Discussion Paper No. 639

CAN WE MAKE MONEY WITH FIFTH-ORDER AUTOCORRELATION IN JAPANESE STOCK PRICES?

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Abstract

We first report that one-minute returns on TOPIX have exhibited significant autocorrelation at five-minute intervals since 1997/98, which implies there is an arbitrage opportunity. Special quotes that are issued whenever there is a price jump in excess of a predetermined band seem to be the source of this autocorrelation, since these have been updated at five-minute intervals since August 1998. Individual stock returns also exhibit fifth-order autocorrelation, but this disappears when the data with special quotes are excluded from the sample. The arbitrage opportunities, however, turn out to be spurious since trading is suspended whenever a special quote is issued.

JEL classification number: G14

Keywords: stock prices, autocorrelation, efficient market hypothesis, Japan

1. Introduction

The efficient markets hypothesis asserts that stock prices follow a random walk and that there is no arbitrage opportunity to make a profit in such markets (Fama 1970). There is a vast literature that has questioned the empirical validity of this hypothesis, but it appears we have no definitive answer to the questions (Fama 1991). In this vein, we present evidence of autocorrelation of one-minute returns at five-minute intervals in Japanese stock prices and attempt to offer an explanation of this phenomenon.

The efficiency of financial markets is also examined with high-frequency data. The markets for foreign exchange and interest rate futures seem to react extremely rapidly to macroeconomic news announcements—within 40 seconds, according to Ederington and Lee (1995) and Almeida *et al*. (1998). However, equity markets respond more slowly to earnings and dividend announcements, requiring ten to 15 minutes (Patell and Wolfson (1984)). The response of the S&P 500 index to unexpected changes in the money supply and Consumer Price Index (CPI) is completed within one hour (Jain (1988)). Tsutsui and Hirayama (2004) examine international linkage of New York and Tokyo stock prices and find the Tokyo market completes reactions to New York within six minutes, but New York reacts to Tokyo within 14 minutes.

Figure 1 plots Autocorrelation Functions (ACFs) of returns at one-minute intervals

in the TOPIX for the period from January 5, 1988 to November 23, 2003. [1] The first-order autocorrelation is significantly greater than zero and the fifth-order autocorrelation is similarly large. The ACFs show spikes at five-minute intervals. The 95% confidence band is also displayed in Figure 1: the ACFs become insignificant only after 40 minutes, exhibiting nontrivial serial correlation.[2]

The ACFs of the same minute-by-minute returns in the S&P 500 are plotted in Figure 2. They exhibit a monotonically and rapidly decreasing pattern without spikes at five-minute intervals. The ACFs become insignificant after ten minutes, implying that the New York Stock Exchange is more efficient than the Tokyo Stock Exchange (TSE).

The fact that there is a significant fifth-order autocorrelation in the TOPIX minute-by-minute returns implies that there is some predictability in the return series. Namely, if there is a high one-minute return, it is likely to be followed by a high return five minutes hence. This suggests that arbitrage opportunities exist.[3] The purpose of this paper is to look into this possibility and to attempt to find the reason behind this five-minute serial correlation.

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[1] The TOPIX is a capitalization-weighted index of all the stocks listed on the Tokyo Stock Exchange.

[2] This fact was first reported in 2002 by Mr. Hiroaki Kaido, then a senior student in the Faculty of Economics, Osaka University. One of the authors sought other researchers in finance who had investigated this phenomenon, but was unable to find any.

[3] We focus on the fifth-order autocorrelation, but not on the first-order one, which is also significantly non-zero. Since one minute is a very short interval, it would be more natural to have serial correlation at this frequency (see footnote 5 below). However, serial correlation at a five-minute interval seems to constitute a systematic anomaly worth investigating. In addition, after 2002 the first-order autocorrelation becomes considerably weaker, while the fifth-order one gets stronger, such that the latter is now three times larger than the former.

2. Features of Fifth-order Autocorrelation

We will present evidence for fifth-order autocorrelation in one-minute TOPIX returns and delineate possible causes in this section. Let us first examine whether this phenomenon is present throughout the entire sample period or whether it emerged at a certain point. The entire sample from January 5, 1988 to November 23, 2003 was split into two subperiods with the break point varied at several dates. Experiments revealed that data before 1997 exhibited no autocorrelation at five-minute intervals. To be more specific on the timing of the emergence of this phenomenon, we carried out two sets of computations: i) we selected data for each one-month or three-month period and computed first- and fifth-order autocorrelations, ii) while fixing the start of the sample at January 4, 1994 we successively deferred the end of the sample from January 31, 1995 by one month and computed the same autocorrelations.[4] Excessive noise in the results for one month and three months made unambiguous conclusions for these periods impossible. Results for the second set are given in Figure 3, which plots the fifth-order autocorrelation denoted as ACF(5) and the ratio of the fifth- to first-order autocorrelation, ACF(5)/ACF(1). ACF(5) shows a slight declining tendency between January 1995 and October 1997, but it exhibits a steep increase

[4] We chose this start date because if January 5, 1988, were selected instead, the number of observations with fifth-order autocorrelation would be overwhelmed by those without it, obscuring the distinction between the two.

between October and December 1997. It becomes stable again, but increases further between September and November 1998. After 1999 through the end of the sample period it increases steadily, albeit slowly.

The ratio ACF(5)/ACF(1), measured along the right scale, is almost constant until August 1997 and increases through January 1998. It then stabilizes, but shows a clear increase between August and November 1998. Subsequently it gradually grows in value. After the year 2000 ACF(5)/ACF(1) rises more quickly than ACF(5), which indicates that ACF(1) is declining. The first-order ACF does exhibit a rapid decrease in the last three years of the sample and this may indicate rising efficiency of the TSE.[5]

We next examined whether the serial correlation at five-minute intervals is observed during particular hours of the day. The Tokyo Stock Exchange is open for trading between 9:00 and 15:00, with a lunch break. Until April 26, 1991, there was a two-hour lunch break between 11:00 and 13:00, which became a 90-minute lunch break between 11:00 and 12:30 after April 30, 1991. After some trial and error we found that the serial correlation disappears when the data between 9:01 and 09:30 are excluded (Figure 4). This strongly suggests that the serial correlation is caused by some characteristics arising during the first half hour of daily trading in the TSE.

