Foreign Exchange Futures Volatility: Day-of-the-Week, Intraday, and Maturity Patterns in the Presence of Macroeconomic Announcements

LI-MING HAN
JOHN L. KLING*
CLIFFORD W. SELL

Using standard deviations and numbers of price changes calculated from tick data for currency futures, this study finds strong day-of-the-week effects for both the Deutsche mark and Japanese yen, mild effects for the British pound, and no effects for the Canadian dollar after controlling for scheduled macroeconomic announcements and

*Correspondence author, College of Business and Economics, Washington State University, Pullman, WA 99164-4746.
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- *Li-Ming Han is an Associate Professor of Finance at Washington State University in Pullman, Washington, currently on leave at the Chinese University of Hong Kong.*
- *John L. Kling holds the Gary P. Brinson Chair in Investments Management at Washington State University in Pullman, Washington.*
- *Clifford W. Sell is a Ph.D. candidate in finance at Washington State University in Pullman, Washington.*

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days to contract expiration. The day-of-the-week effects are found to be caused either by Mondays' low volatility, or by Thursdays' or Fridays' high volatility. This result suggests that the day-of-the-week effects in the currency futures are not driven by the announcements of macroeconomic indicators as proposed in previous studies, but rather by other factors, such as private information-based trading or by market microstructure. This study also finds that the announcements are processed equally across the days of the week for all four currency futures. Jrl Fut Mark 19: 665–693, 1999

INTRODUCTION

Asset prices change in response to public and private information, and as a result of pricing errors (French & Roll, 1986). Recent studies of common stocks and spot foreign exchange rates suggest that market microstructure and trading process per se may also cause price changes even in the absence of relevant information (for example, Romer, 1993; Brock & Kleidon, 1992; Hsieh & Kleidon, 1996; Andersen & Bollerslev, 1998).

Foreign currency exchange rates were once thought to be moved primarily by public information. For example, Harvey and Huang (1991) attribute higher volatility of price changes for futures of major currencies on Thursdays and Fridays to the concentration of scheduled announcements of macroeconomic indicators on those days of the week.[1] Ederington and Lee (1993) and Leng (1996) both report higher volatility of currency futures and interest rate futures shortly after these announcements.[2] Ederington and Lee further show that volatility differs across days of the week on announcement days but not on nonannouncement days, thus claiming support for Harvey and Huang's hypothesis.[3]

On the other hand, Andersen and Bollerslev (1998) suggest that the market structure and trading process drive the volatility of the spot Deutsche mark. They find that, although the concentration of public information releases on Thursdays and Fridays explains the day-of-the-week effect, scheduled announcements of macroeconomic indicators explain little of the overall volatility. Cutler, Poterba, and Summers (1989) find that public announcements contribute very little to the overall volatility

[1] Following French and Roll (1986), they examine the volatility patterns of currency futures. Their chi-square tests reject the equality of volatility across days of the week for the Swiss franc, the British pound, and the Japanese yen, and fail to reject for the Deutsche mark and the Canadian dollar.

[2] Leng (1996) also reports the market response to the announcements in terms of number of price changes, price range, and the first-order autocorrelation.

[3] Using a Brown-Forsythe-modified Levene test, they reject the homoskedasticity of volatility across days of the week for selected intervals and attribute this days-of-the-week effect to the presence of announcements.

of stock returns. Ito, Lyons, and Melvin (1998) observe that the intraday volatility patterns of the spot Japanese yen and Deutsche mark traded in Japan flatten out after the Japanese government lifted its ban on lunch hour trading. These authors thus attribute the change in the intraday volatility pattern to private information–motivated trading resumed during the lunch hours.

If the announcement of macroeconomic indicators explains only a small portion of return volatility of stocks and of the Deutsche mark spot exchange rate, some of the other factors discussed above must play a role in shaping the day-of-the-week effect observed in the currency futures (that is, higher volatility on Thursdays and Fridays) and in the Deutsche mark spot exchange rates. Unfortunately, it is often difficult to distinguish trading motivated by private information from trading reflecting the market structure and trading process. Some studies (for example, Brock & Kleidon, 1992; Hsieh & Kleidon, 1996) question the adequacy of explaining the u-shaped intraday patterns in currency spot rates with the concentrated private information–based trading at the opening (see, for example, Admati & Pfleiderer, 1988, and Foster & Viswanathan, 1990, for theoretical arguments). They instead suggest traders' sudden exposure to the market at the opening and the subsequent need for having a feel for the market before plunging into serious trading as possible explanations. Romer (1993) also points out that asset price movements in the absence of news is consistent with rationality.

Therefore, when examining and explaining trading activity patterns of currency futures, it is important to consider the effect of market microstructure and trading process. Futures markets are, among others, characterized by open-outcry auctions and the lack of officially designated market makers. Market participants include hedgers, speculators, day traders, and scalpers. Day traders are generally short-term speculators, whereas scalpers act as voluntary market makers, providing the liquidity that is essential to the markets. Scalpers generate income by identifying short-term imbalances between bids and asks. On average scalpers hold trading positions for less than two minutes (see, for example, Silber, 1984; Kuserk & Locke, 1993). The trading behavior, trading time horizon, and information processing of these short-term traders, as well as of hedgers, has the potential to affect the basic intraday and intraweek (also referred to as day-of-the-week) patterns.

Unlike common stock, futures expire. Thus futures volatility is affected by the number of days until expiration. Samuelson (1965) postulates that futures volatility should be expected to increase as the futures contract approaches its maturity. As the futures contract approaches maturity and the futures price is forced to converge to the spot price, the futures price—as the expected future spot price—is more responsive to information about the underlying asset. This negative relationship between volatility and days to maturity is often referred to as the maturity effect. Empirically, Galloway and Kolb (1996) find no such maturity effect for major currency futures traded on the Chicago Mercantile Exchange.

The announcement effect and maturity effect have been studied separately. The day-of-the-week effect has been attributed largely to the concentration of scheduled macroeconomic announcements on Thursdays and Fridays.[4] However, the possibility that the day-of-the-week effect is shaped by factors other than public information and maturity has yet to be explored. Thus, while examining the day-of-the-week effect controlling for announcement and maturity effects would allow us to better understand the intraday and intraweek trading patterns of currency futures. That is the objective of this study.

