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## The Effects of Conversion from American- to European-Style Options on Price Discovery Process of Nikkei 225 Index**

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# Abstract

Beginning with contracts expiring in June 1992, the Nikkei 225 Index options were converted to a European-style from a hybrid form of an American-style contract. Prior to the conversion, early exercises were possible, but only once a week on Thursdays and on the expiration day falling on the second Thursday of the month. This study is designed to examine the effects of this conversion on the underlying price discovery processes of the Nikkei 225 Index. Our analysis indicates that: (i) greater volatility on Thursdays than on other weekdays was caused not by early exercises rather by settlement procedures in the pre-conversion period; and (ii) the conversion had little impact on price volatility, price reversals, and trading noise.

# The Effects of Conversion from American- to European-Style Options on Price Discovery Process of Nikkei 225 Index

In the U.S. market, concerns were expressed about extreme volatility when the Standard & Poor's (S&P) 500 futures and S&P 100 options expired simultaneously on the third Friday of the contract month (March, June, September, and December). In response to these concerns, settlement procedures were altered in 1987. Beginning with the June 1987 S&P 500 futures contract, final settlements are based on the opening index on the expiration day rather than the closing index, whereas expiration procedures for the S&P 100 options did not change.[1] Therefore, expiration of the two index derivatives is no longer synchronized.

Herbst and Maberly (1990) and Stoll and Whaley (1991) report that the change in settlement procedures reduced price volatility at the close in the post-June 1987 period and expiration-day trading volume was more or less split between open and close. Sofianos (1994) observes from transaction data how small expiration-related effects are in contradiction to the findings of earlier studies and concludes that the New York Stock Exchange absorbs the expiration-related effects with minimal stress. The Japanese market also adopted the U.S. settlement procedures for the Nikkei 225 Index futures beginning in December 1989.[2] Karolyi (1996) compiles comprehensive empirical evidence on the

[1] The settlement price of the S&P 500 futures contract is based on the value of the S&P 500 Special Expiration Index (SEI) that is a market-value-weighted-average of the "opening" prices of the S&P 500 component stocks. The SEI differs from the reported S&P 500 Index at the market open because S&P 500 Index is computed using "last trade" prices when no opening prices are available. Therefore, the opening SEI rarely coincides with the opening S&P 500 Index. For details, see Sofianos (1994).

[2] See Rhee (1993) and Karolyi (1996).

expiration day effects in Japan. He observes intraday volatility in the last hours of trading on expiration days and the first hours following expirations is only marginally greater than on non-expiration days. He also reports economically insignificant price reversals prior to and subsequent to expirations. Similar findings are reported on the expiration day effects in other Asia-Pacific markets [Stoll and Whaley (1997) and Bollen and Whaley (1999)]. While numerous past studies examined the price and volume behavior at expirations of index futures and options, one interesting event remains unexplored. The case in point occurred in the Japanese markets.

On June 12, 1989, the Osaka Securities Exchange (OSE) introduced Nikkei 225 Index call and put options. These options were a hybrid form of an American-style option given that early exercise was possible prior to the expiration date, but they were exercisable once a week only on Thursdays and on the expiration day occurring on the second Thursday of the month. Many market participants believed that Nikkei 225 Index component stock prices were more volatile on Thursdays than warranted due to option exercises.[3] Empirical evidence in support of this belief was provided by Nagumo, Mashima, Shinozuka, and Matoyama (1992) who compare market volatility in two periods before (January 4, 1989 – June 9, 1989) and after (June 12, 1989 – December 1991) Nikkei 225 Index options were introduced. Thus, Japanese market participants appealed to the regulatory authorities that the Nikkei 225 Index options be changed to either an authentic American-style contract which can be exercisable any time prior to the expiration day or a European-style contract which can be exercisable only on the

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[3] Before the conversion, a total of 639,938 contract exercises was recorded according to the OSE statistics. Of

expiration day, mitigating seemingly large fluctuations in index values on Thursdays. In response to this appeal, Nikkei 225 Index options were converted to European-style options beginning with the contracts expiring in June 1992. This change provides a rare opportunity to study the effects of conversion from a hybrid form of American- to European-style options on the underlying price discovery processes of the Nikkei 225 Index. This study is designed to answer the following two questions: (i) Was cash market volatility on Thursdays indeed greater than any other weekdays due to Thursday exercises of the Nikkei 225 options in the pre-conversion period? and (ii) Did the conversion make any difference in the price volatility of the underlying cash market? The change in the option contract-style is an interesting event providing a useful insight into how the price discovery processes of the underlying cash market index change. We therefore examine not only the price volatility but also two critical variables defining price discovery processes: price reversals and trading noise on the cash market.[4]

Our analysis indicates that: (i) greater volatility on Thursdays than on other weekdays was caused not by early exercises but by settlement procedures in the pre-conversion period; and (ii) the conversion had little impact on price volatility, price reversals, and trading noise. In retrospect, the conversion of the index options contracts from an American- to European-style was unnecessary. Rather, what was needed was the improvement in settlement procedures.

## I. The Study Period and Summary Statistics of Key Variables

The study period commences on June 12, 1989 and concludes on July 28, 1995

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which 113,296 exercises were early exercises or 17.8% of total exercises.

because June 12, 1989 was the first trading day of the Nikkei 225 Index options and July 28, 1995 was the last day of data availability for this study. As illustrated in Figure 1, Period I (from June 12, 1989 to May 8, 1992) is the pre-conversion period in which the hybrid form of American-style options were traded and Period II (from May 11, 1992 to July 28, 1995) is the post-conversion period in which the European-style options were traded in Osaka. We further identify two subperiods with and without option expiration weeks in each of the pre- and post-conversion periods in order to isolate the expiration day effect from the effect of early option exercises.

| | | |
|---|---|---|
| Period I (Pre-Conversion Period): | | 709 trading days |
| a. | Subperiod without option expiration weeks: | 544 trading days |
| b. | Subperiod with option expiration weeks only: | 165 trading days |
| Period II (Post-Conversion Period): | | 794 trading days |
| a. | Subperiod without option expiration weeks: | 607 trading days |
| b. | Subperiod with option expiration weeks only: | 187 trading days |

Two additional stock index options, Tokyo Stock Price Index (TOPIX) options (American-style) and Nagoya Option 25 contracts (European-style), were launched in October 1989 by the Tokyo Stock Exchange (TSE) and the Nagoya Stock Exchange, respectively. In February 1994, the Nikkei 300 Index options (European-style) were introduced by OSE. The existence of American-style TOPIX options and other European-style index options is expected to cause minimal bias to our analysis since the trading volume in each of three index options was insignificant. For example, the Nikkei 300 Index options, TOPIX options, and Nagoya Option 25 accounted for only 1.9%, 0.6%, and

[4] Due to the lack of volume data, we are unable to study the volume effects.

0.2%, respectively, of the total trading value in index options in Japan. Meanwhile, the market share of the Nikkei 225 Index options exceeded 97% in 1995 which was the last year of our study period.

<Insert Figure 1>

The following key market microstructure variables are selected to study the effects of conversion from American- to European-style options contracts: (i) price volatility measure; (ii) price reversal measure; and (iii) trading noise measure. The data employed in this study are the Nikkei 225 Index observed at every 15 minute interval from morning market open to afternoon market close.

### *A.* Price Volatility

Price volatility is measured by the absolute value of returns denoted by $|R_{cj}|$, where $R_{cj}$ is the rate of return over time interval j (=1,2,3,4, and 5) prior to the market close. Specifically, each $R_{cj}$ is defined as:

$R_{c1}$ = return for the interval between 2:45 p.m. and market close;

$R_{c2}$ = return for the interval between 2:30 p.m. and market close;

$R_{c3}$ = return for the interval between 2:15 p.m. and market close;

$R_{c4}$ = return for the interval between 2:00 p.m. and market close; and

$R_{c5}$ = return for the interval between afternoon market session open and market close.

Price volatility is also measured at the market open using the absolute value of returns denoted by $|R_{ok}|$, where $R_{ok}$ is the rate of return over time interval k (=1,2,3,4, and 5) after the morning market open. Each $R_{ok}$ is defined as:

$R_{o1}$ = return for the interval between market open and 9:15 a.m.;

$R_{o2}$ = return for the interval between market open and 9:30 a.m.;

$R_{o3}$ = return for the interval between market open and 9:45 a.m.;

$R_{o4}$ = return for the interval between market open and 10:00 a.m.; and

$R_{o5}$ = return for the interval between market open and morning session close.

Table 1 presents summary statistics of the price volatilities measured at the market close and market open. For each of pre- and post-conversion periods, we estimate price volatility with and without including option expiration weeks to isolate any expiration effects. Since the last trading of all index options is the second Thursday of each month, the second week of each month is excluded. From the summary statistics, two key findings are noted: First, the overall volatility level is higher in the post-conversion period than the pre-conversion period at the market close, while the opposite is true at the market open. For example, one-hour price volatility at the market close is approximately 50% greater in Period II than Period I. In contrast, one-hour volatility after the market open is approximately 20% lower in Period II than Period I. Second, index option expirations appear to cause the volatility to increase at the market close, but not at the market open. Although price volatility was also measured by squared returns and Parkinson's (1980) variance, overall conclusions of this study are robust regardless of the definition of price volatility introduced. Hence, the results based on these two volatility measures are not reported.

