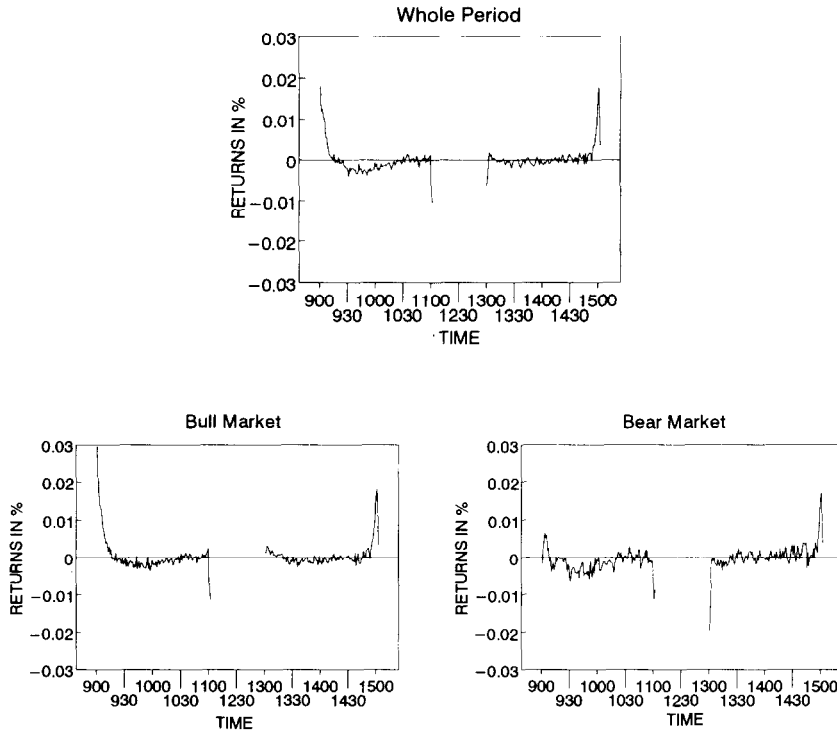


Fig. 1. Intraday returns across trading time.

trading days, including returns over the two non-trading periods plotted against trading minutes. Summary statistics for intraday returns are provided in table 2. As expected, a large overnight return, r_{901} , of 0.0181% is recorded during the 818-day study period. During the next five-minute period, the average return over one-minute intervals is 0.0125% (not shown in table 2). This contrasts with the average return of 0.0028% over the first 30-minute trading time. This implies that high initial returns rapidly converge to zero, taking approximately no more than 15 minutes before minute-by-minute returns reach below zero, and then span around zero. Note that the average returns over each 30-minute period are all negative except the last half hour before the afternoon market close, as shown in the first column of table 2. A careful review suggests two return anomalies. First, the behavior of the index return at the afternoon close is not consistent with Harris' (1989) findings from the NYSE stocks. Harris reports a large mean price change on the last daily NYSE transactions. The TSE results indicate that the return over the last closing minute, 3:02 p.m. to 3:03 p.m., is only 0.0035%, which is about

Table 2

Summary statistics for intraday returns. Intraday returns are defined as the natural logarithm of the index relative multiplied by 100: $r_i = \log(I_i/I_{i-1}) \times 100$, where I_i signifies the TOPIX observed at minute i , and I_{i-1} is the TOPIX observed at the prior minute. The minute-by-minute returns are averaged across the 818 trading days. The morning open return denotes an overnight non-trading period return computed using the morning opening index value and the afternoon closing index value on the preceding day. The morning closing return is a one-minute return prior to the market close in the morning. The afternoon open return is computed using the morning closing index and the afternoon opening index. The afternoon closing return is the one-minute return prior to the afternoon market close. M.C. and A.C. denote morning close and afternoon close, respectively. Average return (%) and average standard deviations are computed for every half hour of the trading period. Standard error of average return is based on 30 observations in every 30-minute period. The variance ratio is defined as the ratio of minute-by-minute return variance to the variance of the afternoon close-to-afternoon close return. The same procedures are repeated for the bull market period (August 12, 1987 to December 28, 1989) and the bear market period (January 4, 1990 to April 26, 1991).

Trading time	Average return (%)	Standard deviation	Standard error of av. return	Skewness	Kurtosis	Variance ratio
<i>A. Whole period</i>						
Morning open	0.0181	0.2046	—	3.5229	58.7165	3.2694
9:01–9:30	0.0028	0.0382	0.0001	0.1718	5.1447	0.2022
9:31–10:00	−0.0025	0.0215	0.0001	0.0605	4.8733	0.0362
10:01–10:30	−0.0011	0.0205	0.0001	0.2398	4.5730	0.0330
10:31–M.C.	−0.0004	0.0215	0.0005	0.5897	4.7131	0.0374
Morning close	−0.0104	0.0378	—	0.5508	3.5607	0.1115
Afternoon open	−0.0063	0.0557	—	0.4656	2.0358	0.2419
1:01–1:30	−0.0004	0.0222	0.0003	0.3595	4.7922	0.0426
1:31–2:00	−0.0005	0.0198	0.0001	0.7467	5.1219	0.0307
2:01–2:30	−0.0001	0.0212	0.0001	0.6403	6.0519	0.0353
2:31–A.C.	0.0026	0.0255	0.0008	0.4176	3.2055	0.0515
Afternoon close	0.0035	0.0239	—	0.4553	2.4395	0.0446
<i>B. Bull market period</i>						
Morning open	0.0296	0.2424	—	3.2448	46.0255	10.7234
9:01–9:30	0.0045	0.0338	0.0014	0.0324	3.3842	0.1073
9:31–10:00	−0.0019	0.0181	0.0002	0.1260	1.3778	0.0008
10:01–10:30	−0.0011	0.0174	0.0001	0.1511	1.2121	0.0005
10:31–M.C.	−0.0002	0.0187	0.0005	0.2712	1.6847	0.0032
Morning close	−0.0114	0.0362	—	0.5412	3.3718	0.2386
Afternoon open	0.0014	0.0479	—	0.8939	3.5643	0.4185
1:01–1:30	0.0006	0.0183	0.0002	0.2227	1.7239	0.0076
1:31–2:00	−0.0009	0.0165	0.0001	0.2233	1.5252	0.0006
2:01–2:30	−0.0003	0.0178	0.0001	0.4064	1.9683	0.0007
2:31–A.C.	0.0024	0.0215	0.0009	0.2605	1.2094	0.0026
Afternoon close	0.0034	0.0240	—	0.2549	1.7922	0.1048
<i>C. Bear market period</i>						
Morning open	−0.0017	0.1105	—	−0.0624	−0.0990	0.4834
9:01–9:30	−0.0000	0.0427	0.0005	0.1964	2.2840	0.0920
9:31–10:00	−0.0036	0.0263	0.0003	0.0556	4.7911	0.0275
10:01–10:30	−0.0012	0.0250	0.0003	0.2705	4.4681	0.0248
10:31–M.C.	−0.0007	0.0256	0.0005	0.7632	5.0613	0.0268
Morning close	−0.0088	0.0405	—	0.5368	3.6620	0.0649
Afternoon open	−0.0197	0.0649	—	0.4716	0.8635	0.1671
1:01–1:30	−0.0021	0.0274	0.0007	0.4639	4.1753	0.0326
1:31–2:00	0.0003	0.0245	0.0002	0.8926	4.5990	0.0239
2:01–2:30	0.0003	0.0261	0.0002	0.6623	5.6615	0.0272
2:31–A.C.	0.0029	0.0310	0.0008	0.4322	2.7387	0.0388
Afternoon close	0.0037	0.0239	—	0.8106	3.6361	0.0225

one-fifth or one-third of the minute-by-minute returns over the preceding three minutes. As illustrated in fig. 1, the return over the closing minute declines. Similar patterns of closing price behavior are observed during the two subperiods, the bull market period and the bear market period.