This study addresses the following issues: in the absence of these scheduled announcements (i) whether the day-of-the-week effect exists, (ii) whether an intraday pattern exists, (iii) whether the maturity effect exists. Additionally, it examines whether scheduled announcements of macroeconomic indicators alter the intraday and intraweek patterns, as well as any maturity effect. This study uses the Chicago Mercantile Exchange tick-by-tick futures prices of the British pound, Canadian dollar, Deutsche mark, and Japanese yen from January 1, 1990 through December 31, 1997. For currency futures, this is the longest sample period that has been studied to date. The standard deviation and number of price changes of each five-minute interval are computed as the measures of trading volatility and intensity, respectively.[5] Intraday and intraweek trading patterns, as reflected on the two measures, are examined by controlling for the announcement effect and maturity effect.[6]

Consistent with Galloway and Kolb (1996), all four currencies in this study exhibit little maturity effect with respect to both standard deviation and number of price changes. The announcements do not alter the lack of the maturity effect. Contrary to the suggestions by Harvey and

[4]Harvey and Huang (1991), in particular, observe that the distribution of announcements and the day-of-the-week pattern might be related. However, this has not been investigated econometrically.

[5]The Mixture of Distributions Hypothesis suggests that the number of price changes reflects information flow and thus can be used as a proxy for trading intensity (see, for example, Clark, 1973, and Harris, 1986).

[6]By construction, the model in this study allows for controlling for the impact of scheduled macroeconomic news announcements, but does not measure the relative importance and the duration of the impact. Detailed discussion of the model follows in this article.

Huang (1991) and Ederington and Lee (1993), this study shows that the concentration of major economic announcements contributes to, but cannot fully explain, the day-of-the-week effect. After controlling for the announcement effect, small day-of-the-week effects are observed for the British pound, and strong effects for the Deutsche mark and Japanese yen for both statistical measures; however, the Canadian dollar exhibits little day-of-the-week effect. For some intervals, the day-of-the-week effects in absence of the announcements can be attributed to the lower volatility on Mondays, and for others to the higher volatility on Thursdays or Fridays.[7] The announcements do not alter the day-of-the-week effects. That is, the currency futures markets do not process the announcements differently across the days of the week, contrary to the findings of Chang, Pinegar, and Ravichandran (1998) that the United States equity markets process the announcements on Mondays differently than on other days.

For all currencies, all days of the week exhibit a similar intraday pattern (almost a w-shaped, rather than a u-shaped, pattern) in both standard deviation and number of price changes after controlling for the announcement effect. This pattern is not driven by the high volatility levels in the opening and closing intervals that are also reported in Webb and Smith (1994). The statistical results are obtained by running a system of linear models (one for each interval) with nonlinear restrictions using the Hansen (1982) generalized method of moments (GMM). The persistence of the intraday pattern, after controlling for the announcement effect, supports the hypothesis that factors other than public information, such as private-based information trading and market microstructure, are main drivers of the volatility pattern. Here the term "market microstructure" is used loosely to refer to the trading practices and trading patterns of market participants that have been developed within the constraints of regulations and rules.[8]

DATA AND VOLATILITY MEASURES

Data

The announcement dates of 18 macroeconomic indicators are collected from the *Wall Street Journal*[9] and *Business Week* from January 1, 1990

[7]A lower average volatility on Mondays is also reported in Harvey and Huang (1991) but not discussed.

[8]Trading motivated by private information may yield superior returns, which is beyond the scope of this study.

[9]For the period of the government shutdowns from November 1995 to January 1996 the actual rather than the planned dates were used. This period partially accounts for the unequal numbers of announcements for the various indicators.

through December 31, 1997. Seven of the 18 macroeconomic indicators are those identified as significant by Ederington and Lee (1993): (i) consumer price index; (ii) durable goods orders; (iii) employment; (iv) gross domestic product; (v) merchandise trade deficit; (vi) producer price index; and (vii) retail sales. The other 11 indicators are considered minor announcements: (i) business inventories; (ii) capacity utilization; (iii) construction spending; (iv) the federal treasury budget; (v) factory inventories, orders, and shipments; (vi) housing starts; (vii) industrial production; (viii) leading indicators; (ix) new single-family homes sales; (x) personal income; and (xi) the National Association of Purchasing Managers (NAPM) survey. Several reports are frequently announced on the same date: the capacity utilization and industrial production announcements overlap over 90% of the time, whereas construction spending and the NAPM survey announcements overlap over 80% of the time.

As shown in Table I, 1716 announcements take place on 1148 days in a sample period of 2922 trading days. The table also shows that the announcements are not distributed uniformly across the days of the week. Whereas some indicators are announced more evenly (for example, federal treasury budget, new single-family homes sales, and NAPM survey), others are concentrated on certain days (for example, durable goods orders, employment, producer price index). Generally, very few of the major macroeconomic indicators are announced early in the week (for example, two announcements on Mondays versus 233 on Fridays).

Tick-by-tick futures data for the British pound, Canadian dollar, Deutsche mark, and Japanese yen from January 1, 1990 to December 31, 1997 are obtained from the data center at the Futures Industry Institute in Washington, DC. At any given time, typically three to four futures contracts on the British pound, Canadian dollar, Deutsche mark, and Japanese yen are traded. But only one contract is used for constructing the data series. Ederington and Lee (1993) use the contract with the highest trading volume. This is resonable but could pose problems when trading volume is affected by factors other than maturity, which can then inadvertently contaminate the data series. Harvey and Huang (1991) always use the nearby contract, except for the expiration day. An advantage of this method is the consistency in switching from one contract to another, preventing unexpected factors from affecting the data series. A disadvantage is the low trading volume on the days close to expiration. Leng (1996) uses the nearby contract up to the expiration month, thus offering a compromise between avoiding contamination in the data and using a contract with high trading volume. This study adopts Leng's method in data series construction. To illustrate, the June contract is used