<Insert Table 1>

### *B.* Price Reversals

Following Stoll and Whaley (1987, 1990, and 1991), overnight price reversals at

the market close as well as opening price reversals at the market open are defined using the following measures:

$$REV_{cj,t+1} = \begin{cases} R_{co,t+1} & \text{if} \quad R_{cj,t} < 0 \\ -R_{co,t+1} & \text{if} \quad R_{cj,t} \geq 0 \end{cases}$$

$$REV_{ok,t+1} = \begin{cases} R_{ok,t+1} & \text{if} \quad R_{co,t+1} < 0 \\ -R_{ok,t+1} & \text{if} \quad R_{co,t+1} \geq 0 \end{cases}$$

where $REV_c$ and $REV_o$ denote overnight price reversals after the market close and opening price reversals after the market open, respectively. $R_{co}$ is defined as overnight returns from afternoon market close to morning market open on the following day. Under this definition, a positive value for $REV_c$ and $REV_o$ indicates a reversal and a negative value indicates a continuation.[5]

Summary statistics on price reversals and continuations are presented in Table 2. A few interesting points are observed. First, overnight price reversals tend to be dominant after the market close while price continuations are more pronounced at the market open. Second, price reversals are more dominant in Period II than in Period I as indicated by the reversal measures that are greater in Period II than in Period I. For example, the 30-minute reversal measure is 0.266% in Period II compared with 0.0046% in Period I. The reversal measure of 0.266% represents about ¥3 given the average Nikkei 225 Index component stock price of ¥1,095.[6] This amount is only about one-third of the quoted bid-ask spread on

[5] Kim and Rhee (1997) introduce another measure of price reversals based on the signs of intraday return series. Although their measure of the price reversal frequency is intuitively appealing, the Stoll and Whaley measure is more convenient to use in the regression analysis of this study.

[6] See Rhee, Wang, and Hashimoto (1997).

the Tokyo market.[7,8] Third, the absolute magnitude of estimated price continuation measures are greater at the market open in Period I than Period II, which implies price continuations are more dominant in the pre-conversion period than the post-conversion period. For example, the 30-minute continuation measure was -0.4174% in Period I as opposed to -0.1303% in Period II.

<Insert Table 2>

### *C.* Trading Noise

The amount of trading noise is measured by the ratio of long- to short-term return variances. This variance ratio is inversely related to the magnitude of trading noise [Roll (1984), Lo and MacKinlay (1988), and Hasbrouck and Schwartz (1988)].[9] The variance ratio should be equal to one if stock prices follow a random walk. Otherwise, one may interpret that the smaller the variance ratio, the noisier the market. Four sets of variance ratios are estimated at the market close as well as at the market open: (i) 15-minute variance ratio; (ii) 30-minute variance ratio; (iii) 45-minute variance ratio; and (iv) one-hour variance ratio. For example, the 15-minute variance ratio at the market close is

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[7] See Lehman and Modest (1994) and Hamao and Hasbrouck (1995).

[8] Prior to April 13, 1998, the quoted bid-ask spreads on the Tokyo Stock Exchange were as follows (1998 TSE Factbook):

If price ≤ ¥1,000, then ¥1;
If price ≤ ¥10,000, then ¥10;
If price ≤ ¥100,000, then ¥100;
If price ≤ ¥1,000,000, then ¥1,000; and
If price >¥1,000,000, then ¥10,000.

[9] Recent application of this variance ratio is found in Skinner (1989); Fama and French (1988); Kaul and Nimalendran (1990); Hamon, Handa, Jacquillat, and Schwartz (1993); and Grünbichler, Longstaff, and Schwartz (1994); and Chang, Hsu, Huang, and Rhee (1999).

measured by $\sigma^2(R_{c5})/[8x\sigma^2(R_{c1})]$, where $\sigma^2(R_{c5})$, the variance of index return from afternoon market open to afternoon market close, is proxied by $(R_{c5})^2$; and, $\sigma^2(R_{c1})$, the variance of 15-minute return before market close, is measured by $(R_{c1})^2$. Unfortunately, these proxy measures are theoretically sound, but the variance ratio may be either unmanageably large or undefined when $R_{c1}$ is either extremely small or zero. In order to generate the variance ratios without this problem, an appropriate adjustment is necessary on the definition of the variance ratio. Since the variance itself is not affected by adding a constant number, the definition of the 15-minute variance is revised to:

$$VR1 = \frac{\sigma^2(R_{c5}) + C_5}{8 \times [\sigma^2(R_{c1}) + C_1]},$$

where VR1 denotes the 15-minute variance ratio, and $C_5$ and $C_1$ are the variances of time-series observations of $R_{c5}$ and $R_{c1}$, respectively. This adjustment makes it possible to avoid the problem caused by either zero or extremely small $(R_{c1})^2$. Likewise, the 30-minute, 45-minute, and one-hour variance ratios are defined as:

$$VR2 = \frac{\sigma^2(R_{c5}) + C_5}{4 \times [\sigma^2(R_{c2}) + C_2]},$$

$$VR3 = \frac{\sigma^2(R_{c5}) + C_5}{\frac{120}{45} \times [\sigma^2(R_{c3}) + C_3]}, \text{ and}$$

$$VR4 = \frac{\sigma^2(R_{c5}) + C_5}{2 \times [\sigma^2(R_{c4}) + C_4]}, \text{ respectively, where } C_2, C_3, \text{ and } C_4 \text{ represent the}$$

variances of time-series observations of $R_{c2}$, $R_{c3}$, and $R_{c4}$. The Tokyo Stock Exchange expanded its afternoon trading hours by 30 minutes to begin trading at 12:30 p.m. from April 30, 1991. As a result, the scalar in the denominator of the above variance ratios has been

adjusted to reflect the increased trading hours. The variance ratios at the market open are also estimated in the same manner as those at the market close. This method allows us to create daily observations of variance ratios so that statistical inferences can be made on Thursdays in comparison with the remaining weekdays. Table 3 summarizes the results on variance ratios. First, trading noise is greater at the market close than the market open as indicated by smaller variance ratios reported. For example, the 15-minute variance ratio is on average 0.2269 at the market close which compares with 0.449 at the market open in Period I. Similar results are observed in Period II. Second, the variance ratios estimated prior to market close tends to be smaller in Period II than Period I, which indicates that trading noise is greater in Period II than Period I. Interestingly, however, this is not the case for the variance ratios estimated after the market open. No significant differences are observed in the variance ratios between the pre- and post-conversion periods. Third, expiration weeks do not necessarily reflect higher trading noise both at the market close and market open.

<Insert Table 3>

## II. Empirical Findings

A multiple regression approach is exercised to conduct mean difference tests between Thursdays and the remaining weekdays of the pre- and post-conversion periods. The following regression model is applied:

$$DV_{j,t} = \alpha_0 + \alpha_1 \cdot MONDAY_{j,t} + \alpha_2 \cdot TUESDAY_{j,t} + \alpha_3 \cdot WEDNESDAY_{j,t} + \alpha_4 \cdot FRIDAY_{j,t} + \eta_{j,t},$$

where $DV_{j,t}$ denotes time series observations of the three variables measuring price volatility, price reversals, and trading noise. Weekday dummies with the exception of Thursday are introduced so the Thursday mean is captured by the intercept term; and, the

mean differences between the remaining weekdays and Thursdays are captured by the slope coefficients for each of the three variables.

### *A.* Price Volatility

Regression results on price volatility in the pre- and post-conversion periods are reported in Table 4. Panel A reports the results based on the observations excluding option expiration weeks and Panel B presents the results for the option expiration weeks only, respectively. Differences in volatility between Thursdays and other weekdays results can be summarized in the following 2x2 matrix:

| | Pre-Conversion Period | Post-Conversion Period |
|---|---|---|
| Subperiod without Option Expiration Weeks | No Difference | No Difference |
| Subperiod with Option Expiration Weeks Only | Significant Difference | No Difference |

First, no differences in volatility are observed between Thursdays and other weekdays prior to the conversion during the subperiod not including option expiration weeks, whereas significant differences are observed during the subperiod with option expiration weeks only. This finding implies that early exercises on Thursdays did not cause the volatility to be greater than other weekdays. Higher volatility in the pre-conversion period reported by Nagumo, et al. (1992) can be attributed not to early exercises but expiration-day effects. Second, expiration-day effects, however, disappeared in the post-conversion period. Despite the fact that settlement procedures for the Nikkei 225 Index options (as well as futures) changed to a special opening quote the day after expiration instead of the close on the expiration day since September 1989 (just three months after

the hybrid form of Nikkei 225 Index options were introduced), one important difference in settlement procedures existed between the pre- and post-conversion periods. Prior to conversion, a special quote-based settlement was allowed only on double-witching days when both index futures and options expired. Hence, we may conclude that this difference in settlement procedures must have caused Thursday volatility to be greater than other weekdays in the pre-conversion period. There were 11 and 13 double-witching weeks in Period I and Period II, respectively when the Nikkei 225 Index options and futures expired simultaneously. We also ran regressions using the observations in these double witching weeks. Similar regressions results were obtained, implying that index futures expirations do not change the results in any material manner. On the basis of these findings, we conclude that the conversion from a hybrid form of an American- to a European-style option was unnecessary and had no impact on the volatility level. Rather, the settlement procedures should have been amended to resolve the Thursday volatility on expiration days.

