

Private information and weekend volatility in the Tokyo and New York stock markets

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The variance of New York stock index returns measured from the close of Friday trading to the open on Monday was more than three times higher when the Tokyo stock market was open on the intervening Saturday than the variance when the Tokyo market was closed on Saturday. The variance of Tokyo returns from the close of Friday trading to the open on Monday was over thirty seven times greater when the Tokyo market traded on Saturday. This suggests that private information revealed through trading in Tokyo not only raises volatility there, but also increases volatility in New York.

1. Introduction

The distribution of stock returns depends on whether the market is open or closed: the variance of open-to-close returns in either the New York or Tokyo stock markets is more than twice the variance of close-to-open returns. However, the literature that distinguishes trading and non-trading time in a single market often ignores the fact that there is trading activity somewhere in the world at virtually any time of the day. For example, while the New York market is closed overnight, the Tokyo market is open for trading, and there is no overlap in the trading times of these markets.

In addition to the separation in time of trading activity in the Tokyo and New York markets, a convenient attribute of the Tokyo market is that it has been open for trading on some, but not all, Saturdays. Barclay, Litzenberger and Warner (1990) take advantage of this to investigate whether stock return volatility is primarily caused by public information, private information, or

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trading noise. They find that the variance of Friday close to Monday close returns on the *Tokyo* stock exchange when there is Saturday trading is more than twice as high as on weekends when the Tokyo market is closed on Saturday. Assuming that the flow of public information on Saturdays is independent of whether the stock market is open, they attribute the higher variance to private information revealed through Saturday trading. They find a similar effect for stock portfolios formed by industry and for individual Japanese stocks. This indicates that the private information revealed through Saturday trading has market wide, industry, and firm-specific components.

This paper uses a similar approach to test whether the variance of returns in *New York* depends on the presence of Saturday trading in Tokyo. I find that the variance of New York stock returns measured from the close of Friday trading to the open on Monday is more than three times as high when the Tokyo market is open on the intervening Saturday as when the Tokyo market is closed. This suggests that private information revealed through trading in Japan has a global component in addition to the domestic components found by Barclay et al. (1990).

In addition to shedding light on the relation of trading hours and stock return volatility, this paper augments previous evidence that the Tokyo and New York stock markets are interrelated. For example, the interaction of international markets is examined by Puffer (1989) and Hamao, Masulis and Ng (1990). These papers estimate time series models where the conditional variance of open-to-close returns in the New York market is a function of the conditional variance of open-to-close returns in Tokyo and/or London. Occasional Saturday trading in Tokyo presents a data alignment problem for their time series models which is solved by omitting Saturdays from the analysis. In contrast, this paper takes advantage of the intermittent Saturday trading in Tokyo to examine how trading in Tokyo affects the New York market both overnight and during the trading day.

The remainder of the paper is organized as follows. The next section describes the data. Section 3 discusses previous theoretical and empirical work on the relation between trading activity and stock return variance. Section 4 examines the effect of Saturday trading in Tokyo on volatility in the Tokyo and New York stock markets. Section 5 concludes the paper.

2. The data

Daily opening and closing quotes on the Dow Jones Industrial Average and the Nikkei Average from March 25, 1985 through January 27, 1989 are used. The Dow Jones data were obtained from I.P. Sharpe, and the Japanese data were obtained from Nikkei Telecom. The time period and indexes were dictated by data availability. The Nikkei Average consists of the 225 most actively traded stocks on the first section of the Tokyo Stock Exchange. It is

Fri. Nikkei close	Fri. Dow open	Fri. Dow close	Sat. Nikkei open	Sat. Nikkei close	Mon. Nikkei open	Mon. Nikkei close	Mon. Dow open	Mon. Dow close
<i>Eastern Standard Time</i>								
1:00 a.m.	9:30 a.m.	4:00 p.m.	7:00 p.m.	9:00 p.m.	7:00 p.m.	1:00 a.m.	9:30 a.m.	4:00 p.m.
<i>Tokyo Standard Time:</i>								
3:00 p.m.	11:30 p.m.	6:00 a.m.	9:00 a.m.	11:00 a.m.	9:00 a.m.	3:00 a.m.	11:30 p.m.	6:00 a.m.

