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Abstract

This paper investigates the behavior of intraday trades and quotes for individual stocks on the Tokyo Stock Exchange (TSE). The TSE has two distinctive institutional features: (1) the absence of market makers who trade for their own accounts, and (2) use of price limits. Our findings suggest that the immediacy available in the market is high, despite the reliance on public limit orders to supply liquidity. The price limit mechanism causes some trades to execute more slowly, but allows many incoming market orders to transact at more favorable prices. We furthermore examine the impact of trades on quotes. The TSE's mechanism is similar in many respects to the electronic limit order book modeled by Glosten (1991). Consistent with Glosten's prediction, we find some evidence for quote reversals subsequent to trades.

1. Introduction.

While the initial surge in empirical analyses of market structure centered on U.S. markets in general and the New York Stock Exchange (NYSE) in particular, interest is now shifting toward markets with more diverse structural features. This paper provides a first glimpse at the behavior of intraday trades and quotes on the Tokyo Stock Exchange (TSE). One of the largest exchanges in the world, the TSE certainly possesses size sufficient to warrant interest. It is also characterized, however, by a number of distinctive institutional features.

Most importantly, the trading mechanism at the TSE relies on no designated dealers or market-makers. All liquidity is supplied by traders who submit limited price orders. The TSE in fact goes one step further in proscribing traders from placing proprietary limit orders on both sides of the market (although they can represent customers on both sides of the market). This effectively discourages traders who, while not formally designated as such, would nevertheless function as *de facto* dealers. In most markets, dealers are responsible for maintaining quotes and liquidity. By examining the TSE, this study seeks to determine the extent to which this function is met by public traders.[1]

The TSE is also distinctive in its implementation of price limits. These mandate a delayed adjustment of quotes, effectively close one or both sides of the market for brief

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[1]The basic setup of the TSE is shared by a number of other exchanges. The Toronto CAT's system has many of the same features. The Toronto system, however, involves a designated market maker. The TSE system is also quite similar to the CAC system. (See Biais, Hillion and Spatt (1991).) The French system, however, handles only a portion of the trading in its listed securities. Large trades are crossed in London. In contrast, virtually all trading in TSE-listed securities is on the TSE itself. Also, stock exchanges in Korea and Taiwan have computerized trading systems that are similar to that of the TSE.

periods, and may introduce delays for orders which involve large price changes. In contrast with the continuity rules of the NYSE, however, there is no requirement that actual trades occur at the intermediate prices to bridge the gap. This study seeks to determine the extent to which the price continuity rules are binding and characterize the delays.

The rest of the paper is organized as follows. Section 2 summarizes trading procedures on the TSE. Section 3 describes the data. The next two sections provide the main results on liquidity. Section 4 discusses preliminary findings on price limits and liquidity. Section 5 analyzes autocorrelation in the order flow. The dynamic properties of trades and quotes are discussed in Section 6. Section 7 presents concluding remarks.

2. Institutional Details.

This section summarizes the key institutional features of the Tokyo Stock Exchange (TSE) and is based on Rules of the Tokyo Stock Exchange and conversations with Exchange personnel. Other English-language descriptions of trading procedures are contained in Amihud and Mendelson (1991), Hamao (1992), Japan Securities Research Institute (1990), and Lindsey and Schaede (1990).

The trading day on the TSE is divided into morning (9:00 am to 11:00) and afternoon (1:00 pm to 3:00 pm) sessions.[2] A trading session on the TSE opens with a call mechanism

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[2] There have been some changes in trading time and days. The exchange was open from 9:00am to 11:00am and from 1:00pm to 3:00pm for Monday through Friday, and from 9:00am to 11:00am on Saturday until December 1972, three Saturdays a month until July 1986, and two Saturdays a month until January 1989. Since February 1989, the market has been closed on all Saturdays. Finally, from April 1991, the trading time in the afternoon was extended by reopening the market at 12:30pm.

(*itayose*), then functions as a continuous double auction (*zaraba*) until the session closes. Another call is used when there is an active order flow at the moment of close. While the trading procedures are highly similar for all stocks in both first and second sections, the implementation of these procedures varies. Most issues (including all three stocks in our sample) are traded through a computerized buy and sell matching system ("system-traded issues"). However, 150 of the most actively traded issues are traded manually ("exchange-traded issues"). In both cases, all orders, either market or limit, placed by member securities firms are transmitted to *saitori* members, who act as middlemen to match orders. The *saitori* is not a dealer: he does not trade for his own account. Nevertheless, the *saitori* does exercise some discretion and judgment in the regulation of the trading process.

The *itayose* mechanism is straightforward. Buyers and sellers submit market or limited price orders which are cumulated into supply and demand schedules. The intersection determines the equilibrium. Hamao (1992) contains an example. After the *itayose* clears, the best unexecuted buy and sell offers establish the bid and ask price for the start of the *zaraba*. Within the *zaraba*, traders may submit limit orders or market orders. The regular quotes *(ippan kehai)* disseminated by the Exchange represent the limit order book, and most incoming market orders execute by hitting the book. The size of the reported trade is determined by the size of the incoming order. A 1,000 share buy order that executes against limit sell orders of 600 and 400 shares, for example, is reported as a 1,000 share trade.

The principal complication in this framework is the existence of price limits, which may delay or prevent the execution of trades and cause the dissemination of quotes that are

essentially hypothetical. There are both daily and intradaily limits on both transaction prices and quotes. Hamao (1992) describes the daily price limits, which are relatively broad. As it happened, none of our stocks hit a daily price limit, despite the high activity and volatility in the sample.

Of greater importance for the present study are the price limits that relate to movements in quotes and execution prices within the day. These are implemented by (1) preventing orders from immediately hitting quotes if the execution price would exceed the limit; (2) issuing indicative quotes that advise the market of the condition; and (3) eventually letting the orders hit the quotes. This process can be best illustrated by the extended example presented in Table 1. For a share price just above ¥1,500, the tick size is ¥10, and the maximum transaction price variation is ¥30. Suppose that the opening *itayose* price is ¥1,540 (time 0), and that at the start of the *zaraba* (time 1), the limit order book and the quotes are as shown. Transaction price limits are most often hit when large incoming orders walk up or down book. Suppose that a 10,000 share market buy order arrives at time 2. The first portion of this order, 9,000 shares, is traded immediately at the prevailing offer (time 3).

The remaining 1,000 shares is not, however, immediately executed at the next higher price (¥1,560). Instead, the order is represented as a warning bid (*kai chui kehai*) at ¥1,550. This warning quote is issued automatically, but the duration of the quote is at the discretion of the *saitori* (depending on the depth of the book). If this waiting period elapses without arrival of a sell order at ¥1,550 or better, the limit order is allowed to hit the ¥1,560 offer on the book (time 4). This process is repeated at each step of the price. In effect, the

unexecuted portion of a market order is converted to a limit order, in a fashion similar to that employed in the Paris CAC system. (See Biais, Hillion and Spatt (1991).) Unlike the Paris system, however, the order is eventually permitted to hit the next higher price.

Transaction price limits are also hit when successive orders would cause large changes. Suppose that a 2,000 share order to sell at the market arrives at time 5. If this were permitted to hit the bid (¥1,520), the resulting change from the previous price (¥1,560) would exceed that permitted (¥30). Here again, a warning quote is disseminated, an offer at ¥1,550 (time 6). At this stage, no execution can take place unless an "executable" buy order (at ¥1,530 or above) arrives. If no such order arrives, the warning offer is progressively revised downward (times 7 and 8), finally hitting the limit order at time 9.

A warning bid implicitly represents a pending sell order (a warning offer, a pending buy). If the number of sellers is two or more, the saitori replaces the warning offer with a *uri tokubetsu kehai* (a special offer quote). In this example, had another seller arrived at time 6, the offer would have been a special quote of ¥1,550. The special quote influences the execution price thereafter; a special quote price becomes a base price and the execution becomes possible within the price limit. In our example, if a buy order comes in, the execution price can be within the price limit from ¥1,550, *i.e.*, ¥1,540, ¥1,530, or ¥1,520. It must be noted that the indicative quotes (warning or special quotes) are "triggered" by incoming orders that would cause price jumps. In other words, the *saitori* will not issue those quotes if there are no orders coming into the market. If there is still no sell order within the ¥30 limit after 5 minutes, the *saitori* may revise the special quote. The unit is the price limit, *i.e.*, the new special quote is ¥1,520. The process is repeated if there is no sell

order generated after 5 minutes again.