<Insert Table 4>

The third interesting finding is related to the overall level of price volatility during the pre- and post-conversion periods. The results in Panels A and B indicate that price volatility is on the average greater in the post-conversion period than the pre-conversion period. For example, the afternoon session price volatility on Thursdays in Period I is 0.5616 which compares with 0.78 in Period II as shown in Panel A, which implies that the volatility level in Period II is about 40% greater than Period I. In contrast, the reverse is true when price volatility is measured in the option expiration weeks only. As shown in Panel B, the afternoon session volatility level on Thursdays in Period I is 0.9089 as compared to 0.63 in Period II.

Fourth, the conversion demonstrates nominal effects on the opening volatility. Thursday volatility does not differ from other weekday volatilities both in Period I and Period II. One exception is that Monday tends to exhibit greater opening volatility than other weekdays including Thursdays. In addition, the opening volatility on Mondays tends to be more pronounced in Period II; but, this cannot be attributed to the conversion of option exercise methods because the same results were obtained in both sets of regressions with and without option expiration weeks. This may be attributed to the uncertainty caused by the long overnight non-trading period as characterized by higher autocorrelations [Bessembinder and Hertzel (1993)] or higher variance at market open than market close [Amihud and Mendelson (1990) and Chang, Fukuda, Rhee, and Tokano (1992)].[10,11]

**B. Price Reversals**

During the pre-conversion period, neither price reversals nor price continuations at the market open are indicated at the market close. However, price reversals are indicated in Period II at the market close everyday including Thursday as depicted in Panel A. This cannot be attributed to the conversion of contract-styles because the regression results based on the option expiration weeks only in Panel B are not consistent with those in Panel A. Panel B results suggest no overnight price reversals in Period II during the option expiration weeks. Also, price continuations are dominant at the market open on every day of the week including Thursdays in the pre- and post-conversion periods as

[10] George and Hwang (1995) report that the variance at market open is not necessarily greater than that at market close for heavily traded Japanese stocks.

[11] This question is beyond the scope of this study. Nevertheless, this finding remains to be examined further because one may raise question why this long non-trading period affects only in Period II not in Period I.

summarized in Panel A. However, regressions based on the observations over the option expiration weeks only demonstrate that overnight price continuations are common every day in Period I but not in Period II. Only Mondays show price continuations at the market open in Period II.

<Insert Table 5>

### *C.* Trading Noise

Given five return series over different trading time-intervals, four sets of variance ratios are estimated with the results summarized in Table 6. The most important finding demonstrates that the conversion of option contract styles reflects no impact whatsoever on the trading noise. The amount of trading noise is not different between Thursdays and other weekdays in both pre- and post-conversion periods. Second, as expected, the variance ratios become smaller as the trading time-interval shortens, which implies that the shorter trading time-interval is subject to more noise. Third, trading noise is greater in Period II than Period I at the market close as indicated by lower variance ratios. For example, 15-minute variance ratios are 0.2242 in Period I and 0.1933 in Period II as summarized in Panel A. Trading noise tends to be smaller, however, in Period II than Period I at the market open. The 15-minute variance ratios at market open are 0.4538 and 0.521 in Period I and Period II, respectively. This may be attributed to overnight trading activities of a substantial number of Japanese stocks in New York and London. Trading overnight on the offshore markets cause the amount of trading noise at the market open in Tokyo to decrease [Amihud and Mendelson (1991)].[12] The TSE reports

that 114 Japanese stocks (6.35 billion shares) traded in London, 10 Japanese stocks (24.3 million shares) traded in New York, and 32 Japanese stocks (8.9 million shares) traded in Paris during 1995, the last year of the study period.[13]

<Insert Table 6>

## III. Summary and Conclusions

This study compiles evidence regarding the effects of the conversion from a hybrid form of American- to European-style options on the price discovery processes of the underlying equity market index in Japan. Because the high volatility associated with the Thursday option exercises is the main concern, we conducted the mean difference tests using a multiple regression approach. Our analysis indicates that greater volatility on Thursdays than on other weekdays was caused not by early exercises but by settlement procedures in the pre-conversion period. Furthermore, the conversion had little impact on price volatility, price reversals, and trading noise.

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[12] A recent study by Chang, Oppenheimer, and Rhee (1997) reports that London trading of Hong Kong stocks reduces their overnight price volatility in Hong Kong, facilitating the price discovery process of Hong Kong stocks without jeopardizing the systemic stability of the Hong Kong market.

[13] See TSE monthly journal “Shouken” Volume 48 No. 572.

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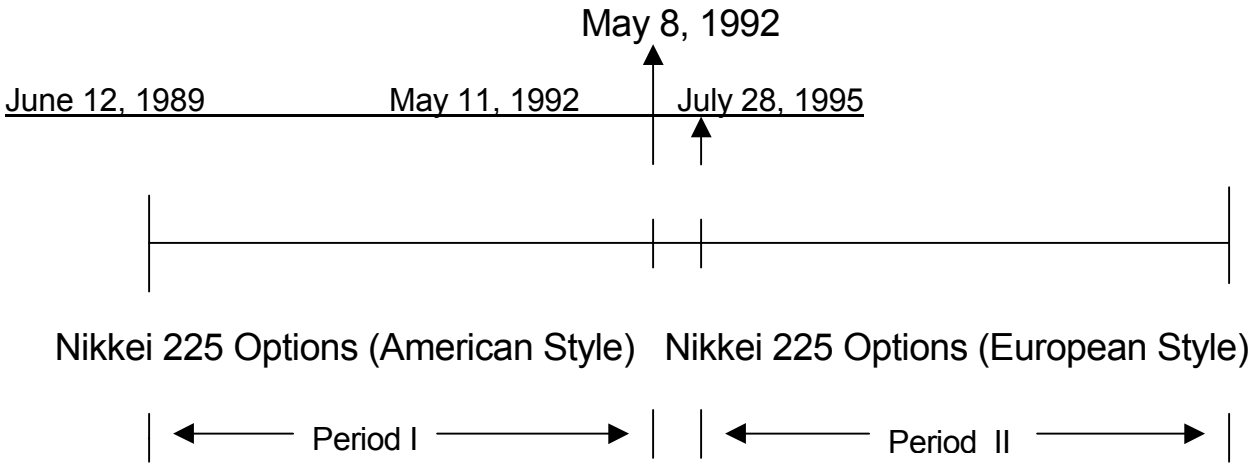
**Figure 1**
**Study Period**




The study period begins from June 12, 1989 and ends on July 28, 1995. June 12, 1989 was the first trading day of the Nikkei 225 Index options and the last day of the study period is dictated by the data availability. Period I (from June 12, 1989 to May 8, 1992) is the pre-conversion period in which the hybrid form of American-style options were traded and Period II (from May 11, 1992 to July 28, 1995) is the post-conversion period in which the European-style options were traded in Osaka.

## Table 1: Summary Statistics: Price Volatility

The study period begins from June 12, 1989 and ends on July 28, 1995. June 12, 1989 was the first trading day of the Nikkei 225 Index options and the last day of the study period is dictated by the data availability. Period I (from June 12, 1989 to May 8, 1992) is the pre-conversion period in which the hybrid form of American-style options were traded and Period II (from May 11, 1992 to July 28, 1995) is the post-conversion period in which the European-style options were traded in Osaka. Price volatility is measured by the absolute value of the intraday rates of return, |R|. The following five trading intervals are introduced prior to the market close: $R_{c1}$ = return for the interval between 2:45 p.m. and market close; $R_{c2}$ = return for the interval between 2:30 p.m. and market close; $R_{c3}$ = return for the interval between 2:15 p.m. and market close; $R_{c4}$ = return for the interval between 2:00 p.m. and market close; and $R_{c5}$ = return for the interval between afternoon market open and market close. The following trading intervals are also introduced after the market open: $R_{o1}$ = return for the interval between market open and 9:15 a.m.; $R_{o2}$ = return for the interval between market open and 9:30 a.m.; $R_{o3}$ = return for the interval between market open and 9:45 a.m.; $R_{o4}$ = return for the interval between market open and 10:00 a.m.; and $R_{o5}$ = return for the interval between market open and morning session close.