TABLE I

Distribution of Announcements

Major Announcement	*Mon*	*Tue*	*Wed*	*Thu*	*Fri*	*Sum*
Consumer price Index	1	23	28	19	26	97
Durable Goods Orders	0	13	43	21	19	96
Employment	0	0	0	3	92	95
Gross Domestic Product	0	10	24	23	35	92
Merchandise Trade Deficit	0	15	24	33	23	95
Producer Price Index	0	14	11	29	43	97
Retail Sales	1	27	15	32	23	98
Sum of Major Announcements	2	102	145	160	261	670
Number of Announcement Days	2	87	134	139	233	595
Minor Announcement	*Mon*	*Tue*	*Wed*	*Thu*	*Fri*	*Sum*
Business Inventories	20	6	27	16	29	98
Capacity Utilization	9	20	20	10	35	94
Construction Spending	37	16	18	11	13	96
Federal Treasury Budget	24	14	13	15	24	91
Factory Orders and Inventories	0	11	28	33	24	96
Housing Starts	0	35	30	19	12	96
Industrial Production	9	21	20	9	36	95
Leading Indicators	3	35	29	5	22	94
New Single-Family Homes	14	28	23	17	13	95
Personal Income	34	3	11	22	25	95
NAPM Survey	36	19	13	15	12	96
Sum of Minor Announcements	186	208	232	172	245	1046
Number of Announcement Days	122	145	154	132	157	712
All Announcements	*Mon*	*tue*	*Wed*	*Thu*	*Fri*	*Sum*
Sum of All Announcements	188	310	377	332	506	1716
Number of Announcement Days	124	210	253	242	319	1148

Notes: Distribution of 18 scheduled macroeconomic indicators from 1 January 1990 through 31 December 1997. The sum of announcements does not consider multiple announcements occurring on the same day, while the number of announcement days refers to the number of days with one or more announcement.

for calculating volatility measures for trades in March, April, and May; and the September contact for trading days in June, July, and August.

The days to maturity on any given trading day are the number of days until the expiration date of the contract used to construct the volatility series.[10] Contracts expire on the third Wednesday of the contract month. To illustrate again, for trades on 2 December 1991, there are 107 days

[10]Samuelson (1965) postulates such an effect based on the time until expiration, not business days to maturity. Therefore we use calendar days to expiration.

until expiration of the March 1992 contract on 18 March 1992. Days to maturity for the sample period range from 15 to 112 days.

Volatility Measures

Following Ederington and Lee (1993) and Leng (1996), we divide the trading day into 80 five-minute intervals. For each of these intervals, two statistics measuring the volatility and intensity of trading are calculated: (i) the standard deviation of the log of the price ratios (STD) and (ii) the number of price changes (NP).

The number of price changes in each interval is calculated to capture both liquidity trading and information trading, as suggested by Clark (1973), Harris (1986), and Leng (1996).

$$NP_i^d = \text{Number of price changes recorded for interval } i \text{ on day } d. \quad (1)$$

Following Schwert (1989), the standard deviation for each interval is calculated as follows:

$$STD_i^d = \left[\sum_{j=1}^{NP_i^d} (r_{i,j+1}^d - \bar{r}_i^d)^2 \right]^{1/2} \text{ for } i = 1, 2, \ldots, 80 \quad (2)$$

where $P_{i,j}^d$ is price j in interval i on day d

$$r_{i,j+1}^d = \ln\left(\frac{P_{i,j+1}^d}{P_{i,j}^d}\right)$$

$$\bar{r}_i^d = \frac{1}{NP_i^d} \sum_{j=1}^{NP_i^d} r_{i,j+1}^d$$

Under the assumption that the tick prices are evenly spaced within the interval, STD_i^d is the square root of the sum of the squared deviations of price changes from the average price changes for the interval.[11] STD_i^d is calculated using all trading prices in the interval; thus every interval in the 2922 trading days in the sample period has a standard deviation. This contrasts with some previous studies in which the interval return is calculated using only the first and last tick prices in the interval. The standard deviation for the interval as a whole, STD_i, is calculated using the return for the same interval of every day in the sample, thereby yielding

[11]Schwert (1989) uses this method to calculate the monthly variance of the S&P 500 portfolio as the sum of the squared daily return deviations from the average daily return in the month.

one standard deviation per interval for the entire sample. The standard deviation measure in this study should be more informative because it is calculated based on all tick prices in the interval. This method of calculation also generates a standard deviation for every interval and thus allows for the study of the intraday and intraweek patterns by interval, as shown below.

STATISTICAL MODEL, HYPOTHESES AND EMPIRICAL RESULTS

Model and Methodology

As noted earlier, this paper examines trading volatility and intensity patterns while controlling for announcement and maturity effects. The following model is proposed for the purpose:

$$\begin{aligned} STAT_{h,i,d} = & \sum_{m=1}^{16} a_{h,i,m} D_{m,d} + b_{h,i} DTM_d + c_{h,i} ANN_d * DTM_d \\ & + \sum_{k=1 \text{ to } 5} d_{h,i,k} DOW_{k,d} + \sum_{k=2,3,4,5} e_{h,i,k} ANN_d \\ & * DOW_{k,d} + u_{h,i,d} \text{ for } i = 1,2, \ldots, 80 \end{aligned} \quad (3)$$

where

$\mathrm{STAT}_{h,i,d}$ stands for statistic h for interval i of day d;

$D_{m,d}$'s are dummy variables for the announcement m on day d[12];

ANN_{d} is the dummy for announcement days, $ANN_{\mathrm{d}} = 1$ for day d if at least one announcement is made that day;

DTM_{d} is days to maturity for day d;

$DOW_{k,d}$ is the dummy for day k of the week, $DOW_{k,d} = 1$ if day d is a Monday.

A dummy variable ($D_{m,d}$) is created for each of the economic indicators, except construction spending and NAPM survey as well as capacity utilization and industrial production. Following Ederington and Lee (1993), the two groups of indicators that frequently overlap are treated as two discrete variables, taking a value of 0 when no announcement occurs, a value of 0.5 when only one of the two indicators occurs, and a value of 1 when both announcements occur. The dummy and discrete variables

[12]Because of the two groups of overlapping indicators explained in this article, the 18 announcements yield 16 dummy variables.

for the announcements are included to recognize the differing effect of each indicator/group of indicators and to capture the intraday and intraweek effects attributable to the announcements.[13]

The coefficient for an announcement dummy ($a_{h,i,m}$) measures impact of that individual indicator[14] over the average of the announcement-related volatility.[15] Because of the assumption of interaction of announcement and day-of-the-week effects, this model precludes the examination of the effects of individual macroeconomic indicators. However, this model enables us to examine the intraweek and intraday patterns more closely by controlling the effects of the 18 macroeconomic indicators. The days-to-maturity variable and its interaction with announcements are self-explanatory and not discussed.