Fig. 1. New York and Tokyo Stock Exchange trading times.

similar in construction to the Dow Jones Industrial Average, i.e., a price weighted average.¹

The New York market is open Monday through Friday, while the Tokyo market has also been open for a half day of trading on some Saturdays. From August 1983 through July 1986, the Tokyo market was closed on the second Saturday of every month. From August 1986 through January 1989, the Tokyo market was closed on the second and third Saturdays of every month. As of February 1989, Saturday trading ceased completely. Fig. 1 illustrates the timing of trading in each market. Trading day t begins in Tokyo at 9:00 a.m. although the opening quote for the Nikkei average was recorded at 9:15 a.m. until December 18, 1987, and at 9:01 a.m. thereafter. The closing quote is collected at 3:00 p.m. Tokyo time on weekdays and at 11:00 a.m. on Saturdays. The opening quote for trading day t in New York is at 9:30 a.m. New York time, eight and a half hours after the close of the Tokyo market (nine and a half hours during daylight savings time), and the New York market closes at 4:00 p.m.

The top panel of table 1 contains descriptive statistics for returns on the Dow Jones Industrial Average and the Nikkei Average for March 25, 1985 through January 27, 1989, excluding October and November 1987. To ensure that close-to-open returns are always calculated over the same number of hours, any trading day that follows a holiday in either market is omitted. Note that the standard deviation of close-to-open returns in each market is approximately half the standard deviation of open-to-close returns. This is consistent with previous studies which find that volatility in the New York

¹The Dow Jones Industrial Average consists of 30 stocks, 11 of which are cross-listed on the Tokyo Stock Exchange. The trading volume of these stocks on the Tokyo market is less than 10% of the volume in New York. The first section of the Tokyo Stock Exchange consists of approximately 1140 of the most actively traded Japanese firms. The second section consists of 440 smaller or newly listed Japanese companies. Since all foreign stocks are traded on the foreign section, no U.S. stocks are included in the Nikkei Average.

Table 1
Descriptive statistics for stock index returns.

	Nikkei ^a			Dow Jones		
	$C_{t-1}-O_t$	O_t-C_t	$C_{t-1}-C_t$	$C_{t-1}-O_t$	O_t-C_t	$C_{t-1}-C_t$
March 25, 1985–January 27, 1989 excluding October and November 1987						
Mean (× 100)	0.070	0.039	0.109	0.032	0.068	0.100
Standard deviation (× 100)	0.309	0.793	0.843	0.422	0.888	0.980
Skewness	2.894	-0.081	0.866	-0.997	-0.612	-0.671
Kurtosis	70.336	5.730	4.335	12.232	5.574	4.998
Minimum (× 100)	-3.427	-4.252	-3.478	-3.971	-6.610	-6.851
Maximum (× 100)	4.120	5.425	5.632	2.040	3.517	3.525
Number of observations	924	924	924	822	822	822
October and November 1987						
Mean (× 100)	-0.011	-0.234	-0.245	-0.108	-0.608	-0.710
Standard deviation (× 100)	0.093	3.176	3.202	3.531	3.116	4.640
Skewness	-0.323	-1.693	-1.639	0.977	-2.396	-2.336
Kurtosis	0.759	10.795	10.398	4.492	10.665	2.077
Minimum (× 100)	-14.895	-0.244	-14.901	-8.905	-15.045	-22.611
Maximum (× 100)	0.220	9.268	9.299	12.137	4.402	10.149
Number of observations	46	46	46	42	42	42

^a $C_{t-1}-O_t$ = close-to-open return = $(open_t - close_{t-1}) / close_{t-1}$.

O_t-C_t = open-to-close return = $(close_t - open_t) / open_t$.

$C_{t-1}-C_t$ = close-to-close return = $(close_t - close_{t-1}) / close_{t-1}$.

market is higher during trading than non-trading hours. It is also apparent that, for both markets, close-to-open returns deviate from normality to an even greater extent than open-to-close or close-to-close returns as indicated by the high measures of kurtosis. As a result, *F*-statistics presented below which assume returns are normally distributed should be interpreted with caution.

From the lower panel in Table 1 it is clear that the behavior of stock returns was very unusual during the two months surrounding the crash. Explaining or interpreting the events surrounding the crash is beyond the scope of this paper, so October and November 1987 are deleted from the remaining analysis. An additional reason for omitting these months from the sample is that the opening quotes on the Nikkei and the Dow Jones are unreliable. During the days following the crash, many stocks did not begin

trading for several hours after each exchange opened. As a result, stale price quotes were used in calculating the opening quotes on the indexes.