| | | Period I | | | Period II | | |
|---|---|---|---|---|---|---|---|
| | | Entire Period | Excluding Option Expiration Weeks | Option Expiration Weeks Only | Entire Period | Excluding Option Expiration Weeks | Option Expiration Weeks Only |
| A. At Market Close | | | | | | | |
| $\|R_1\|$ | Mean ($\times 10^2$) | 0.2682 | 0.2598 | 0.2962 | 0.5034 | 0.4960 | 0.5274 |
| | (Std.Dev.)($\times 10^2$) | (0.2386) | (0.2218) | (0.2861) | (0.7279) | (0.6506) | (0.9374) |
| | Median ($\times 10^2$) | 0.2046 | 0.2065 | 0.1959 | 0.2643 | 0.2618 | 0.2651 |
| $\|R_2\|$ | Mean ($\times 10^2$) | 0.3483 | 0.3390 | 0.3789 | 0.5762 | 0.5618 | 0.6232 |
| | (Std.Dev.)($\times 10^2$) | (0.3439) | (0.3307) | (0.3837) | (07664) | (0.6874) | (0.9807) |
| | Median ($\times 10^2$) | 0.2447 | 0.2418 | 0.2725 | 0.3285 | 0.3292 | 0.3250 |
| $\|R_3\|$ | Mean ($\times 10^2$) | 0.3976 | 0.3939 | 0.4098 | 0.6229 | 0.6217 | 0.6694 |
| | (Std.Dev.)($\times 10^2$) | (0.4178) | (0.4112) | (0.4402) | (0.7896) | (0.7165) | (0.9919) |
| | Median ($\times 10^2$) | 0.2695 | 0.2753 | 0.2519 | 0.4010 | 0.4013 | 0.4006 |
| $\|R_4\|$ | Mean ($\times 10^2$) | 0.4445 | 0.4375 | 0.4678 | 0.6765 | 0.6646 | 0.7150 |
| | (Std.Dev.)($\times 10^2$) | (0.4738) | (0.4734) | (0.4758) | (0.8078) | (0.7365) | (1.0063) |
| | Median ($\times 10^2$) | 0.2963 | 0.2960 | 0.2924 | 0.4250 | 0.4205 | 0.4443 |
| $\|R_5\|$ | Mean ($\times 10^2$) | 0.6157 | 0.6042 | 0.6537 | 0.7926 | 0.7872 | 0.8103 |
| | (Std.Dev.)($\times 10^2$) | (0.6873) | (0.6799) | (0.7121) | (0.8982) | (0.8736) | (0.9764) |
| | Median ($\times 10^2$) | 0.4019 | 0.3938 | 0.4535 | 0.5271 | 0.5101 | 0.5758 |
| No. of Observations | | 709 | 544 | 165 | 794 | 607 | 187 |
| B. At Market Open | | | | | | | |
| $\|R_1\|$ | Mean ($\times 10^2$) | 0.4835 | 0.4825 | 0.4867 | 0.3971 | 0.4038 | 0.3750 |
| | (Std.Dev.)($\times 10^2$) | (0.3872) | (0.3863) | (0.3914) | (0.3388) | (0.3438) | (0.3218) |
| | Median ($\times 10^2$) | 0.3782 | 0.3848 | 0.3753 | 0.2998 | 0.3061 | 0.2640 |
| $\|R_2\|$ | Mean ($\times 10^2$) | 0.5591 | 0.5608 | 0.5533 | 0.4500 | 0.4560 | 0.4305 |
| | (Std.Dev.)($\times 10^2$) | (0.4944) | (0.4906) | (0.5086) | (0.4137) | (0.4190) | (0.3962) |
| | Median ($\times 10^2$) | 0.4088 | 0.4102 | 0.3884 | 0.3349 | 0.3369 | 0.3086 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| $\|R_3\|$ | Mean ($x10^2$) | 0.5777 | 0.5760 | 0.5833 | 0.4757 | 0.4798 | 0.4624 |
| | (Std.Dev.)($x10^2$) | (0.5743) | (0.5645) | (0.6077) | (0.4539) | (0.4625) | (0.4254) |
| | Median ($x10^2$) | 0.4106 | 0.4193 | 0.3562 | 0.3539 | 0.3559 | 0.3479 |
| $\|R_4\|$ | Mean ($x10^2$) | 0.6024 | 0.6038 | 0.5979 | 0.5058 | 0.5115 | 0.4872 |
| | (Std.Dev.)($x10^2$) | (0.6282) | (0.6244) | (0.6427) | (0.5042) | (0.5200) | (0.4496) |
| | Median ($x10^2$) | 0.4138 | 0.4199 | 0.3968 | 0.3615 | 0.3508 | 0.3737 |
| $\|R_5\|$ | Mean ($x10^2$) | 0.7785 | 0.7699 | 0.8072 | 0.6806 | 0.6909 | 0.6470 |
| | (Std.Dev.)($x10^2$) | (0.8507) | (0.8424) | (0.8797) | (0.7010) | (0.7176) | (0.6441) |
| | Median ($x10^2$) | 0.4913 | 0.4918 | 0.4913 | 0.4925 | 0.4932 | 0.4909 |
| No. of Observations | | 715 | 550 | 165 | 800 | 613 | 187 |

# Table 2: Summary Statistics: Price Reversals

The study period begins from June 12, 1989 and ends on July 28, 1995. June 12, 1989 was the first trading day of the Nikkei 225 Index options and the last day of the study period is dictated by the data availability. Period I (from June 12, 1989 to May 8, 1992) is the pre-conversion period in which the hybrid form of American-style options were traded and Period II (from May 11, 1992 to July 28, 1995) is the post-conversion period in which the European-style options were traded in Osaka. Overnight price reversals at the market close as well as opening price reversals at the market open are measured by: $REV_{cj,t+1} = R_{co,t+1}$ if $R_{cj,t} < 0$ and $-R_{co,t+1}$ if $R_{cj,t} \geq 0$; and $REV_{ok,t+1} = R_{ok,t+1}$ if $R_{co,t+1} < 0$ and $-R_{ok,t+1}$ if $R_{co,t+1} \geq 0$, where $REV_c$ and $REV_o$ denote overnight price reversals/continuations at the market close and opening price reversals at the market open, respectively, and $R_{co}$ is overnight returns from afternoon market close to morning market open on the following day. Under this definition, a positive value for $REV_c$ and $REV_o$ indicates a reversal and a negative value indicates a continuation.

| | | Period I | | | Period II | | |
|---|---|---|---|---|---|---|---|
| | | Entire Period | Excluding Option Expiration Weeks | Option Expiration Weeks Only | Entire Period | Excluding Option Expiration Weeks | Option Expiration Weeks Only |
| A. At Market Close | | | | | | | |
| REV1 | Mean ($x10^2$) | 0.0026 | 0.0029 | 0.0016 | 0.2715 | 0.2617 | 0.3032 |
| | (Std.Dev.)($x10^2$) | (0.1461) | (0.1483) | (0.1392) | (0.7278) | (0.6516) | (0.9349) |
| | Median ($x10^2$) | -0.0016 | 0.0009 | -0.0020 | 0.0901 | 0.0907 | 0.0875 |
| REV2 | Mean ($x10^2$) | 0.0046 | 0.0036 | 0.0077 | 0.2660 | 0.2557 | 0.2992 |
| | (Std.Dev.)($x10^2$) | (0.1461) | (0.1483) | (0.1390) | (0.7299) | (0.6540) | (0.9362) |
| | Median ($x10^2$) | -0.0016 | -0.0038 | 0.0087 | 0.0806 | 0.0865 | 0.0728 |
| REV3 | Mean ($x10^2$) | 0.0002 | -0.0021 | 0.0079 | 0.2644 | 0.2549 | 0.2954 |
| | (Std.Dev.)($x10^2$) | (0.1462) | (0.1483) | 0.1390 | (0.7304) | (0.6543) | (0.9374) |
| | Median ($x10^2$) | -0.0022 | -0.0065 | 0.0087 | 0.0879 | 0.0986 | 0.0728 |
| REV4 | Mean ($x10^2$) | -0.0039 | -0.0061 | 0.0036 | 0.2645 | 0.2536 | 0.3002 |
| | (Std.Dev.)($x10^2$) | (0.1461) | (0.1482) | 0.1392 | (0.7304) | (0.6548) | (0.9358) |
| | Median ($x10^2$) | -0.0100 | -0.0124 | 0.0024 | 0.0917 | 0.0986 | 0.0797 |
| REV5 | Mean ($x10^2$) | -0.0157 | -0.0146 | -0.0196 | 0.2397 | 0.2202 | 0.3030 |
| | (Std.Dev.)($x10^2$) | (0.1453) | (0.1476) | (0.1378) | (0.7389) | (0.6668) | (0.9349) |
| | Median ($x10^2$) | -0.0183 | -0.0187 | -0.0156 | 0.0724 | 0.0678 | 0.0876 |
| No. of Observations | | 709 | 545 | 164 | 794 | 607 | 187 |
| B. At Market Open | | | | | | | |
| REV1 | Mean ($x10^2$) | -0.3995 | -0.4014 | -0.3931 | -0.1629 | -0.1838 | -0.0946 |
| | (Std.Dev.)($x10^2$) | (0.4735) | (0.4701) | (0.4859) | (0.4961) | (0.4977) | (0.4857) |
| | Median ($x10^2$) | -0.3515 | -0.3567 | -0.3458 | -0.1530 | -0.1663 | -0.0794 |
| REV2 | Mean ($x10^2$) | -0.4174 | -0.4209 | -0.4057 | -0.1303 | -0.1539 | -0.0529 |
| | (Std.Dev.)($x10^2$) | (0.6189) | (0.6150) | (0.6330) | (0.5974) | (0.6001) | (0.5835) |
| | Median ($x10^2$) | -0.3434 | -0.3492 | -0.3049 | -0.1212 | -0.1450 | -0.0995 |
| REV3 | Mean ($x10^2$) | -0.4066 | -0.4005 | -0.4272 | -0.1231 | -0.1374 | -0.0764 |
| | (Std.Dev.)($x10^2$) | (0.7060) | (0.7003) | (0.7266) | (0.6461) | (0.6524) | (0.6245) |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Median ($x10^2$) | -0.3021 | -0.3037 | -0.2896 | -0.1160 | -0.1291 | -0.0597 |
| REV4 | Mean ($x10^2$) | -0.3956 | -0.3898 | -0.4152 | -0.1150 | -0.1337 | -0.0535 |
| | (Std.Dev.)($x10^2$) | (0.7755) | (0.7765) | (0.7741) | (0.7051) | (0.7173) | (0.6617) |
| | Median ($x10^2$) | -0.2548 | -0.2600 | -0.2418 | -0.0912 | -0.1070 | -0.0395 |
| REV5 | Mean ($x10^2$) | -0.4477 | -0.4491 | -0.4429 | -0.0828 | -0.1024 | -0.0187 |
| | (Std.Dev.)($x10^2$) | (1.0629) | (1.0494) | (1.1099) | (0.9738) | (0.9912) | (0.9140) |
| | Median ($x10^2$) | -0.3073 | -0.3093 | -0.2814 | -0.0402 | -0.0403 | -0.0384 |
| No. of Observations | | 715 | 550 | 165 | 800 | 613 | 187 |