The gradual and progressive revision of quotes on the TSE is mandated with a view toward smoothing the price transition path and reducing the impact of transient liquidity shocks. On the NYSE, this purpose is served by price continuity rules, and it is illuminating to compare the two approaches. The contrasting features may be summarized as follows. Suppose for concreteness that the market is hit by a large public information shock that necessitates a price adjustment. On the TSE, the quotes will exhibit a smooth transition path, but there need not be any transactions along this path. Successive transaction prices may widely separated. On the NYSE, the specialist (designated market maker) is required to establish a smooth path in transaction prices. Providing continuity in transaction prices may require the specialist to engage in trades that in view of the public information are disadvantageous. A further distinction lies in the time needed to complete the transition. On the TSE, adjustment of the quotes may necessitate intervals of waiting at the intermediate price levels. On the NYSE, there are no restrictions on the adjustment speed (in natural time): the transactions establishing the adjustment may be executed within seconds of each other.

Although most transactions result from the interaction of two anonymous orders, the TSE does permit a broker to effect a cross. Rules for large block trading were streamlined in 1967 when block trading outside the competitive exchange trading was prohibited. The current system allows member brokerage firms to (1) split large sell orders to small quantities and execute them off the exchange, or (2) execute large block trades completely on a competitive basis on the exchange. The second method is not popularly employed because

of the complexity of its procedure, which does not allow the same broker to be on both buy and sell side. Instead, so called "cross" transactions of large blocks by the same broker on the exchange are mainly used in this practice.

The TSE is also distinctive in the level of information permitted to the various classes of participants. Table 2 summarizes market participants and their access to information and order entry facilities. Of particular note is the relatively narrow dissemination given to regular quotes. Off-exchange, these are available only at a member firm's lead office, and electronic collection or rebroadcast is strictly prohibited. These terminals are also the only vehicle for entry of orders from off the exchange.

3. Data and Preliminary Analysis.

The data sample underlying this study consists of the ordered sequence of transactions and quotes for three securities in the period January 4, 1990 through March 31, 1990, time-stamped to the last minute. The data were provided by the Exchange in the form of photostat computer printouts (roughly 5,000 pages), converted into machine-readable form using an optical scanner, checked and edited. The securities, randomly chosen from electronically-traded issues in the first section, are: Mitsui Construction (security code 1821), Nikon (7731) and Japan Airlines (9201). There were 59 trading days in this period. January 4, 1990 was the first trading day of the year, and the market was open only in the morning. Due to mishaps in the collection of the data, we are missing one day for each stock (February 27 for Nikon and Japan Airlines, and March 2 for Mitsui Construction). This leaves 58 morning sessions and 57 afternoon sessions.

Besides regular (code 80), warning (81) and special (20) quotes, there are some records of quotes with no price indicated (00). This is a recording convention used when a regular quote becomes way out of the executable price range, but is not converted to an indicative quotes because of the lack of incoming order that triggers issuing an indicative quote.

Over this observation period, the Tokyo market experienced a downward movement; the closing value of the value-weighted Tokyo Stock Price Index (TOPIX) went down from 2,867.70 on January 4 to 2,227.48 on March 30. Our three stocks also experienced downward price movements. Figures 1, 2 and 3 show time series of daily closing prices during the sample period.

Table 3 reports various summary statistics. At current exchange rates, the median transaction sizes roughly correspond to dollar values of $21,000 (Mitsui Construction), $36,000 (Nikon), and $26,000 (Japan Air Lines). Average spreads are very close to their respective minimum tick size, and in percentage terms, they are all 1% or less.

As in the U.S. data, most market statistics exhibit a marked intradaily pattern.[3] Figures 4, 5 and 6 present plots of average squared return, average proportional spread, and average trading volume for ten-minute intervals throughout the trading day. The mean squared return and spread tend to be elevated at the beginning and end of the trading day. The volume tends to be elevated at the beginning and end of the trading sessions.

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[3]See Admati and Pfleiderer (1988), Foster and Viswanathan (1990, 1991), Harris (1986, 1989), Jain and Joh (1988), McInish and Wood (1992), Mulherin and Gerety (1989), and Wood, McInish and Ord (1985).

4. TSE Liquidity: The Effect of Price Limits.

Price limits of any sort are generally supposed to impede the trading process, and are implemented in the pursuit of a trading process that is in some sense more orderly. In this section, we present three pieces of evidence bearing on the impact of the TSE's price limit mechanism described in Section 2. To measure the impedimentary effect of price limits, we examine the periods in which the market is effectively closed and the extent of the delay introduced into order execution. Assessing the hypothetical benefits is more difficult. Here, we simply report the number of times that the delay appeared to result in a better price.

When a warning or special quote is in effect, execution of the current order is essentially suspended, and the market is effectively closed to all other incoming orders on the same side. Table 4 summarizes the number and total durations of such times. As a percentage of the TSE's nominal hours of operation, the periods of effective closure are relatively small. The maximum is 5%. This may, of course, overstate the liquidity, because the market may be closed exactly when the demand for liquidity is high.

The price limit mechanism also delays the execution of orders. While our database does not characterize individual orders, it does support inferences concerning certain order groups. In accordance with the discussion of Section 2, for example, a special quote is used when two or more orders are pending. When a trade occurs, it is not possible to determine which order was executed. In lieu of this, the following analysis is based on order sequences. An order sequence is a group of consecutive orders that may be inferred from the sequence of transactions and special quotes. A single order working its way through the book, for example, reveals itself in a sequence of executions and warning quotes.

More precisely, an order sequence is said to start when there is either a transaction, or a warning/special quote indicating that a trade is pending. Continuation of the order sequence is inferred from warning/special quotes following any executions. The ending point of an order sequence is fixed by the posting of a regular quote, or by the end of trading. First transactions of both morning and afternoon sessions are excluded since they employ a call auction (*itayose*).

Table 5 describes the distribution of order sequence durations for each of the three stocks. It is apparent that the preponderance of orders are executed immediately or within one minute. The data reveal, nevertheless, some extreme observations. On March 20, 1990, Mitsui Construction closed at ¥1,220. On the next trading day (March 22), a special offer of ¥1,200 (indicating two or more sell orders) was posted at 9:13, with no valid bids. The special offer was revised gradually downward to ¥1,140, but no trades were permitted to occur in the morning session. At the start of the afternoon session, Mitsui Construction opened at ¥1,140.

It might reasonably be conjectured that larger orders result in longer execution durations. Scatter plots did not appear to conclusively support this hypothesis. More formally, we computed Spearman rank-order correlations between the volume of each grouped trade and the execution duration. These correlations were positive and statistically significant at the usual levels, but the magnitudes were small: .20 (Mitsui Construction), .10 (Nikon), and .12 (Japan Air Lines). This does not imply, of course, that at any given time a large order may be submitted with little penalty in execution time. Order submission strategy is endogenous to market conditions. The submitted orders depend on the expected

market depth, and our weak correlations may simply reflect a tendency of traders to submit larger orders when the market is more capable of accommodating them.

The putative benefit of impeding an order's execution derives from the supposition that a delay is likely to lead to improvement in the price of the counterpart order. Consider, for example, a market sell order in the process of working through the book. Suppose that the first part of the order has been executed at ¥1,200, and that the best bid on the book is ¥1,190. In an indication that an active order is pending, a warning offer will be posted at ¥1,200. In the absence of a price limit, the order would immediately hit the book bid. With the delay, there is the possibility that the higher warning offer may be hit by an incoming buy order. There is also the risk, however, that the book bid of ¥1,190 may be withdrawn.

Table 6 documents the frequency of these occurrences for warning and special quotes. The analysis considers all transactions which were preceded by warning or special quotes. Warning quotes are hit by incoming orders in roughly one fifth of all instances, indicating improvement over the prevailing regular counterpart quote. Furthermore, there were no instances in which the prevailing counterpart quote deteriorated. Special quotes are hit in roughly half of the instances.

