Private Information, Trading Volume, and Stock-Return Variances

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New evidence is provided on the determinants of stock-return variances. First, when the Tokyo Stock Exchange is open on Saturday, the weekend variance increases; weekly variance is unaffected, however, despite an increase in weekly volume. Second, the listing of U.S. stocks in Tokyo substantially increases the number of trading hours, but Tokyo volume is negligible for these U.S. stocks and their 24-hour variance is unaffected. The overall results are consistent with the predictions of private-information–based rational trading models, but inconsistent with both the irrational trading noise and public-information hypotheses.

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Return variances for common stocks are higher during trading than nontrading hours [Fama (1965), Granger and Morgenstern (1970), Oldfield and Rogalski (1980), Christie (1981)]. The higher return variances are not fully explained by more public information released during trading hours [French and Roll (1986)]. This article provides new evidence on the determinants of stock-return variance, and in particular on the relation between variance, private information, and trading volume.

The Tokyo Stock Exchange is the world's largest exchange,[1] and has two institutional features that provide an almost ideal experiment for our study. First, until recently, the Tokyo Stock Exchange was open for half a normal trading day approximately three Saturdays per month, and closed on other Saturdays. By examining the variance of stock returns over weekends with and without Saturday trading, we can analyze the effects of trading on stock-return variance, holding constant the normal flow of public information. This Tokyo weekend analysis is similar to French and Roll (1986), who examine how the variance of New York Stock Exchange (NYSE) returns was affected when the NYSE closed on 24 Wednesdays in 1968 to clear a paperwork backlog. The present study, however, examines Tokyo trading volume as well as return variances, and it is based on a much longer time series of data. The volume data allow us to study the separate effects of trading volume and trading hours on stock-return variance.

A second feature of the Tokyo Stock Exchange is that trading takes place when the U.S. exchanges are closed, and vice versa.[2] Thus, U.S. stocks traded on the Tokyo exchange or Japanese stocks traded on U.S. exchanges have increased trading hours. The volume of a stock traded on a foreign exchange is light, however, in relation to its volume traded in the domestic market. Internationally listed firms, therefore, permit study of the effects of increasing the number of available trading hours, holding constant total trading volume.

When the Tokyo Stock Exchange is open on Saturday, the weekend (i.e., Friday close to Monday close) variance of Japanese stock returns is roughly twice as large as when the exchange is closed on Saturday. The weekly variance does not increase, however, even though Saturday trading increases weekly share volume. The increase in variance over weekends with Saturday trading appears to be offset by lower variance on surrounding days.

[1] The total market value of equities listed on the Tokyo Stock Exchange in December 1987 was $2515 billion, 13 percent larger than on the New York Stock Exchange. See Nomura Research Institute (1988, p. 21).

[2] On weekdays, the Tokyo Stock Exchange is open from 9 to 11 A.M. and from 1 to 3 P.M. local time. Since Tokyo is 14 hours ahead of New York, this corresponds to 7 to 9 P.M. and 11 P.M. to 1 A.M. Eastern Standard Time. Saturday trading hours on the Tokyo Stock Exchange were from 9 to 11 A.M. local time.

The higher weekend but unchanged weekly variance is consistent with the analysis of Kyle (1985), who provides a structural link between the volume of trading and stock-return variance. Kyle models the trading strategy of uninformed liquidity traders and traders with private information, and shows that variance is caused by private information revealed through trades. An alternative explanation for the higher weekend variance is that traders overreact to each other's trades. Although this irrational trading noise hypothesis is loosely specified, several versions are inconsistent with the data. For example, if irrational trading noise is related to either hours or volume of trading, then weeks with Saturday trading should have higher weekly variance. We also reject the view that the higher variance during exchange trading hours is due to increased public-information releases.

Secondary listing on a foreign stock exchange does not affect the pattern or increase the level of stock-return variance. Moreover, U.S. firms traded on the Tokyo exchange do not have a higher weekend variance when the Tokyo exchange is open on Saturday. Both pieces of evidence suggest that there is no causal relation between trading hours and stock-return variance as would be expected if irrational noise is related to the number of hours of trading. A significant volume of trading is required for private information to be incorporated into stock prices. This is consistent with the analysis of Admati and Pfleiderer (1988), who conclude that it is optimal for traders with private information (and a low intraday rate of information decay) to execute their trades during periods when uninformed liquidity traders are normally most active.

In Section 1, the article's testable propositions are discussed. The results are presented in Section 2, and the conclusions in Section 3.

1. Theory and Empirical Implications

In this section, the role of private information in generating variance is discussed first. The theoretical work of Kyle (1985) and Admati and Pfleiderer (1988) provides a useful framework for developing our predictions. These predictions of the private-information hypothesis are then contrasted with the predictions of the irrational trading noise and public-information hypotheses.

1.1 Private information and stock-return variances: background

The recent work of Kyle and Admati and Pfleiderer provides a structural link between private information, trading volume, and stock-return variances. Kyle models a market with three types of traders:

informed investors who trade strategically to maximize the profits from their private information, random liquidity traders whose buy and sell orders arrive randomly and exogenously through time, and a specialist who has no private information, but learns from price and volume changes. In this model, private information is incorporated into prices over time at a constant rate per trading hour, with the price at the end of the relevant trading interval reflecting all private information. The variance of returns over the entire trading interval reflects only the arrival of new information. Within the trading interval, the variance is affected by the volume of trade by random liquidity traders because specialists cannot distinguish between informed and liquidity trades. Thus, trading noise (i.e., variance in excess of that generated in a fully revealing rational expectations model) arises endogenously in this model because price movements and associated volumes are noisy signals for the information of informed traders. This trading noise is rational, however, since the price established by the specialist is an unbiased estimate of the true price conditional on his information set, and the trading noise does not result in pricing errors that are systematically reversed. The variance generated in this model is associated with trading volume, and trading hours per se do not cause variance.