3. Private information and stock return volatility

There is considerable evidence that trading hours and stock return volatility are positively related. Fama (1965), Granger and Morgenstern (1970), Oldfield and Rogalski (1980) and Christie (1981) all document this phenomenon. More recently, French and Roll (1986) study volatility during trading and non-trading time in the New York stock market. Using returns measured from the close of trading on Tuesday to the close on Thursday, they compare the variance of returns when the market was closed on Wednesdays in 1968 to clear paper backlogs to the variance when the market was open. They find higher volatility when the market was open than when the market was closed.

Two possible explanations for these results have been suggested in the literature. Either traders overreact to each others' trades or private information is revealed through trading. Although trader overreaction is not formally modeled, French and Roll (1986) argue that it implies negative serial correlation in returns as pricing errors are reversed. They determine that only 4 to 12% of daily volatility is caused by mispricing. They conclude that the primary source of volatility is private information revealed through trading.

This conclusion is consistent with models developed by Kyle (1985) and Admati and Pfleiderer (1988) which relate the variance of returns and volume of trading to private information revealed through the actions of informed traders. Kyle (1985) models the behavior of three types of investors: random liquidity traders, informed traders, and a specialist who does not have private information but who learns from price and volume changes. In his model, return variance is positively associated with trading volume, but the opportunity to trade (i.e., when markets are open) does not by itself result in volatility.

Admati and Pfleiderer (1988) investigate the effects of adding discretionary liquidity traders to Kyle's model. These traders participate in the market to satisfy liquidity requirements, but they have some discretion over the timing of their trades. Admati and Pfleiderer show that these traders prefer to execute their trades when informed traders are most active and vice versa. This clustering of trades on the part of informed and discretionary liquidity traders results in higher variance when trading volume is high and private information is revealed through trading. As in Kyle's model, trading hours alone are not associated with return variance; trading volume is the key.

Barclay et al. (1990) test the private information hypothesis by performing an experiment similar to French and Roll using daily returns on the TOPIX

index² of the Tokyo Stock Exchange from January 1973 through January 1989. The key assumption is that occasional Saturday trading does not affect the flow of public information over the weekend. If this is true, then higher volatility on weekends when the market is open on Saturday can be attributed to private information revealed through trading. The idea can be summarized as follows. Express the variance of the return on the TOPIX index from the close of trading on Friday to the close on Monday as a function of independent components:

$$VTOPIX = I^W + I^M + P^S + P^M, \quad (1)$$

where

- I^W = public information revealed over the weekend,
- I^M = public information revealed on Monday,
- P^S = private information revealed through Saturday trading,
- P^M = private information revealed through Monday trading.

Whether or not the stock market is open for trading on Saturday, the flow of public information on the weekend and on Monday ($I^W + I^M$) should be unaffected. Barclay et al. argue that the Saturdays that non-financial firms are open are independent of the Saturdays the stock exchange operates, and that firm-specific announcements are rarely made on Saturdays. The ratio of the variance of returns on weekends with Saturday trading ($VTOPIX_S$) relative to weekends without Saturday trading ($VTOPIX_{NS}$) can therefore be expressed as

$$VRATIO = \frac{VTOPIX_S}{VTOPIX_{NS}} = \frac{I^W + I^M + P^S + P^M_S}{I^W + I^M + P^M_{NS}}. \quad (2)$$

If private information revealed through trading increases the volatility of the TOPIX index and there is more private information revealed through trading on both Saturday and Monday than on Monday alone when the market is closed Saturday (i.e., $P^S + P^M_S > P^M_{NS}$), then $VRATIO$ will be greater than 1.

Barclay et al. estimate this ratio to be 2.12, so the variance of returns on the TOPIX index from Friday close to Monday close is more than twice as high when the market is open for Saturday trading as when the market is closed. They report that the variance for the whole week (measured from Wednesday close to Wednesday close) is unaltered by Saturday trading so that the increased variance caused by Saturday trading is offset by lower volatility on surrounding days. The variance of returns from the close on

²The TOPIX index is broader than the Nikkei since it consists of all stocks traded on the first section of the Tokyo Stock Exchange. It is a value weighted index similar to the S&P 500.

Monday to the close on Wednesday following Saturday trading is 72% of the variance when there is no trading on the preceding Saturday, suggesting that some privately informed traders accelerate their trades from Tuesday and Wednesday to the preceding Saturday. Since their data do not permit them to determine whether traders also accelerate trades from Monday to the preceding Saturday, this issue is examined below. Although weekly volatility is unaffected by Saturday trading, Barclay et al. find that weekly trading volume is 21% higher when the Tokyo market is open on Saturday. Since increased trading hours and volume do not increase weekly returns variance, the results are inconsistent with the hypothesis that trading noise is permanent and proportional to trading volume or hours of trading.³ Barclay et al. also find little evidence to support the theory that volatility due to Saturday trading arises from pricing errors that are reversed the following week. These results are consistent with the rational trading models of Kyle (1985) and Admati and Pfleiderer (1988) which predict that weekly variance will be unaffected if there is no change in the arrival of private information over the whole week. The evidence supports the hypothesis that stock return variance is caused primarily by private information revealed through trading.