5. Autocorrelation in Trade Direction.

It has been noted that successive transactions on the NYSE tend to take place on the same side of the quote: a transaction at the bid is likely to be followed by another transaction at the bid. This apparently implies that order flow (whether a trade is buyer- or seller-initiated) is also positively correlated. On the NYSE, there are a number of factors which

might lead to this behavior: transaction price continuity requirements, fragmentation of reported trades, stale limit orders and price discreteness.

The price continuity requirement refers to the affirmative obligation of the NYSE specialist to bridge large price swings by transactions at intermediate prices, preferably at one-tick intervals. A price movement of one dollar, for example, will lead to successive transactions at 1/8, 1/4, 3/8, etc.., all of which are on the same side of the market. Reporting fragmentation refers to the practice of reporting as multiple transactions those trades that involve multiple buyers and sellers. Both stale limit orders and quote discreteness can lead to quotes that do not fully reflect the public information. Such quotes may be more likely to be hit on one side or the other.[4]

In contrast, successive transactions on the TSE are not subject to price continuity requirements (although quotes are). Put another way, there are no rules that compel a buyer or seller to transact at an inferior price in order to smooth the transaction price path. Any trade autocorrelation on the TSE, therefore, must be attributed to other factors.

To investigate this, we constructed a trade series as follows. In accordance with the usual practice, trades were signed by reference to the prevailing quote: positive if they occurred at the offer and negative if at the bid. For U.S. data, this procedure generally leaves as many as half of the trades unsigned because they occur within the stated spread. Under the TSE's structure, however, this can happen only for crosses, which are relatively

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[4]Inventory control can also in principle lead to autocorrelation in trades. The predicted direction of the autocorrelation is, however, negative. (Inventory imbalances are eliminated by reversing trades.) In the short run, at least, there is no evidence of negative autocorrelation in trades. See Hasbrouck and Ho (1987) and Hasbrouck (1988, 1991a).

infrequent. The proportion of unclassified TSE trades is therefore much lower, under 1% in our sample.

We next computed the total signed trade volume for each minute in which a trade occurred. We then computed the autocorrelations in the signed trade volume series. These autocorrelations are strongly positive: the first-order autocorrelations in signed trade volume are .24, .28 and .17 for Mitsui Construction, Nikon and Japan Airlines (respectively). Furthermore, these autocorrelations decay very slowly. As noted, once mandated transaction price continuity and reporting fragmentation are ruled out, the factors of price discreteness and stale limit orders remain.

6. The Impact of Trades on Quotes.

This section explores the relations between trades and quotes on the TSE. This behavior is of interest because it provides clues about the information contained in trades, and how this information is incorporated into prices. We employ two approaches. The first involves a basic vector autoregression model in which trades are characterized solely by their signed volume and the price variable of interest is taken to be the quote midpoint. This analysis is well-suited to investigating the adjustment process of the quote midpoint, and in particular, how the TSE's price limit mechanism affects this adjustment. The second analysis focuses on the behavior of quotes relative to the transaction price, with the purpose of characterizing the information contained in the trades.

Trades and Quotes: a Vector Autoregressive Model.

Applications of vector autoregressions (VARs) in microstructure analysis are described in Hasbrouck (1991a, 1991b, 1992). All variables of interest (spreads, quotes and trades) are jointly modeled to capture their dynamic interactions. Variable definitions are given in Table 8. The notation and terminology are essentially identical to those employed by Hasbrouck (1991a) for the NYSE data. The most significant departure from the earlier paper involves the time subscript. Here, t refers to minutes and not transactions. The motivation for this change stems from the central role played in the TSE's price limit mechanism by standard wall-clock time. The drawback of this choice is that it renders suspect the stationarity assumption underlying the VARs.

The trade variables (x_t and its transformations) attempt to reflect the incoming order flow, signed positively for buyer-initiated trades and negatively for seller-initiated trades. We follow the conventional practice of imputing this sign by reference to the prevailing quotes. As noted earlier, the vast majority of the TSE trades can be unambiguously signed in this fashion.

To capture the state of the market when a price limit is in effect, we construct a signed trade-pending variable, $pend_t$. This is an indicator variable set to +1 if the pending bid quote at the end of minute t is a warning quote. This indicates that a buy order is either walking up the book or is being held to satisfy the continuity requirements. Similarly, $pend_t$ is set to -1 if the pending offer quote at the end of minute t is a warning quote.

The first set of VAR estimations is directed at assessing the impact on quote-midpoints of an incoming order. The variable set is $\{r_t, x_t^0, x_t, x_t^{1/2}, pend_t\}$ and the

estimations employ ten lags. Based on the estimated VARs, Figures 7-9 depict the response of the quote midpoints to incoming buy orders. For each security, two types of buy orders were considered. The first (solid line) corresponds to a buy order at time 0 of size equal to the 90th percentile of the actual trade size distribution for the stock, where the order is assumed to have been executed in its entirety at time 0 (no more pending). The second price path (dashed line) involves an initial order of the same size, but with an indication that more is pending. For all three securities, there is little evidence of lagged adjustment in the first case, but pronounced lagged adjustment in the second.

Trades and Quotes: The Limit Order Book After a Trade.

In many markets, it is possible for the quote-setter to condition the bid and offer on the full size of the incoming trade. This is trivially the case when trade size is restricted to a single magnitude, but also obtains when a single market-maker quotes a price schedule. Many theoretical models, including Glosten and Milgrom (1985) and Easley and O'Hara (1987) conform to this structure. There are also, on the other hand, many markets in which the quote setter or limit-order trader does not know the full size of the trade that triggers the order. When the quotes derive from a limit order book with many traders, a limit order may be executed in the process of filling an order of much greater size. Rock (1989) and Glosten (1991) model markets of this latter sort.

A significant feature of Glosten's model of an electronic limit order book is that, in the absence of non-informational transaction costs (fixed order processing fees and the like), the revision in the expected security value is less than the total price change. Conditional on

the knowledge that a rational limit sell order was the last one hit in the course of filling a market buy order, the expected value of the security is lower than the limit order price. (The trader placing the limit sell order had to allow for another possibility, *viz.*, that it might execute as an intermediate counterpart of an incoming buy order.) Limit orders placed after the execution will reflect this new expectation. Absent other transaction costs, the new offer price will lie below the last executed offer. Similarly after a sell order, the revised buy price will be above the last executed offer. For expositional simplicity, we will term such phenomena quote reversals.

The TSE cannot, of course, be assumed free of non-informational transaction costs. It nevertheless approximates the structure of Glosten's market in the key respects that virtually all executions take place against the limit order book and that the limit order traders do not know the full size of the order that triggers execution. It is therefore a natural setting in which to investigate quote reversals.

We define the price-quote continuation for a buyer-initiated order sequence as:

$$C = (\textit{Revised Offer}) - (\textit{Last Transaction Price})$$

The *Revised Offer* is the offer quote posted after the last trade in the order sequence. The *Last Transaction Price* is the price at which the last part of the order is filled. For a buy order working its way through the book, this will generally be the highest price at which any part of the order is executed. Signed in this fashion, C is positive if the revised offer is higher than the last transaction price, and negative if there is a quote reversal. The definition

is symmetric for a seller-initiated order sequence:

$$C = (\textit{Last Transaction Price}) - (\textit{Revised Bid})$$

Now as a matter of TSE procedure following the trade, the stock is requoted and the best bid and offer from the limit order book are displayed. Since this allows no meaningful interval for the revision of orders, it may also be necessary to investigate the new quotes subject to a delay. Accordingly, we compute variants of C where the bid and offer quotes employed are those prevailing 2, 5 and 10 minutes after the trade.

Table 7 presents means and mean standard errors for the continuations for all order sequences. In the full sample, at all time lags (first four rows of the table) one finds little evidence for quote reversals: continuations are positive and significantly so. Some such evidence emerges, however, when we dichotomize the order sequence sample according to whether or not the transaction or transactions in the sequence took place at a single price. The sequences that are executed at multiple prices are precisely those which stem from orders working through the book. The analysis here is more suggestive. Orders filled at a single price exhibit continuations. Those filled at multiple prices exhibit reversals, particularly relative to the delayed quotes.