In related work, Admati and Pfleiderer (1988) extend Kyle's analysis to include a fourth class of traders called discretionary liquidity traders. Discretionary liquidity traders have no private information. Unlike the random liquidity traders, these traders have some discretion over the timing of their trades. Admati and Pfleiderer show that, in general, trades of both discretionary liquidity traders and informed traders will cluster, with each group preferring to trade when the market is thick. This clustering of trades causes variance to be highest when trading is most active. Only random liquidity traders and informed traders for whom the intraday rate of decay for private information is high will trade during inactive periods when markets are thin. As in Kyle's model, returns are serially uncorrelated (conditional on the uninformed traders' information set), and trading hours per se do not cause variance.

1.2 Saturday trading: testable propositions

Although neither Kyle nor Admati and Pfleiderer explicitly examine the impact of increased trading hours, their analyses provide useful intuition. Specifically, Kyle's model suggests that opening the Tokyo exchange on Saturday should not change the variance of weekly returns as long as the total amount of new public and private information is unaltered. Within the week, however, a change in the pattern of daily variances would be expected, reflecting the effects of the new trading

hours on the arrival of traders. If the normal volume of liquidity trading on Saturdays is substantial, informed traders will shift some of their trades from the surrounding days to Saturday. If some discretionary liquidity traders (as in the Admati and Pfleiderer model) also move their trades to Saturday, the shift of informed trades will be reinforced. This shift of informed trades will cause the return variance to be larger during weekends when the exchange is open on Saturday because of the additional private information revealed through trading during this interval. Assuming that the arrival of private informtion to informed investors is unaffected by Saturday trading, variance will be lower on surrounding days because of the reduction in the amount of information revealed through informed trades.

Our tests also provide information on the nature of traders' private information. The variances examined in this article are for a market index, a variety of industry indexes, and individual Japanese stocks that are also listed on the NYSE. If the private information revealed through trading is predominantly firm-specific, significant increases in the weekend return variances for individual stocks are expected when there is Saturday trading. Since firm-specific information is effectively diversified away in large portfolios, however, no change in the variance of the industry indexes or the market index is expected. On the other hand, if private information contains firm-specific, industry, and marketwide components, then the weekend return variances will also increase for the industry and market indexes.

Saturday trading and irrational trading noise. In contrast to analyses in which variance is caused by private information, the possibility that variance is caused by the overreaction of traders to each other's trades has been raised by a number of authors [e.g., Shiller (1981, 1986), Black (1986), French and Roll (1986), and Summers (1986)]. Although the specific model underlying irrational trading noise is often imprecise, Tokyo Saturday trading provides information about several plausible versions.

Permanent trading noise. French and Roll (1986, p. 14) assume that any permanent irrational trading noise is related to the number of trading hours. Unlike the private-information view, their characterization of irrational trading noise predicts a positive relation between the weekly variance and the amount of trading time in a week. For Japanese stocks, weeks with Tokyo Saturday trading should have higher variance than weeks with no Saturday trading. Moreover, if irrational trading noise is related only to the amount of trading time, variances on days surrounding weekends should not be affected by whether or not there is Saturday trading. An alternative character-

ization of permanent irrational trading noise is that it is positively related to trading volume. Under this view, if the additional weekend volume caused by Saturday trading also increases the weekly volume for weeks with Saturday trading, then an increase in weekly return variance is predicted.

Temporary trading noise. If irrational trading noise is temporary and if the increased variance generated by Saturday trading is attributable to pricing errors that are reversed in the following week, the covariance between the Saturday return and the return early in the following week will be negative. We investigate several aspects of this issue, although a detailed model of how trading noise affects the autocorrelation structure of returns is beyond the scope of this paper.

Saturday trading and public information. Our tests also provide insights into whether the higher variance during trading hours is caused by public-information releases. Saturday is not a normal business day in Japan. Although many Japanese companies are open on some Saturdays, the Saturdays that nonfinancial firms are open appear to be independent of the Saturdays the exchange is open.[3] In addition, Japanese corporations infrequently release information on a Saturday. This reduces the likelihood that any discretionary public-information releases will occur or be timed to whether the exchange is open or closed on Saturday.[4] Thus, if variance is caused primarily by public information, there should be no difference between the weekend return variance with and without Saturday trading.

1.3 The effect of listing on a foreign exchange

Trading in Tokyo takes place when U.S. exchanges are closed, and vice versa. Thus, U.S. stocks traded on the Tokyo Stock Exchange and Japanese stocks traded in the United States have increased trading hours. These extended trading hours provide the basis for several additional tests.

If a stock is traded in more than one market, liquidity traders will concentrate their activity in the market with the lowest transaction costs. For stocks that are internationally listed, transaction costs are likely to be lower on the domestic than on the foreign exchange.[5]

[3] Some financial institutions, including banks and foreign exchange traders, are open on the same Saturdays as the exchange. In addition, the financial wire service is operating whenever the exchange is open.

[4] This summary is based on informal interviews with individuals at Japanese banks, brokerage firms, and the Tokyo Stock Exchange.