Barclay et al. augment their results for the TOPIX index with similar evidence for Japanese industry indexes and individual stocks. For 28 industry indexes, the average Friday close to Monday close variance from July 1982 through January 1989 is 118% higher with Saturday trading than without Saturday trading. For 8 individual Japanese stocks from July 1982 through December 1986, the weekend return variance with Saturday trading averages 80% higher than without Saturday trading. This suggests that the private information revealed through trading consists of market wide, industry, and firm-specific components.

4. Empirical results

This section examines the influence of Saturday trading in Tokyo on volatility in both the Tokyo and New York stock markets. Two different measures of the ratio of the variance of returns around weekends when there is trading on Saturday relative to weekends when the Tokyo stock market is closed are presented. The first is simply the unweighted ratio of the variances. However, these ratios are biased downwards since the frequency of non-trading Saturdays doubled in August 1986, and trading volume and volatility also increased substantially. Barclay et al. derive weights for each observation with Saturday trading that yield unbiased variance ratios. For

³In contrast, French and Roll (1986) do not find lower variance on days surrounding Wednesdays when the New York Stock Exchange was closed, and they suggest that the effect of trading hours on volatility could be permanent.

the weighted ratios, each observation with Saturday trading in the first subperiod (March 25, 1985 to July 31, 1986) is weighted by

$$W1 = (T1_{NS}/T1_S)/[(T1_{NS} + T2_{NS})/(T1_S + T2_S)],$$

and observations with Saturday trading in the second subperiod (August 1, 1986 to January 27, 1989) are weighted by

$$W2 = (T2_{NS}/T2_S)/[(T1_{NS} + T2_{NS})/(T1_S + T2_S)],$$

where

- $T1_S$ = number of Saturdays with trading in the first subperiod,
- $T1_{NS}$ = number of Saturdays without trading in the first subperiod,
- $T2_S$ = number of Saturdays with trading in the second subperiod,
- $T2_{NS}$ = number of Saturdays without trading in the second subperiod.

Table 1 verifies that the normality assumption underlying the F -test for whether the ratio of variances is different from one tends to be violated for intradaily data. Even if returns are distributed normally, the weighted variance ratios are no longer F -distributed. Therefore, a bootstrap procedure is used to assess the statistical significance of the ratios, too.⁴

Another way to obtain unbiased variance ratios is to estimate unweighted ratios separately for the subperiods March 25, 1985 through July 31, 1986 and August 1, 1986 through January 27, 1989. These subperiods also facilitate comparison with some of the results of Barclay et al.

4.1. *Tokyo stock return variance and Saturday trading*

Since both opening and closing quotes on the Nikkei average are used here rather than the closing quotes on the TOPIX used in Barclay et al., this section re-examines the effect of Saturday trading activity on volatility in the Tokyo stock market. Table 2 contains the ratio of the variance of the Nikkei returns around weekends when there is trading on Saturday relative to weekends when the Tokyo stock market is closed. The unweighted Friday

⁴The bootstrap probability is calculated as follows for the unweighted variance ratios. Let T_S be the number of weekends with Saturday trading in Tokyo, and T_{NS} be the number with no Saturday trading. Choose a random sample with replacement of the T_S observations with Saturday trading and calculate the variance of these returns. Calculate the variance of a random sample of the T_{NS} returns in a similar fashion. Compute the ratio of these variances. Repeat this procedure 1000 times. The bootstrap probability reported is the percentage of ratios that are less than one [see Efron (1982) for a review of this technique]. Note that although the bootstrap procedure does not assume normality, both the F -test and the bootstrap assume independence. The bootstrap procedure for the weighted ratios is similar and is described in detail in Barclay et al. (1990, Appendix).

Table 2

Ratio of Nikkei variances following weekends when the Tokyo Stock Exchange is open on Saturday relative to when the Tokyo Stock Exchange is closed.