The behavior implied by these results may be described as follows. A large buy order may work through the book by hitting progressively higher limit sell orders. Once the order has been fully executed, however, there is a tendency for incoming limit sell orders to be priced below the final execution price. This is consistent with the Glosten's model. It is also consistent, however, with the more mundane explanation that delays in order placement lead to stale incoming orders. There is furthermore no explanation as to why this effect is

not visible in the single-price order sequences.

7. Conclusions.

This paper is a first investigation of the properties of intraday trades and quotes on the Tokyo Stock Exchange (TSE). In comparison with of the world's other principal equity markets, the TSE is distinctive in two respects. First, the Exchange uses no dealers, and relies on limit-order traders to provide liquidity. Second, the Exchange imposes timed price limits to smooth adjustment in quotes.

Our findings are consistent with the following conclusions.

(i) Overall liquidity on the TSE is good. The prevailing bid and offer quotes generally possess a narrow spread and lie within the permissible price limits, affording immediate execution for small orders.

(ii) The price limits have a detectable effect on liquidity. Roughly five percent of the time there is no quote for at least one side of the market, effectively making such trades unavailable.

(iii) The price limits do appear to improve execution prices of orders. Roughly one fifth of the time, orders which are held receive better execution prices than if they had been permitted to walk through the book.

(iv) Following the completion of order sequences that involve multiple transaction prices (orders that have worked through the book), there appears to be reversion in the revised quotes. Following the last transaction of a buy order, for example, the revised offer quote is generally below the last transaction price. This is consistent

with Glosten's (1991) model in which limit order traders cannot condition on the full size of the order.

Work is underway to extend and refine these conclusions.

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Table 1.

Evolution of the Limit Order Book.

Time 0. Opening trade at ¥1,540.

Time 1.

The Book:	Sell Quantity	Price (¥)	Buy Quantity
	3,000	1,560	
	9,000	1,550	
		1,540	
		1,530	
		1,520	5,000
		1,510	4,000

Quotes: ¥1,520 bid; ¥1,550 offered.

Time 2. Order arrival: 10,000 shares to buy at the market.

Time 3. Transaction: 9,000 shares at ¥1,550

Book:	Sell Quantity	Price (¥)	Buy Quantity
	3,000	1,560	
		1,550	
		1,540	
		1,530	
		1,520	5,000
		1,510	4,000

Quotes: ¥1,550 bid *(warning)*; ¥1,560 offered.

Time 4. Transaction: 1,000 shares at ¥1,560.

Book:	Sell Quantity	Price (¥)	Buy Quantity
	2,000	1,560	
		1,550	
		1,540	
		1,530	
		1,520	5,000
		1,510	4,000

Quotes: ¥1,520 bid; ¥1,560 offered.

Time 5. Order arrival: 2,000 shares to sell at market.

Time 6. Quotes: ¥1,520 bid; ¥1,550 offered *(warning)*.

Time 7. Quotes: ¥1,520 bid; ¥1,540 offered *(warning)*.

Time 8. Quotes: ¥1,520 bid; ¥1,530 offered *(warning)*.

Time 9. Transaction: 2,000 shares at ¥1,520.

Table 2.

Information Available to Market Participants

Participant	*Location*	*Information*	*Order Entry Facilities*
General Public	Display units available by subscription.	Last transaction price, open, high and low prices, special quotes, cumulative volume.	No
Members	Member's Branch Offices	Same as above.	Orders must be routed to member's lead office.
	Member's Lead Office	Above, plus all orders in the book (without order identification)	Yes
	Member booths at TSE	Same as above.	Yes
	Saitori post	Same as above [1]	No [2].
TSE	Monitoring facilities.	Same as above.	No.

Notes:

[1] In exchange-traded issues, Saitori can place orders in the system (on behalf of other members).

[2] In exchange-traded issues, Saitori can display large orders with names.

Table 3.
Summary Statistics.

	Mitsui Construction	*Nikon*	*Japan Air Lines*
Average Daily Closing Price Per Share (¥, January 4, 1990 - March 31, 1990)	1,268	1,521	16,702.
Market Capitalization (March, 1990, Billion ¥)	235	531	2,422
Average Number of Daily Transactions	50.6	93.7	138.7
Ranking among all TSE section 1 stocks in average ¥ transaction volume	413	146	55
Median Transaction Size (100-Share lots)	20	30	2
Average Spread (¥ per Share)	12.55	12.48	109.24
Average Spread Relative to Quote Midpoint (%)	1.00	.83	.66

Table 4.

Times With no Prevailing Regular Quotes.

		Mitsui Construction	*Nikon*	*Japan Airlines*
Times with no regular bid	Number	105	206	134
	Minutes Total	444	731	169
	Percentage of time	3.2	5.3	1.2
Times with no regular offer	Number	131	206	189
	Minutes Total	496	701	199
	Percentage of time	3.6	5.1	1.4
Times with no regular bid and offer	Number	38	66	15
	Minutes Total	295	535	88
	Percentage of time	2.1	3.9	.6

Notes: Table gives number and total duration of times in the sample (January,1990 through March, 1990) when regular quotes were not available. Percentages are relative to the total time that the market was in principle open.

Table 5

Distribution of Duration of Order Sequences.

Duration of order sequence (minutes)	*Mitsui Construction*	*Nikon*	*Japan Air Lines*
0	93.3%	96.6%	98.1%
1	4.5%	1.9%	1.5%
≥2	2.2%	1.5%	.4%

Notes: An order sequence is a sequence of trade and quote records that is presumed to relate to a single order. Table gives relative frequencies of the duration times.

Table 6.

The Performance of Warning and Special Quotes.

			Mitsui Construction	*Nikon*	*Japan Air Lines*
Warning Quotes	No Transaction		28	56	15
	Transaction	Quote Hit	48	76	77
		Not Hit	177	332	253
		Total	225	408	330
	Total		253	464	345
Special Quotes	No Transaction		7	9	1
	Transaction	Quote Hit	14	19	6
		Not Hit	5	10	6
		Total	19	29	12
	Total		26	38	13

Notes: Table reports number of instances in which special and warning quotes occurred, and the outcomes of these occurrences.

Table 7.
Transaction Price/Quote Continuations.

Sample	*Minimum Quote Revision Time (Minutes)*	*Mitsui Construction*	*Nikon*	*Japan Airlines*
All order sequences	0	2.31 (.11)	1.93 (.08)	10.45 (.41)
	2	2.73 (.15)	2.50 (.11)	12.61 (.60)
	5	3.03 (.17)	2.81 (.13)	15.49 (.73)
	10	3.15 (.20)	3.37 (.16)	18.91 (.89)
Order sequences at a single price.	0	2.24 (.11)	1.94 (.08)	10.84 (.40)
	2	2.90 (.15)	2.63 (.11)	13.37 (.54)
	5	3.25 (.17)	2.95 (.13)	16.30 (.73)
	10	3.42 (.20)	3.52 (.16)	19.73 (.88)
Order sequences involving multiple prices.	0	3.89 (.73)	1.57 (.49)	-5.61 (4.04)
	2	-1.19 (1.03)	-.37 (.70)	-18.13 (4.95)
	5	-1.98 (1.12)	-.44 (.79)	-18.89 (6.44)
	10	-3.20 (1.32)	-.21 (1.00)	-17.58 (8.93)

Notes: Table reports average price/quote continuations for all order sequences. A price quote continuation is defined as the last transaction price in an order sequence minus the next regular bid if the order sequence is a sale, and the next regular offer minus the last transaction price if the order is a purchase. T-statistics are given in parentheses.

Table 8.
Variable Descriptions.

Variable	*Definition*
$pend_t$	*signed indicator of pending transaction: +1 if a buy is pending; -1 if a sale is pending.*
q_t^b	*regular bid quote prevailing at end of minute t.*
q_t^a	*regular offer quote prevailing at end of minute t.*
q_t	*quote midpoint,* $(q_t^a+q_t^b)/2$.
r_t	*change in quote midpoint,* q_t-q_{t-1}.
$x_t^{1/2}$	*signed square-root trade variable,* $sign(x_t) \mid x_t \mid^{1/2}$
x_t^0	*trade indicator variable,* $sign(x_t) = +1$ *if the inferred direction of the order is a purchase; -1 if a sale.*
x_t	*total signed trade volume for minute t. (Trades are signed as positive if the inferred direction of the trade is a purchase; negative if a sale.)*

Figure 1.
Daily Closing Price for Mitsui Construction.