The coefficient for a day of the week ($d_{h,i,k}$) is the average of the volatility for that day of the week in the absence of announcements. Thus, testing the equality of $d_{h,i,k}$ across k allows for the examination of intraweek patterns (or day-of-the-week effects) and testing the equality across h allows for the examination of intraday patterns after controlling for the announcement effect.[16]

The model also captures an interaction of announcement and maturity ($c_{h,i}$), and an interaction of announcement and day-of-the-week ($e_{h,i,k}$).[17] However, because of the small number of observations for most indicators on a given day of the week, this model examines an interaction of the day-to-maturity and day-of-the-week effects with announcements in general (that is, all announcements are treated as equal), rather than with any specific announcement.[18] As a result of this limitation, it is possible to test only whether the presence of the announcements as a whole alters the maturity and day-of-the-week effects or the lack of such.

The test of intraweek pattern is performed by running the regression model identified as eq. (3) using least squares for each of the 80 intervals, with the covariance matrices corrected for heteroskedasticity using White (1980) and for serial autocorrelation using Newey and West (1987) with 10 lags. The test for intraday equality is performed by applying generalized

[13]Creating a single dummy variable covering all announcements would carry the assumption that all announcements have a similar impact. Ederington and Lee (1993) have shown that this is not the case.

[14]For the indicators that were grouped, the coefficient measures the impact of those variables as a group.

[15]This interpretation of the coefficients a is due to the interaction term of the announcement and the days of the week dummies. See below for more discussion.

[16]The detailed discussion of tests follows below.

[17]$ANN_d * DOW_{1,d}$ is dropped to avoid the dummy trap problem.

[18]For example, there are only nine Producer Price Index announcements on Wednesday and five Leading Indicator announcements on Thursday.

method of moments (GMM) to a system of equations wherein each equation represents an interval. For example, suppose the test is performed for the standard deviation across intervals 6, 20, 34, 48, 62, and 76. Hansen's GMM is applied to a system of six equations, each represented by eq. (3) for $i = 6, 20, 34, 48, 62$, and 76, with the explanatory variables serving as instruments. The test for intraday equality for each day of the week is a test for equality of the following coefficients:

$$d_{h,6,k} = d_{h,20,k} = \ldots = d_{h,76,k}, \text{ for } k = 1, 2, \ldots, 5. \tag{4}$$

The joint test for intraday as well as intraweek equality is a test for equality of the following coefficient vectors:

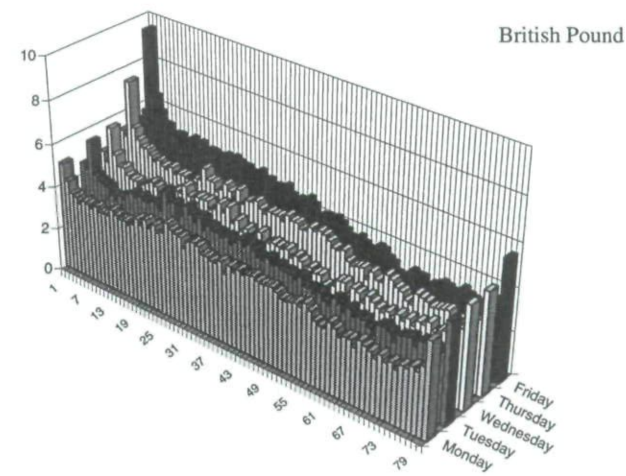
$$\begin{bmatrix} d_{h,6,1} \\ d_{h,6,2} \\ \cdot \\ \cdot \\ d_{h,6,5} \end{bmatrix} = \begin{bmatrix} d_{h,20,1} \\ d_{h,20,2} \\ \cdot \\ \cdot \\ d_{h,20,5} \end{bmatrix} = \ldots = \begin{bmatrix} d_{h,76,1} \\ d_{h,76,2} \\ \cdot \\ \cdot \\ d_{h,76,5} \end{bmatrix} \tag{5}$$

In both cases, the covariance matrix is estimated using Newey-West (1987) with ten lags to correct for possible serial correlation of the $u_{\mathrm{h},i,d}$'s. Hansen's (1982) χ^2 $(r - a)$ test for overidentifying restrictions is used to test the equality conditions, where r is the number of orthogonality conditions and a is the number of coefficients to be estimated. For the restrictions in eq. (4), $r - a = 5$, whereas for the restrictions in eq. (5), $r - a = 25$.

Hypotheses and Empirical Results

The coefficients for the day-of-the-week dummy variables show the average volatility and intensity by days of the week after controlling for any announcement and maturity effects. Thus, any volatility and intensity patterns revealed by the coefficients would contradict the claim that announcements drive the intraday and intraweek patterns observed in currency futures.[19] Figure 1A graphs the regression coefficients for the day-of-the-week dummies for the standard deviation, and Figure 1B for the number of price changes. For all four currencies, the volatility and intensity measures of the 80 intervals display a u-shaped pattern for the trading day. The general pattern for the number of price changes is quite similar

[19]The statement is subject to two assumptions. First, the 18 indicators capture all the announcement effect, which is presumed in all previous studies. Second, the linear model specified in eq. (3) is sufficient for controlling for the effect of the announcements of the 18 economic indicators.



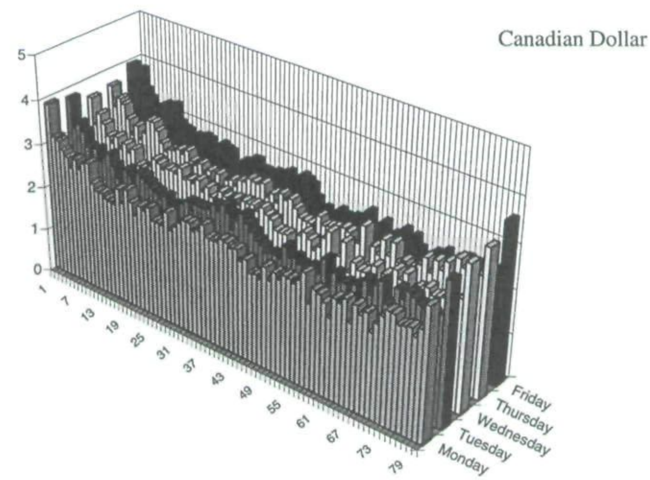
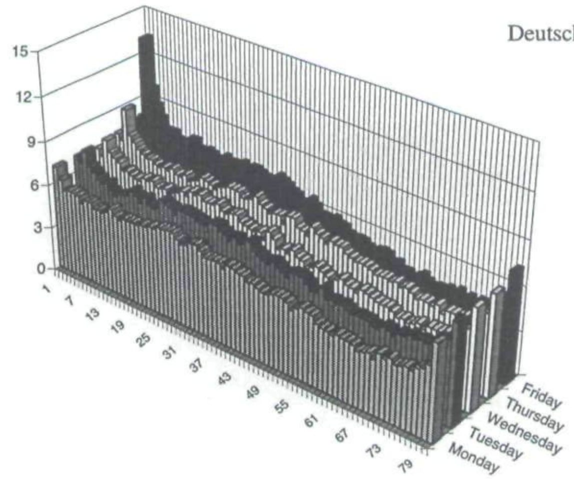