Statistical measures of one-minute returns, denoted by *Rhhmm*, are presented in

[5] Serial correlation may not contradict the random walk hypothesis. However, when minute-by-minute data is used, absence of trading (which is likely at such a high frequency) leads to stale prices and therefore serial correlation.

Table 1. These measures are computed across days. Specifically, rather than considering one-minute returns as one long series, each one-minute return is considered as a separate variable and is treated as a daily sample. Note that *R0901* is the daily overnight return from the previous day's close to the opening of the day. Means are most notably positive and large for *R0901* and *R0906*. Maximum and minimum values are also very large for these two variables compared with other adjacent returns. The fifth-order Ljung-Box Q statistic is also computed. Note, again, that each variable is observed at a daily frequency, thus the null hypothesis of this portmanteau test is that all the first- through fifth-order autocorrelation coefficients at daily frequency are zero. This statistic exhibits a very high (daily) serial correlation for *R0901* and *R0906*. These characteristics more or less apply to *R0911* and *R0916*, which also implies the existence of some seasonality at five-minute intervals.[6]

These results may imply that there is an underlying cause of the correlation occurring between returns at five-minute intervals at 9:01, 9:06, 9:11, and 9:16. Figure 5 plots the ACFs of one-minute returns excluding observations at these four minutes. As expected, the fifth-order autocorrelation disappears almost completely. Thus, this autocorrelation seems to be caused by data at those four particular minutes, i.e. at 9:01, 9:06, 9:11, and 9:16. If the overnight return observed at 9:01 (*R0901*) is positive (negative), then

[6] A similar regularity at five-minute intervals is reported in Tsutsui and Hirayama (2004) who estimated the reaction of the TOPIX one-minute returns to the previous day's daily return in New York.

we would expect to see a rise (fall) in the one-minute return at 9:06. A natural question we are tempted to ask is 'Can we make money by exploiting this autocorrelation?' We devised a hypothetical investment strategy in which one buys (sells short) TOPIX when the overnight return is positive (negative) and one sells (buys) TOPIX at 9:06. We computed five-minute returns between 9:01 and 9:06 based on this strategy in Table 2 with the data restricted to the year 2003. The row labeled 'Long Position' is the result of taking a long position in TOPIX between 9:01 and 9:06. Out of 245 days in 2003, there were 148 days when the overnight return was positive. The mean return for this long position is 0.166%. 'Short Position' is the result of taking a short position following a negative overnight return at 9:01. The mean is 0.180%. Both have a *t*-statistic in excess of 7.0, which is highly significant. If the two results are merged, the mean return for the year is 0.171%. Since you can expect to earn this return every day during the 245-day period, its annualized return is almost 42% (0.171 x 245 = 41.895). Tsutsui (2003) reports a tendency of Japanese stock prices to rise during the night, but the average overnight return during 2003 is 0.148% according to Table 2, which is smaller than the mean five-minute return we have just analyzed.

There are two possible causes of this correlation.[7] Firstly, the Volume Weighted Average Price (VWAP) transactions are a candidate for the cause of this anomaly, since they

[7] This was communicated to us in private correspondence from Mr. Masato Hirota, then at the Tokyo Stock Exchange.

were introduced in November 1997 and securities companies that undertake them are said to place most of their buy and sell orders at five-minute intervals to minimize impacts on the market price. Another candidate is special quotes, which are announced whenever the next equilibrium price exceeds a predetermined band. The quotes are set at the ceiling or the floor of this band and execution of orders is suspended temporarily. The announcement is designed to alert market participants to a substantial change in price and to encourage them to place orders to exploit the new information. When a special quote fails to induce the price to stay within the band, the band is doubled and after five minutes a new special quote is announced. Thus, the purpose of these quotes is to smooth out the price path. The TSE instituted an automated system of updating these special quotes at five-minute intervals in August 1998, which is likely to produce autocorrelation at this frequency. In addition, the overwhelming majority of special quotes are announced at the opening, which will be discussed in detail below.

We observed a gradual increase in fifth-order autocorrelation in late 1997 and the fall of 1998 in Figure 3, which is consistent with both the introduction of VWAP transactions in November 1997 and the start of automated announcement of special quotes in August 1998. However, VWAP transactions are conducted throughout the day, which therefore fails to explain the fact that the five-minute periodicity appears only during the 9:01–9:30 period. Therefore, in the next section we will utilize data on individual stock

prices to explore whether special quotes are the cause of autocorrelation at five-minute intervals.

3. Are Special Quotes the Cause of Fifth-order Autocorrelation?

We focus on individual stock prices in this section and examine whether special quotes cause the fifth-order autocorrelation. We ruled out VWAP transactions as the cause of the observed autocorrelation, because these transactions are conducted throughout the day whereas the autocorrelation appears only between 9:01 and 9:30. The same observation may hold true for special quotes, which are also announced throughout the day whenever the required condition is satisfied. We thus attempt to show that the bulk of special quotes are observed during the first half hour of daily trading and that they are the likely cause of the autocorrelation. We utilize tick-by-tick data obtained from the MAINS (Market Information System) of the TSE. 200 stocks were selected out of around 1,500 listed in the first section of the TSE. The criterion was that the average daily trading volume exceeds 500 times the trading unit of the stock.[8] The sample period is from April 2003 to December 2003.

Let us first examine when special quotes are observed most frequently during the

[8] The trading unit is the minimum number of shares to be bought and sold. The majority of stocks traded in TSE have a trading unit of 1,000 shares, but some have different trading units. The reason for selecting those stocks with a daily volume over 500 times the trading unit is to analyze those with sufficient liquidity.

day. Table 3 lists the number of occurrences of special quotes classified by their timing: i) opening of the morning session, ii) *Zaraba* trading (continuous auction) during the morning session, iii) opening of the afternoon session, and iv) *Zaraba* trading during the afternoon session.[9] The second column gives the number of occurrences of special quotes for all the stocks and the third column shows their proportions of the total. Over three quarters of special quotes (77.1%) occur at the opening of the morning session. The opening of the afternoon session also exhibits many instances of special quotes, but the proportion to the total is 12.8%. The reason for the substantial share at the opening of the morning session is probably that new information gathered overnight gives rise to discontinuous price jumps.