[5] For example, in a speech delivered to the Brookings Institute, Mr. Kurokawa, Chairman of Nomura Securities International, stated: "Although stocks of 93 foreign companies are listed on the [Tokyo

Since discretionary liquidity traders in rational trading models prefer to cluster their trades, most liquidity trading would be expected to occur on the lower-cost domestic market. Since informed traders attempt to conceal their identity by trading when liquidity trading is normally high, informed traders having a sufficiently low intraday decay rate for private information will also concentrate their trades in the domestic market. Thus, the Admati and Pfleiderer model suggests that volume will be lower in the foreign than in the domestic market, and that international listing of a common stock will have little effect on either the level or the pattern of the stock-return variance. With few informed traders active in the foreign market, the extended trading hours will have little effect on return variance.

Secondary listing on a foreign exchange and permanent irrational trading noise. If irrational trading noise is permanent and positively related to the number of trading hours, a stock's overnight return variance will increase when the firm is listed internationally. Similarly, U.S. stocks traded in Tokyo will have higher weekend return variances when the exchange is open on Saturday. If irrational trading noise is positively related to volume, however, and secondary listing does not increase total trading volume, return variance will be unchanged. Under these conditions, the predictions of the volume-related irrational trading noise hypothesis and the private-information hypothesis are the same.

2. Empirical Results

2.1 General characteristics of returns on the Tokyo Stock Exchange Composite Index

Table 1 shows the pattern of daily trading volume on the Tokyo Stock Exchange and the pattern of daily return variance for the Tokyo Composite Index.[6] The variance of the return on the Tokyo Composite Index is no higher over a typical weekend than over a single trading day, even though the weekend is two or three times as long.[7] The

Stock Exchange], their trading volume in Tokyo is not very heavy. The reason for this is that large institutional investors tend to trade foreign stocks in each mother country, where there is greater liquidity. A major portion of the orders from non-residents is directed to each stock's home market." See Kurokawa (1988).

[6] The Tokyo Stock Exchange Composite Index (TOPIX) is a value-weighted portfolio of all stocks listed on the first section of the exchange. The first section includes most active issues traded in Japan (1055 issues in 1986). The index is not adjusted for dividend payments. See the Tokyo Stock Exchange (1987). Our sources for the Tokyo return data are the Nikkei Telecom data retrieval service and Nomura Securities.

[7] The Monday return variance is calculated using two-day returns (measured from Saturday close to Monday close) for weekends when the exchange is open on Saturday and three-day returns (measured from Friday close to Monday close) when the exchange is closed on Saturday.

Table 1
Variance of returns and trading volume for the Tokyo Stock Exchange Composite Index by day of week, January 1, 1973, to January 31, 1989

Day of week	Ratio of return variance to average weekday return variance	Ratio of trading volume to average weekday trading volume
Monday	0.96	0.77
Tuesday	0.91	0.91
Wednesday	1.04	1.05
Thursday	0.99	1.00
Friday	1.01	1.04
Saturday	0.63	0.60
One-day holiday	1.30	0.86
Year-end six-day holiday	1.34	0.51

Monday's return is based on Saturday close to Monday close for weeks when the exchange was open on Saturday and Friday close to Monday close for other weeks. Weekday (Tuesday through Friday) returns are 24-hour close-to-close returns. The average weekday return variance is 4.70×10^{-5}. The average weekday volume is 441,946,000 shares.

variance of returns is also lower over holidays when the Tokyo exchange is closed than when it is open. For example, the variance of two-day returns including a one-day holiday is only 30 percent higher than the variance over a normal trading day, and the variance of seven-day returns including a six-day year-end holiday is only 34 percent higher than the variance over a normal trading day. This evidence of higher stock-return variance during Tokyo exchange trading hours than during nontrading hours is similar to the relation between variance and exchange trading hours found in previous studies of U.S. markets.

From January 1973 through January 1989, the Tokyo Stock Exchange was open for half a normal trading day on 585 Saturdays and closed on 254. From Table 1, both the average volume and the return variance are lower on trading Saturdays than on any of the five weekdays. However, the return variance as a fraction of the normal weekday return variance, 0.63, and the trading volume as a fraction of the normal weekday trading volume, 0.60, are both similar to the relative number of trading hours, 0.50. Thus, although Saturday is not a normal business day, neither the trading volume nor the return variance is lower per hour of trading on Saturday than during the rest of the week. This suggests that the release of public information is not the primary determinant of stock-return variances.

2.2 Saturday trading on the Tokyo Stock Exchange

Methodology. Our tests compare the volume and variance for intervals (e.g., Friday close to Monday close) with Saturday trading to the volume and variance over the same intervals without Saturday trading. As discussed in the Appendix, estimation procedures that give equal

Table 2
Ratio of return variances and trading volumes for the Tokyo Stock Exchange Composite Index for periods near Saturdays when the exchange is open in relation to periods near Saturdays when the exchange is closed, January 1, 1973, to January 31, 1989

	Ratio of variances	Ratio of volumes
Periods including Saturdays		
Friday to Monday	2.12*	1.92‡
	(0.001)	(0.001)
Friday to Tuesday	1.21	1.46‡
	(0.156)	(0.001)
Friday to Wednesday	0.91	1.32‡
	(0.622)	(0.001)
Wednesday to Wednesday	0.87	1.21‡
	(0.744)	(0.002)
Periods preceding Saturdays		
Wednesday to Friday	1.25	1.04
	(0.826)	(0.284)
Periods following Saturdays		
Monday to Wednesday	0.72†	1.06
	(0.094)	(0.181)

p values are in parentheses. For periods including Saturdays, the variance ratio *p* value is the fraction of the empirical bootstrap distribution that is less than 1.0; for periods excluding Saturdays, the variance ratio *p* value is the fraction of the empirical bootstrap distribution that exceeds 1.0. For the volume ratios, the *p* values are the tail probabilities of the normal distribution for a two-tailed difference of means test. All returns are calculated with closing prices.