The second return anomaly is observed at the market close in the morning. The return over the last closing minute, 11:01 a.m. to 11:02 a.m., is -0.0104% . This negative return is the smallest throughout the whole trading day. The existence of a large decline in TOPIX at the end of the morning trading session as well as at the end of the afternoon trading session is puzzling. This is not a phenomenon unique to a particular subperiod. In fact, this phenomenon appears to be common in the two subperiods. As a result, with unusual irregularities detected for the returns at the morning close and at the afternoon close, the intraday returns cannot be characterized by a single, smooth U-shaped curve throughout the trading day, as was found by Wood et al. (1985).

The bear market period shows a different price movement at the beginning of the morning trading session. Initially, the return over the overnight non-trading period is negative, unlike the whole period and the bull market period. It is followed by positive returns for the next seven minutes, and then the price behavior becomes more or less the same as the price behavior in the whole period and the bull market period.

2.2. Behavior of intraday return variance

As shown in fig. 2, the standard deviations of the intraday returns follow a pattern similar to that of average returns, with large volatility at the beginning of the morning trading session and at the close of the afternoon trading session. The standard deviations show two distinct U-shaped curves: one in the morning and another in the afternoon. The standard deviation of 0.2046 observed at the market open is the highest, and its magnitude is about 10 times the lowest 30-minute average during the day. However, the standard deviation of the overnight return is not as high as it appears once it is prorated using 1,077 minutes during the overnight non-trading period. In fact, the magnitude of standard deviation per minute is only 0.0002 during the overnight period.

Without including the overnight return, the standard deviation at the beginning of the morning trading is large in comparison with the rest of the trading day. The average standard deviation of the first five intraday returns (not including r_{901}) is 0.0578, which compares with the lowest level of standard deviation of 0.0205 observed between 10:01 a.m. and 10:30 a.m. in the morning. After the initial high volatility observed at the beginning of the two trading sessions, the standard deviations gradually decline to a stable pattern in the middle of the trading sessions. Prior to market close in the

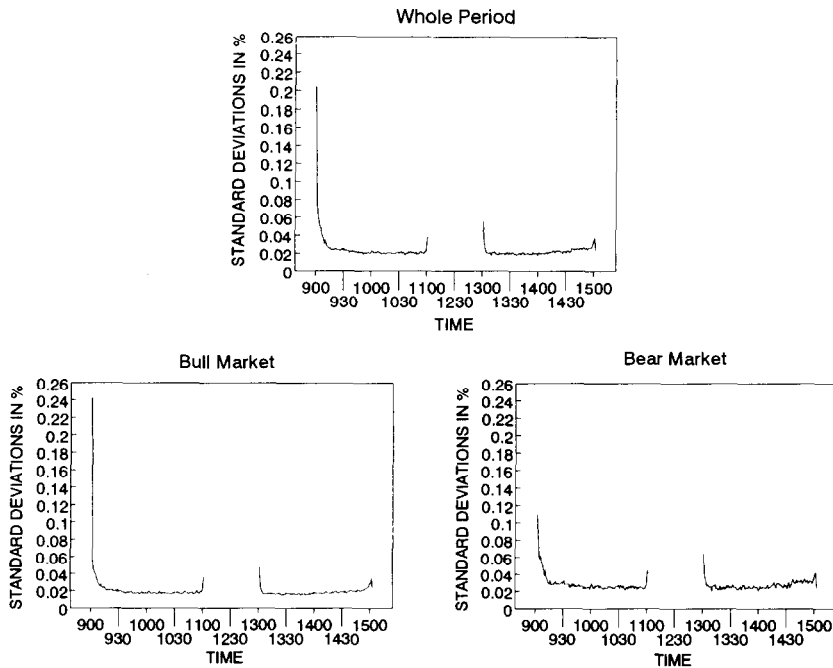


Fig. 2. Standard deviations of intraday returns.

morning, the standard deviations rise to another peak, to complete a U-curve. Similar patterns are observed in the afternoon trading session, with two differences from the morning session: first, the volatility computed at the market open in the afternoon trading session is not as large as that in the morning session, but it is the second largest of the day; and, second, the volatility at the market close in the afternoon is about the same as that observed at the market close in the morning.

The TSE results are almost identical to those reported by Wood, et al. (1985) and Lockwood and Scott (1990). They are also consistent with the rational trading noise hypothesis proposed by Kyle (1985) and Admati and Pfleiderer (1988). In the simplified world of Kyle, informed traders' private information is reflected in securities prices, and the prices converge to unbiased estimates of the underlying value of the securities as trading progresses. Thus, a quick decline of stock return volatility should be observed in the early part of the two trading sessions. Kyle's hypothesis was examined by the past studies, using interday 24-hour returns mainly because of his assumption that trading takes place over one trading day. [See Stoll and Whaley (1990) Barclay et al. (1990), Gerety and Mulherin (1991),

among others.] However, a test of Kyle's hypothesis does not have to be limited to interday returns. As long as it is allowed that each auction takes place on a minute-by-minute basis, a sequence of variances measuring the volatility of intraday price fluctuations from auction to auction is perfectly acceptable for the examination of the rational trading noise hypothesis. Additionally, high volatility observed at the market open and at the market close is consistent with the clustering of discretionary liquid traders and informed traders, as perceived by Admati and Pfleiderer (1988) and empirically observed by Barclay et al. (1990). This indicates that the liquidity demand of discretionary liquid traders is realized either after the market closes or late in the trading day.

Skewness and kurtosis measures are extremely high at the market open in the morning, indicating instability and non-normality of the overnight non-trading period returns. Positive third moments about the mean reported in table 2 suggest that the distribution of intraday returns is skewed to the right during the study period. The coefficients of kurtosis are mostly positive during the whole period as well as during the two subperiods, indicating that density functions are more peaked near their center. One interesting contrast is the difference in the magnitude of skewness and kurtosis measures between the bull and the bear market periods. The reason is not immediately clear, but the returns from the overnight non-trading period during the bear market period have small and negative skewness and kurtosis measures.

2.3. Volatility in trading and non-trading periods

To examine stock return volatility over trading and non-trading periods, intraday returns are computed over four time intervals in each trading day: (i) afternoon close to morning open; (ii) morning open to morning close; (iii) morning close to afternoon open; and (iv) afternoon open to afternoon close. In addition, we also computed returns from morning open to afternoon close and daily returns from afternoon close to afternoon close to facilitate the comparison among different return series.

It is not surprising to note from table 3 that the return variance per hour is about 140 times greater during the morning trading period and about 60 times greater during the afternoon trading period than it is during the overnight non-trading period. The volatility during the lunch break is even smaller. The average return variance of the morning (afternoon) trading session is about 200 times (90 times) larger than the lunch time volatility. The results are consistent with the hypothesis that private information is disclosed during trading hours. This private information hypothesis has been tested by French and Roll (1986) and Barclay et al. (1990). French and Roll report that return variances are reduced by both the election day closing and the exchange holidays, whereas Barclay et al. support the same hypothesis

Table 3

Volatility in trading and non-trading periods. Return variances are computed for four time intervals in each trading day: (i) afternoon close to morning open; (ii) morning open to morning close; (iii) morning close to afternoon open; and (iv) afternoon open to afternoon close. In addition, we also computed variances of returns from morning open to afternoon close and daily returns from afternoon close to afternoon close to facilitate the comparison among different return series.