We next examine whether the frequency of special quotes is related to the liquidity of the stock. We would expect to see more special quotes for stocks with low liquidity. For this purpose we classified 200 stocks according to the size of market capitalization.[10] The largest 40 stocks are called Group 5, the next largest 40 Group 4, and so forth. Occurrences of special quotes for each of these groups are displayed in Table 3. Group 5 has 1877 occurrences of special quotes, which is somewhat fewer than for the other groups.

[9] The TSE is open for trading from 9:00 to 11:00 for the morning session and from 12:30 to 15:00 for the afternoon session. Orders are accepted from 8:00 for the morning session and from 12:05 for the afternoon session. The opening prices of these sessions are determined by the *itayose* method in which all orders are treated as arriving simultaneously and as many shares as possible are traded at a single equilibrium price. After the opening, trading is done by the *zaraba* method which is a continuous auction. However, whenever trading is halted, say, due to the announcement of a special quote, the subsequent price is determined by the *itayose* method. Amihud and Mendelson (1991) analyze the *itayose* system and argue that this difference in the two price formation processes, *itayose* and *zaraba*, may produce differences in prices and trading volumes.

[10] Market capitalization is regarded as a proxy for liquidity of the stock.

However, as the size of the stock decreases, we observe no tendency for the occurrences to increase. Thus, there seems to be no clear correlation between the frequency of special quotes and the liquidity of each stock. However, the timing of special quotes is overwhelmingly concentrated at the opening of the morning session. There were 8,922 cases of special quotes for 200 stocks during the nine-month period (about 180 business days). For each stock there were an average of about 45 occurrences ($8{,}922 \div 200$), which translates approximately into one occurrence for every four days ($180 \div 45$).

Our focus is then on when these special quotes are dissolved. Special quotes are invoked whenever a large price change is required to clear the market. Suppose, for example, that favorable information about a certain company results in a market order for 50,000 shares to be purchased and another market order for 1,000 shares to be sold. If the closing price of the previous day is 1,200 yen, the regulation of the TSE dictates that a special quote of 1,220 yen be announced to inform market participants of the existence of a large buy order. If someone entered a sell order of 49,000 shares, the market clears at 1,220 yen. However, if there is no sell order, the special quote is updated after five minutes to 1,240 yen in order to entice a sell order at this higher price. This updating of a special quote continues until it reaches the daily price limit. Expecting a higher price, potential sellers seem to wait for the next special quote to be announced. Thus, new sell orders are likely to be placed at five-minute intervals at which subsequent special quotes are

announced. Table 4 gives the cumulative distribution of the time at which a special quote is dissolved. As expected, dissolution occurs at 9:01, 9:06, 9:11, 9:16, etc., at five-minute intervals. In particular there are 3,773 dissolutions at 9:06, which is about 42% of the special quotes announced at the opening of the morning session.

In order to assert that special quotes are the cause of fifth-order autocorrelation in minute-by-minute stock returns, we need to have two special quotes occurring consecutively. These prices have then to rise or decline by a substantial margin in the same direction, resulting in positive autocorrelation in stock returns. This is limited by the number of special quotes that are dissolved immediately following the opening of the morning and afternoon sessions when most of the special quotes are observed. If a substantial proportion of them are dissolved within five minutes of opening, observed fifth-order autocorrelation is not explained by special quotes. Table 5 indicates the cumulative number of dissolutions following opening of the morning or afternoon sessions. After the market opens in the morning, only 33% of the special quotes at the opening are dissolved within five minutes. In other words, 67% of the special quotes at the opening are updated and reannounced as special quotes after five minutes, vindicating the assertion above. However, about 80% of special quotes that occur at the opening of afternoon sessions are dissolved within five minutes according to Table 5. This is quite consistent with the fact that the fifth-order autocorrelation seems to be caused only by data between 9:01 and 9:30

(Figure 4). In summary, the above analyses indicate that fifth-order autocorrelation is caused by the existence of a substantial number of special quotes that persist for over five minutes after the opening of the morning session.

We now attempt to provide direct evidence of special quotes in individual stock prices giving rise to autocorrelation. We first verify that autocorrelation is also present with individual prices. We then exclude special quotes immediately following the opening from the individual stock prices by checking all entries in the tick-by-tick data. If this leads to the disappearance of fifth-order autocorrelation, we shall have additional evidence linking special quotes with autocorrelation.

We selected five individual stocks from different sectors, for which special quotes occur most frequently: UFJ Bank, Softbank, Oracle Japan, Oki Electric, and Acom. Due to limited space, we only present results for Oracle Japan, but results for the other companies are basically the same. During our nine-month sample period (approximately 180 days), the stock of Oracle Japan experienced 78 special quotes at the opening of the morning session, which is close to one special quote every two days. Computation of minute-by-minute returns requires us to select a single price value for each minute. When we have a special quote, it is the price we use. However, during the ordinary *zaraba* trading, we chose the mid value of bid and ask prices because the actual transaction price exhibits a significant negative autocorrelation due to bid-ask bounces. Adoption of

mid-range values substantially mitigates the apparent volatility caused by bid-ask bounces.

The ACFs of one-minute returns of Oracle Japan exhibit spikes at five-minute intervals (Figure 6) just like TOPIX returns. When we exclude returns involved with special quotes, the ACFs of Oracle Japan stock returns show no spikes at all (Figure 7). Exactly the same difference is reproduced with the other four individual stock returns. Therefore, analyses with individual stock prices also verify our hypothesis that fifth-order autocorrelation in stock returns is caused by special quotes.