Number of observations: 585 Saturdays with trading and 254 Saturdays with no trading.

* One-tailed test significantly greater than 1.0 at .01 level using a bootstrap algorithm.

† One-tailed test significantly less than 1.0 at .1 level using a bootstrap algorithm.

‡ One-tailed test significantly greater than 1.0 at .01 level using difference of means *t*-test.

weight to each observation yield severely downward-biased estimates of the volume and variance ratios. This bias arises because the relative frequency of nontrading Saturdays doubled after August 1986,[8] and annual trading volume and return variance increased dramatically at that time. Our estimation procedures weight the observations to provide unbiased estimates of the volume and variance ratios. These procedures are described in the Appendix.

Effects of Saturday trading on trading volume. Table 2 shows trading volume for weeks with and without Saturday trading.[9] The average combined Saturday and Monday volume when there is Saturday trading exceeds the average Monday volume when there is no Saturday trading by 92 percent. The *t*-statistic for the difference is

[8] The Tokyo Stock Exchange was closed on the third Saturday of the month from January 1973 to July 1983, on the second Saturday of the month from August 1983 to July 1986, and on the second and third Saturdays of the month from August 1986 through January 1989. The exchange is now closed on all Saturdays.

[9] Data for 1987 exclude October to insulate the results from any undue influence of the global market crash. The conclusions are not sensitive to this deletion.

11.32. The average weekly volume (measured Wednesday close to Wednesday close) centered on a trading Saturday is 21 percent higher than the average weekly volume centered on a nontrading Saturday, and the difference is statistically significant at the .01 level using a one-tailed test ($t = 2.84$). The higher weekly volume appears largely attributable to the higher weekend volume. Although the average trading volume over our sample period is from 2 to 6 percent higher for each weekday near a Saturday when the exchange is open, the differences are not statistically significant.

Effects of Saturday trading on return variance. From Table 2, the weekend return variance for the Tokyo Composite Index, measured from Friday close to Monday close, is 112 percent higher for weekends with Saturday trading than for weekends without Saturday trading. Using a bootstrap algorithm,[10] the variance ratio of 2.12 is statistically significantly greater than 1.0 at the .01 level. This evidence is inconsistent with the hypothesis that the higher variance during trading hours is caused by a greater flow of public information, since the likelihood of a public-information release on a Saturday when the exchange is open does not differ from the corresponding likelihood on a Saturday when the exchange is closed. Our conclusion about the significance of the increase in the weekend variance does not appear to be sensitive to the bootstrap test procedure. To examine the robustness of the results, we use a squared ranks test for equal variances to calculate significance levels for all variance ratios in Table 2.[11] The qualitative results are unchanged.

Despite the increased weekend variance, it does not appear that the weekly return variance on the Tokyo Stock Exchange Composite Index is higher for weeks with Saturday trading than for weeks without Saturday trading. The ratio of weekly return variances (measured Wednesday close to Wednesday close) for weeks with and without Saturday trading is 0.87, which is not statistically different from 1.0 at the .1 level using the bootstrap test.[12]

Our finding that the increased weekly volume and number of trading hours do not increase the weekly return variance helps distinguish between competing explanations for why variance occurs. The finding is consistent with rational trading models such as Kyle's. These models predict that the weekly variance will be unaffected if there is no change in the arrival of private information. Our results do not support

[10] The algorithm for calculating bootstrap p values is provided in the Appendix.

[11] The squared ranks test is described in the Appendix.

[12] Fractiles for the empirical distribution of the bootstrap weekly variance ratios are 0.01 (0.59), 0.05 (0.69), 0.1 (0.73), 0.9 (1.14), 0.95 (1.22), 0.99 (1.33).

the hypothesis that irrational trading noise is permanent and proportional to either hours of trading or trading volume. If irrational trading noise is proportional to trading volume, the weekly volume and variance ratios should be equal. Using a bootstrap procedure, we reject this hypothesis at the .02 level.

The evidence also does not support the view that the higher weekend variance is generated by temporary pricing errors that are reversed in the following week. For weeks with Saturday trading, the correlation between the Friday close to Saturday close return and the Saturday close to Wednesday close return on the Tokyo Composite Index is .01, and is not significantly different from zero.[13] Stock indexes typically exhibit positive serial correlation caused by the nonsynchronous trading of the stocks in the index. As discussed below, we have return data for eight Japanese stocks. The average correlation between the Friday close to Saturday close return and the Saturday close to Wednesday close return is −.08 (three of the correlation coefficients are significant at the .05 level).

There is some evidence that the dissipation of the variance generated during Saturday trading is explained by reduced variance for the weekdays immediately following Saturdays when the exchange is open. From Monday close to Wednesday close, the ratio of the variance with Saturday trading to the variance without Saturday trading is only 0.72, with a bootstrap p value of .09. Individually, the Tuesday and Wednesday variance ratios are 0.80 and 0.70.[14] A lower return variance but unchanged volume on individual weekdays following Saturday trading is inconsistent with the hypothesis that irrational trading noise is related to volume. Rather, the variance ratios suggest that privately informed traders accelerate some of their trades from Tuesday and Wednesday to the preceding Saturday when there is Saturday trading. The variance ratio for the preceding Wednesday through Friday is 1.25 (with a p value of 0.83) and suggests that informed traders do not postpone their trades from Thursday or Friday until Saturday.

Results for industry indexes and individual stocks. In addition to daily return data for the Tokyo Stock Exchange Composite Index, our tests use daily return data from July 1982 through January 1989 for 28 Japanese industry indexes and eight Japanese stocks that are also listed on the NYSE. This period includes 219 Saturdays when the Tokyo exchange was open and 119 Saturdays when it was closed.