Trading time	Variance	Variance ratio
<i>A. Whole period</i>		
1. Afternoon close to morning open	0.0419	0.0327
2. Morning open to afternoon close	1.1544	0.9013
3. Morning open to morning close	0.6338	0.4948
4. Morning close to afternoon open	0.0031	0.0024
5. Afternoon open to afternoon close	0.2920	0.2280
6. Afternoon close to afternoon close	1.2808	1.0000
7. (1) + (2) - (6)	-0.0845	-0.0660
8. (3) + (4) + (5) - (2)	-0.2255	-0.1761
9. (1) + (3) + (4) + (5) - (6)	-0.3100	-0.2421
<i>B. Bull market period</i>		
1. Afternoon close to morning open	0.0588	0.1072
2. Morning open to afternoon close	0.4426	0.8076
3. Morning open to morning close	0.2315	0.4225
4. Morning close to afternoon open	0.0023	0.0042
5. Afternoon open to afternoon close	0.1244	0.2269
6. Afternoon close to afternoon close	0.5480	1.0000
7. (1) + (2) - (6)	-0.0466	-0.0852
8. (3) + (4) + (5) - (2)	-0.0844	-0.1540
9. (1) + (3) + (4) + (5) - (6)	-0.1310	-0.2392
<i>C. Bear market period</i>		
1. Afternoon close to morning open	0.0122	0.0048
2. Morning open to afternoon close	2.3685	0.9384
3. Morning open to morning close	1.3131	0.5203
4. Morning close to afternoon open	0.0042	0.0017
5. Afternoon open to afternoon close	0.5828	0.2309
6. Afternoon close to afternoon close	2.5238	1.0000
7. (1) + (2) - (6)	-0.1431	-0.0568
8. (3) + (4) + (5) - (2)	-0.4684	-0.1855
9. (1) + (3) + (4) + (5) - (6)	-0.6115	-0.2423

using an opposite case in which return variances are increased by Saturday trading at the TSE.⁴ Additionally, note that the return volatility in the morning trading session is more than two times greater than the volatility measured during the afternoon trading session. This confirms that private

⁴Barclay et al. (1990) report that the weekend variance of TSE stock returns is 112% higher for weekends with Saturday trading than for weekends without Saturday trading in support of the rational trading noise hypothesis proposed by Kyle (1985) and Admati and Pfleiderer (1988).

information is not produced at a constant rate even during the trading period. It also implies fewer price reversals as trade proceeds.

Line 7 of Panel A presents the difference between the sum of return variances during two time intervals (overnight non-trading period and daytime period from morning open to afternoon close) and the daily return variance measured over the period from afternoon close to afternoon close. Line 8 presents the difference between the sum of return variances measured over three time intervals, including morning trading session, lunch break, and afternoon trading session, and the variance measured during the daytime. Line 9 presents the difference in return variances between the sum of four separate intervals, including overnight period, morning session, lunch break, and afternoon session, and the 24-hour period from afternoon close to afternoon close. One would expect positive differences for the three cases considering a large amount of noise which dissipates through the trading day. Amihud and Mendelson (1991) report that the sum of variances of the four separate time intervals, including overnight, morning session, lunch break, and afternoon session, exceeds the close-to-close return variance by 21.7%.

However, negative differences are reported for Lines 7, 8, and 9. Note that the sum of variances of the four partitioned periods of a trading day is 24% smaller than the variance of return measured from afternoon close to afternoon close. The same results also hold for the two subperiods. These seemingly inconsistent results are attributed to the difference between the price data used by Amihud and Mendelson (1991) and by this study. Amihud and Mendelson have used stock prices of individual firms, whereas our price data is for TOPIX, a large market portfolio.

At the individual firm level, correlations between the adjacent return series – for example, the returns during the overnight non-trading period and the returns during the daytime period – tend to be negative, implying price reversals. Due to negative correlations observed at the individual firm level, the sum of variances of the separate time intervals is smaller than the return variance over the entire period encompassing the partitioned time intervals. However, the correlations between the adjacent return series at the portfolio level will not necessarily be negative because of the influence of positive cross-covariances across securities. Lo and MacKinlay (1990) point out a similar empirical finding when autocorrelations are measured at the individual firm level and at the portfolio level. They report weakly *negative* average autocorrelation coefficients for returns on individual securities, whereas autocorrelations are strongly *positive* for index returns. They further report that over half of the expected profits from contrarian investment strategies are due to the effects of positive cross-autocovariances across the component securities in the index rather than negative autocorrelations in individual securities returns.

Table 4

Correlations between the returns in each of the four intervals (overnight, morning session, lunch break, and afternoon session) and the returns in the immediately preceding four intervals. Four series of returns, r_k , are defined, where subscript k denotes the four time intervals: $k=1$ for afternoon close to morning open, $k=2$ for morning open to morning close, $k=3$ for morning close to afternoon open, and $k=4$ for afternoon open to afternoon close. $\rho(r_k, r_{-n})$ signifies the correlation between the return k and the return in the preceding n th interval such that: $\rho(r_2, r_{-1})$ signifies the correlation between the morning session return and the preceding overnight return; $\rho(r_2, r_{-2})$ the correlation between the morning session return and the afternoon session return of the previous day; $\rho(r_2, r_{-3})$ the correlation between the morning session return and the return over lunch break of the previous day; and $\rho(r_2, r_{-4})$ the autocorrelation with a one-day lag. Statistical significance is noted by: ** at the 0.01 level, * at the 0.05 level, and + at the 0.10 level.

	r_{-1}	r_{-2}	r_{-3}	r_{-4}
<i>A. Whole period</i>				
r_1	0.1340**	0.0469	0.1028**	0.0613 +
r_2	0.2471**	0.3326**	0.0854*	0.1817**
r_3	0.0651 +	0.0262	-0.0022	0.1499**
r_4	0.2549**	0.2133**	0.0235	-0.0038
<i>B. Bull market period</i>				
r_1	0.1321**	0.0193	0.1048*	0.0583
r_2	0.1045**	0.2317**	-0.0536	0.1326**
r_3	-0.0581	-0.0037	-0.0594	0.1084*
r_4	0.2935**	0.1348**	-0.0059	-0.1204**
<i>C. Bear market period</i>				
r_1	0.2384**	0.0925	0.1681**	0.0436
r_2	0.5290**	0.4012**	0.0542	0.1854**
r_3	0.1057 +	0.0678	0.0327	0.1264*
r_4	0.2559**	0.2411**	0.0984	0.0437

As a check, we replicated Amihud and Mendelson's (1991) test of correlations between the returns in each of the four intervals (overnight, morning session, lunch break, and afternoon session) and the returns in the immediately preceding four intervals. For the ease of comparison, the notations used by Amihud and Mendelson are used. Thus, four series of returns, r_k , are defined, where subscript k denotes the four time intervals: $k=1$ for afternoon close to morning open, $k=2$ for morning open to morning close, $k=3$ for morning close to afternoon open, and $k=4$ for afternoon open to afternoon close.⁵ Table 4 summarizes the results. $\rho(r_k, r_{-n})$ signifies the correlation between the return k and the return in the

⁵Note that r_1 and r_3 are the same as r_{901} and r_{101} previously introduced.

preceding n th interval such that: $\rho(r_2, r_{-1})$ signifies the correlation between the morning session return and the preceding overnight return; $\rho(r_2, r_{-2})$ the correlation between the morning session return and the afternoon session return of the previous day; $\rho(r_2, r_{-3})$ the correlation between the morning session return and the return over lunch break; and $\rho(r_2, r_{-4})$ the autocorrelation with a one-day lag. It is not surprising to observe that the majority of correlations reported in table 4 are positive.⁶ Interestingly, the reported correlations for $\rho(r_k, r_{-1})$, where $k = 1, 2, 3$, and 4 , are all positive and significant, whereas the same set of correlations are negative in Amihud and Mendelson (1991).⁷ If the opening prices are reversed by the prices set during the morning trading session, then $\rho(r_2, r_{-1})$ would be negative at the individual firm level. Amihud and Mendelson report that this correlation is -0.194 , which is more negative than any other correlations, $\rho(r_k, r_{-1})$, for $k = 1, 3$, and 4 . At the index return level, both $\rho(r_2, r_{-1})$ and $\rho(r_4, r_{-1})$ are 0.2471 and 0.2549 , both significant at the 0.01 level.⁸ The two correlations are more positive than $\rho(r_k, r_{-1})$, for $k = 1$ and 3 . Recall that $\rho(r_2, r_{-1})$ is supposed to measure price reversals between the morning trading session and the overnight non-trading period, while $\rho(r_4, r_{-1})$ indicates price reversals between the afternoon trading session and the lunch break non-trading period. Apparently, these significantly positive correlations indicate some interesting phenomena at work at the portfolio level. These phenomena are further examined in the following section using correlations between adjacent minute-by-minute return series and autocorrelations of the intraday returns.