# Table 3: Summary Statistics: Trading Noise

The study period begins from June 12, 1989 and ends on July 28, 1995. June 12, 1989 was the first trading day of the Nikkei 225 Index options and the last day of the study period is dictated by the data availability. Period I (from June 12, 1989 to May 8, 1992) is the pre-conversion period in which the hybrid form of American-style options were traded and Period II (from May 11, 1992 to July 28, 1995) is the post-conversion period in which the European-style options were traded in Osaka. Four variance ratios are computed to measure the degree of trading noise at the market close as well as at the market open: (i) VR1=15-minute variance ratio; (ii) VR2=30-minute variance ratio; (iii) VR3=45-minute variance ratio; and (iv) VR4=one-hour variance ratio.

| | | Period I | | | Period II | | |
|---|---|---|---|---|---|---|---|
| | | Entire Period | Excluding Option Expiration Weeks | Option Expiration Weeks Only | Entire Period | Excluding Option Expiration Weeks | Option Expiration Weeks Only |
| A. At Market Close | | | | | | | |
| VR1 | Mean | 0.2269 | 0.2273 | 0.2258 | 0.1882 | 0.1890 | 0.1856 |
| | (Std.Dev.) | (0.0667) | (0.0716) | (0.0476) | (0.0450) | (0.0488) | (0.0295) |
| | Median | 0.2254 | 0.2253 | 0.2258 | 0.1813 | 0.1813 | 0.1814 |
| VR2 | Mean | 0.3723 | 0.3726 | 0.3714 | 0.3122 | 0.3140 | 0.3062 |
| | (Std.Dev.) | (0.0822) | (0.0866) | (0.0659) | (0.0636) | (0.0687) | (0.0427) |
| | Median | 0.3773 | 0.3772 | 0.3781 | 0.3036 | 0.3036 | 0.3035 |
| VR3 | Mean | 0.4707 | 0.4704 | 0.4719 | 0.3473 | 0.3487 | 0.3428 |
| | (Std.Dev.) | (0.1137) | (0.1166) | (0.1041) | (0.0574) | (0.0608) | (0.0444) |
| | Median | 0.5072 | 0.5063 | 0.5087 | 0.3404 | 0.3403 | 0.3405 |
| VR4 | Mean | 0.6040 | 0.6035 | 0.6058 | 0.5092 | 0.5112 | 0.5028 |
| | (Std.Dev.) | (0.1137) | (0.1149) | (0.1102) | (0.0758) | (0.0791) | (0.0633) |
| | Median | 0.6233 | 0.6226 | 0.6247 | 0.5003 | 0.5003 | 0.5005 |
| No. of Observations | | 709 | 544 | 165 | 794 | 607 | 187 |
| B. At Market Open | | | | | | | |
| VR1 | Mean | 0.4490 | 0.4485 | 0.4509 | 0.4717 | 0.4736 | 0.4657 |
| | (Std.Dev.) | (0.3039) | (0.3152) | (0.2637) | (0.3560) | (0.3767) | (0.2783) |
| | Median | 0.4053 | 0.4066 | 0.4025 | 0.4253 | 0.4270 | 0.4228 |
| VR2 | Mean | 0.6330 | 0.6307 | 0.6408 | 0.6726 | 0.6721 | 0.6742 |
| | (Std.Dev.) | (0.3969) | (0.4095) | (0.3527) | (0.4527) | (0.4492) | (0.4653) |
| | Median | 0.5881 | 0.5845 | 0.5999 | 0.6042 | 0.6054 | 0.6002 |
| VR3 | Mean | 0.8346 | 0.8330 | 0.8401 | 0.8569 | 0.8640 | 0.8338 |
| | (Std.Dev.) | (0.5544) | (0.5798) | (0.4609) | (0.4648) | (0.4822) | (0.4027) |
| | Median | 0.7731 | 0.7671 | 0.7835 | 0.7794 | 0.7757 | 0.7867 |
| VR4 | Mean | 0.9546 | 0.9471 | 0.9795 | 0.9776 | 0.9827 | 0.9608 |
| | (Std.Dev.) | (0.4427) | (0.4464) | (0.4303) | (0.4825) | (0.5039) | (0.4054) |
| | Median | 0.9022 | 0.9000 | 0.9076 | 0.9040 | 0.9023 | 0.9102 |
| No. of Observations | | 715 | 550 | 165 | 800 | 613 | 187 |

# Table 4: Price Volatility

A multiple regression approach is used to conduct a mean difference test between Thursdays and the remaining weekdays of the two subperiods and to compare the two subperiods with a specific focus on the weekday pattern of the three variables. The following regression model is used:

$$DV_t = \alpha_0 + \alpha_1 \cdot MONDAY_t + \alpha_2 \cdot TUESDAY_t + \alpha_3 \cdot WEDNESDAY_t + \alpha_4 \cdot FRIDAY_t + \eta_t,$$

where $DV_t$ denotes time series observations of price volatility measure. Price volatility is measured by the absolute value of the intraday rates of return, |R|. The following five trading intervals are introduced prior to the market close: $R_{c1}$ = return for the interval between 2:45 p.m. and market close; $R_{c2}$ = return for the interval between 2:30 p.m. and market close; $R_{c3}$ = return for the interval between 2:15 p.m. and market close; $R_{c4}$ = return for the interval between 2:00 p.m. and market close; and $R_{c5}$ = return for the interval between afternoon market open and market close. The following trading intervals are also introduced after the market open: $R_{o1}$ = return for the interval between market open and 9:15 a.m.; $R_{o2}$ = return for the interval between market open and 9:30 a.m.; $R_{o3}$ = return for the interval between market open and 9:45 a.m.; $R_{o4}$ = return for the interval between market open and 10:00 a.m.; and $R_{o5}$ = return for the interval between market open and morning session close. Weekday dummies with the exception of Thursday are introduced so the Thursday effect is captured by the intercept term and the mean differences between Thursdays and the remaining weekdays are captured by the slope coefficients for each of the three variables in the three variables. The study period begins from June 12, 1989 and ends on July 28, 1995. June 12, 1989 was the first trading day of the Nikkei 225 Index options and the last day of the study period is dictated by the data availability. Period I (from June 12, 1989 to May 8, 1992) is the pre-conversion period in which the hybrid form of American-style options were traded and Period II (from May 11, 1992 to July 28, 1995) is the post-conversion period in which the European-style options were traded in Osaka. Figures in the parentheses are t-values. Statistical significance at 1% and 5% is indicated by * and +, respectively.