	Unweighted			Weighted ^a	
	Variance ratio	One-tail <i>p</i> -value ^b	Bootstrap probability ^c	Variance ratio	Bootstrap probability
March 25, 1985 – January 27, 1989 excluding October and November 1987 (100 trading Saturdays, 67 non-trading Saturdays)					
Friday close to Monday open ^d	23.553	0.000	0.000	37.666	0.000
Friday close to Monday close	1.645	0.016	0.065	2.533	0.004
Monday open to Monday close	0.719	0.932	0.835	1.114	0.385

^aObservations with Saturday trading are weighted to yield unbiased variance ratio estimates (see Section 4).

^bOne tail *p*-value of the standard *F*-test for equal variances.

^cBootstrap probability that the ratio is less than one.

^dIf Friday or Monday is a holiday in Tokyo, that weekend is omitted from the analysis.

close to Monday close variance ratio of 1.645 is significantly greater than one (*p*-value=0.016, bootstrap probability=0.065). The weighted variance ratio is 2.533 with a bootstrap probability of being less than one of 0.004 and is similar to the Barclay et al. ratio of 2.12 estimated over the period January 1973 through January 1989.

The availability of opening as well as closing quotes on the Nikkei average is useful for determining whether Saturday trading only affects the variance of returns from the close on Friday to the open on Monday, or whether it also influences volatility during trading on Monday. If the market is efficient and reacts immediately to new information, the opening quote on Monday should reflect all the information revealed through trading on Saturday and there should be no increase in volatility during trading on Monday. The variance of returns from Monday's open to close will increase following Saturday trading if the market is slow to react to the private information revealed through trading on Saturday. This could be because uninformed market participants disagree about the interpretation of Saturday's trading activity, or because informed investors continue to trade on Monday.⁵ Barclay et al. suggest that privately informed investors who would otherwise trade on Tuesday or Wednesday accelerate their trades to Saturday. If this

⁵Bessembinder and Seguin (1989, p. 5) suggest that although it was developed to explain intraday trading patterns, the Admati and Pfleiderer (1988) model is applicable to interday periods so that private information is valuable and influences trading activity for more than one day.

also applies to Monday, then Monday's variance will be lower following weekends with Saturday trading.

When weekend returns are separated into close-to-open and open-to-close segments, the results shown in table 2 are striking. The Friday close to Monday open unweighted variance ratio is 23.553 and the weighted ratio is 37.666. Both ratios are clearly greater than one since none of the ratios calculated using the bootstrap is less than one. There is little evidence to support the hypothesis that some privately informed investors trade on Saturday rather than wait until the following Monday. The Monday open-to-close weighted ratio is 1.114,⁶ and is not reliably different from one since 38.5% of the bootstrap ratios were less than one. Although the point estimate of the unweighted ratio of open-to-close returns is less than one, it is biased downwards and insignificantly different from one. This result is surprising since Barclay et al. suggest that traders advance trades from the following Tuesday and Wednesday to the previous Saturday. The effect of private information revealed through trading on Saturday appears to be incorporated immediately in Monday's opening quote in Tokyo. The presence of Saturday trading is an important determinant of the variance of returns from the close on Friday to the open on Monday, but it does not significantly influence the variance of returns from Monday's open to close. This evidence does not support the theory that investors are slow to react or that they trade on private information for more than one day. However, both the weighted and unweighted variance ratios for Friday close to Monday close returns are reliably greater than one, so more private information is revealed through Saturday and Monday trading than through trading on Monday alone when the market is closed on Saturday.

The variance ratios for the Nikkei average for the two subperiods determined by the relative frequency of Saturday trading are presented in table 3. Although the weighting technique used in table 2 yields unbiased estimates of the variance ratios, separate estimates over each subperiod provide further insight into whether the influence of Saturday trading changed after August 1986 when the frequency of Saturday trading was reduced and the volume of trading in Tokyo generally increased. According to table 3, the influence of Saturday trading on the variance of Nikkei returns over the weekend increased substantially. In the first subperiod, the variance of returns from the close on Friday to the open on Monday was approximately five times greater when there was Saturday trading, and this ratio increased to 56.450 in the second subperiod. The ratio of variances from the open to close on Monday is 0.461 during the first subperiod and is

⁶Note that although the close-to-open ratio is 37.666 and the open-to-close ratio is 1.114, this is not inconsistent with a close-to-close variance ratio of only 2.533 since (from table 1) the variance of Friday close to Monday open returns is much smaller than the variance of open-to-close returns.

Table 3

Ratio of Nikkei variances following weekends when the Tokyo Stock Exchange is open on Saturday relative to when the Tokyo Stock Exchange is closed.