3. Price reversals

3.1. Correlations between adjacent minute-by-minute return series

The U-shaped standard deviation curve observed for the minute-by-minute returns is a clear indication of the uncertainty traders face at the beginning

⁶When correlations were estimated, it was required that only adjacent return series be used for the computation. Thus, those trading days that were not consecutive had to be dropped to estimate correlations. As a result, we used 774 observations for the whole period, 492 observations for the bull market period, and 282 observations for the bear market period.

⁷Assume that we have a two-asset market portfolio of asset a and asset b . r_{1a} and r_{1b} denote an individual asset's overnight return, and w_a and w_b are the weight assigned to two assets, while r_{-1a} and r_{-1b} denote the returns over the afternoon session of the previous day for asset a and asset b , respectively. Since $r_{1p} = w_a r_{1a} + w_b r_{1b}$ and $r_{-1p} = w_a r_{-1a} + w_b r_{-1b}$, we can define $\text{Cov}(r_{1p}, r_{-1p}) = w_a^2 \text{Cov}(r_{1a}, r_{-1a}) + w_b^2 \text{Cov}(r_{1b}, r_{-1b}) + w_a w_b \text{Cov}(r_{1a}, r_{-1b}) + w_a w_b \text{Cov}(r_{1b}, r_{-1a})$. The first two terms on the right-hand side are in general expected to be negative because they represent covariances between the individual securities' returns in two adjacent time intervals, while the last two terms represent the cross-covariances across two assets and across two time intervals that tend to be positive.

⁸Even at the individual firm level, Stoll and Whaley (1990) report a positive correlation between the daytime returns and the following overnight returns. They also find positive first-order autocorrelations for large-size firms, which imply negative bid-ask spreads, if Roll's (1984) estimate of spreads, $2(-\text{Cov})^{1/2}$, is used.

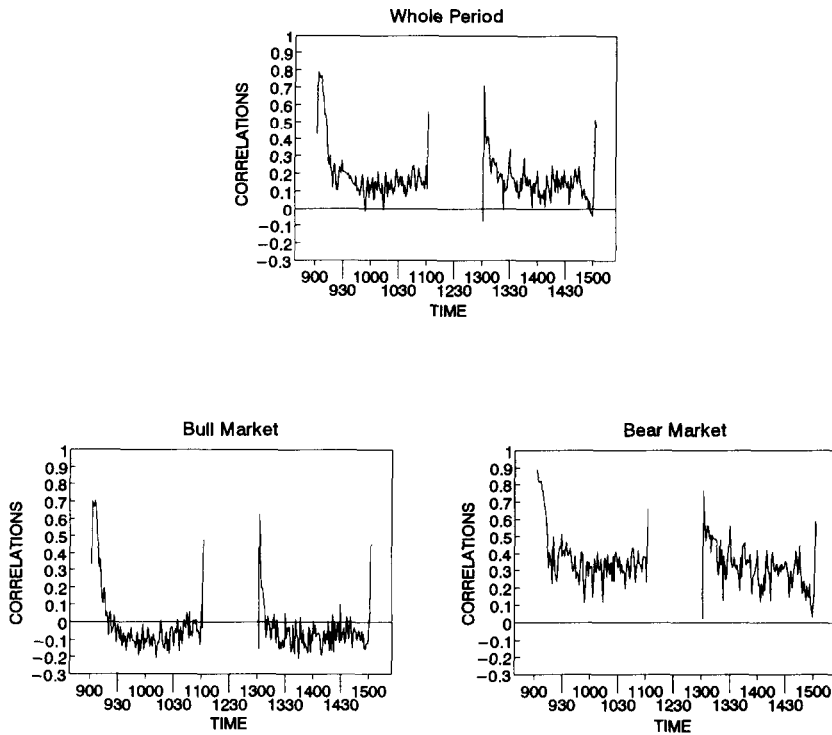


Fig. 3. Average correlations of intraday returns in adjacent periods.

and at the end of a trading session. The observed volatility on both ends of the trading session suggests that both pricing errors and trading noise, rational as well as irrational, change over time. This change will be reflected in price reversals over the trading session. Empirically, price reversals can be examined using either correlations between adjacent return series or autocorrelations. Stoll and Whaley (1990) observe from the NYSE common stocks that the correlation between the overnight and following daytime returns is negative, and smaller than the correlation between the daytime and following overnight returns. As was discussed in the previous section, Amihud and Mendelson (1991) find that the correlation between the overnight and following daytime returns is negative. The negative correlation suggests that the prices set during the morning trading session reverse the returns set at the opening transactions.

Fig. 3 presents a graphic illustration of the estimated correlations. The first correlation of the day was computed using two return series, r_{901} and r_{902} , and the last correlation was estimated using two return series, r_{302} and r_{303} .

The estimated correlations reach the highest level of the day during the first 10 minutes of the morning session, decline to the lowest level in the middle of the session, and then start climbing to another peak toward the end of the morning session. A similar pattern shows up in the afternoon session: high correlations at the beginning of the session, gradual decline during the session, and a jump at the end of the session. Thus, there are four peaks on a trading day. The two curves for the bull market period and the bear market period show an interesting contrast. The overall magnitude of correlations is much smaller during the bull market period than it is for the bear market period. In the previous section, it was noted that market volatility was substantially higher during the bear market period than during the bull market period. At the index return level, low correlations between the adjacent return series imply a greater degree of price reversals, whereas high correlations imply the opposite. Thus, it can be inferred that price reversals tend to be smaller in magnitude as well as in frequency during the bear market period than they are during the bull market period.

The first correlations in the morning and in the afternoon are very low and that they are followed by high correlations at the next minute. This is not unexpected because of the way the TOPIX is computed at the beginning of a trading period. As was noted earlier, it takes about five minutes for all stocks to have opening prices. For the computation of TOPIX, the TSE uses closing prices of the previous day for those stocks whose opening prices will not be determined until after the first few minutes of the morning session.⁹ For those stocks whose afternoon opening prices will not be determined until after the first few minutes of the afternoon session, the TSE also uses the morning closing prices. As a result, many of the listed stocks will have zero returns, and this will understate the correlations. The negative correlation estimated at the beginning of the afternoon session clearly reflects this bias resulting from the way TOPIX is computed.¹⁰

Table 5 presents related summary statistics of the estimated correlations between the adjacent minute-by-minute return series. Average correlations over every 30-minute interval are presented along with average standard deviations and standard errors of the correlations. Also, the minimum, maximum, and median correlations are presented in the last three columns. During the first 30 minutes into the morning and the afternoon trading sessions, the average correlations are the largest of the day at 0.3816 and

⁹There is an exception to this rule. When a stock experiences a major order imbalance, the TSE requires the *Saitori* to indicate a 'special bid quote' or 'special asked quote.' This special quote is publicly disseminated through the market information system of the TSE. When there is a special quote for a stock, then such a quote will be used to compute the TOPIX.

¹⁰To further confirm our conjecture, we estimated correlations between the opening return in the morning, r_{901} , and the previous day's closing return, r_{303} , for the three periods. As expected, the correlations were -0.0130 , -0.0049 , and -0.0465 for the whole period, the bull market period, and the bear market period, respectively.

Table 5

Summary statistics of estimated correlations between the adjacent minute-by-minute return series. Average correlations over every 30-minute interval are presented along with average standard deviations and standard errors of the average correlations. Also the minimum, maximum, and median correlations are presented in the last three columns. The first correlation of the day is computed using two return series, r_{901} and r_{902} , and the last correlation was estimated using two return series, r_{302} and r_{303} . M.C. and A.C. denote morning close and afternoon close, respectively.