4. Conclusion

In this paper we first reported that one-minute returns in Japanese stock price index (TOPIX) exhibit significant autocorrelation at five-minute intervals. We then found that this autocorrelation seems to have been caused by returns at 9:01, 9:06, 9:11, 9:16, etc. since around 1997. There are two possible causes for this phenomenon: VWAP transactions and special quotes. The former candidate is easily ruled out because the observed fifth-order autocorrelation is mainly caused by data between 9:01 and 9:30, whereas VWAP transactions are executed throughout the day. However, almost 80% of special quotes are announced at the opening of the morning session of the TSE and two thirds of them are renewed as special quotes after five minutes. New special quotes are announced at five-minute intervals at higher or lower prices than the previous special quote, thus giving

rise to a positive autocorrelation at five-minute intervals. We also analyzed individual stock prices. They also exhibit a fifth-order autocorrelation in one-minute stock returns, but this disappears when the data with special quotes are excluded from the sample. Thus special quotes, which started to be automatically updated at five-minute intervals starting in August 1998, seem to be the definitive cause of the fifth-order autocorrelation in one-minute Japanese stock returns.

The implication of this finding is serious. Existence of autocorrelation contradicts the popular Random Walk Hypothesis of stock prices. It can be construed as evidence against the efficiency of a stock market. However, this does not necessarily present feasible arbitrage opportunities. It should be noted that whenever a special quote is announced, trading is halted, thus preventing the arbitrageur from executing his/her order. Consecutive special quotes at five-minute intervals indicate that the pause in trading is prolonged. Therefore, the arbitrage opportunities we found turn out to be spurious.[11]

[11] If the arbitrage between the spot and futures prices of TOPIX is active, autocorrelation in spot prices may be transmitted to futures prices. We examined the data for TOPIX futures, but their minute-by-minute returns exhibit no autocorrelation. However, this should be the case because one cannot make an arbitrage with special quotes in the spot market.

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Table 1. Descriptive Statistics of One-Minute Returns in TOPIX

	Mean	Max.	Min.	Std. Dev.	Q(5)	Signif.
R0901	0.0237	1.2910	–1.3846	0.3037	39.0008	0.0000
R0902	0.0099	0.5316	–0.4680	0.1221	22.4958	–0.0004
R0903	0.0029	0.3138	–0.3706	0.0667	8.7334	–0.1202
R0904	0.0021	0.3359	–0.3077	0.0537	6.4776	–0.2625
R0905	–0.0002	0.3043	–0.2597	0.0494	16.0823	–0.0066
R0906	0.0053	0.8742	–0.8379	0.1305	20.3686	–0.0011
R0907	–0.0002	0.3728	–0.4153	0.0546	13.8090	–0.0169
R0908	–0.0004	0.2938	–0.2944	0.0488	7.2123	–0.2053
R0909	–0.0022	0.2871	–0.3363	0.0463	12.9162	–0.0242
R0910	–0.0017	0.2574	–0.2314	0.0427	11.8728	–0.0366
R0911	–0.0008	0.6286	–0.6789	0.0710	40.5825	0.0000
R0912	–0.0016	0.3382	–0.3036	0.0434	8.5337	–0.1292
R0913	–0.0024	0.2259	–0.2589	0.0419	4.8515	–0.4343
R0914	–0.0016	0.2651	–0.3010	0.0411	5.0042	–0.4154
R0915	–0.0004	0.3317	–0.2638	0.0404	8.7014	–0.1216
R0916	–0.0010	0.4101	–0.4157	0.0497	20.9279	–0.0008
R0917	–0.0024	0.2943	–0.2274	0.0406	3.1367	–0.6789
R0918	–0.0019	0.2364	–0.2524	0.0380	4.9443	–0.4227
R0919	–0.0014	0.2408	–0.2661	0.0389	7.1877	–0.2070
R0920	–0.0017	0.2358	–0.2320	0.0374	10.7319	–0.0570
R0921	–0.0009	0.3059	–0.2989	0.0429	5.2743	–0.3833

Notes: *Rhhmm* refers to one-minute TOPIX returns for each day in the sample period: January 5, 1988 to November 28, 2003. Q(5) is the Ljung-Box statistic testing the null hypothesis that all the first- to fifth-order autocorrelation coefficients are zero.

Table 2. Five-minute Returns between 9:01 and 9:06 on Positions According to the Overnight Return

	Mean	S.E. of Mean	*t*-stat	*p*-value	Num. of Obs.
Long Position	0.166	0.022	7.591	0.000	148
Short Position	0.180	0.025	7.072	0.000	97
Total	0.171	0.017	10.342	0.000	245
Reference: *R0901*	0.148	0.036	4.137	0.000	245

Notes: 'Long Position' is the five-minute return on taking a long position on the TOPIX between 9:01 and 9:06 when the overnight return (*R0901*) is positive. 'Short Position' is the five-minute return on a short position on the TOPIX between 9:01 and 9:06 when the overnight return is negative. 'Total' is the sum of these two returns. S.E. is the standard error. *t*-stat tests a null hypothesis that the mean is zero. The same statistics are computed for the overnight return, *R0901*, for reference.

Table 3. Frequency of Special Quotes Classified by the Timing of their Announcements

	All Stocks	Proportion	Group 5	Group 4	Group 3	Group 2	Group 1
Opening, Morning Session	8922	77.1	1749	1970	2086	1593	1524
Zaraba Trading, Morning Session	804	6.9	20	57	158	258	311
Opening, Afternoon Session	1481	12.8	101	240	321	318	501
Zaraba Trading, Afternoon Session	370	3.2	7	26	62	105	170
Total	11577	100	1877	2293	2627	2274	2506

Notes: Frequencies of special quotes for 200 stocks selected from the first section of the TSE are tabulated according to the timing of their announcements. Tick-by-tick data from April 2003 to December 2003 were utilized to count the frequency. Group 5 is comprised of the 40 stocks with the largest market capitalization; Group 4 is the next largest 40, etc.