	Variance ratio	One-tail p -value ^a	Bootstrap probability ^b
March 25, 1985 – July 31, 1986 (45 trading Saturdays, 16 non-trading Saturdays)			
Friday close to Monday open ^c	5.051	0.001	0.000
Friday close to Monday close	0.854	0.671	0.574
Monday open to Monday close	0.461	0.976	0.820
August 1, 1986 – January 27, 1989 excluding October and November 1987 (55 trading Saturdays, 51 non-trading Saturdays)			
Friday close to Monday open	56.450	0.000	0.003
Friday close to Monday close	2.189	0.003	0.010
Monday open to Monday close	0.938	0.592	0.578

^aOne tail p -value of the standard F -test for equal variances.

^bBootstrap probability that the variance ratio is less than one.

^cIf Friday or Monday is a holiday in Tokyo, that weekend is omitted from the analysis.

quite reliably less than one (p -value=0.976, bootstrap probability that it is less than one=0.820) which suggests that some informed traders were accelerating trades they might otherwise make on Monday to the preceding Saturday. This is consistent with Barclay et al.'s hypothesis that traders were also accelerating some of their trades from Tuesday and Wednesday to the preceding Saturday. However, there is no evidence that informed traders were accelerating their trades in the second subperiod since the Monday open-to-close ratio is 0.938 and indistinguishable from one (p -value=0.592, bootstrap probability=0.578).

4.2. New York stock return variance and Saturday trading in Tokyo

The focus of French and Roll (1986) is trading vs. non-trading time in the New York market. They do not emphasize that when the New York market is closed overnight there is trading in Tokyo. Barclay et al. focus primarily on trading activity in Tokyo, but they recognize the potential interrelation of

the Tokyo and New York markets by examining the volatility of cross-listed stocks. Other studies provide mixed evidence concerning the interrelation of the Tokyo and New York stock markets. For example, the correlation of returns in these markets varies greatly over time [King, Wadhvani and Sentana (1990)], and high open-to-close volatility in New York tends to be followed by high open-to-close volatility in Tokyo, but not vice versa [Hamao, Masulis and Ng (1990) and Puffer (1989)]. If private information revealed through trading in Tokyo is relevant to the New York market, then trading activity in Tokyo will affect volatility in New York.

This issue is examined by Barclay et al. in the context of individual cross-listed stocks. Barclay et al. hypothesize that since the volume of trading on the Tokyo market in cross-listed stocks with a primary listing in New York is low, little firm-specific private information is revealed through Saturday trading in Tokyo. As a result, the volatility of returns on these individual stocks from the Friday close in New York to the Monday open in New York should not depend on whether the Tokyo market is open on the intervening Saturday. Their average variance ratio for January 1980 through December 1986 is 1.15 and insignificantly different from one which is consistent with their hypothesis. An implicit assumption is that the volatility of these individual stock returns does not depend significantly on the market wide component of private information revealed through trading in Tokyo.

Rather than concentrating on individual stocks, I investigate whether the volatility of the New York stock market as a whole depends on private information revealed through trading in Tokyo. The test is analogous to the test for the Tokyo market alone. To see this, express the variance of the Dow Jones Industrial Average returns from the close of trading on Friday to the open on Monday as

$$VDJCO = IUS^W + IJ^W + IJ^M + PJ^S + PJ^M, \quad (3)$$

where

IUS^W = public information revealed in the U.S. over the weekend,

IJ^W = public information revealed in Japan over the weekend,

IJ^M = public information revealed in Japan on Monday,

PJ^S = private information revealed through Tokyo Saturday trading,

PJ^M = private information revealed through Tokyo Monday trading.

Since the New York market is closed over the weekend, the U.S. private information component is assumed to be zero. Even if private information is produced during this period, it obviously cannot be revealed through trading in New York.

The ratio of the variances when there is Saturday trading in Tokyo relative to when there is not can be written as

Table 4

Ratio of Dow Jones variances following weekends when the Tokyo Stock Exchange is open on Saturday relative to when the Tokyo Stock Exchange is closed.

	Unweighted			Weighted ^a	
	Variance ratio	One-tail <i>p</i> -value ^b	Bootstrap probability ^c	Variance ratio	Bootstrap probability
March 25, 1985 – January 27, 1989 excluding October and November 1987 (83 trading Saturdays, 64 non-trading Saturdays)					
Friday close to Monday open ^d	2.480	0.0001	0.079	4.108	0.014
Friday close to Monday close	0.833	0.783	0.856	1.108	0.375
Monday open to Monday close	0.711	0.927	0.717	0.967	0.524

^aObservations with Saturday trading are weighted to yield unbiased variance ratio estimates (see Section 4).