[13] The correlation is similar if the return from Saturday close to the following Friday is substituted for the Saturday close to Wednesday close return.

[14] Consistent with the conclusion that variance is lower following Saturday trading, Puffer (1989) finds that the variance ratio for the period from Monday open to Monday close is 0.72 for the Nikkei index from 1985 to 1989.

Table 3
Ratio of variances for 28 industrial group indexes and 8 individual stocks for periods including Saturdays when the Tokyo Stock Exchange is open and periods including Saturdays when the exchange is closed. All returns are calculated with closing prices, July 1, 1982, to January 31, 1989

	Friday to Monday	Friday to Tuesday	Friday to Wednesday	Wednesday to Wednesday
	Panel A: 28 Industrial groups			
Average	2.18	1.49	1.30	1.17
Marine	2.88†	1.25	1.62*	1.03
Mining	2.38†	2.19†	1.45*	1.79†
Construction	2.33†	1.97†	1.22	0.81
Foods	2.44†	1.53	1.40	1.32
Fiber/textiles	2.28†	1.52*	1.14	1.09
Pulp/paper	2.41†	1.20	1.07	1.40
Chemicals	2.21†	1.31	1.32	1.26
Oil/coal	2.11†	1.78†	1.66*	1.77†
Gum	2.64†	2.08†	1.77*	0.97
Glass/cement	2.07†	1.46*	1.14	0.98
Steel	2.74†	1.66*	0.98	0.98
Nonsteel	2.66†	1.53*	1.57*	1.29
Metal	1.96†	2.51†	1.90†	1.22
General machinery	1.76†	1.45*	1.28	1.08
Electrical	1.79*	1.38	1.25	0.90
Shipbuilding/automobile	2.56†	1.53*	1.44*	1.23
Precision instruments	1.93†	1.46*	1.24	0.94
Other manufacturing	1.94†	1.41	1.47*	1.12
Trade/retail	2.37†	1.72*	1.37	1.05
Financial	1.70	0.96	1.84	0.59
Real estate	2.05†	1.58*	1.25	1.39
Transportation: Land	2.05†	1.02	0.84	0.91
Sea	2.14†	1.49*	1.40	1.46*
Air	1.53	0.89	0.66	0.75
Warehouses	1.64*	1.31	1.69*	1.93†
Communication	1.82*	0.86	1.03	0.85
Utilities	2.61†	1.06	0.97	1.49*
Leisure	2.03†	1.57†	1.55†	1.23
	Panel B: 8 Individual stocks			
Average	1.80	1.38	1.17	0.99
Hitachi	2.01†	1.27	1.19	1.08
Matsushita	1.73*	1.37	1.31	0.95
Sony	1.46	1.23	0.83	0.77
Honda	1.32	1.27	1.12	0.93
TDK	1.91*	1.52*	1.28	1.11
Pioneer	1.88†	1.43*	1.26	1.20
Kubota	1.99†	1.63*	1.40	1.00
Kyocera	1.92†	1.30	0.98	0.88

Number of observations: 219 Saturdays with trading, 119 Saturdays with no trading.

* One-tailed test significant at .05 level using a bootstrap algorithm.

† One-tailed test significant at .01 level using a bootstrap algorithm.

From Table 3, the average weekend return variance with Saturday trading is 118 percent higher for the 28 industry indexes and 80 percent higher for the eight Japanese stocks than the weekend return variance with no Saturday trading. The weekend return variance is greater when there is Saturday trading for all 28 industry indexes and for all eight of the internationally traded Japanese stocks. The ratios

for these industry indexes and the individual stocks are strikingly similar to the results for the composite index, suggesting that private information revealed through trading has marketwide, industry, and firm-specific components.

2.3 Internationally listed firms

Under the private-information hypothesis, the addition of exchange trading hours when liquidity traders are normally inactive should have little impact on the rate of dissemination of private information. Informed traders having a sufficiently low intraday rate of decay in the value of their private information will postpone their trades to periods when liquidity traders are more active. Thus, the listing of an NYSE stock on the Tokyo exchange accompanied by inactive trading on the Tokyo exchange should not significantly affect the stock's overnight variance. An alternative to the private-information hypothesis is that irrational trading noise causes variance and is related to the number of hours of trading. In this view, a stock's overnight return variance should rise when a firm is listed internationally. If irrational trading noise is positively related to volume, however, and secondary exchange volume is negligible, there will be no change in the overnight return variance.

Tests using a matched sample. The ratios of trading day (open to close) to 24-hour (close-to-close) NYSE return variance are examined for 21 stocks with a primary listing on the NYSE and a secondary listing on the Tokyo Stock Exchange and compared with the ratios for a matched sample of firms that are not listed internationally.[15] The matched sample is chosen on the basis of both industry and size.[16] Although many of the 21 internationally listed U.S. firms have large international operations, the trading volume in Tokyo is small in relation to the NYSE volume. The average trading volume per issue of non-Japanese stocks listed on the Tokyo Stock Exchange increased dramatically between 1980 and 1986, from approximately 150 shares per day to about 30,000. Even in the latter period, however, Table 4 indicates that the Tokyo volume is less than 10 percent of the average NYSE volume for U.S. stocks having secondary listings on the Tokyo exchange.

[15] The matched sample is constructed from firms not traded in either Tokyo or London. The sample of internationally listed U.S. firms includes all U.S. firms that were listed on both the NYSE and the Tokyo Stock Exchange for at least 40 trading days between 1980 and 1986.

[16] For each of the 21 internationally listed U.S. firms, we choose the firm in the same Value Line industry classification with the closest match in line of business and market value. The results are similar using matched pairs that have the closest market value within two- or four-digit SIC categories.