Table 4. Number of Dissolutions of Special Quotes Following the Opening of the Morning Session

Time of Dissolution	All Stocks	Group 5	Group 4	Group 3	Group 2	Group 1
9:01	1077	212	260	251	169	185
9:02	628	101	151	164	112	100
9:03	496	99	109	100	97	91
9:04	401	77	74	106	72	72
9:05	360	88	67	90	69	46
9:06	3773	751	832	860	713	617
9:07	251	50	52	56	46	47
9:08	171	39	32	47	29	24
9:09	147	23	35	39	20	30
9:10	118	20	27	34	16	21
9:11	815	176	164	195	148	132
9:12	78	20	9	17	12	20
9:13	52	10	14	9	7	12
9:14	44	7	8	6	10	13
9:15	38	8	10	11	3	6
9:16	226	35	60	53	40	38
9:17	20	5	7	2	1	5
9:18	30	3	8	6	4	9
9:19	17	5	3	0	4	5
9:20	16	1	3	5	1	6
9:21	55	7	13	17	10	8
9:22	16	1	5	5	2	3
9:23	5	1	4	0	0	0
9:24	9	2	2	1	0	4
9:25	2	0	0	0	1	1
9:26	23	3	4	7	1	8
9:27	4	0	1	1	0	2
9:28	5	0	1	1	0	3
9:29	3	0	3	0	0	0
9:30	0	0	0	0	0	0
9:31	8	1	3	0	0	4

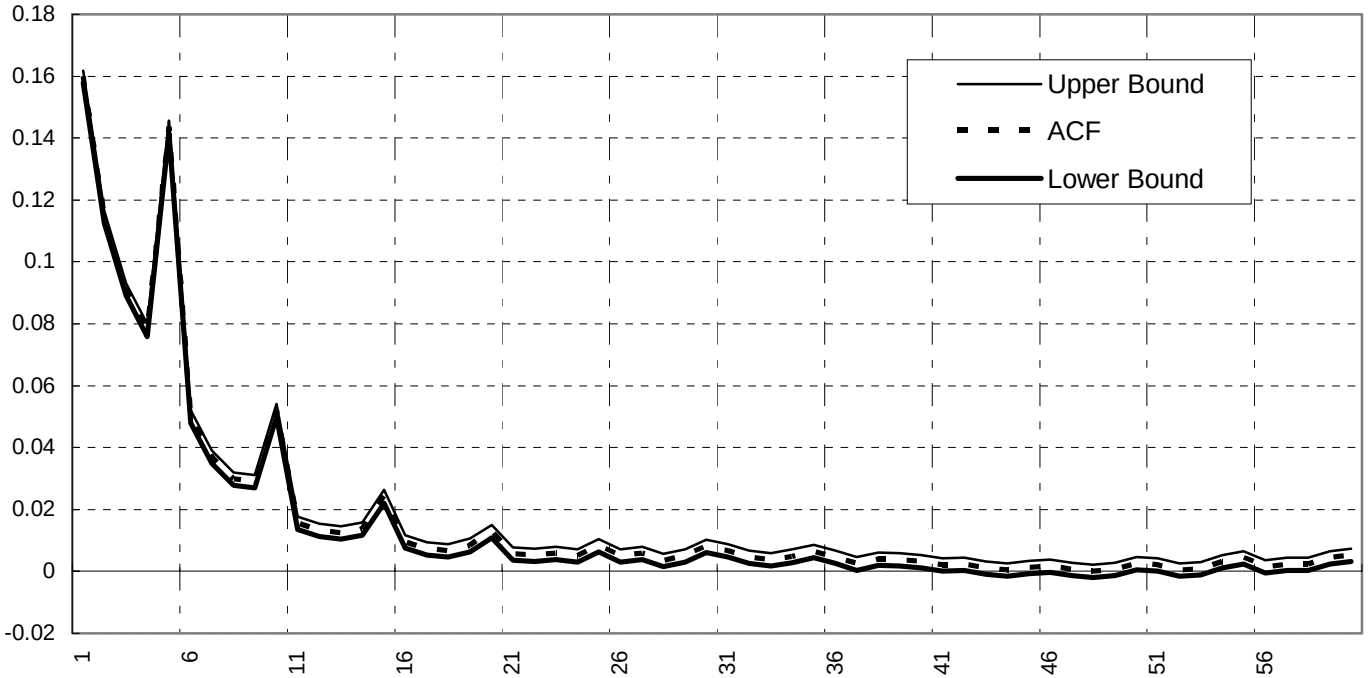
Notes: The number of special quotes that were dissolved by the indicated time is given in each row. Tick-by-tick data for 200 stocks from April 2003 to November 2003 were utilized. Group 5 is comprised of the 40 stocks with the largest market capitalization, Group 4 is the next largest 40, etc.

Table 5. Frequency of Cumulated Dissolutions of Special Quotes Following the Opening of the Morning and Afternoon Session

Time Elapsed (min.)	Morning Session		Afternoon Session	
	Cum. Num. of Dissolutions	Proportion to Total	Cum. Num. of Dissolutions	Proportion of Total
1	1,077	12%	796	54%
2	1,705	19%	999	67%
3	2,201	25%	1,081	73%
4	2,602	29%	1,135	77%
5	2,962	33%	1,186	80%
6	6,735	75%	1,336	90%