Trading time	Average correlation	Average standard deviation	Standard error of average correlation	Minimum	Maximum	Median
<i>A. Whole period</i>						
9:02-9:30	0.3816	0.2327	0.0432	0.1034	0.7892	0.2749
9:31-10:00	0.1393	0.0556	0.0102	-0.0147	0.2114	0.1404
10:01-10:30	0.1262	0.0546	0.0100	-0.0084	0.2262	0.1170
10:31-M.C.	0.1676	0.0865	0.0153	0.0683	0.5620	0.1476
1:01-1:30	0.2467	0.1535	0.0280	-0.0753	0.7122	0.2260
1:31-2:00	0.1475	0.0560	0.0102	0.0087	0.2887	0.1537
2:01-2:30	0.1259	0.0595	0.0109	0.0073	0.2463	0.1207
2:31-A.C.	0.1261	0.1185	0.0206	-0.0487	0.5154	0.1141
<i>B. Bull market period</i>						
9:02-9:30	0.2111	0.2676	0.0497	-0.1149	0.7043	0.1057
9:31-10:00	-0.0973	0.0444	0.0081	-0.1940	-0.0106	-0.0984
10:01-10:30	-0.0978	0.0525	0.0096	-0.2109	0.0124	-0.1015
10:31-M.C.	-0.0191	0.1078	0.0191	-0.1688	0.4803	-0.0409
1:01-1:30	0.0134	0.1780	0.0328	-0.1529	0.6295	-0.0272
1:31-2:00	-0.0926	0.0660	0.0121	-0.2114	0.0296	-0.0985
2:01-2:30	-0.0729	0.0696	0.0127	-0.1937	0.1030	-0.0674
2:31-A.C.	-0.0357	0.1352	0.0235	-0.1535	0.4534	-0.0610
<i>C. Bear market period</i>						
9:02-9:30	0.5321	0.2131	0.0396	0.2192	0.8914	0.4568
9:31-10:00	0.3345	0.0842	0.0154	0.1133	0.4682	0.3552
10:01-10:30	0.2125	0.0743	0.0136	0.1171	0.4162	0.3145
10:31-M.C.	0.3390	0.0849	0.0150	0.1922	0.6643	0.3359
1:01-1:30	0.4243	0.1488	0.0272	0.0229	0.7692	0.4726
1:31-2:00	0.3340	0.0745	0.0136	0.1647	0.4643	0.3311
2:01-2:30	0.2848	0.0764	0.0140	0.1159	0.4227	0.2953
2:31-A.C.	0.2507	0.1249	0.0217	0.0295	0.5911	0.2365

0.2467, respectively. The smallest correlations are observed in the middle of both trading sessions. The average correlations in the last half hour in the morning and afternoon sessions are much smaller than those observed in the beginning of the trading sessions. Compare the magnitude of average correlations estimated for the bull market and bear market periods during the first 30 minutes after the morning and afternoon open. The average correlations in the bear market period are 0.5321 and 0.4243, and in the bull

market period 0.2111 and 0.0134. With the exception of the first 30 minutes into trading, average correlations are negative during the bull market period, while all averages are positive during the bear market period. These results are in support of empirical evidence that price reversals are more frequent and much larger during the bull market period than during the bear market period. They further imply that irrational trading noise caused by the traders' overreaction tends to be larger during the bear market period than during the bull market period. Nevertheless, the overall shape of the correlation curves in the two subperiods are essentially the same.

3.2. Autocorrelations

As another means of investigating price reversals, we computed autocorrelation coefficients on each of the 818 trading days in the sample. Autocorrelations for lag between one and 12 minutes are estimated using the minute-by-minute returns in the first hour of trading in the morning. Averages of autocorrelations across the 818 days are reported in table 6, with standard errors of the autocorrelations shown in parentheses. The same procedures were repeated for the next one-hour periods: 9:31 a.m. to 10:30 a.m., 10:01 a.m. to morning close, 1:01 p.m. to 2:00 p.m., 1:31 p.m. to 2:30 p.m., and 2:01 p.m. to afternoon close. The autocorrelations analyzed in this study are different from those of French and Roll (1986), Stoll and Whaley (1990), and Amihud and Mendelson (1991). Their autocorrelations are computed using interday 24-hour returns – such as open-to-open returns and close-to-close returns with lags of one-day or multiple days – while the reported autocorrelations reported in table 6 were computed using the returns over one-minute intervals with lags between one to 12 minutes. Hence, our results should be more comparable to Wood et al. (1985) who also used intraday data.

The first-order autocorrelations are all significant with the exception of the one-hour period between 10:01 a.m. and 11:02 a.m. during the whole period. In the first hour of the morning trading session, a consistent decaying trend is noted for the estimated autocorrelations. Price reversals introduce this decaying trend over time as negative correlations between component stocks reduce the influence of positive cross-autocovariances within the index returns. Eventually, negative first-order autocorrelations show up in the subsequent one-hour periods in the morning. Similar trends are observed in the afternoon trading session.

The first-order autocorrelations tend to be high at the beginning and the end of a trading session, but low in the middle of the session. Similar patterns are observed for autocorrelations with lags of multiple minutes. The same pattern is also found for the bull market period as well as the bear market period. However, two different pictures emerge from the summary

Table 6

Average of autocorrelation coefficients. Autocorrelation coefficients are computed on each of the 818 trading days in the sample. Autocorrelations for lag between one and 12 minutes are estimated using the minute-by-minute returns in the first hour of trading in the morning. Averages of autocorrelations across the 818 days are reported in table 6, with standard errors of the autocorrelations shown in parentheses. The same procedures are repeated for the next one-hour periods: 9:31 a.m. to 10:30 a.m., 10:01 a.m. to morning close (M.C.), 1:01 p.m. to 2:00 p.m., 1:31 p.m. to 2:30 p.m., and 2:01 p.m. to afternoon close (A.C.). Likewise, autocorrelations are estimated for the bull market period and the bear market period.

Trading time	Lags in minutes											
	1	2	3	4	5	6	7	8	9	10	11	12
<i>A. Whole period</i>												
9:01-10:00	0.2223 (0.0095)	0.1950 (0.0076)	0.1738 (0.0066)	0.1538 (0.0061)	0.1308 (0.0056)	0.1113 (0.0049)	0.0861 (0.0049)	0.0752 (0.0044)	0.0639 (0.0042)	0.0556 (0.0040)	0.0446 (0.0038)	0.0244 (0.0037)
9:31-10:30	-0.0447 (0.0078)	0.0150 (0.0057)	0.0235 (0.0052)	0.0228 (0.0049)	0.0215 (0.0047)	0.0224 (0.0046)	0.0041 (0.0048)	0.0081 (0.0044)	0.0046 (0.0043)	-0.0038 (0.0042)	0.0084 (0.0042)	-0.0122 (0.0042)
10:01-M.C.	-0.0096 (0.0074)	0.0107 (0.0056)	0.0219 (0.0050)	0.0238 (0.0046)	0.0255 (0.0045)	0.0260 (0.0044)	0.0119 (0.0043)	0.0043 (0.0042)	0.0017 (0.0042)	-0.0007 (0.0040)	0.0041 (0.0041)	-0.0010 (0.0038)
1:01-2:00	0.0438 (0.0082)	0.0493 (0.0057)	0.0354 (0.0052)	0.0287 (0.0049)	0.0190 (0.0047)	0.0165 (0.0045)	0.0064 (0.0046)	0.0063 (0.0042)	0.0035 (0.0041)	0.0030 (0.0041)	0.0040 (0.0038)	-0.0112 (0.0038)
1:31-2:30	-0.0298 (0.0078)	0.0094 (0.0056)	0.0101 (0.0053)	0.0147 (0.0049)	0.0057 (0.0047)	0.0059 (0.0046)	0.0006 (0.0045)	-0.0043 (0.0041)	-0.0041 (0.0042)	-0.0059 (0.0043)	0.0016 (0.0041)	-0.0163 (0.0040)
2:01-A.C.	0.0192 (0.0071)	0.0202 (0.0053)	0.0171 (0.0047)	0.0128 (0.0045)	0.0042 (0.0043)	0.0072 (0.0044)	0.0010 (0.0042)	-0.0075 (0.0042)	-0.0038 (0.0040)	-0.0051 (0.0039)	-0.0050 (0.0040)	-0.0055 (0.0039)