| | Period I | | | | | Period II | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $\lvert R_1 \rvert$ | $\lvert R_2 \rvert$ | $\lvert R_3 \rvert$ | $\lvert R_4 \rvert$ | $\lvert R_5 \rvert$ | $\lvert R_1 \rvert$ | $\lvert R_2 \rvert$ | $\lvert R_3 \rvert$ | $\lvert R_4 \rvert$ | $\lvert R_5 \rvert$ |
| **A. Excluding Option Expiration Weeks** | | | | | | | | | | |
| 1. At Market Close ($x10^2$) | | | | | | | | | | |
| Intercept | 0.2746 | 0.3315 | 0.3861 | 0.4411 | 0.5616 | 0.4474 | 0.5012 | 0.5779 | 0.6349 | 0.7800 |
| | (13.10)* | (10.58)* | (9.93)* | (9.83)* | (8.72)* | (7.57)* | (8.02)* | (8.86)* | (9.47)* | (9.80)* |
| Monday | -0.0302 | 0.0005 | 0.0581 | 0.0220 | 0.0580 | 0.0511 | 0.0504 | 0.0222 | 0.0251 | 0.0362 |
| | (-0.99) | (0.01) | (1.03) | (0.34) | (0.62) | (0.61) | (0.57) | (0.24) | (0.27) | (0.32) |
| Tuesday | -0.0414 | -0.0096 | -0.0319 | -0.0218 | 0.1032 | -0.0214 | 0.0054 | -0.0027 | -0.0345 | -0.0423 |
| | (-1.40) | (-0.22) | (-0.58) | (-0.35) | (1.14) | (-0.26) | (0.06) | (-0.03) | (-0.36) | (-0.38) |
| Wednesday | 0.0092 | 0.0123 | -0.0056 | -0.0181 | 0.0287 | 0.0905 | 0.1098 | 0.0962 | 0.0936 | -0.0064 |
| | (0.31) | (0.28) | (-0.10) | (-0.29) | (0.32) | (1.08) | (1.24) | (1.04) | (0.99) | (-0.06) |
| Friday | -0.0128 | 0.0349 | 0.0242 | 0.0028 | 0.0231 | 0.1231 | 0.1379 | 0.1039 | 0.0652 | 0.0483 |
| | (-0.42) | (0.78) | (0.43) | (0.04) | (0.25) | (1.47) | (1.56) | (1.13) | (0.69) | (0.43) |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Adjusted $R^2$ (%) | -0.01 | -0.53 | -0.21 | -0.63 | -0.46 | 0.03 | -0.01 | -0.24 | -0.28 | -0.53 |
| F-value | 0.98 | 0.29 | 0.72 | 0.15 | 0.38 | 1.05 | 0.98 | 0.64 | 0.58 | 0.21 |

2. At Market Open (x$10^2$)

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Intercept | 0.4413 | 0.5118 | 0.4907 | 0.5268 | 0.7540 | 0.3729 | 0.4110 | 0.4354 | 0.4596 | 0.6927 |
| | (12.12)* | (11.11)* | (9.28)* | (9.00)* | (9.52)* | (12.05)* | (10.89)* | (10.48)* | (9.82)* | (10.70)* |
| Monday | 0.0599 | 0.1400 | 0.2147 | 0.2187 | 0.1684 | 0.0985 | 0.1443 | 0.1787 | 0.1920 | 0.1473 |
| | (1.14) | (2.10)+ | (2.80)* | (2.58)* | (1.47) | (2.26)+ | (2.71)* | (3.05)* | (2.91)* | (1.61) |
| Tuesday | 0.0707 | 0.0652 | 0.0882 | 0.0531 | -0.0747 | -0.0130 | 0.0077 | -0.0220 | 0.0228 | -0.1024 |
| | (1.38) | (1.00) | (1.18) | (0.64) | (-0.67) | (-0.30) | (0.14) | (-0.38) | (0.35) | (-1.12) |
| Wednesday | 0.0272 | -0.0013 | 0.0467 | 0.0542 | -0.0154 | -0.0022 | 0.0313 | 0.0282 | 0.0128 | -0.0524 |
| | (0.53) | (-0.02) | (0.62) | (0.65) | (-0.14) | (-0.05) | (0.59) | (0.48) | (0.19) | (-0.57) |
| Friday | 0.0502 | 0.0485 | 0.0882 | 0.0709 | 0.0143 | 0.0708 | 0.0411 | 0.0369 | 0.0310 | -0.0023 |
| | (0.97) | (0.74) | (1.17) | (0.85) | (0.13) | (1.62) | (0.77) | (0.63) | (0.47) | (-0.03) |
| Adjusted $R^2$ (%) | -0.29 | 0.36 | 0.83 | 0.61 | 0.16 | 1.08 | 0.89 | 1.68 | 1.22 | 0.71 |
| F-value | 0.60 | 1.50 | 2.15 | 1.85 | 1.22 | 2.66 | 2.38 | 3.62 | 2.89 | 2.10 |

**B. Option Expiration Weeks Only**

1. At Market Close (x$10^2$)

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Intercept | 0.4900 | 0.5938 | 0.6237 | 0.6939 | 0.9089 | 0.4379 | 0.5882 | 0.5937 | 0.6099 | 0.6300 |
| | (10.54)* | (9.39)* | (8.44)* | (8.70)* | (7.53)* | (2.83)* | (3.63)* | (3.63)* | (3.67)* | (3.94)* |
| Monday | -0.2535 | -0.3246 | -0.3092 | -0.2999 | -0.4519 | 0.3241 | 0.2515 | 0.3197 | 0.3025 | 0.4850 |
| | (-3.80)* | (-3.57)* | (-2.91)* | (-2.62)* | (-2.61)* | (1.47) | (1.09) | (1.37) | (1.28) | (2.13)+ |
| Tuesday | -0.2663 | -0.2890 | -0.2893 | -0.3458 | -0.2010 | 0.0225 | -0.0014 | 0.0606 | 0.1003 | 0.2232 |
| | (-3.99)* | (-3.18)* | (-2.73)* | (-3.02)* | (1.16) | (0.10) | (-0.01) | (0.27) | (0.43) | (0.99) |
| Wednesday | -0.2473 | -0.2939 | -0.2468 | -0.2842 | -0.3491 | 0.0998 | 0.0062 | 0.0650 | 0.0464 | 0.1276 |
| | (-3.73)* | (-3.26)* | (-2.34)+ | (-2.50)+ | (-2.03)+ | (0.46) | (0.03) | (0.28) | (0.20) | (0.56) |
| Friday | -0.2110 | -0.1802 | -0.2355 | -0.2139 | -0.2852 | 0.0134 | -0.0689 | -0.5301 | 0.0830 | 0.0779 |
| | (-3.21)* | (-2.01)+ | (-2.25)+ | (-1.90) | (-1.67) | (0.06) | (-0.30) | (-0.23) | (0.36) | (0.35) |
| Adjusted $R^2$ (%) | 10.21 | 7.59 | 4.21 | 4.37 | 2.27 | -0.52 | -0.92 | -0.51 | -1.14 | 0.76 |
| F-value | 5.62 | 4.37 | 2.80 | 2.87 | 1.95 | 0.76 | 0.58 | 0.76 | 0.48 | 1.36 |

2. At Market Open ($x10^2$)

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Intercept | 0.4433 | 0.5179 | 0.5166 | 0.5394 | 0.6688 | 0.3198 | 0.3347 | 0.3835 | 0.3856 | 0.5069 |
| | (6.57)* | (5.89)* | (9.26)* | (4.85)* | (4.40)* | (6.10)* | (5.19)* | (5.61)* | (5.28)* | (4.87)* |
| Monday | 0.0105 | 0.0610 | 0.1103 | 0.0919 | 0.2384 | 0.1778 | 0.2417 | 0.2654 | 0.2773 | 0.4339 |
| | (0.11) | (0.48) | (0.73) | (0.58) | (1.09) | (2.38)+ | (2.63)* | (2.73)* | (2.67)* | (2.93)* |
| Tuesday | 0.1024 | 0.0921 | 0.0948 | 0.0948 | 0.1130 | 0.0156 | 0.0520 | -0.0503 | 0.0269 | 0.1066 |
| | (1.06) | (0.73) | (0.63) | (0.59) | (-0.52) | (0.21) | (0.57) | (-0.52) | (0.26) | (0.73) |
| Wednesday | 0.0056 | -0.0271 | 0.0358 | 0.0091 | 0.1780 | 0.0483 | 0.1174 | 0.1236 | 0.1125 | 0.1180 |
| | (0.05) | (-0.22) | (0.24) | (0.06) | (0.82) | (0.52) | (1.29) | (1.28) | (1.09) | (0.80) |
| Friday | 0.0993 | 0.5397 | 0.9570 | 0.0994 | 0.1683 | 0.0391 | 0.0744 | 0.0651 | 0.0981 | 0.0554 |
| | (1.04) | (0.43) | (0.64) | (0.63) | (0.78) | (0.53) | (0.83) | (0.68) | (0.96) | (0.38) |
| Adjusted $R^2$ (%) | -1.02 | -1.76 | -2.00 | -2.00 | -1.63 | 1.65 | 2.05 | 4.48 | 2.45 | 3.33 |
| F-value | 0.59 | 0.29 | 0.19 | 0.20 | 0.34 | 1.78 | 1.97 | 3.18 | 2.17 | 2.60 |

# Table 5: Price Reversals

A multiple regression approach is used to conduct a mean difference test between Thursdays and the remaining weekdays of the two subperiods and to compare the two subperiods with a specific focus on the weekday pattern of the three variables. The following regression model is used:

$DV_t = \alpha_0 + \alpha_1 \cdot MONDAY_t + \alpha_2 \cdot TUESDAY_t + \alpha_3 \cdot WEDNESDAY_t + \alpha_4 \cdot FRIDAY_t + \eta_t$,

where $DV_t$ denotes time series observations of price reversal//continuations measure. Weekday dummies with the exception of Thursday are introduced so the Thursday effect is captured by the intercept term and the mean differences between Thursdays and the remaining week days are captured by the slope coefficients for each of the three variables in the three variables. The study period begins from June 12, 1989 and ends on July 28, 1995. June 12, 1989 was the first trading day of the Nikkei 225 Index options and the last day of the study period is dictated by the data availability. Period I (from June 12, 1989 to May 8, 1992) is the pre-conversion period in which the hybrid form of American-style options were traded and Period II (from May 11, 1992 to July 28, 1995) is the post-conversion period in which the European-style options were traded in Osaka. Figures in the parentheses are t-values. Statistical significance at 1% and 5% is indicated by * and +, respectively.