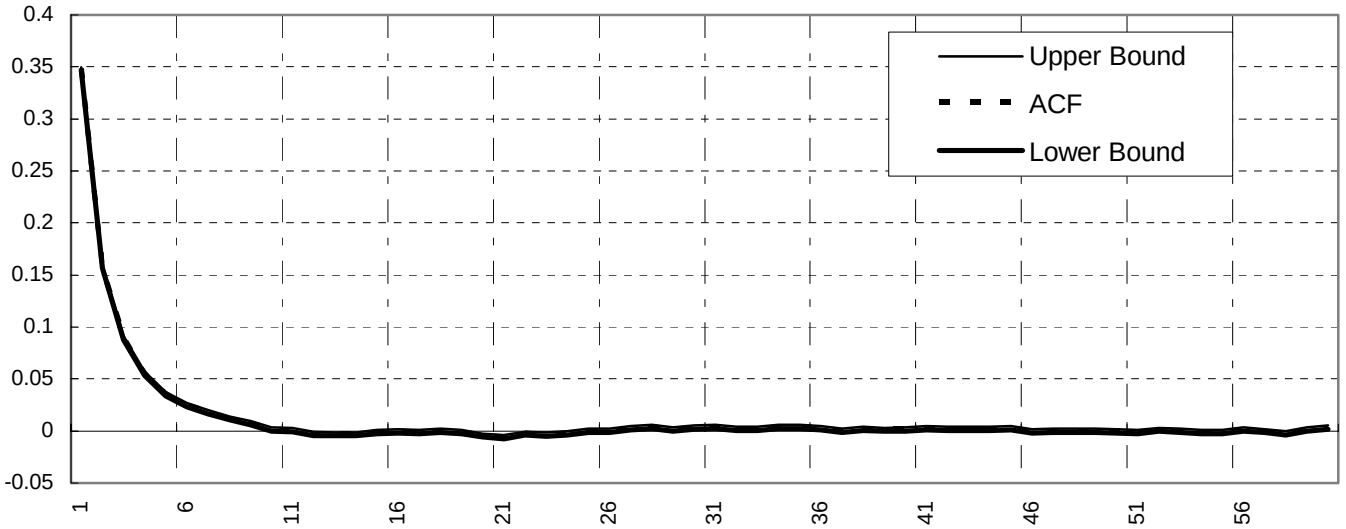
Notes: The cumulative number of dissolutions of special quotes is given for the first six minutes after the opening of the morning and afternoon sessions. Those for the morning session are the cumulative sums of the first six entries of the second column of Table 3.

Figure 1. ACF of TOPIX One-Minute Returns
(01/05/1988 - 11/28/2003)



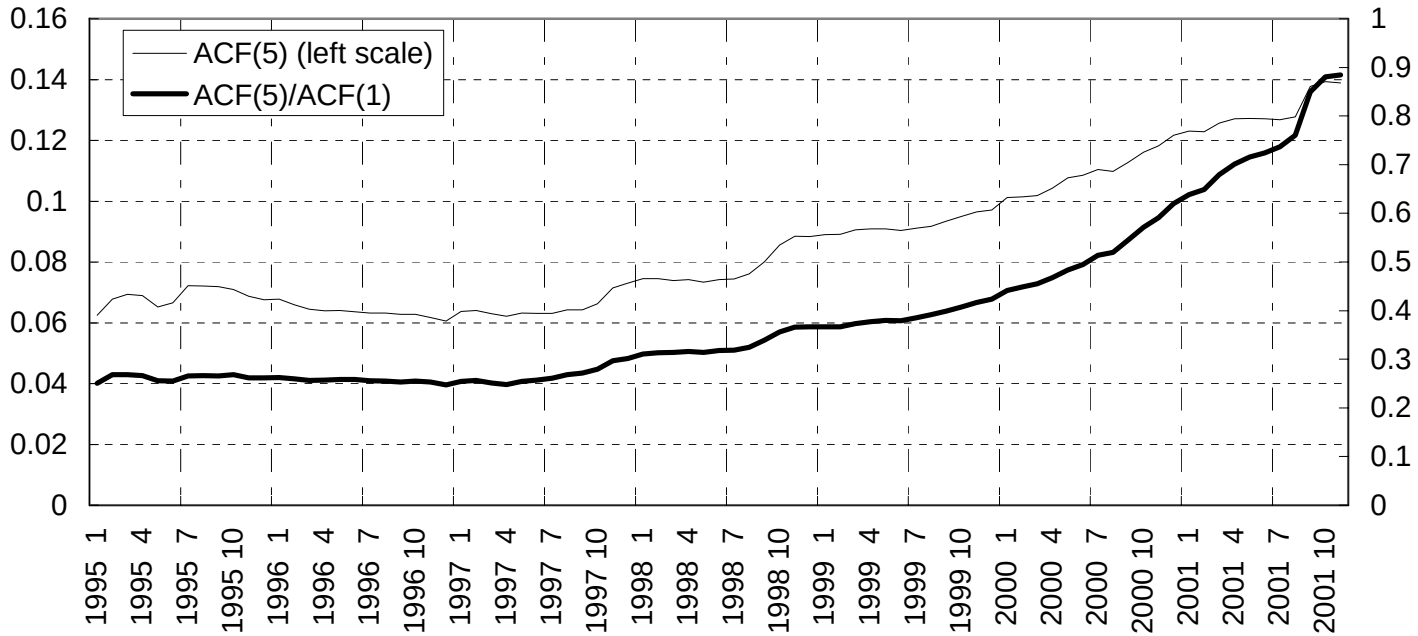
Note: The autocorrelation functions (ACFs) of one-minute returns in TOPIX are plotted.

Figure 2. ACF of S&P500 One-Minute Returns
(01/05/1988 - 11/28/2003)



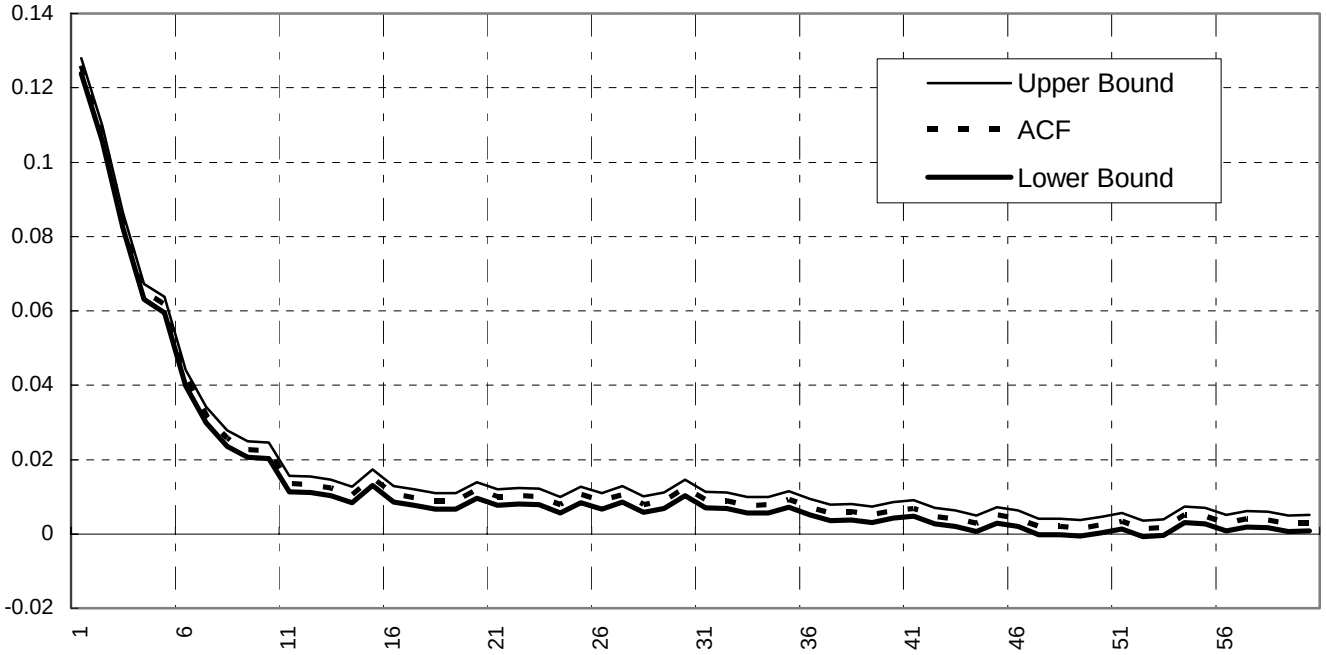
Note: The ACFs of one-minute S&P 500 returns are plotted.