FIGURE 1A

Coefficients of day-of-the-week effect dummy variable for standard deviation. The coefficients d of the day-of-the-week dummy variables are estimated for 80 five-minute intervals for the model:

$$STAT_{h,i,d} = \sum_{m=1}^{16} a_{h,i,m} D_{m,d} + b_{h,i} DTM_d + c_{h,i} ANN_d * DTM_d + \sum_{k=1\text{ to }5} d_{h,i,k} DOW_{k,d} + \sum_{k=2,3,4,5} e_{h,i,k} ANN_d * DOW_{k,d} + u_{h,i,d}$$

Note that the values are multiplied by 10,000.



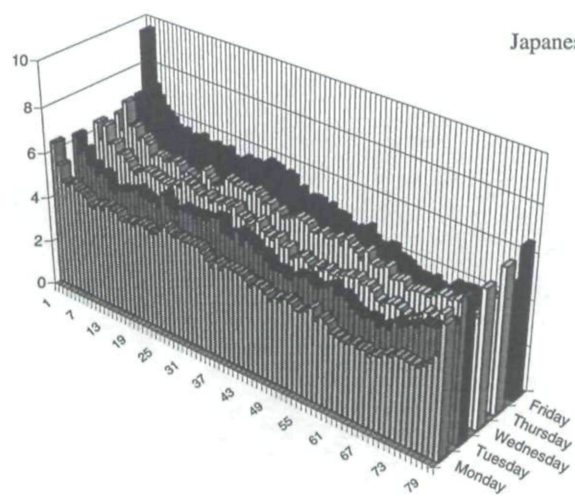


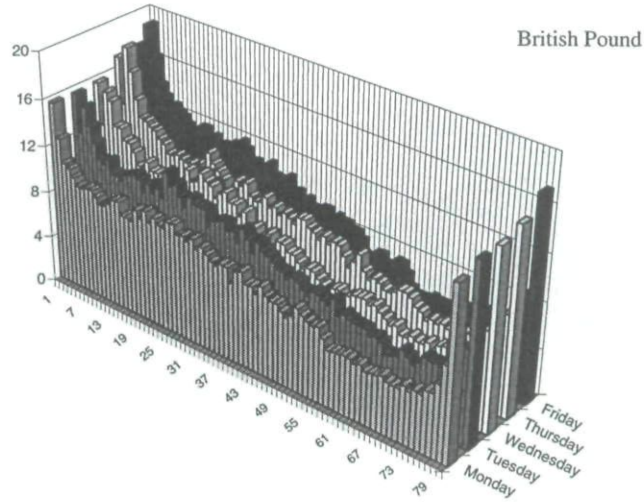
FIGURE 1A (Continued)

Coefficients of day-of-the-week effect dummy variable for standard deviation. The coefficients d of the day-of-the-week dummy variables are estimated for 80 five-minute intervals for the model:

$$STAT_{h,i,d} = \sum_{m=1}^{16} a_{h,i,m} D_{m,d} + b_{h,i} DTM_d + c_{h,i} ANN_d * DTM_d$$

$$+ \sum_{k=1\,\mathrm{to}\,5} d_{h,i,k} DOW_{k,d} + \sum_{k=2,3,4,5} e_{h,i,k} ANN_d * DOW_{k,d} + u_{h,i,d}$$

Note that the values are multiplied by 10,000.



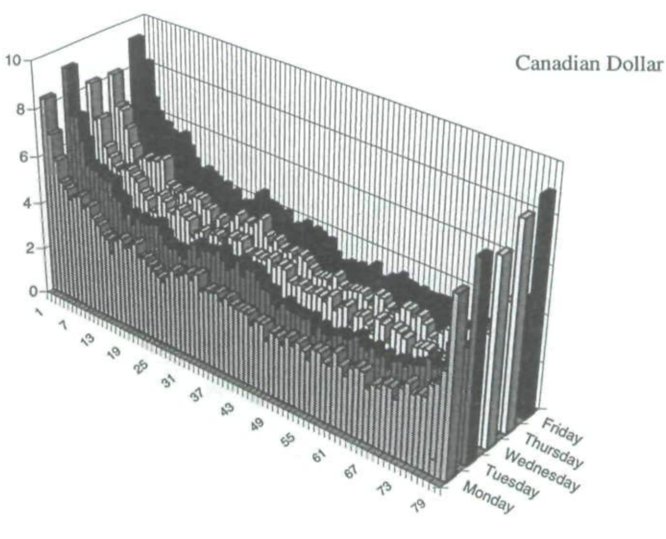
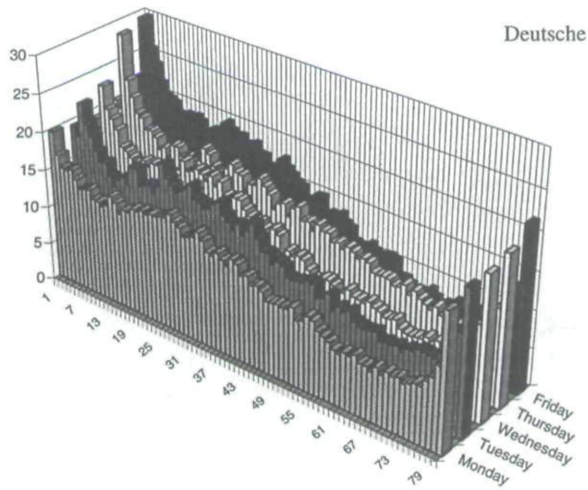