^bOne tail *p*-value of the standard *F*-test for equal variances.

^cBootstrap probability that the variance ratio is less than one.

^dIf Friday or Monday is a holiday in Tokyo or New York, that weekend is omitted from the analysis.

$$VRATIO = \frac{VDJCO_S}{VDJCO_{NS}} = \frac{IUS^W + IJ^W + IJ^M + PJ^S + PJ_S^M}{IUS^W + IJ^W + IJ^M + PJ_{NS}^M} \quad (4)$$

The variance ratio is greater than one only if the influence of private information revealed through Saturday and Monday trading in Tokyo ($PJ^S + PJ_S^M$) on New York volatility is greater than the effect of private information normally revealed through Monday trading in Tokyo (PJ_{NS}^M). An underlying assumption is that the flow of public information in each market (IUS^W , IJ^W , and IJ^M) does not depend on the presence of Saturday trading in Tokyo.

Table 4 contains the variance ratios for the weekend returns on the Dow Jones Industrial Average when there is trading in Tokyo on Saturday relative to when the Tokyo market is closed on Saturday. The unweighted ratio for Friday close to Monday open returns is 2.48,⁷ and the weighted ratio is 4.108. Both estimates are reliably different from one according to either the standard *F*-test or the bootstrap algorithm. This supports the

⁷The corresponding ratio is 2.28 when October 15 through 30, 1987 are excluded rather than all of October and November 1987. When the whole sample is used, the ratio is only 0.50. This is because the Tokyo market was closed on Saturday, October 17, 1987, and the return on the Dow from the close on Friday, October 16 to the open on Monday, October 19 is -8.9%, as compared to the mean return of 0.03%. This outlier causes the Friday close to Monday open variance when there is no Saturday trading in Tokyo to quadruple from 0.000016 (when October and November 1987 are omitted) to 0.000061, which is the denominator of the variance ratio.

hypothesis that Saturday trading in Tokyo reveals private information that is relevant to the New York market. It is not surprising that this ratio is much smaller than the corresponding ratio for the Tokyo market. Private information revealed through trading in Tokyo is of greater importance in the Tokyo market than in the New York market.

The Monday open-to-close variance ratios in New York are similar to the results for the Tokyo market. The unweighted and weighted ratios for New York are insignificantly different from one. This indicates that although Saturday trading in Tokyo affects the weekend variance in New York, information revealed through Tokyo trading is incorporated at the open in New York. There is no evidence that informed investors trade in Tokyo on Saturday rather than wait to trade in New York the following Monday. It is also likely that the news that arrives during the trading day in New York is the more important determinant of New York return volatility on Monday than inferred news from Tokyo. The Friday close to Monday close ratios are also indistinguishable from one.⁸

The subperiod results for New York are presented in table 5. The results are remarkably similar across subperiods. The variance of returns from the close on Friday to the open on Monday in New York is over three times greater when there is Saturday trading in Tokyo than when the Tokyo market is closed on Saturday. The ratios for open-to-close and close-to-close returns are less than, but not reliably different from, one in both periods. The conclusions for the whole sample are confirmed for each subperiod: private information revealed through trading in Tokyo increases overnight volatility in New York, but there is no evidence that the reaction to the information is slow, or that informed traders accelerate their trades.

The strong influence of private information revealed through trading in Tokyo on the volatility of the New York stock market is surprising in light of results for cross-listed stocks in Barclay et al. Using Friday close to Monday open returns in New York, they measure the ratio of the variance when there is Saturday trading in Tokyo relative to when there is no Saturday trading for individual stocks. The average ratio for their sample of 17 stocks is 1.15 and although 11 stocks had ratios greater than one, only two were statistically significant. Since 11 of the cross-listed stocks in the

⁸Saturday trading in Tokyo does not have much effect on the variance of returns in New York on the following days. The variance ratios for Monday, Tuesday, and Wednesday open-to-close returns are all close to one. Variance ratios measured from Friday close to Tuesday or Wednesday open or close are all close to one. This provides further evidence that Saturday trading in Tokyo affects the variance of Friday close to Monday open returns, but does not affect the total variance over longer periods. Table 1 shows that the variance of close-to-open returns is generally less than 20% of the variance of close-to-close returns. Therefore, the additional variance over the weekend due to trading in Tokyo need not be offset by lower variance on other days in order for the variance ratios over longer periods to be insignificantly different from one.