B. Bull market period

9:01-10:00	0.1238 (0.0108)	0.1420 (0.0088)	0.1356 (0.0077)	0.1261 (0.0072)	0.1010 (0.0065)	0.0898 (0.0058)	0.0665 (0.0058)	0.0601 (0.0054)	0.0519 (0.0050)	0.0441 (0.0048)	0.0405 (0.0047)	0.0240 (0.0046)
9:31-10:30	-0.1535 (0.0066)	-0.0315 (0.0059)	-0.0071 (0.0058)	0.0003 (0.0056)	0.0056 (0.0054)	0.0152 (0.0054)	-0.0042 (0.0057)	0.0032 (0.0054)	0.0014 (0.0052)	-0.0130 (0.0050)	0.0118 (0.0053)	-0.0088 (0.0051)
10:01-M.C.	-0.1056 (0.0069)	-0.0326 (0.0061)	-0.0061 (0.0057)	0.0090 (0.0054)	0.0116 (0.0052)	0.0226 (0.0053)	0.0076 (0.0053)	-0.0012 (0.0051)	0.0002 (0.0051)	-0.0041 (0.0047)	0.0042 (0.0050)	-0.0023 (0.0048)
1:01-2:00	-0.0604 (0.0077)	0.0026 (0.0060)	0.0077 (0.0059)	0.0105 (0.0055)	0.0082 (0.0056)	0.0100 (0.0053)	-0.0026 (0.0053)	-0.0019 (0.0048)	0.0011 (0.0049)	-0.0013 (0.0049)	0.0036 (0.0048)	-0.0116 (0.0048)
1:31-2:30	-0.1323 (0.0067)	-0.0330 (0.0059)	-0.0173 (0.0061)	0.0013 (0.0054)	-0.0080 (0.0053)	0.0007 (0.0054)	-0.0040 (0.0055)	-0.0136 (0.0049)	-0.0013 (0.0052)	-0.0111 (0.0053)	0.0081 (0.0054)	-0.0125 (0.0051)
2:01-A.C.	-0.0571 (0.0075)	-0.0091 (0.0061)	0.0016 (0.0056)	0.0046 (0.0052)	-0.0095 (0.0051)	0.0069 (0.0053)	-0.0015 (0.0051)	-0.0099 (0.0050)	-0.0025 (0.0050)	-0.0021 (0.0047)	0.0007 (0.0047)	-0.0023 (0.0049)

C. Bear market period

9:01-10:00	0.3923 (0.0133)	0.2866 (0.0124)	0.2398 (0.0113)	0.2016 (0.0106)	0.1821 (0.0097)	0.1485 (0.0086)	0.1200 (0.0086)	0.1014 (0.0074)	0.0847 (0.0071)	0.0754 (0.0068)	0.0519 (0.0064)	0.0251 (0.0062)
9:31-10:30	0.1432 (0.0118)	0.0953 (0.0101)	0.0763 (0.0093)	0.0615 (0.0087)	0.0489 (0.0085)	0.0349 (0.0083)	0.0186 (0.0083)	0.0166 (0.0077)	0.0103 (0.0075)	0.0119 (0.0075)	0.0027 (0.0070)	-0.0180 (0.0072)
10:01-M.C.	0.1563 (0.0110)	0.0854 (0.0094)	0.0703 (0.0089)	0.0494 (0.0082)	0.0494 (0.0082)	0.0317 (0.0079)	0.0194 (0.0073)	0.0137 (0.0075)	0.0043 (0.0076)	0.0052 (0.0071)	0.0037 (0.0070)	0.0011 (0.0063)
1:01-2:00	0.2238 (0.0125)	0.1300 (0.0099)	0.0833 (0.0091)	0.0602 (0.0090)	0.0377 (0.0085)	0.0278 (0.0082)	0.0220 (0.0084)	0.0205 (0.0076)	0.0078 (0.0073)	0.0105 (0.0074)	0.0048 (0.0064)	-0.0104 (0.0062)
1:31-2:30	0.1474 (0.0122)	0.0825 (0.0102)	0.0573 (0.0094)	0.0378 (0.0094)	0.0295 (0.0087)	0.0150 (0.0085)	0.0086 (0.0078)	0.0118 (0.0073)	-0.0089 (0.0073)	0.0031 (0.0072)	-0.0095 (0.0063)	-0.0229 (0.0066)
2:01-A.C.	0.1509 (0.0108)	0.0708 (0.0093)	0.0439 (0.0082)	0.0270 (0.0083)	0.0278 (0.0075)	0.0077 (0.0078)	0.0054 (0.0076)	-0.0035 (0.0073)	-0.0061 (0.0066)	-0.0102 (0.0069)	-0.0148 (0.0071)	-0.0110 (0.0065)

statistics for the bull and the bear market periods. The magnitude of autocorrelations is far greater during the bear market period than it is during the bull market period. This suggests that prices are sticky and traders tend to be swept up by the market sentiment when the market index is on the downturn. This phenomenon may be attributed, in part, to a smaller transaction volume during the bear market period than the bull market period. Negative autocorrelations are frequently observed in the bull market period, implying the dominance of price reversals of the component stocks over the cross-autocovariances.

4. The Itayose clearing house transaction method and return volatility

Amihud and Mendelson (1991) discuss two distinct trading methods employed by the TSE: the *Itayose* method and the *Zaraba* method. The former is basically a periodic auction where orders are batched for execution at a single price. This method is used twice a day at the TSE, at the morning open and the afternoon open. Buy and sell orders are submitted prior to the opening of the two trading sessions, and the match price of a stock is the price at which the most number of shares can be executed. All TSE-listed stocks are subject to the Itayose method for the opening prices. The Zaraba method is a continuous auction applicable to the subsequent transactions as bids and offers are submitted continuously over time, and transactions occur when the orders cross.¹¹ Madhavan (1992) suggests that the periodic auction alleviates the problem of information asymmetry that causes failure in price continuity especially for thinly traded stocks. Although the loss of price continuity might be the reason for the greater return volatility in the market opening transactions, Amihud and Mendelson (1991) conclude that it is caused by the preceding long period of non-trading rather than the Itayose method. Their conclusion is drawn from the comparison of variability of interday 24-hour returns, such as morning open to morning open and afternoon open to afternoon open. They note that the return volatility at the afternoon open is not different from the volatility observed at the afternoon close, even though the same Itayose method is employed for the market opening transaction in the afternoon.

This section is intended to corroborate Amihud and Mendelson's (1991) findings using interday 24-hour index returns measured at one-minute intervals. We are also interested in comparing the bull and bear market periods for the behavior of the volatility of interday 24-hour returns. This is

¹¹For a detailed discussion of trading methods at different stock exchanges, refer to Huang and Stoll (1991) and Domowitz (1992).

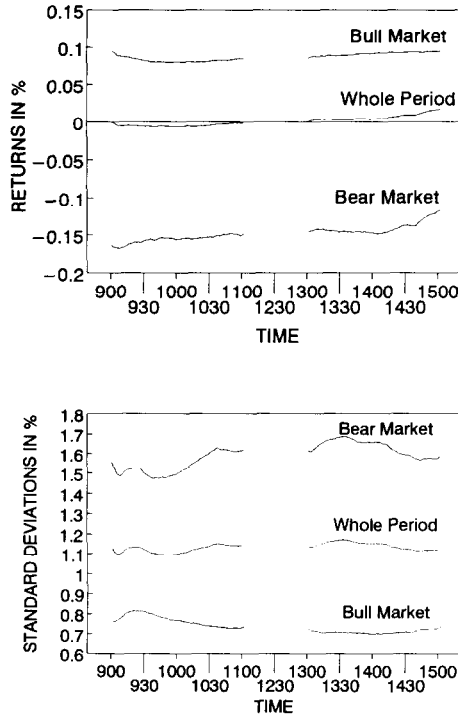


Fig. 4. Means and standard deviations of interday returns.

warranted because the bull market period and the bear market period appear to have a different degree and frequency of price reversals.