FIGURE 1B

Coefficients of day-of-the-week effect dummy variable for number of price changes. The coefficients d of the day-of-the-week dummy variables are estimated for 80 five-minute intervals for the model:

$$STAT_{h,i,d} = \sum_{m=1}^{16} a_{h,i,m} D_{m,d} + b_{h,i} DTM_d + c_{h,i} ANN_d * DTM_d + \sum_{k=1 \text{ to } 5} d_{h,i,k} DOW_{k,d} + \sum_{k=2,3,4,5} e_{h,i,k} ANN_d * DOW_{k,d} + u_{h,i,d}$$



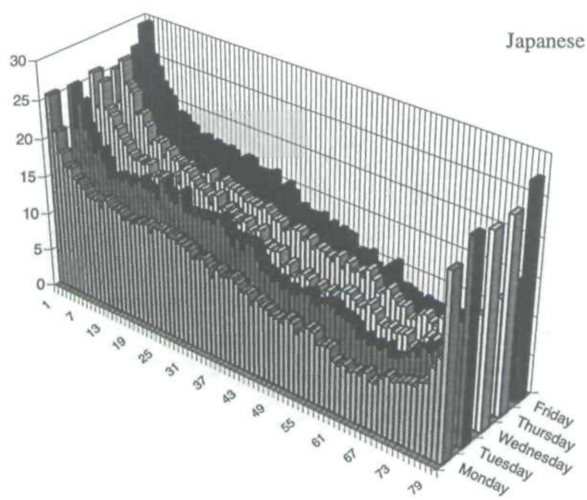


FIGURE 1B (Continued)

Coefficients of day-of-the-week effect dummy variable for number of price changes. The coefficients d of the day-of-the-week dummy variables are estimated for 80 five-minute intervals for the model:

$$STAT_{h,i,d} = \sum_{m=1}^{16} a_{h,i,m} D_{m,d} + b_{h,i} DTM_d + c_{h,i} ANN_d * DTM_d$$
$$+ \sum_{k=1\text{ to }5} d_{h,i,k} DOW_{k,d} + \sum_{k=2,3,4,5} e_{h,i,k} ANN_d * DOW_{k,d} + u_{h,i,d}$$

to that observed by Leng (1996), in which the maturity and day-of-the-week effects are not controlled for. However, it is also noticeable that, for all days of the week, the first half of the day shows higher volatility and intensity than the second half, yielding in many cases a w-shaped pattern.

Figures 1A and 1B also reveal major differences across days of the week. Mondays often have the lowest volatility and intensity for almost all intervals. As the week progresses, volatility and intensity generally increase for any given interval. The coefficients for Friday afternoons, however, are smaller than for the preceding days. These intraday and intraweek patterns suggest possible day-of-the-week effects, even after controlling for the announcement and maturity effects. For a better comprehension of the intraday and intraweek patterns, a trading day is divided into 10 segments (that is, eight intervals in a segment), and the averages of coefficients by segment and by days of the week are calculated. The results are reported in Tables IIA and IIB. These tables show that trading days often start with high volatility and intensity. As the day progresses, volatility and intensity level off and then decline until the market is about to close. In the 80th interval, both volatility and intensity surge, consistent with the market closing effect observed by Ferguson, Mann, and Schneck (1998). Their data, similar to Figures 1A and 1B, also strongly suggest some intraday and intraweek patterns. Further, it appears that, after controlling for the announcements, Mondays' low volatility and/or Thursdays' and Fridays' high volatility may be the main sources for the day-of-the-week effect. A series of tests are performed to examine the statistical significance of the intraday and intraweek patterns. The hypotheses and results are reported below.

Day-of-the-Week Effects in the Absence of Announcements

Three hypotheses are tested to examine the existence of and the possible sources for the day-of-the-week effect in the absence of announcements.

Hypothesis $H_o(1)$: All days of the week are equal for a given interval.[20]

$$\text{Test: } d_1 = d_2 = d_3 = d_4 = d_5$$

Hypothesis $H_o(2)$: Tuesday through Friday are equal for a given interval.

$$\text{Test: } d_2 = d_3 = d_4 = d_5$$

Hypothesis $H_o(3)$: Monday through Wednesday are equal for a given interval.

[20]All subscripts, except for the one for the day of the week, are dropped for conciseness.

TABLE IIA

Coefficients of Day-of-the-Week Dummy Variables for Standard Deviation

British Pound						*Canadian Dollar*					
Segment	*DOW1*	*DOW2*	*DOW3*	*DOW4*	*DOW5*	*Segment*	*DOW1*	*DOW2*	*DOW3*	*DOW4*	*DOW5*
1	3.9	4.3	4.5	5.3	6.1	1	3.0	3.0	3.0	3.1	3.4
2	3.6	3.9	4.0	4.3	5.0	2	2.5	2.6	2.6	2.9	3.0
3	3.8	4.3	4.3	4.4	4.9	3	2.4	2.5	2.7	2.7	2.8
4	4.1	4.3	4.3	4.4	4.8	4	2.3	2.5	2.6	2.5	2.6
5	3.7	4.0	3.8	4.3	4.5	5	2.5	2.7	2.6	2.7	2.7
6	3.7	3.8	3.6	4.3	4.1	6	2.2	2.3	2.3	2.5	2.4
7	3.5	3.5	3.2	3.7	3.6	7	2.3	2.3	2.4	2.4	2.3
8	3.1	3.2	3.1	3.4	3.1	8	2.2	2.3	2.3	2.4	2.4
9	2.9	3.0	3.0	3.1	3.2	9	2.2	2.4	2.3	2.4	2.2
10	3.1	3.4	3.5	3.4	3.6	10	2.5	2.6	2.5	2.8	2.6
Average	3.5	3.8	3.7	4.1	4.3	Average	2.4	2.5	2.5	2.6	2.6
Deutsche Mark						*Japanese Yen*					
Segment	*DOW1*	*DOW2*	*DOW3*	*DOW4*	*DOW5*	*Segment*	*DOW1*	*DOW2*	*DOW3*	*DOW4*	*DOW5*
1	6.0	6.7	6.8	7.3	9.0	1	5.0	5.3	5.7	6.0	7.0
2	5.6	5.9	6.1	6.2	7.3	2	4.4	4.7	4.9	5.1	5.7
3	5.7	6.2	6.3	6.4	7.1	3	4.3	4.8	5.1	4.9	5.5
4	6.0	6.4	6.5	6.6	7.1	4	4.6	5.0	5.0	5.2	5.7
5	5.6	6.2	6.0	6.3	6.8	5	4.2	4.8	4.6	4.9	5.3
6	5.2	5.6	5.4	6.0	5.9	6	3.9	4.2	4.2	4.7	4.8
7	4.9	5.3	5.0	5.6	5.2	7	3.8	4.2	4.1	4.6	4.4
8	4.3	4.7	4.8	5.1	4.6	8	3.5	3.9	3.9	4.1	3.8
9	4.1	4.6	4.3	4.6	4.5	9	3.4	3.9	3.8	4.1	3.7
10	4.7	5.4	5.1	5.1	5.2	10	4.1	4.9	4.6	4.6	4.6
Average	5.2	5.7	5.6	5.9	6.3	Average	4.1	4.6	4.6	4.8	5.0