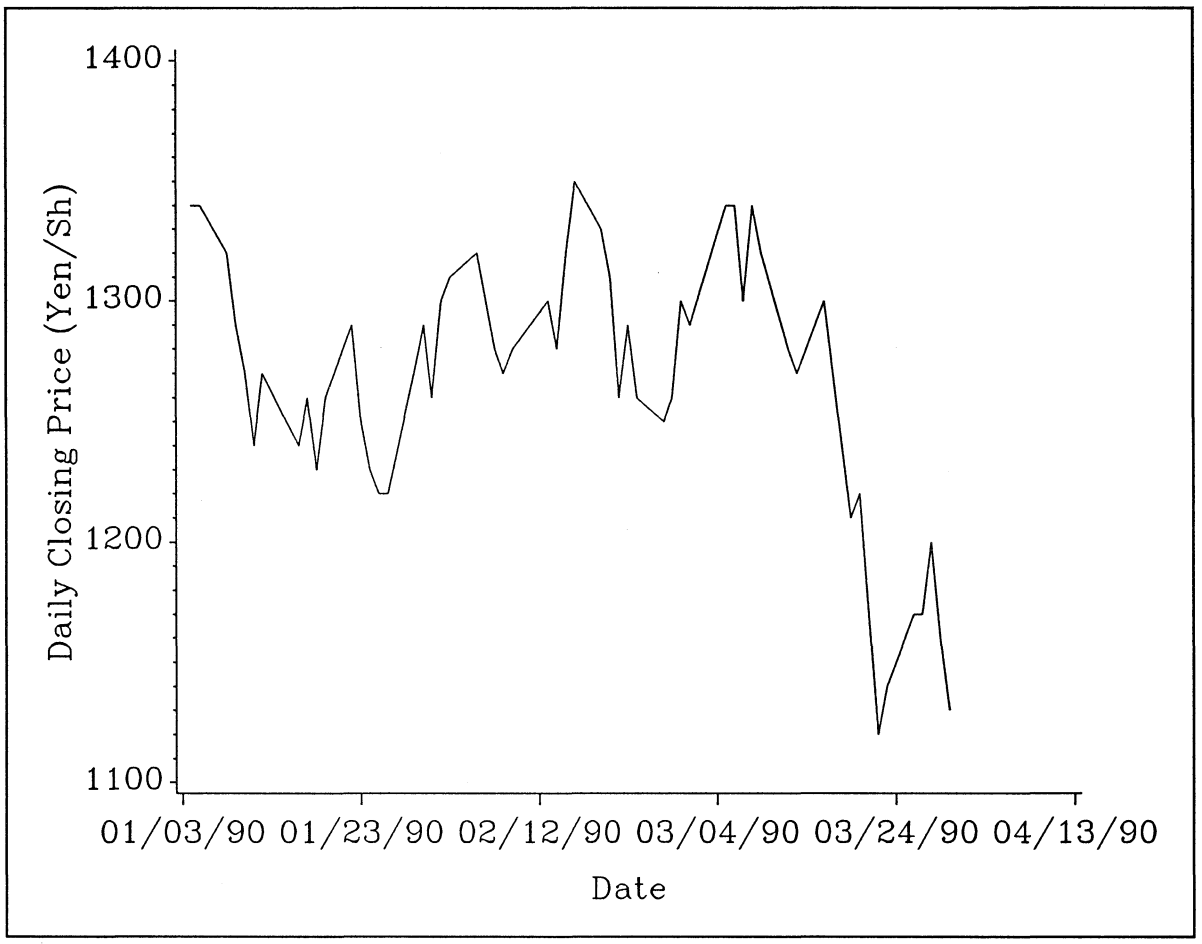


Figure 2.
Daily Closing Price for Nikon.

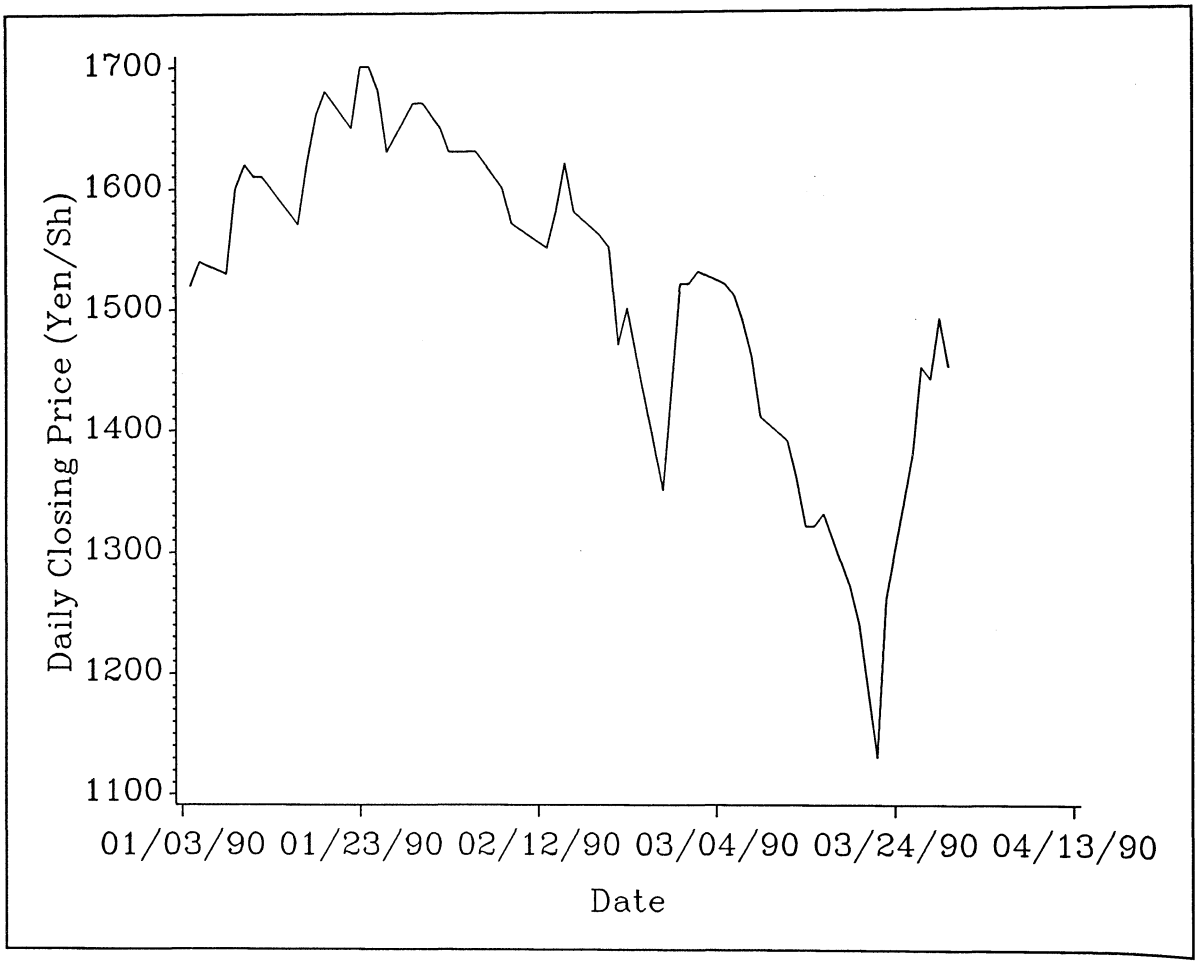


Figure 3.
Daily Closing Price for Japan Air Lines.