Table 4
Trading volume of internationally listed stocks on the foreign market as a percentage of their domestic trading volume, 1982–1986

Year	Average volume of U.S. stocks on the Tokyo Stock Exchange as a percentage of their volume on the NYSE,[1] %	Average volume of Japanese stocks on the NYSE as a percentage of their volume on the Tokyo Stock Exchange, %
1982	0.17	4.01
1983	0.59	5.14
1984	0.53	6.67
1985	9.36	9.48
1986	7.83	2.74

Source: *Manual of Securities Statistics,* Nomura Research Institute, Tokyo, Japan.

[1] Volume of U.S. stocks on the Tokyo Stock Exchange is estimated as the average share volume of all non-Japanese stocks on the Tokyo exchange.

From Table 5, the average ratio of within-day (open-to-close) to 24-hour (close-to-close) return variance for the internationally traded U.S. stocks is 0.83, which is almost identical to the corresponding average ratio for the matched non-internationally-traded stocks, 0.82. Further, results for individual firms indicate that international listing does not result in a greater fraction of a firm's total variance occurring overnight during the period of foreign trading hours. For each internationally traded firm and its match, we examine the ratio of the trading day to 24-hour variance. The statistical significance of the difference is assessed using an asymptotic test statistic based on a general convergence result for the distribution of a function of random variables.[17] Only one of the 21 internationally traded stocks has a trading day to 24-hour variance ratio significantly different from that of its matched pair at the .05 level. These results are consistent with the private-information hypothesis and the hypothesis that irrational trading noise is permanent and related to trading volume, but inconsistent with the hypothesis that trading noise is directly related to trading hours.[18]

The absolute level of both the 24-hour return variance and the within-day return variance is lower for the internationally traded stocks than for their matched pairs. This is likely to occur because the inter-

[17] Let σ_1^2 be the sample variance of the open-to-close returns and σ_2^2 be the sample variance of the close-to-close returns for the internationally traded firm and let σ_3^2 and σ_4^2 be the corresponding sample return variances for the matched firm. Finally, let $R_1 = \sigma_1^2/\sigma_2^2$ and let $R_2 = \sigma_3^2/\sigma_4^2$. Then $T^{1/2}(R_1 - R_2)$ is asymptotically normally distributed with mean 0 and variance $\alpha'\Sigma\alpha$ where T is the number of observations per firm, Σ is the 4 × 4 covariance matrix for the squared returns, and $\alpha' = [1/\sigma_2^2, -\sigma_1^2/(\sigma_2^2)^2, -1/\sigma_4^2, \sigma_3^2/(\sigma_4^2)^2]$. For the general convergence result, see Dhrymes (1974, pp. 112–113). The number of observations per firm ranges from 40 to 1366.

[18] Foreign stocks on the Tokyo Stock Exchange currently trade four hours per day, the same as Japanese stocks. Prior to January 4, 1986, however, foreign stocks traded only one hour per day (one-half hour on Saturdays). All of our results are unaffected when the pre- and post-January 1986 periods are examined separately.

Table 5
Variance of returns on the New York Stock Exchange for stocks that are also traded on the Tokyo Stock Exchange, January 1, 1980, to December 31, 1986

	Open-to-close return variance (×10,000)	Close-to-close return variance (×10,000)	Ratio of variances
Stocks of 21 U.S. firms also traded in Tokyo			
Mean	2.334	2.883	.833
Median	2.121	2.565	.839
Matched sample of 21 stocks not internationally traded			
Mean	3.659	5.351	.819
Median	2.426	3.240	.834
Stocks of 7 Japanese firms also traded in New York			
Mean	1.294	5.058	.261
Median	1.117	4.520	.245

nationally listed firms tend to be the largest firms in their industry, making them difficult to match by size. Nevertheless, there is no evidence that international listing increases the overall variance.

Table 5 also indicates that on average the trading day return variance on the New York Stock Exchange for Japanese stocks is only about one-fourth of the average 24-hour return variance.[19] This contrasts sharply with U.S. stocks listed on the NYSE, for which on average approximately 80 percent of the 24-hour variance occurs during the trading day. Although this is consistent with the view that significant trading volume is necessary for stock prices to reflect private information, it is also consistent with the hypothesis that variance is mainly generated by increased public-information releases during trading hours on the primary exchange.

Variance changes following Tokyo listing. Sixteen of the 21 internationally listed U.S. stocks used in the matched pair tests were first listed on the Tokyo Stock Exchange between 1980 and 1986. In Table 6, we examine the ratio of trading day to 24-hour variance for these 16 NYSE firms before and after they were listed on the Tokyo exchange. The average of the 16 variance ratios before Tokyo listing is 0.852, lower than the corresponding average ratio after Tokyo listing of 0.856. No firm has a statistically significantly lower trading day to 24-hour variance ratio following Tokyo listing.

There is also no evidence that the 24-hour variances increase following Tokyo listing. The mean and median of the 16 individual 24-hour return variance estimates are lower after Tokyo listing than before. The result that 24-hour variances do not rise after international listing

[19] We had too few New York prices to calculate meaningful statistics for Kubota Corp. Thus, when we are using New York data, we present results for only seven Japanese stocks.