Notes: The trading day starting 7:20 and ending 14:00 is divided into ten segments lasting 40 minutes each. For the model

$$STD_{i,d} = \sum_{m=1}^{16} a_{i,m}D_{m,d} + b_i DTM_d + c_i ANN_d * DTM_d + \sum_{k=1}^{5} d_{i,k}DOW_{k,d} + \sum_{k=2,3,4,5} e_{i,k}ANN_d * DOW_{k,d} + u_{i,d}$$

the average coefficients for $DOW_{k,d}$ are reported for these ten segments.

$$\text{Test: } d_1 = d_2 = d_3$$

Failure to reject hypothesis 1 suggests that no day-of-the-week effect exists after controlling for the announcement effect, supporting Harvey and Huang (1991). Logically, if hypothesis 1 is not rejected, the hypotheses 2 and 3 should also not be rejected, with very few exceptions. In other words, if there is no day-of-the-week effect for the entire week, the subsets of certain days of the week should not differ, either. Failure to reject hypotheses 1, 2, and 3 suggests no day-of-the-week effect and is referred

TABLE IIB

Coefficients of Day-of-the-Week Dummy Variables for Number of Price Changes

British Pound						*Canadian Dollar*					
Segment	*DOW1*	*DOW2*	*DOW3*	*DOW4*	*DOW5*	*Segment*	*DOW1*	*DOW2*	*DOW3*	*DOW4*	*DOW5*
1	10.9	12.4	13.1	14.3	15.0	1	5.7	6.4	6.0	6.0	7.0
2	10.0	10.0	9.8	10.6	11.6	2	3.8	4.4	4.4	4.6	5.0
3	9.9	10.6	10.2	10.5	11.2	3	3.5	3.8	4.0	4.0	4.1
4	9.0	9.9	10.2	9.7	10.4	4	3.2	3.7	3.8	3.9	4.1
5	8.0	9.3	8.5	9.2	9.2	5	3.3	3.9	3.8	3.8	3.9
6	7.3	8.0	7.4	8.7	8.5	6	2.8	3.2	3.4	3.3	3.3
7	6.6	7.0	6.4	7.3	6.8	7	2.7	2.8	3.1	3.1	3.2
8	5.1	6.1	6.0	6.5	5.4	8	2.7	3.0	3.1	3.2	3.3
9	4.7	5.4	5.3	5.5	5.3	9	2.7	3.0	2.9	3.1	2.8
10	6.9	7.8	7.8	7.6	7.9	10	4.0	4.4	4.1	4.7	4.4
Average	7.8	8.6	8.5	9.0	9.1	Average	3.4	3.9	3.9	4.0	4.1
Deutsche Mark						*Japanese Yen*					
Segment	*DOW1*	*DOW2*	*DOW3*	*DOW4*	*DOW5*	*Segment*	*DOW1*	*DOW2*	*DOW3*	*DOW4*	*DOW5*
1	15.8	18.4	19.0	21.1	23.5	1	15.8	18.4	19.6	20.8	23.0
2	13.4	15.0	15.3	16.4	18.6	2	13.8	15.8	15.7	15.9	17.7
3	14.0	16.2	16.5	16.4	18.6	3	13.5	16.0	16.4	15.2	16.8
4	14.4	16.4	16.4	16.3	17.2	4	12.8	15.2	14.5	14.5	15.7
5	13.1	15.3	14.0	15.1	15.6	5	11.3	13.4	12.2	13.0	13.2
6	11.1	12.5	11.3	13.8	13.0	6	9.5	10.7	9.8	11.6	11.5
7	9.8	10.9	9.6	12.1	10.7	7	8.8	10.5	9.8	10.7	9.7
8	7.9	9.3	9.0	10.6	8.2	8	6.9	8.6	8.6	9.0	7.7
9	7.2	8.5	7.9	9.2	8.1	9	7.5	9.0	8.7	9.4	8.3
10	9.7	11.8	11.0	11.2	11.3	10	12.6	15.4	14.1	14.3	14.4
Average	11.6	13.4	13.0	14.2	14.5	Average	11.3	13.3	12.9	13.4	13.8

Notes: The trading day starting 7:20 and ending 14:00 is divided into ten segments lasting 40 minutes each. For the model

$$NP_{i,d} = \sum_{m=1}^{16} a_{i,m}D_{m,d} + b_i DTM_d + c_i ANN_d * DTM_d + \sum_{k=1}^{5} d_{i,k}DOW_{k,d} + \sum_{k=2,3,4,5} e_{i,k}ANN_d * DOW_{k,d} + u_{i,d}$$

the average coefficients for $DOW_{k,d}$ are reported for these ten segments.

to as scenario 1. The few intervals for which either hypothesis 2 or 3 is rejected, and at the same time hypothesis 1 is not, are not interpreted for their rarity.

Rejection of hypothesis 1 suggests that a day-of-the-week effect exists even after controlling for the announcement effect. The inequality may be driven by either the lower volatility/intensity on Mondays or higher volatility/intensity on Thursdays or Fridays. The test results for hypotheses 2 and 3 are intended to identify the source of the inequality. If hypothesis 2 is not rejected and hypothesis 3 is rejected, then the day-of-the-week effect is likely to be driven by the lower volatility on Mondays. This is scenario 2.

If hypothesis 1 is rejected, the rejection of hypothesis 2 and failure to reject hypothesis 3 would suggest that Thursdays' and/or Fridays' higher volatility is an explanation for the day-of-the-week effect. This is scenario 3. All other combinations of the results for hypotheses 2 and 3 are not informative and are categorized as scenario 4.