| | Period I | | | | | Period II | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | REV1 | REV2 | REV3 | REV4 | REV5 | REV1 | REV2 | REV3 | REV4 | REV5 |
| **A. Excluding Option Expiration Weeks** | | | | | | | | | | |
| 1. At Market Close ($x10^2$) | | | | | | | | | | |
| Intercept | -0.0034 | 0.0015 | -0.0074 | -0.0064 | -0.0036 | 0.2867 | 0.2645 | 0.2955 | 0.2782 | 0.2302 |
| | (-0.24) | (0.11) | (-0.53) | (-0.46) | (-0.26) | (4.83)* | (4.44)* | (4.97)* | (4.67)* | (3.80)* |
| Monday | 0.0040 | 0.0043 | 0.0138 | 0.0087 | -0.0079 | 0.0101 | 0.0216 | 0.0051 | 0.0124 | 0.0619 |
| | (0.19) | (0.21) | (0.69) | (0.43) | (-0.39) | (0.12) | (0.26) | (0.06) | (0.15) | (0.72) |
| Tuesday | 0.0091 | -0.0019 | 0.0068 | 0.0129 | -0.0187 | -0.0264 | 0.0208 | -0.0156 | 0.0138 | -0.0036 |
| | (0.46) | (-0.10) | (0.35) | (0.66) | (-0.95) | (-0.31) | (0.25) | (-0.19) | (0.16) | (-0.04) |
| Wednesday | -0.0262 | -0.0271 | -0.0333 | -0.0377 | -0.0337 | -0.0717 | -0.0763 | -0.1444 | -0.1122 | -0.0920 |
| | (-1.33) | (-1.38) | (-1.70) | (-1.92) | (-1.71) | (-0.85) | (-0.91) | (-1.71) | (-1.33) | (-1.07) |
| Friday | 0.0463 | 0.0371 | 0.0415 | 0.0191 | 0.0066 | -0.0374 | -0.0107 | -0.0494 | -0.0379 | -0.0178 |
| | (2.33)+ | (1.86) | (2.09)+ | (0.96) | (0.33) | (-0.45) | (-0.13) | (-0.59) | (-0.45) | (-0.21) |
| Adjusted $R^2$ (%) | 1.74 | 1.19 | 1.94 | 1.16 | 0.21 | -0.47 | -0.36 | 0.05 | -0.14 | -0.12 |
| F-value | 3.41 | 2.64 | 3.69 | 2.59 | 1.29 | 0.30 | 0.45 | 1.07 | 0.79 | 0.82 |
| 2. At Market Open ($x10^2$) | | | | | | | | | | |
| Intercept | -0.3656 | -0.3855 | -0.3427 | -0.3317 | -0.4381 | -0.1986 | -0.1829 | -0.1459 | -0.1058 | -0.0232 |
| | (-8.26)* | (-6.67)* | (-5.23)* | (-4.56)* | (-4.45)* | (-4.41)* | (-3.37)* | (-2.47)+ | (-1.63) | (-0.26) |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Monday | -0.0664 | -0.1495 | -0.2432 | -0.2596 | -0.2198 | -0.0137 | -0.0139 | -0.0599 | -0.1143 | -0.2271 |
| | (-1.04) | (-1.79) | (-2.56)+ | (-2.47)+ | (-1.54) | (-0.22) | (-0.18) | (-0.72) | (-1.25) | (-1.79) |
| Tuesday | 0.0023 | 0.0160 | 0.0004 | 0.0108 | 0.1436 | 0.0816 | 0.1214 | 0.0829 | -0.0090 | -0.0503 |
| | (0.04) | (0.20) | (0.00) | (0.10) | (1.03) | (1.28) | (1.58) | (0.99) | (-0.10) | (-0.40) |
| Wednesday | -0.0522 | -0.0358 | -0.0635 | -0.0617 | -0.0025 | 0.0314 | 0.0362 | 0.0263 | 0.0158 | -0.0438 |
| | (-0.83) | (-0.44) | (-0.68) | (-0.60) | (-0.02) | (0.49) | (0.47) | (0.31) | (0.17) | (-0.35) |
| Friday | -0.0668 | -0.0172 | 0.0031 | 0.0045 | 0.0056 | -0.0252 | 0.0009 | -0.0065 | -0.0314 | -0.0738 |
| | (-1.06) | (-0.21) | (0.03) | (0.04) | (0.04) | (-0.40) | (0.01) | (-0.08) | (-0.34) | (-0.58) |
| Adjusted $R^2$ (%) | -0.29 | 0.15 | 1.03 | 0.95 | 0.47 | -0.06 | 0.02 | -0.14 | -0.25 | -0.04 |
| F-value | 0.61 | 1.20 | 2.43 | 2.31 | 1.65 | 0.91 | 1.03 | 0.78 | 0.63 | 0.95 |

**B. Option Expiration Weeks Only**

1. At Market Close ($x10^2$)

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Intercept | 0.0333 | 0.0513 | 0.0537 | 0.0425 | 0.0006 | 0.2190 | 0.1919 | 0.1838 | 0.2112 | 0.2025 |
| | (1.41) | (2.18)+ | (2.32)+ | (1.81) | (0.02) | (1.42) | (1.25) | (1.20) | (1.37) | (1.32) |
| Monday | -0.0834 | -0.0880 | -0.1117 | -0.0730 | -0.0634 | 0.3197 | 0.4148 | 0.4280 | 0.3473 | 0.3815 |
| | (-2.44)+ | (-2.58)+ | (-3.34)* | (-2.14)+ | (-1.88) | (1.46) | (1.90) | (1.96) | (1.58) | (1.74) |
| Tuesday | -0.0278 | -0.0592 | -0.0685 | -0.0759 | -0.0274 | -0.0246 | 0.0139 | -0.0111 | -.0006 | 0.0155 |
| | (-0.82) | (-1.75) | (-2.06)+ | (-2.25)+ | (-0.82) | (-0.11) | (0.06) | (-0.05) | (-.00) | (0.07) |
| Wednesday | -0.0436 | -0.0529 | -0.0426 | -0.0436 | -0.0414 | 0.0865 | 0.0684 | 0.0788 | 0.0598 | 0.0596 |
| | (-1.29) | (-1.58) | (-1.29) | (-1.30) | (-1.25) | (0.40) | (0.32) | (0.36) | (0.27) | (0.27) |
| Friday | -0.0088 | -0.0232 | -0.0130 | -0.0070 | 0.0266 | 0.0506 | 0.0531 | 0.0763 | 0.0498 | 0.0580 |
| | (-0.26) | (-0.70) | (-0.40) | (-0.21) | (0.81) | (0.24) | (0.25) | (0.36) | (0.23) | (0.27) |
| Adjusted $R^2$ (%) | 2.03 | 2.39 | 5.93 | 2.89 | 2.88 | -0.47 | 0.52 | 0.76 | -0.13 | 0.08 |
| F-value | 1.84 | 2.00 | 3.57 | 2.22 | 2.21 | 0.78 | 1.24 | 1.35 | 0.80 | 1.04 |

2. At Market Open ($x10^2$)

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Intercept | 0.3607 | -0.3951 | -0.3864 | -0.3100 | -0.1810 | -0.0057 | 0.0809 | 0.0123 | 0.0018 | -0.0333 |
| | (4.30)* | (-3.61)* | (-3.08)* | (-2.33)+ | (-0.96) | (-0.07) | (0.86) | (-0.12) | (0.02) | (-0.22) |
| Monday | 0.0076 | -0.0775 | -0.1343 | -0.2253 | -0.5708 | -0.2640 | -0.3691 | -0.3036 | -0.2585 | -0.0864 |
| | (0.06) | (-0.49) | (-0.74) | (-1.18) | (-2.10)+ | (-2.35)+ | (-2.74)* | (-2.09)+ | (-1.69) | (-0.40) |
| Tuesday | -0.0299 | 0.0385 | 0.0157 | -0.0691 | -0.1003 | -0.0864 | -0.0850 | 0.0166 | 0.1195 | 0.1780 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | (-0.25) | (0.24) | (0.09) | (-0.36) | (-0.37) | (-0.78) | (-0.64) | (0.12) | (0.79) | (0.84) |
| Wednesday | -0.0004 | 0.0667 | 0.0334 | -0.0107 | -0.1732 | 0.0148 | -0.0340 | -0.0161 | 0.0093 | 0.0751 |
| | (-0.00) | (0.43) | (0.19) | (-0.06) | (-0.64) | (0.13) | (-0.25) | (-0.11) | (0.06) | (0.35) |
| Friday | -0.1360 | -0.0794 | -0.1187 | -0.2230 | -0.4714 | -0.1122 | -0.1857 | -0.1462 | -0.1514 | -0.0950 |
| | (-1.15) | (-0.51) | (-0.67) | (-1.18) | (-1.77) | (-1.02) | (-1.41) | (-1.03) | (-1.01) | (-0.45) |
| Adjusted $R^2$ (%) | -1.21 | -1.59 | -1.52 | -0.78 | 1.55 | 2.03 | 3.00 | 1.60 | 1.91 | -0.89 |
| F-value | 0.51 | 0.36 | 0.39 | 0.68 | 1.64 | 1.96 | 2.44 | 1.76 | 1.91 | 0.59 |