Interday 24-hour returns, $R_{i,t}$, are computed at every minute after trading begins at the TSE using the following definition:

$$R_{i,t} = \log(I_{i,t}/I_{i,t-1}) \times 100, \quad (2)$$

where $I_{i,t}$ and $I_{i,t-1}$ denote TOPIX values observed at minute i on trading days t and $t-1$, respectively. For example, $R_{901,t}$ represents the morning open-to-morning open returns, while $R_{902,t}$ denotes a 24-hour return between 9:02 a.m. on day $t-1$ and 9:02 a.m. on day t . A total of 245 interday 24-hour return series were computed, 122 series in the morning and 123 series in the afternoon. Fig. 4 presents a graphic illustration of interday returns averaged across the 818 trading days and the standard deviations plotted against trading minutes. Fig. 4 reveals that both interday returns and standard deviations fluctuate within a very narrow range throughout the trading day. During the whole study period, the range of fluctuation in returns is very narrow, between -0.0068% and 0.0180% . The interday return begins with

−0.0002% at the market open in the morning, followed by a gradual increase, to peak at 0.0180% at the afternoon closing. The morning interday returns are all negative, whereas the afternoon interday returns are all positive. As expected, interday returns during the bull market period are all positive, ranging from 0.0797% to 0.0957%, with no particular pattern shown. During the bear market period, the returns are all negative, ranging from −0.1679% to −0.1162%. The magnitude of the standard deviation is about two times greater during the bear market period than during the bull market period.

Table 7 summarizes variance ratios averaged across every 30-minute trading period. For the first 30 minutes, we computed the interday return series, R_i 's, where $i=901, 902, \dots, 930$. We then estimated variance ratios for each of 30 series using the variance of the return measured from afternoon close to afternoon close as denominator. The variance ratios are averaged across 30 return series, and the standard errors of the ratios are reported. For the purpose of comparison, we also reported variance ratios for interday returns at the morning open, at the morning close, at the afternoon open, and the afternoon close. Additionally, we also computed average variance ratios during the first five minutes after the market open in the morning as well as in the afternoon. Considering the fact that it takes about five minutes for all listed stocks to have opening prices using the Itayose method, one would expect a larger variance ratio during the first five minutes compared to the rest of the trading period if market volatility is indeed affected by the Itayose method.

Table 7 indicates that the variance ratios are relatively stable and close to unity throughout the trading day during the whole period. This implies that: (i) the variance ratio at the market open is not greater than unity; and (ii) the variance ratio at the afternoon open is not different from the ratio observed at the market open. Although the latter observation is consistent with Amihud and Mendelson's findings, the former observation does not support their results. In fact, this result does not support empirical evidence reported by the past studies. Previously reported variance ratios have been: 1.20 by Amihud and Mendelson (1987); 1.13 by Stoll and Whaley (1990); the range from 1.14 to 1.49 compiled by Gerety and Mulherin (1991); and 1.23 by Forster and George (1991). What is particularly noteworthy is that the variance ratio estimated in this study is also smaller than the 1.18 reported by Amihud and Mendelson (1991) using 50 active TSE stocks.

A further examination also suggests that the magnitude of the variance ratios is sensitive to: (a) the day of the week; and (b) the sample period. For example, Gerety and Mulherin (1991) report that the variance ratios are less than one on Mondays during the two subperiods of 1952–63 and 1963–68, and Wednesdays and Fridays during 1970–74, and Fridays during 1985–90. Our results also indicate that the variance is substantially smaller at the

Table 7

Variance ratio of interday returns. Interday 24-hour returns, $R_{i,t}$, are computed at every minute after trading begins at the TSE using the following definition: $R_{i,t} = \log(I_{i,t}/I_{i,t-1}) \times 100$, where $I_{i,t}$ and $I_{i,t-1}$ denote TOPIX values observed at minute i on trading days t and $t-1$, respectively. For example, $R_{901,t}$ represents the morning open-to-morning open returns, while $R_{902,t}$ denotes a 24-hour return between 9:02 a.m. on day $t-1$ and 9:02 a.m. on day t . A total of 245 interday 24-hour return series were computed, 122 series in the morning and 123 series in the afternoon. For the first 30 minutes, we computed interday return series, R_i 's, where $i=901, 902, \dots, 930$. We then estimated the variance ratio for each of the 30 series using the variance of the return measured from afternoon close to afternoon close as denominator. The variance ratios averaged across 30 return series and the standard errors of the average ratios are reported. For the purpose of comparison, we also report variance ratios for interday returns at the morning open, at the morning close (M.C.), at the afternoon open, the afternoon close (A.C.), and the first five-minute period in the morning and the afternoon sessions.

Trading time	Variance ratio	Standard error of ratio
<i>A. Whole period</i>		
Morning open	0.9934	—
First five minutes	0.9679	—
9:01–9:30	0.9810	0.0040
9:31–10:00	0.9446	0.0022
10:01–10:30	0.9757	0.0038
10:31–M.C.	1.0231	0.0011
Morning close	1.0270	—
Afternoon open	1.0140	—
First five minutes	1.0084	—
1:01–1:30	1.0386	0.0037
1:31–2:00	1.0512	0.0025
2:01–2:30	1.0157	0.0039
2:31–A.C.	0.9774	0.0012
Afternoon close	1.0000	—
<i>B. Bull market period</i>		
Morning open	1.0664	—
First five minutes	1.0687	—
9:01–9:30	1.1605	0.0105
9:31–10:00	1.1295	0.0075
10:01–10:30	1.0382	0.0045
10:31–M.C.	0.9835	0.0017
Morning close	0.9919	—
Afternoon open	0.9610	—
First five minutes	0.9454	—
1:01–1:30	0.9255	0.0021
1:31–2:00	0.9103	0.0012
2:01–2:30	0.9083	0.0013
2:31–A.C.	0.9473	0.0035
Afternoon close	1.0000	—

Table 7 (continued)

Trading time	Variance ratio	Standard error of ratio
<i>C. Bear market period</i>		
Morning open	0.9605	–
First five minutes	0.9241	–
9:01–9:30	0.9088	0.0034
9:31–10:00	0.8718	0.0015
10:01–10:30	0.9497	0.0069
10:31–M.C.	1.0359	0.0012
Morning close	1.0381	–
Afternoon open	1.0318	–
First five minutes	1.0299	–
1:01–1:30	1.0792	0.0057
1:31–2:00	1.1019	0.0031
2:01–2:30	1.0533	0.0058
2:31–A.C.	0.9873	0.0016
Afternoon close	1.0000	–

morning open than at the afternoon close on certain days of the week. For example, the Monday variance ratio was only 0.57 and the Wednesday variance ratio was 0.50.¹² Choe and Shin's (1993) findings based upon the Korca Stock Price Index also indicate that the variance ratios are less than unity for the subperiods of 1988 and 1989.

The fact that the variance ratio is not different from unity at market open remains a puzzle, but it gives indirect support to Stoll and Whaley's (1990) conclusion that a greater monopoly power exercised by specialists makes opening prices more volatile. Unlike NYSE's specialists, TSE's *saitori* members are not allowed to trade on their own account. They serve simply as middlemen between member broker firms, maintaining central order books for each of their franchise stocks to match trade orders. The absence of market makers in the TSE market may be one reason why the variance ratio at the market open is not different from unity.

The average variance ratio observed during the first five-minute period is lower than that for the first 30-minute period. The top panel for the whole period indicates that the ratios are 0.9679 and 1.0084 during the first five minutes, as opposed to 0.9810 and 1.0386 during the first 30 minutes. These results may be an indication that the Itayose method does not necessarily increase market volatility when the Itayose method is compared with the continuous auction trading method. In interpreting these results, however, one must be cautious. The averages of variance ratios observed during the first five minutes are greater than those computed for the first 30 minutes in

¹²The results for different days of the week are not reported, but they will be made available to interested readers.

the afternoon session of the bull market and the morning session of the bear market. Another interesting observation is that the variance ratios in the two subperiods behave differently. For example, the variance ratios tend to be greater than unity in the morning trading session but smaller than unity in the afternoon trading session during the bull market period. Interestingly, the opposite results hold during the bear market period. For example, the ratio of morning open-to-morning open return variance to afternoon close-to-afternoon close return variance is 1.0664 in the bull market period, while the same ratio is 0.9605 in the bear market period. The ratios of open-to-open return variance to close-to-close return variance in the afternoon is 0.9610 and 1.0318 in the bull and the bear market periods, respectively. Thus, once these ratios are averaged over the whole period, it can be observed that the variance ratio is not significantly different from unity.