Table 5

Ratio of Dow Jones variances following weekends when the Tokyo Stock Exchange is open on Saturday relative to when the Tokyo Stock Exchange is closed.

	Variance ratio	One-tail p -value ^a	Bootstrap probability ^b
March 25, 1985 – July 31, 1986 (38 trading Saturdays, 16 non-trading Saturdays)			
Friday close to Monday open ^c	3.756	0.004	0.001
Friday close to Monday close	0.966	0.556	0.497
Monday open to Monday close	0.772	0.746	0.648
August 1, 1986 – January 27, 1989 excluding October and November 1987 (45 trading Saturdays, 48 non-trading Saturdays)			
Friday close to Monday open	3.016	0.0001	0.088
Friday close to Monday close	0.873	0.674	0.625
Monday open to Monday close	0.730	0.852	0.800

^aOne tail p -value of the standard F -test for equal variances.

^bBootstrap probability that the variance ratio is less than one.

^cIf Friday or Monday is a holiday in either New York or Tokyo, that weekend is omitted from the analysis.

Barclay et al. sample with a primary listing in New York are components of the Dow Jones Industrial Average, it is puzzling that Saturday trading in Tokyo affects the weekend variance of the Dow Jones Industrial Average, but not the variance of the individual stocks.

One reason for the discrepancy is that Saturday trading in Tokyo reveals market-wide private information that is relevant to the New York stock market but the volume of trading in Tokyo of cross-listed stocks is insufficient to reveal enough firm-specific information to increase New York volatility for these stocks.

Another possibility is that the influence of trading in Tokyo on the New York market has increased over time: the Barclay et al. sample for individual stocks is from 1980 through 1986, and the sample for the Dow runs from March 1985 through January 1989. The increase in the globalization of international financial markets through the 1980s could have contributed to such a change in the interrelation of the Tokyo and New York stock markets. For example, beginning in 1985, Japan relaxed capital market

restrictions to allow greater foreign participation in the Tokyo stock market. The number of American stocks listed on the Tokyo Stock Exchange increased from 10 in 1984 to more than 112 in 1989. Beginning in 1986, foreign firms gained access to the floor of the Tokyo Stock Exchange thereby reducing the cost of trading in Tokyo for these firms trading on their own account and on behalf of other American investors. Unfortunately, additional data are required to isolate the source of the difference in the results for the Dow and for individual stocks since the available evidence is inconclusive. The New York Friday close to Monday open variance ratio from 1980 through 1986 for an equally weighted portfolio of the stocks in the Barclay et al. sample is insignificantly different from one. This suggests that either the information was not relevant to the New York market over the 1980–1985 period or that an equally weighted portfolio of 17 or fewer stocks is not sufficiently diversified to reflect the market-wide information revealed through trading in Tokyo. Although the results for the Dow for the subperiod from March 1985 through August 1986 suggest that the discrepancy is not just due to an increase in the effect over time, that subperiod could be too short and too recent to pick up any difference.

5. Conclusion

The evidence in tables 2 through 5 suggests that private information conveyed through Saturday trading in Tokyo has both a domestic market-wide component and an international component. Trading activity in Tokyo influences the overnight return volatility in both the Tokyo and New York stock markets. From March 1985 through January 1989, the variance of Friday close to Monday open returns in Tokyo was more than 30 times greater when the Tokyo market was open on Saturday than when the Tokyo market was closed on Saturday. The corresponding weekend variance of Dow Jones returns was more than three times as high when there was trading in Tokyo than when there was not. Since it seems reasonable to assume that the flow of public information in either market is unrelated to Saturday trading, these results suggest that volatility in both Tokyo and New York is a function of private information revealed through trading in Tokyo. The Dow Jones Industrial Average reacts to this information for two reasons. First, the U.S. and Japanese economies are interdependent, so market-wide information that influences the Tokyo stock market will also influence the New York stock market. Second, many investors' portfolios contain both Japanese and American stocks, so the information that causes them to alter their holdings of Japanese stocks can cause them to rebalance the American component of their portfolios as well.

These results are in sharp contrast to the conclusion of Hamao, Masulis and Ng (1990) that New York volatility 'spills over' to Tokyo, but not vice

versa. Their results suggest that New York stock market volatility does not depend on volatility in Tokyo, but they do not distinguish between volatility due to public information or due to private information. The evidence presented here clearly demonstrates that volatility in New York from the close of trading on Friday to the open on Monday depends on private information revealed through trading in Tokyo. Observing Tokyo trading activity overnight is therefore important for traders who transact at the open of trading in New York.

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