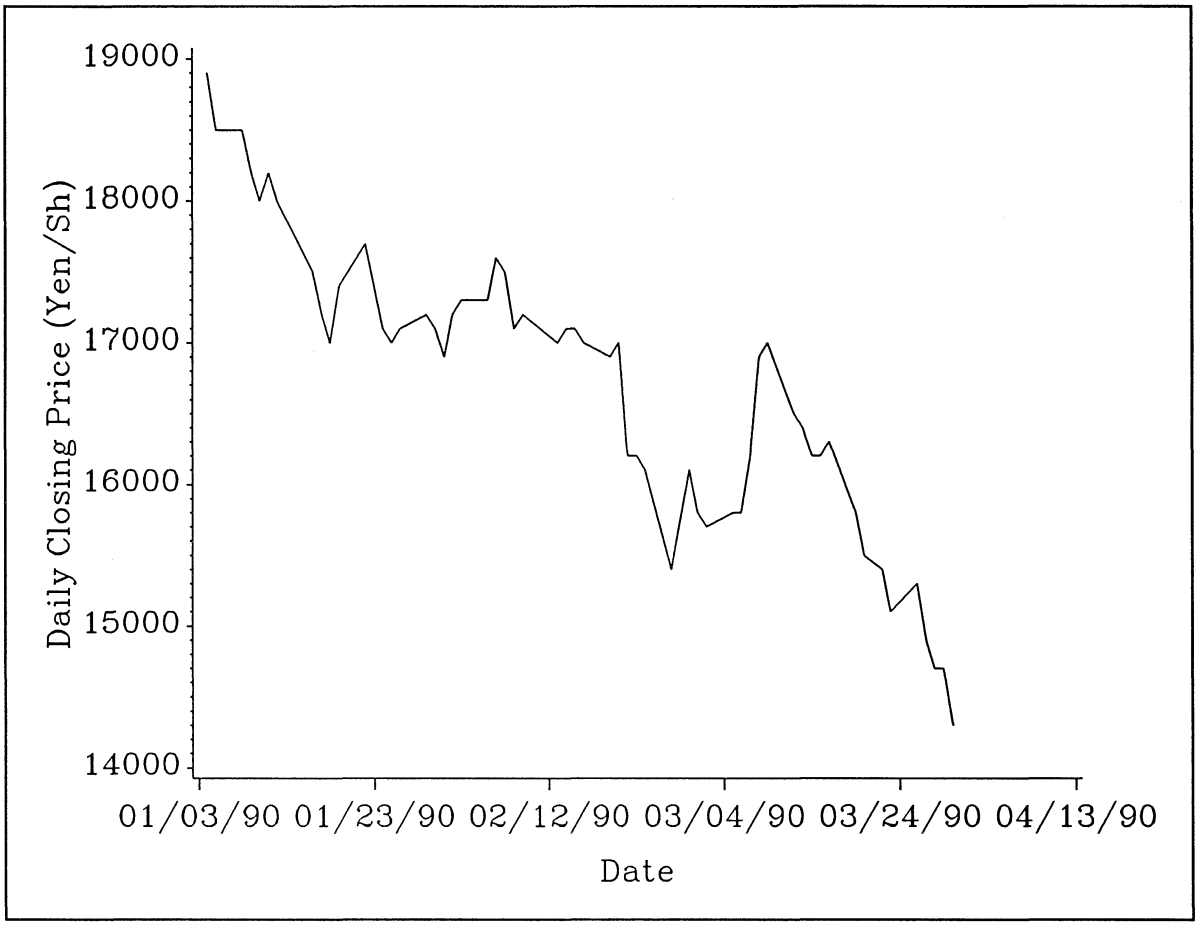


Figure 4.
10-Minute Interval Mean Squared Return.

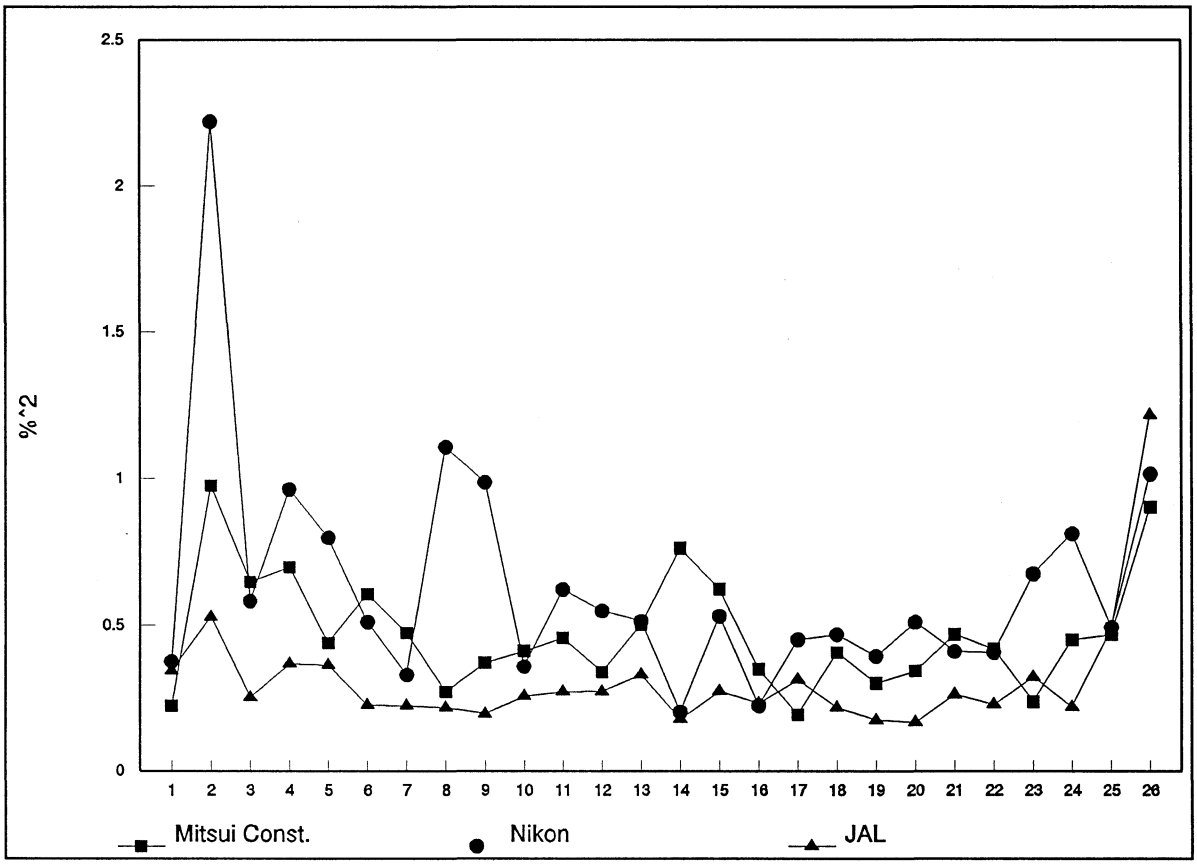


Figure 5.
10-Minute Interval Mean Relative Spread.