Table 6
Variance of returns on the New York Stock Exchange before and after listing on the Tokyo Stock Exchange for 16 U.S. firms listed on the Tokyo Stock Exchange between January 1, 1980, and December 31, 1986

	Open-to-close return variance (×10,000)	Close-to-close return variance (×10,000)	Ratio of variances
Panel A: Stocks of 16 U.S. firms newly listed in Tokyo			
Before Tokyo listing			
Mean	2.481	2.871	.852
Median	2.398	2.836	.840
After Tokyo listing			
Mean	1.925	2.302	.856
Median	1.855	2.206	.858
Panel B: Matched sample of 16 stocks not internationally traded			
Before Tokyo listing for matched pair			
Mean	3.602	4.514	.832
Median	2.630	3.513	.843
After Tokyo listing for matched pair			
Mean	3.929	5.661	.803
Median	2.143	3.130	.826

is unchanged after controlling for general marketwide changes in the level of return variances. As Table 6 indicates, for the 16 matched pair firms over the same period, the mean of the point estimates of the 24-hour return variances increases slightly although the median falls slightly. These results on overnight and 24-hour variance changes following Tokyo listing again indicate that stock-return variance is more closely related to the level of normal trading volume than to the number of hours a stock is traded on world markets.

Weekend variances for internationally listed firms. Since trading on a foreign exchange is light in relation to domestic volume, if trading volume (rather than simply more trading hours) is necessary for private information to be revealed through trading, Tokyo Saturday trading should have a different effect for U.S. companies than for Japanese firms. Our earlier tests for the effects of Saturday trading are repeated for the 17 U.S. firms traded in Tokyo with sufficient available data.[20] As Table 7 indicates, the average New York Friday close to Monday open variance ratio with and without Saturday trading is only 1.15 (median = 1.09). Of the 17 stocks, 11 have ratios in excess of 1.0, but only two of these are statistically significant. Similar results are obtained using Tokyo Friday close to Monday close prices. The

[20] All U.S. firms were included in this analysis if they were listed on both the NYSE and the Tokyo Stock Exchange for at least 10 weeks with Saturday trading in Tokyo and at least 10 weeks with no Saturday trading in Tokyo between 1980 and 1988. Four firms included in the matched pairs test did not meet this criterion and thus were not included in this analysis.

Table 7
Average ratios of return variances with and without Saturday trading for 17 U.S. firms that are also traded on the Tokyo Stock Exchange and 7 Japanese firms that are also traded on the New York Stock Exchange, January 1, 1980, to December 31, 1986

Period	Japanese stocks also traded on NYSE	U.S. stocks also traded on Tokyo Stock Exchange
Friday close to Monday open using New York prices	1.93	1.15
Friday close to Monday close using Tokyo prices	1.47	1.14

unchanged weekend variance for the Tokyo-listed U.S. stocks when there is Tokyo Saturday trading again indicates that longer trading hours do not themselves increase variance.[21]

3. Conclusions

We have provided new evidence on the determinants of stock-return variances. The results are generally consistent with the rational trading models of Kyle (1985) and Admati and Pfleiderer (1988), in which private information revealed through trading causes variance. The results do not support the irrational trading noise hypothesis, which is based on the notion that variance is the result of traders' overreaction to each other's trades. We also reject the view that higher variance during exchange trading hours is due to increased public-information releases.

Saturday trading. When the Tokyo exchange is open on Saturday, the weekend variance is 112 percent higher than when the exchange is closed. While weekly volume also increases, the weekly variance is unaffected. The unchanged weekly variance does not support the hypothesis that variance is generated by irrational trading noise that is permanent and directly related to either trading hours, trading volume, or both.

The dissipation of the higher weekend variance is not caused by temporary pricing errors that are reversed in the following week. Rather, the evidence suggests that the dissipation of the variance generated during Saturday trading is explained by reduced variance for the weekdays immediately following Saturday trading. Since vol-

[21] For Japanese companies listed on the NYSE, Tokyo Saturday trading is also associated with statistically significant additional variance on the NYSE in the following week, although the impact on 24-hour variance is small. The average open-to-close return variance ratio for Monday following Saturdays with Tokyo trading in relation to Mondays without Saturday Tokyo trading is 1.52, and the average volume ratio is 1.25. Similar results apply to Tuesday. This suggests that New York traders react to the additional private information revealed through price changes during Tokyo Saturday trading.

ume is no lower on weekdays following Saturdays with trading, lower variance on these days cannot be explained by a reduction in irrational trading noise that is related to volume. If variance is related to private information, however, then lower variance on weekdays following Saturday trading is expected if privately informed traders accelerate some of their trades to Saturday.

International listing. Secondary listing of U.S. stocks on the Tokyo exchange does not increase the overall level of variance or affect its overnight pattern, despite a substantial increase in trading hours. This result applies in both time-series and matched pair tests, and is inconsistent with the hypothesis that there is a causal relationship between trading hours and variance. Similarly, the higher weekend variance associated with Saturday trading does not occur for U.S. firms listed in Tokyo. Since the volume of foreign trading is light, this evidence suggests that substantial normal trading volume is required to affect return variance.

Appendix

This appendix describes the volume ratio and variance ratio tests reported in the article. Two important features of the data are reflected in our tests. First, the frequency of trading and nontrading Saturdays changed over time. The Tokyo Stock Exchange was closed one Saturday per month from January 1973 through July 1986, and two Saturdays per month from August 1986 through January 1989. Second, the levels of volume and variance were much higher in the latter period. In 1986, 1987,[22] and 1988, the average daily share volume on the Tokyo Stock Exchange was, respectively, 2.4, 3.2, and 3.5 times the average daily volume from 1973 through 1985. The average daily volume in these three years ranked third, second, and first, respectively, out of the 16 years from 1973 through 1988. The daily return variance on the Tokyo Composite Index in 1986, 1987, and 1988 was, respectively, 2.5, 4.1, and 1.7 times the daily return variance from 1973 through 1985, and the variance during these three years ranked third, first, and fifth, respectively, out of the 16 years from 1973 to 1988.