Figure 3. Fifth-order ACF and Its Ratio to First-order ACF



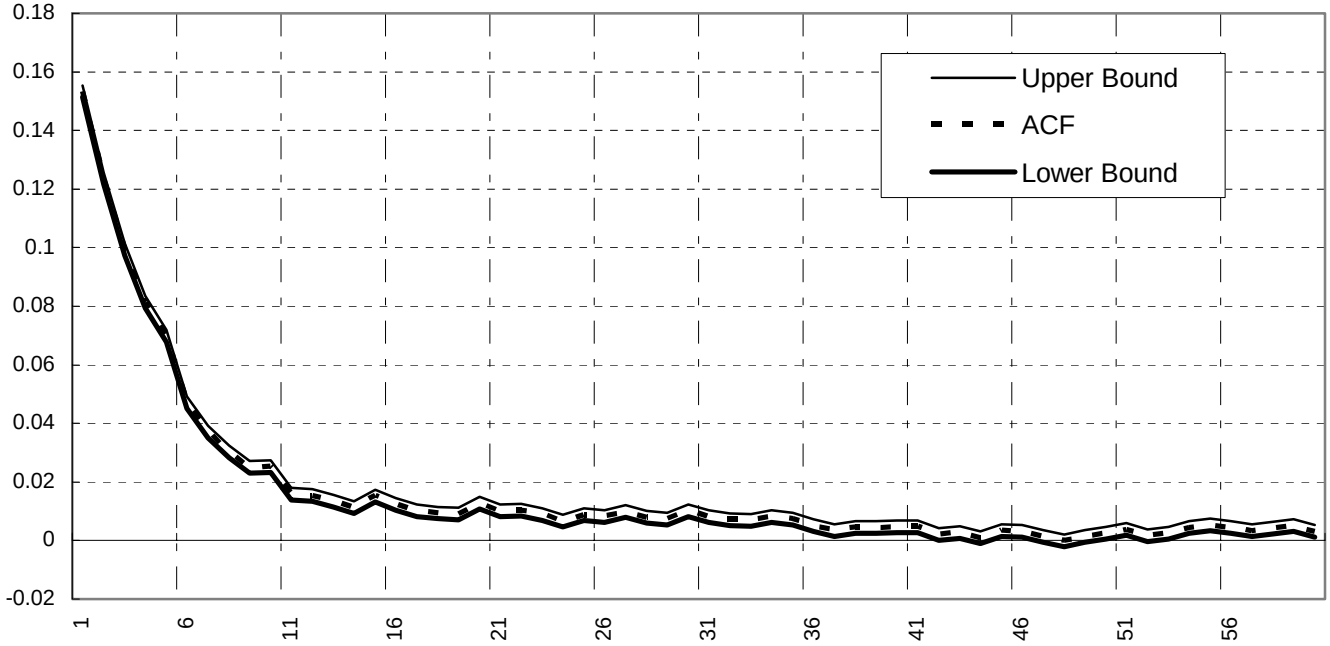
Note: Fifth-order ACF and its ratio to first-order ACF in TOPIX one-minute returns are plotted.

Figure 4. ACFs of TOPIX One-Minute Returns
(Data between 9:01 and 9:30 excluded.)