Thus, the effects of the Itayose method on the return volatility is far from resolved, since the variance ratios at the market open in both trading sessions are not identical during the two subperiods, even though they may be the same during the whole period due to the effect of averaging. Hence, the question remains as to why the variance ratios behave in a different manner during the two subperiods as well as on five weekdays. Although this question is beyond the scope of this study, we can at least provide some intuitive interpretation as to why the variance ratio is rising [falling] as trading progresses during the bull [bear] market period. Consistent with the analysis of correlations between adjacent intraday return series and the autocorrelations observed for the two subperiods in the previous section, it appears that price reversals may explain the different behavior of the variance ratios. Given more frequent and a greater degree of price reversals during the bull market period than the bear market period, the return variance measured at the afternoon market close is expected to be smaller during the bull market period than the bear market period relative to the volatility measured at the morning open. A larger trading volume during the bull market period than the bear market period may be one of many factors underlying the results.

5. Summary and Conclusions

This study investigates the behavior of intraday return and volatility as measured by minute-by-minute observations of TOPIX during the period from August 12, 1987 to April 26, 1991. With irregularities detected for the returns at the morning close and at the afternoon close, intraday returns do not show a smooth U-shaped curve as was illustrated by Wood et al. (1985) using U.S. data. In contrast, the standard deviations of the intraday returns in this study show two distinct U-shaped curves, one in each of the trading

sessions. The results of this study, however, are consistent with the rational trading noise hypothesis proposed by Kyle (1985) in that a rapid decline of volatility is observed as trade proceeds. This decline mirrors the phenomenon that informed traders' private information is assimilated into securities prices and the prices converge to unbiased estimates of the securities' underlying value. High volatility observed at the market open and at the market close is also consistent with the clustering of discretionary liquid traders and informed traders, as perceived by Admati and Pfleiderer (1988). From the analysis of volatility in trading and non-trading periods, the behavior of the index returns is drastically different from that of individual stock return volatility. For example, the difference in return variances between the sum of four separate intervals (overnight period, morning session, lunch break, and afternoon session) and the 24-hour interval from afternoon close to afternoon close is positive at the individual firm level, but negative at the market portfolio level. This discrepancy is caused by the cross-covariances among the component securities and across the time intervals within a trading day, which is typical of the index return variance.

Intraday price reversals are strongly indicated by both correlations and autocorrelations of minute-by-minute returns. Additionally, the average correlations in the bear market period are found to be substantially higher than those in the bull market period, implying that the price reversals are more frequent and much larger during the bull market period than during the bear market period. Consistent with the two U-shaped standard deviation curves, the first-order autocorrelations also show two distinct U-shaped curves in the two daily trading sessions. The average autocorrelations are also larger during the bear market period than during the bull market period.

Interestingly, the variance ratios are found to be relatively stable and close to unity throughout a trading day. This finding implies that: (i) the variance ratio at the market open is not greater than unity; and (ii) the variance ratio at the afternoon open is not different from the ratio observed at the market open. These results raise a serious question about the effect of the Itayose clearing house trading method on market volatility. It is our conclusion that the answer to this puzzle lies in a further analysis of the bull and bear market periods. During the two subperiods, the variance ratios are no longer close to unity. During the bull market period, the variance ratio at the beginning of the morning trading session is far greater than unity, but it declines over time to become much smaller than unity in the afternoon. The opposite is true during the bear market period. Many factors may be at work to produce these surprising results. The difference in trading volume and the absence of market makers who can supply liquidity to get compensated when prices reverse emerge as potential causes of this disparity. This question must be further addressed by follow-up studies.

References

- Admati, A. R. and P. Pfleiderer, 1988, A theory of intraday trading patterns: Volume and price variability, *Review of Financial Studies* 1, 3–40.
- Amihud, Yakov and Haim Mendelson, 1987, Trading mechanisms and stock returns: An empirical investigation, *Journal of Finance* 42, 533–553.
- Amihud, Yakov and Haim Mendelson, 1991, Volatility, efficiency, and trading: Evidence from the Japanese stock market, *Journal of Finance* 46, 1765–1789.
- Barclay, Michael J., Robert H. Litzenberger and Jerold B. Warner, 1990, Private information, trading volume, and stock-return variances, *Review of Financial Studies* 2, 233–253.
- Choe, Hyuk and Hung Sik Shin, 1993, An analysis of interday and intraday return volatility: Evidence from the Korea Stock Exchange, *Pacific-Basin Finance Journal*, forthcoming.
- Domowitz, Ian, 1992, Automating the price discovery process: Some international comparisons and regulatory implications, Working Paper (Northwestern University).
- Forster, Margaret M. and Thomas J. George, 1991, Volatility, trading mechanisms and international cross-listing, Working Paper (Ohio State University).
- French, Kenneth R. and Richard R. Roll, 1986, Stock return variances: The arrival of information and the reaction of traders, *Journal of Financial Economics* 17, 5–26.
- Gerety, Mason S. and J. Harold Mulherin, 1991, Price formation on stock exchanges: The evolution of trading within the day, Working Paper (U.S. Securities and Exchange Commission).
- Harris, Lawrence, 1986, A transaction data study of weekly and intradaily patterns in stock returns, *Journal of Financial Economics* 16, 99–117.
- Harris, Lawrence, 1989, A day-end transaction price anomaly, *Journal of Financial and Quantitative Analysis* 24, 29–45.
- Harris, Lawrence, 1990, Liquidity, trading rules, and electronic trading systems, NYU Salomon Center Monograph Series in Finance, No. 1990–4.
- Huang, Roger D. and Hans R. Stoll, 1991, The design of trading systems: Lessons from abroad, Working Paper 91–22 (Vanderbilt University).
- Jain, Prem C. and Gun-Ho Joh, 1988, The dependence between hourly prices and trading volume, *Journal of Financial and Quantitative Analysis* 23, 269–283.
- Karpoff, Jonathan M., 1987, The relation between price changes and trading volume: A survey, *Journal of Financial and Quantitative Analysis* 22, 109–126.
- Kato, Kiyoshi, 1990, Weekly patterns in Japanese stock returns, *Management Science* 36, 1031–1043.
- Kyle, Albert S., 1985, Continuous auctions and insider trading, *Econometrica* 53, 1315–1335.
- Lo, Andrew W. and A. Craig MacKinlay, 1990, When are contrarian profits due to stock market overreaction? *Review of Financial Studies* 3, 175–205.
- Lockwood, Larry J. and Scott C. Linn, 1990, An examination of stock market return volatility during overnight and intraday periods, 1964–1989, *Journal of Finance* 45, 591–601.
- Madhavan, Ananth, 1992, Trading mechanisms in securities markets, *Journal of Finance* 47, 607–641.
- Makhija, Anil K. and Robert Nachtmann, 1990, Variance effects of cross-listing of NYSE stocks in Tokyo, in *Pacific-Basin Capital Markets Research Volume I* (S. Ghon Rhee and Rosita P. Chang, editors) (Amsterdam: Elsevier Science Publishers B.V.), 215–226.
- New York Stock Exchange, 1991, Fact Book 1991 (New York: New York Stock Exchange, Inc.).
- Rogalski, Richard J., 1984, New findings regarding day-of-the-week returns over trading and non-trading periods: A note, *Journal of Finance* 39, 1603–1614.
- Roll, Richard, 1984, A simple implicit measure of the bid/ask spread in an efficient market, *Journal of Finance* 39, 1127–1139.
- Smirlock, Michael and Laura Starks, 1986, Day-of-the-week and intraday effects in stock returns, *Journal of Financial Economics* 17, 197–210.
- Stoll, Hans R. and Robert E. Whaley, 1990, Stock market structure and volatility, *Review of Financial Studies* 3, 37–71.
- Tokyo Stock Exchange, 1991, 1991 Fact Book (Tokyo Stock Exchange, Tokyo).
- Wood, Robert A., Thomas H. McInish and J. Keith Ord, 1985, An investigation of transactions data for NYSE stocks, *Journal of Finance* 40, 723–741.