The combined effect of the higher frequency of nontrading Saturdays and higher levels of volume and variance after August 1986 is to bias downward any estimate of the volume and variance ratios that gives equal weight to all observations. To illustrate this bias, consider

[22] Data for 1987 used in the article exclude the month of October to insulate the results from any undue influence of the global market crash.

the following numerical example. Suppose there are data for eight weeks, comprising two subperiods of four weeks each. Suppose also that trading volume (and return variance) is unaffected by whether or not there is Saturday trading, but both the number of nontrading Saturdays and the total level of trading volume are higher in the second subperiod. Specifically, suppose the first subperiod has three weeks with Saturday trading, each with a trading volume of 1.0, and one week with no Saturday trading, also with a volume of 1.0; and suppose the second subperiod has two weeks with Saturday trading, each with a trading volume of 2.0, and two weeks with no Saturday trading, also each with a trading volume of 2.0. In this example, the true ratio of volumes for weeks with and without Saturday trading is always 1.0. However, the estimated ratio of volumes is only 0.84 if each observation is given equal weight.[23]

Weighting procedures

Throughout the article, we report volume and variance ratios that are weighted to provide unbiased estimates.[24] The procedure is as follows. First, the data are partitioned into two subperiods, pre-August 1986 when the exchange was closed one Saturday per month, and post-August 1986 when the exchange was closed two Saturdays per month. The observations in the numerator of the variance or volume ratio are then weighted to yield the same relative weighted frequency of trading and nontrading Saturdays in each subperiod. The observations in the denominator each receive equal weight.

The weights are calculated as follows. Let $N_{1,t}$ be the number of Saturdays with trading in the first subperiod, let $N_{1,n}$ be the number of Saturdays without trading in the first subperiod, and let $N_{2,t}$ and $N_{2,n}$ be the number of Saturdays with and without trading, respectively, in the second subperiod. Then for each of the weeks with Saturday trading (in the numerator of the volume or variance ratio) the observation is weighted by

$$W_1 = (N_{1,n}/N_{1,t})/[(N_{1,n} + N_{2,n})/(N_{1,t} + N_{2,t})] \qquad \text{(A1)}$$

[23] Partitioning the sample into subperiods yields unbiased estimates of the ratios in each subperiod, but this procedure is inefficient. Discarding a number of observations to leave the same relative frequency of trading and nontrading Saturdays in every subperiod also yields unbiased estimates, but it is again inefficient.

[24] As a check, we compared the article's results using these weighting procedures to those using unweighted procedures. The biases using unweighted procedures are in the predicted direction and, in several cases, sufficiently severe to result in false inferences. For example, weekly volume ratios with and without Saturday trading are greater than 1.0 using unweighted data in each of the subperiods, but less than 1.0 using unweighted data for the entire period. With our weighting procedure, however, the estimated weekly volume ratio is statistically significantly greater than 1.0 for the overall period.

if it is in the first subperiod, or by

$$W_2 = (N_{2,n}/N_{2,t})/[(N_{1,n} + N_{2,n})/(N_{1,t} + N_{2,t})] \qquad \text{(A2)}$$

if it is in the second subperiod.

In the numerical example above, the weights are $\frac{5}{9}$ for each week with Saturday trading in the first subperiod, and $\frac{5}{3}$ for each week with Saturday trading in the second subperiod. These weights yield a volume ratio of 1.0 in the numerical example.

Statistical tests

It is straightforward to assess the statistical significance of volume ratios based on weighted data. A t-statistic from a difference of (weighted) means test is used.

Under the null hypothesis, variance ratios based on unweighted data are distributed F if the underlying returns are normally distributed. The F-test, however, is highly sensitive to departures from normality. In addition, with our weighting of the observations used to calculate the variances, the variance ratio is no longer distributed F. Consequently, we use a bootstrap procedure to assess the statistical significance of the variance ratios. The estimation and interpretation of the bootstrap p values follow Efron (1982, chap. 5, especially pp. 31–33).

The bootstrap p values are estimated with the following algorithm. Using the notation above, sample with replacement $N_{1,t}$ times from the set of first-period returns with Saturday trading, $N_{2,t}$ times from the set of second-period returns with Saturday trading, and calculate the sample variance using the weights W_1 and W_2 given above. Next, sample with replacement $N_{1,n}$ times from the set of first-period returns without Saturday trading, $N_{2,n}$ times from the set of second-period returns without Saturday trading, and calculate the (unweighted) sample variance. Then calculate the variance ratio. Finally, repeat this procedure 10,000 times to estimate the empirical distribution of the variance ratio. The fraction of these variance ratios that exceed (are less than) 1.0 is the bootstrap probability that the population variance ratio exceeds (is less than) 1.0.

As an alternative to the bootstrap procedures, we use a standard nonparametric test for equal variances, the squared rank test [see Conover (1980, pp. 239–248) for a detailed discussion]. To use this test, $N_{1,t} - N_{1,n}N_{2,t}/N_{2,n}$ observations are discarded at random from the set of first-period weeks with Saturday trading. All of the returns (for weeks with and without Saturday trading) are then converted into deviations from their respective means and squared. The squared deviations are ranked (for the combined sample) and the test statistic

is the sum of the squared ranks of the returns in weeks with Saturday trading.

Although discarding some of the observations is inefficient, this procedure yields the same relative frequency of trading and nontrading Saturdays in the two subperiods. Thus, the standard squared ranks test will be unbiased (given the higher variance and frequency of nontrading weeks after August 1986). The squared ranks test thus provides a check that the bootstrap results are not induced by our weighting scheme.

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