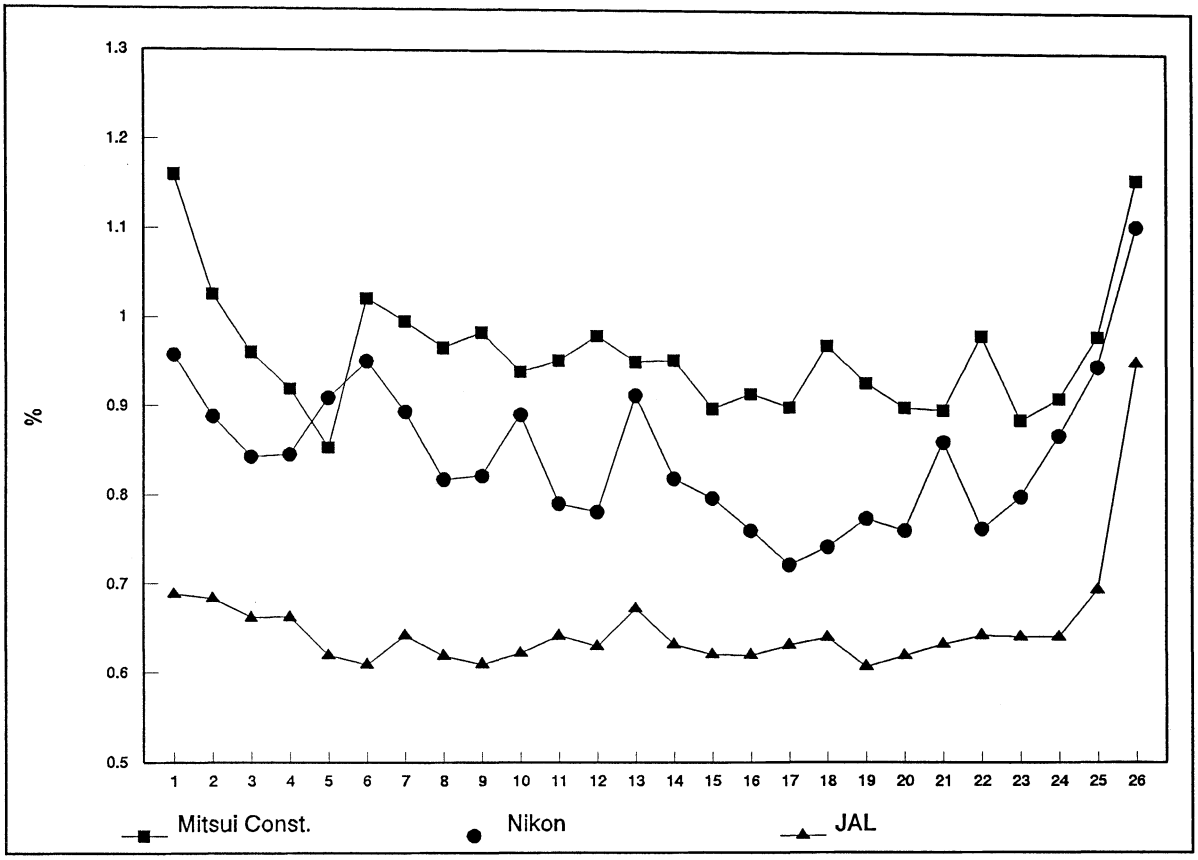


Figure 6.
10-Minute Interval Mean Volume.

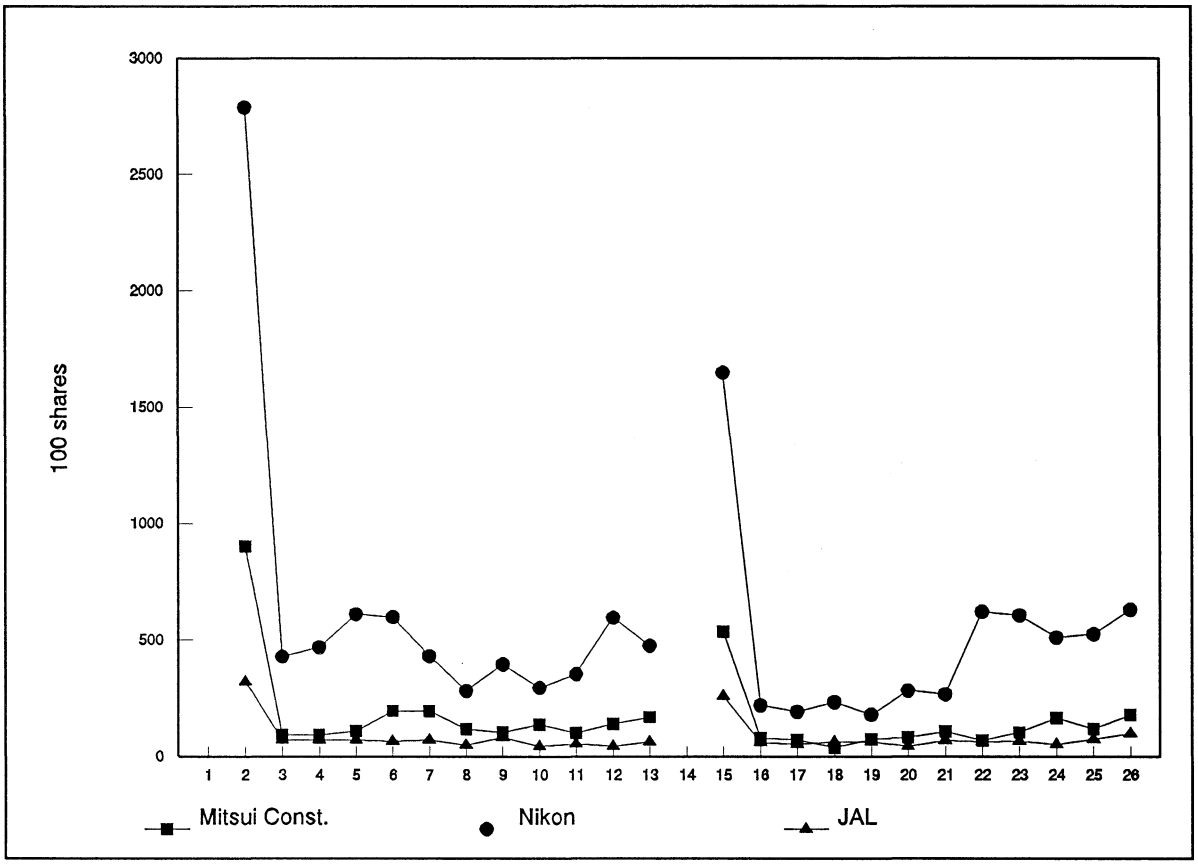


Figure 7.

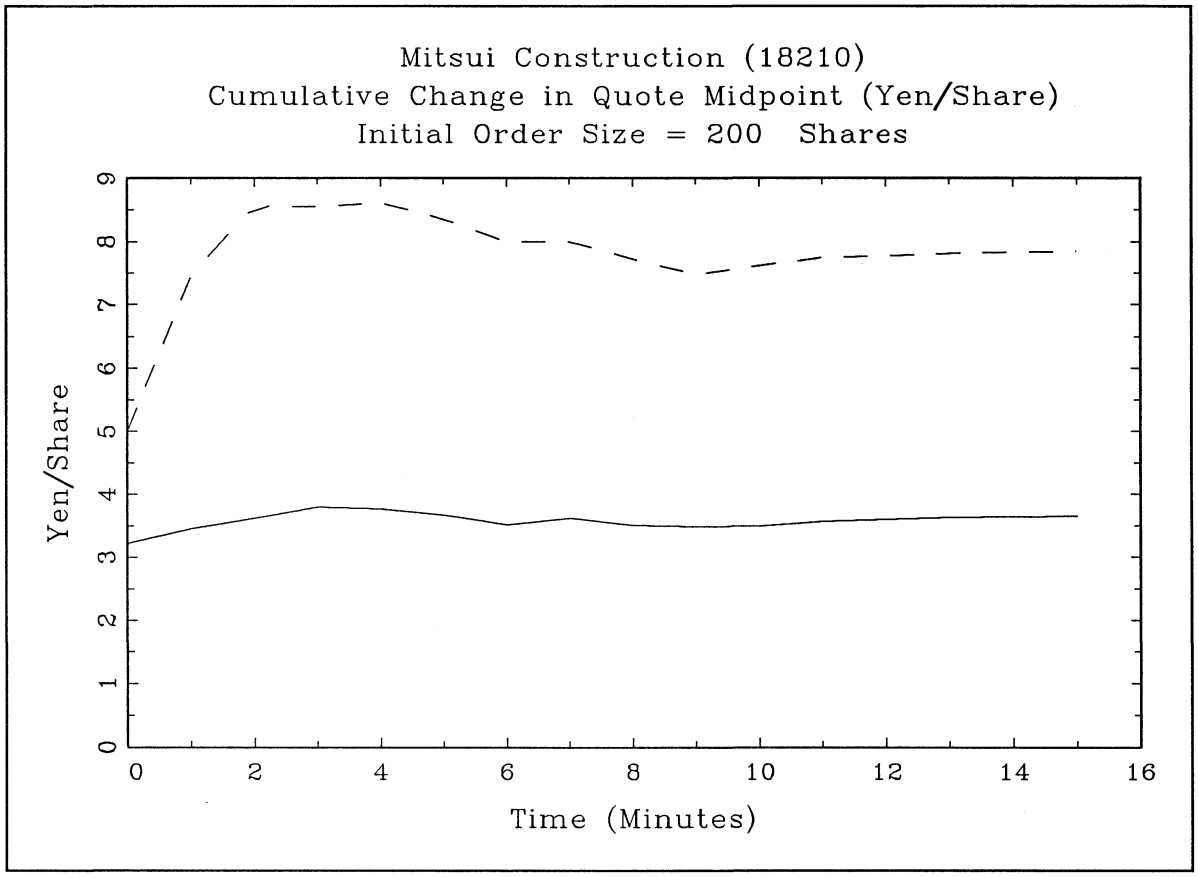

Mitsui Construction (18210)
Cumulative Change in Quote Midpoint (Yen/Share)
Initial Order Size = 200 Shares
Yen/Share
0
1
2
3
4
5
6
7
8
9
0
2
4
6
8
10
12
14
16
Time (Minutes)

Figure 8.