# Table 6: Trading Noise

A multiple regression approach is used to conduct a mean difference test between Thursdays and the remaining weekdays of the two subperiods and to compare the two subperiods with a specific focus on the weekday pattern of the three variables. The following regression model is used:

$DV_t = \alpha_0 + \alpha_1 \cdot MONDAY_t + \alpha_2 \cdot TUESDAY_t + \alpha_3 \cdot WEDNESDAY_t + \alpha_4 \cdot FRIDAY_t + \eta_t$,

where $DV_t$ denotes time series observations of the variance ratios measuring trading noise. Weekday dummies with the exception of Thursday are introduced so the Thursday effect is captured by the intercept term and the mean differences between Thursdays and the remaining week days are captured by the slope coefficients for each of the three variables in the three variables. The study period begins from June 12, 1989 and ends on July 28, 1995. June 12, 1989 was the first trading day of the Nikkei 225 Index options and the last day of the study period is dictated by the data availability. Period I (from June 12, 1989 to May 8, 1992) is the pre-conversion period in which the hybrid form of American-style options were traded and Period II (from May 11, 1992 to July 28, 1995) is the post-conversion period in which the European-style options were traded in Osaka. Figures in the parentheses are t-values. Statistical significance at 1% and 5% is indicated by * and +, respectively.

| | Period I | | | | Period II | | | |
|---|---|---|---|---|---|---|---|---|
| | VR1 | VR2 | VR3 | VR4 | VR1 | VR2 | VR3 | VR4 |
| **A. Excluding Option Expiration Weeks** | | | | | | | | |
| 1. At Market Close | | | | | | | | |
| Intercept | 0.2242 | 0.3703 | 0.4689 | 0.6009 | 0.1933 | 0.3197 | 0.3530 | 0.5137 |
| | (33.14)* | (45.21)* | (42.46)* | (55.19)* | (43.50)* | (51.19)* | (63.83)* | (71.33)* |
| Monday | 0.0064 | 0.0076 | 0.0027 | 0.0046 | -0.0018 | 0.0002 | 0.0013 | 0.0058 |
| | (0.66) | (0.64) | (0.17) | (0.29) | (-0.28) | (0.02) | (0.17) | (0.57) |
| Tuesday | 0.0114 | 0.0114 | 0.0098 | 0.0092 | -0.0045 | -0.0076 | -0.0050 | -0.0021 |
| | (1.20) | (0.99) | (0.63) | (0.60) | (-0.71) | (-0.86) | (-0.64) | (-0.21) |
| Wednesday | -0.0017 | -0.0022 | 0.0014 | 0.0031 | -0.0063 | -0.0094 | -0.0088 | -0.0104 |
| | (-0.18) | (-0.19) | (0.09) | (0.20) | (-1.00) | (-1.06) | (-1.12) | (-1.02) |
| Friday | -0.0006 | -0.0056 | -0.0068 | -0.0040 | -0.0086 | -0.0119 | -0.0090 | -0.0057 |
| | (-0.06) | (-0.48) | (-0.43) | (-0.26) | (-1.38) | (-1.35) | (-1.15) | (-0.56) |
| Adjusted $R^2$ (%) | -0.23 | -0.20 | -0.53 | -0.59 | -0.26 | -0.14 | -0.16 | -0.19 |
| F-value | 0.69 | 0.73 | 0.29 | 0.20 | 0.61 | 0.79 | 0.76 | 0.71 |
| 2. At Market Open | | | | | | | | |
| Intercept | 0.4538 | 0.6511 | 0.8982 | 1.0241 | 0.5210 | 0.7431 | 0.9317 | 1.0614 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | (15.33)* | (16.88)* | (16.46)* | (24.46)* | (15.27)* | (18.28)* | (21.34)* | (23.31)* |
| Monday | 0.0483 | -0.0117 | -0.0657 | -0.1221 | -0.0543 | -0.0973 | -0.1059 | -0.1214 |
| | (1.13) | (-0.21) | (-0.83) | (-2.01)+ | (-1.13) | (-1.70) | (-1.72) | (-1.89) |
| Tuesday | -0.0539 | -0.0757 | -0.1416 | -0.1338 | -0.0783 | -0.1122 | -0.1013 | -0.1448 |
| | (-1.29) | (-1.39) | (-1.84) | (-2.26)+ | (-1.63) | (-1.96) | (-1.64) | (-2.25)+ |
| Wednesday | -0.0180 | -0.0167 | -0.0803 | -0.0921 | -0.0295 | -0.0698 | -0.0746 | -0.0693 |
| | (-0.43) | (-0.30) | (-1.04) | (-1.55) | (-0.61) | (-1.21) | (-1.21) | (-1.08) |
| Friday | 0.0020 | 0.0038 | -0.0377 | -0.0395 | -0.0744 | -0.0755 | -0.0564 | -0.0570 |
| | (0.05) | (-0.07) | (-0.48) | (-0.66) | (-1.55) | (-1.32) | (-0.92) | (-0.89) |
| Adjusted $R^2$ (%) | 0.36 | -0.22 | -0.05 | 0.58 | -0.05 | 0.08 | -0.02 | 0.37 |
| F-value | 1.49 | 0.69 | 0.93 | 1.80 | 0.93 | 1.13 | 0.97 | 1.57 |

**B. Option Expiration Weeks Only**

1. At Market Close

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Intercept | 0.2330 | 0.3744 | 0.4734 | 0.6087 | 0.1815 | 0.2957 | 0.3352 | 0.4944 |
| | (28.43)* | (32.97)* | (26.28)* | (32.20)* | (37.24)* | (42.15)* | (45.91)* | (47.40)* |
| Monday | -0.0138 | -0.0093 | -0.0076 | -0.0185 | 0.0046 | 0.0162 | 0.0118 | 0.0220 |
| | (-1.18) | (-0.57) | (-0.29) | (-0.68) | (0.66) | (1.62) | (1.13) | (1.48) |
| Tuesday | 0.0004 | 0.0114 | 0.0159 | 0.0290 | 0.0102 | 0.0175 | 0.0144 | 0.0144 |
| | (0.03) | (0.70) | (0.62) | (1.07) | (1.49) | (1.78) | (1.41) | (0.98) |
| Wednesday | -0.0107 | -0.0055 | -0.0088 | -0.0083 | 0.0009 | 0.0056 | 0.0002 | 0.0039 |
| | (-0.92) | (-0.34) | (-0.34) | (-0.31) | (0.13) | (0.57) | (0.02) | (0.27) |
| Friday | -0.0117 | -0.0115 | -0.0065 | -0.0156 | 0.0042 | 0.0128 | 0.0113 | 0.0027 |
| | (-1.01) | (-0.72) | (-0.26) | (-0.58 | (0.62) | (1.31) | (1.11) | (0.18) |
| Adjusted $R^2$ (%) | -0.81 | -0.93 | -1.72 | -0.08 | -0.69 | 0.27 | -0.22 | -0.46 |
| F-value | 0.67 | 0.62 | 0.31 | 0.97 | 0.68 | 1.13 | 0.90 | 0.79 |

2. At Market Open

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Intercept | 0.4287 | 0.6336 | 0.8465 | 0.9683 | 0.4358 | 0.6306 | 0.7998 | 0.9159 |
| | (9.47)* | (10.42)* | (10.59)* | (13.00)* | (9.47)* | (8.18)* | (12.04)* | (13.73)* |
| Monday | 0.0664 | 0.0150 | -0.0244 | 0.0315 | 0.0676 | 0.1189 | 0.0630 | 0.1073 |
| | (1.02) | (-0.17) | (-0.21) | (0.29) | (1.03) | (1.08) | (0.67) | (1.13) |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Tuesday | -0.0245 | -0.0552 | -0.0157 | -0.0307 | 0.0283 | 0.0371 | 0.1162 | 0.1189 |
| | (-0.38) | (-0.63) | (-0.14) | (-0.29) | (0.44) | (0.34) | (1.25) | (1.27) |
| Wednesday | 0.0751 | 0.0784 | 0.0327 | 0.0691 | 0.0591 | 0.0282 | -0.0065 | 0.0231 |
| | (1.16) | (0.91) | (0.29) | (0.65) | (0.91) | (0.26) | (-0.07) | (0.25) |
| Friday | -0.0046 | -0.0034 | -0.0253 | -0.0133 | -0.0025 | 0.0362 | -0.0020 | -0.0208 |
| | (-0.07) | (-0.04) | (-0.22) | (-0.13) | (-0.04) | (0.34) | (-0.02) | (-0.22) |
| Adjusted $R^2$ (%) | -0.11 | -1.00 | -2.27 | -1.81 | -1.09 | -1.47 | -0.70 | -0.17 |
| F-value | 0.95 | 0.60 | 0.09 | 0.27 | 0.50 | 0.33 | 0.68 | 0.92 |