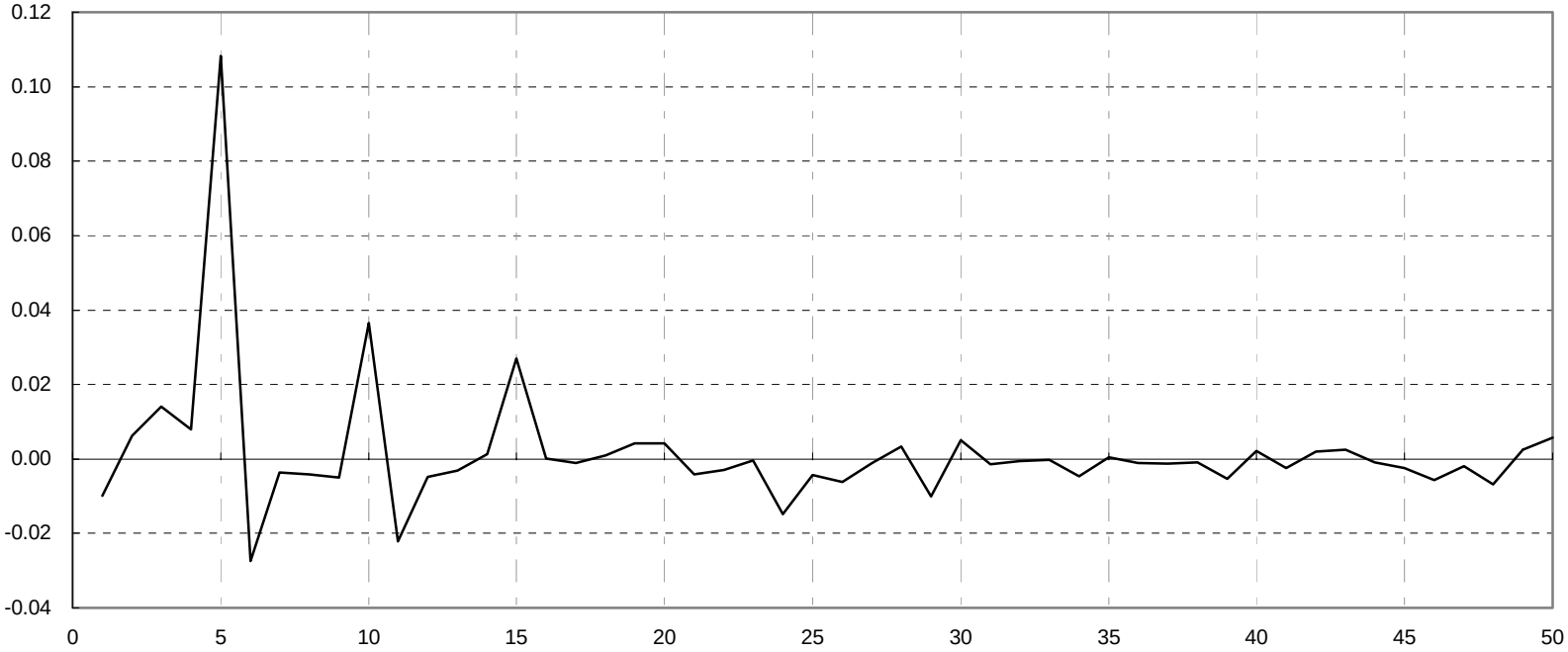
Notes: One-minute returns between 9:01 and 9:30 are excluded from the sample.

Figure 5. ACFs of TOPIX One-Minute Returns
(09:01, 09:06, 09:11, and 09:16 Obs. are excluded.)



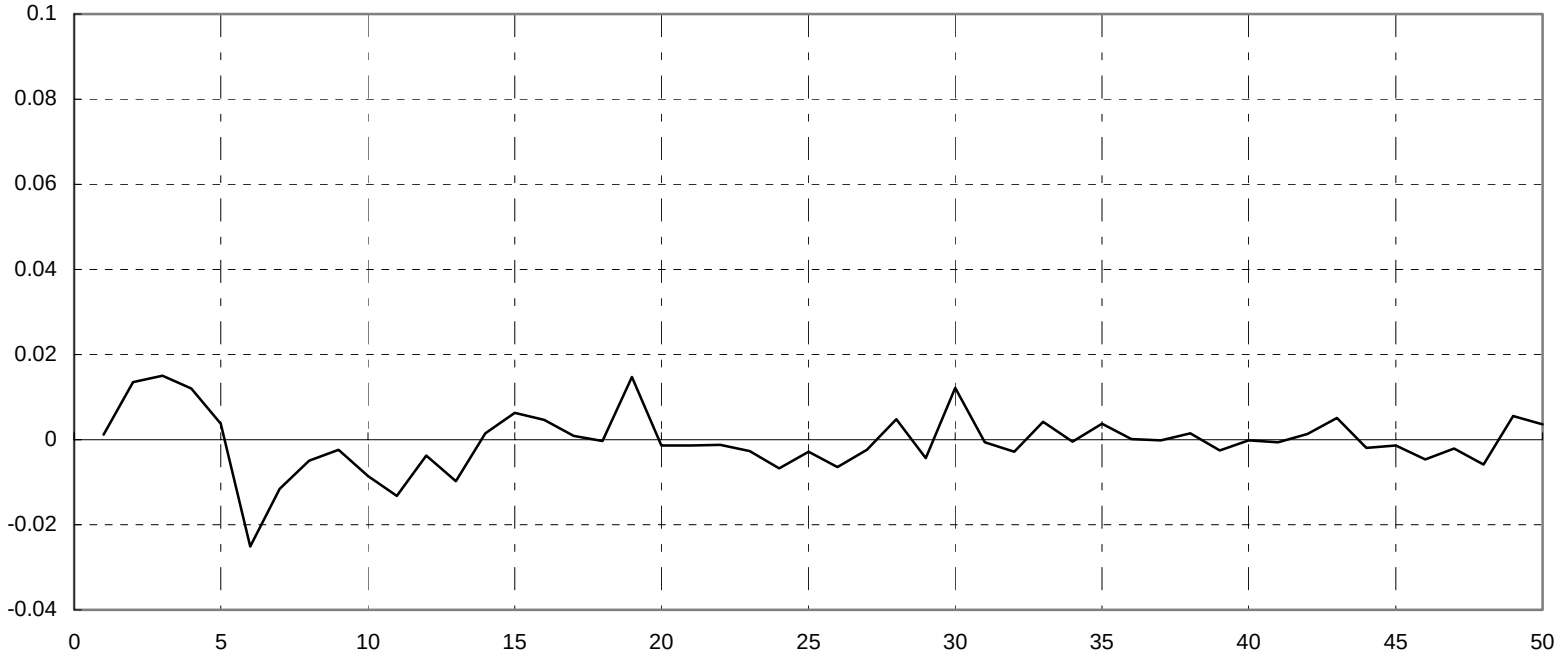
Notes: Four data points at 9:01, 9:06, 9:11, and 9:16 each day are excluded from the sample.

Figure 6. ACFs of One-Minute Return of Oracle Japan



Notes: ACFs of one-minute returns in Oracle Japan shares are plotted. The sample period is from April 2003 to November 2003.

Figure 7. ACFs of One-Minute Return of Oracle Japan
(Special quotes are excluded.)



Notes: ACFs of one-minute returns of Oracle Japan are plotted, but the data involved with special quotes immediately following the opening of the morning session are excluded. The sample period is from April 2003 to November 2003.