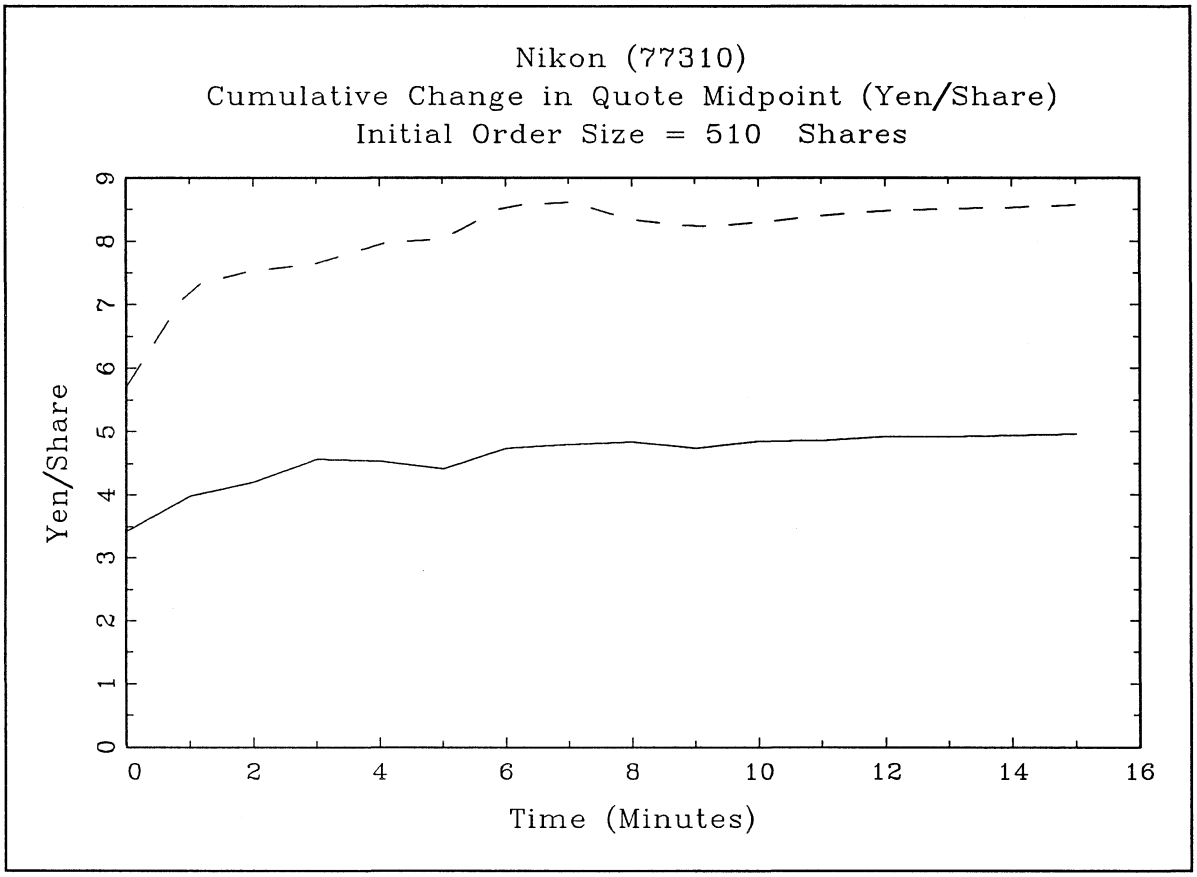
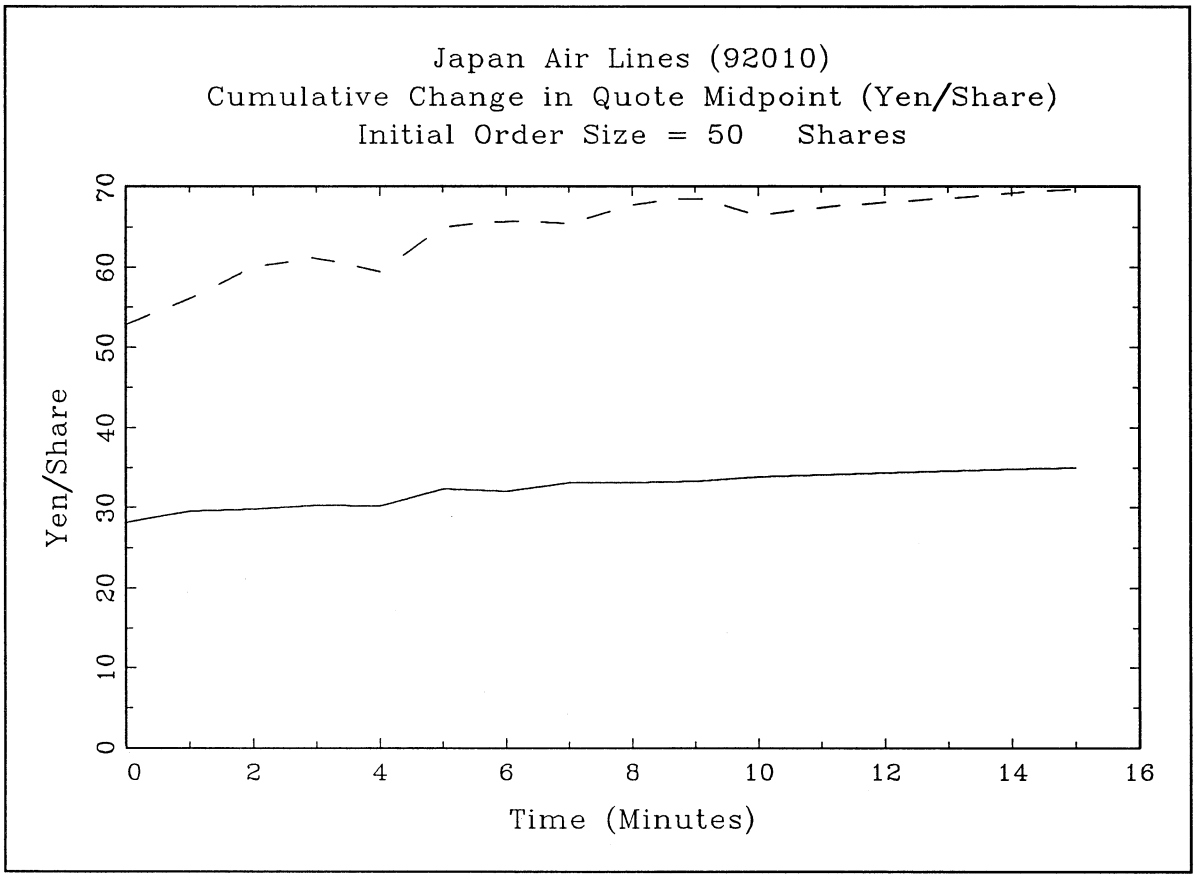

Nikon (77310)
Cumulative Change in Quote Midpoint (Yen/Share)
Initial Order Size = 510 Shares
Yen/Share
0
1
2
3
4
5
6
7
8
9
0
2
4
6
8
10
12
14
16
Time (Minutes)

Figure 9.


Japan Air Lines (92010)
Cumulative Change in Quote Midpoint (Yen/Share)
Initial Order Size = 50 Shares
Yen/Share
0
10
20
30
40
50
60
70
0
2
4
6
8
10
12
14
16
Time (Minutes)