As expected, intervals differ as to the existence of a day-of-the-week effect and as to possible explanations for the day-of-the-week effect, if one exists. The results are summarized by segment and reported in Table III.[21] Because the results for the number of price changes and the standard deviation are similar, the discussion does not differentiate between them. The results differ quite dramatically by currency, so each currency is discussed individually.[22]

With respect to the British pound, scenario 1 (that is, the hypothesis that all days are equal cannot be rejected) holds for 49 and 46 intervals, respectively for standard deviation and number of price changes, most of which are in the afternoons. In other words, afternoon intervals mostly exhibit no day-of-the-week effect. Scenario 2 holds for 17 and 18 intervals, respectively, mostly in the second and third segments (that is, 8:00 AM–9:20 AM CST). It seems that trading between 8:00 AM–9:20 AM CST exhibits day-of-the-week effects that are driven primarily by the lower volatility/intensity on Monday mornings. Scenario 3 holds only for nine intervals for both statistical measures, concentrated in late mornings.

A different picture emerges with respect to the Deutsche mark. Scenario 1 holds for 34 and 30 intervals, respectively, mostly concentrated in the afternoons. Scenario 2 holds for 18 intervals for both statistical measures, mostly around midmorning. Scenario 3 holds for 18 and 22 intervals, respectively. The results suggest that day-of-the-week effects exist for more than half of the intervals, of which about half are driven by Mondays' low volatility/intensity and half by Thursdays' or Fridays' high volatility/intensity.

For the Japanese yen, scenario 1 holds for 10 intervals for both statistical measures mostly between 11:20 and 14:00 CST. Scenario 2 holds

[21]The test results by interval are available upon request.

[22]Connolly (1991) finds that outliers are a significant factor in tests of the day-of-the-week effect. The skewness and kurtosis measures of this data by interval indicate that outliers display no systematic patterns and play a role only in few, if any, intervals.

TABLE III

Explanatory Scenarios for Day-of-the-Week Effect

	British Pound									*Canadian Dollar*							
	Scenarios STD				*Scenarios NP*					*Scenarios STD*				*Scenarios NP*			
Segment	*S1*	*S2*	*S3*	*S4*	*S1*	*S2*	*S3*	*S4*	*Segment*	*S1*	*S2*	*S3*	*S4*	*S1*	*S2*	*S3*	*S4*
1	5	0	2	1	4	0	2	2	1	8	0	0	0	8	0	0	0
2	1	6	1	0	1	6	1	0	2	3	4	0	1	3	5	0	0
3	1	6	0	1	1	6	0	1	3	6	2	0	0	6	2	0	0
4	5	2	0	1	5	2	0	1	4	7	1	0	0	7	1	0	0
5	4	2	1	1	5	2	1	0	5	7	1	0	0	7	1	0	0
6	6	0	2	0	5	0	2	1	6	6	1	1	0	5	2	1	0
7	6	0	1	1	6	0	1	1	7	6	2	0	0	6	2	0	0
8	6	0	2	0	6	0	2	0	8	8	0	0	0	8	0	0	0
9	7	1	0	0	7	1	0	0	9	6	1	1	0	6	1	1	0
10	8	0	0	0	6	1	0	1	10	7	1	0	0	7	1	0	0
Sum	49	17	9	5	46	18	9	7	Sum	64	13	2	1	63	15	2	0
	Deutsche Mark									*Japanese Yen*							
	Scenarios STD				*Scenarios NP*					*Scenarios STD*				*Scenarios NP*			
Segment	*S1*	*S2*	*S3*	*S4*	*S1*	*S2*	*S3*	*S4*	*Segment*	*S1*	*S2*	*S3*	*S4*	*S1*	*S2*	*S3*	*S4*
1	2	1	3	2	2	1	3	2	1	2	2	3	1	2	2	3	1
2	3	0	3	2	3	0	3	2	2	0	2	6	0	0	1	6	1
3	1	4	3	0	1	4	3	0	3	0	5	3	0	0	4	4	0
4	5	3	0	0	4	3	0	1	4	0	8	0	0	0	8	0	0
5	2	5	1	0	2	5	1	0	5	0	5	1	2	0	5	1	2
6	1	1	4	2	1	1	4	2	6	0	1	4	3	0	1	4	3
7	8	0	0	0	6	0	2	0	7	2	0	3	3	2	0	3	3
8	4	1	2	1	3	1	4	0	8	2	3	3	0	2	3	3	0
9	2	1	2	3	2	1	2	3	9	2	4	0	2	2	4	0	2
10	6	2	0	0	6	2	0	0	10	2	5	1	0	2	4	1	1
Sum	34	18	18	10	30	18	22	10	Sum	10	35	24	11	10	32	25	13

For the model

$$STAT_{h,i,d} = \sum_{m=1}^{16} a_{h,i,m} D_{m,d} + b_{h,i} DTM_d + c_{h,i} ANN_d * DTM_d + \sum_{k=1}^{5} d_{h,i,k} DOW_{k,d} + \sum_{k=2,3,4,5} e_{h,i,k} ANN_d * DOW_{k,d} + u_{h,i,d}$$

The coefficients for $DOW_{k,d}$ are tested for the three hypotheses $H_0(1)$: $d_1 = d_2 = d_3 = d_4 = d_5$, $H_0(2)$: $d_2 = d_3 = d_4 = d_5$, and $H_0(3)$: $d_1 = d_2 = d_3$. The results are summarized in four scenarios: Scenario 1: Failure to reject $H_0(1)$ implies that there is no day-of-the-week effect. Scenario 2: Rejection of $H_0(1)$, failure to reject $H_0(2)$, and rejection of $H_0(3)$ indicates a Monday-driven day-of-the-week effect. Scenario 3: Rejection of $H_0(1)$ and $H_0(2)$, and failure to reject $H_0(3)$ indicates a Thursday/Friday-driven day-of-the-week effect. Scenario 4: Other combinations of $H_0(2)$ and $H_0(3)$ are not informative. For example, the number in the S1 column is the number of intervals satisfying the definition of scenario 1 in each segment. Note that announcements take place in segments 1, 2, 3, and 9.

for 35 and 32 intervals, respectively; and scenario 3 holds for 24 and 25 intervals, respectively. The Japanese yen exhibits strong day-of-the-week effects for almost all intervals; and the day-of-the-week effects are driven more by Mondays' low volatility/intensity than by Thursdays' or Fridays' high volatility/intensity. In sum, the British pound, Deutsche mark, and Japanese yen exhibit different degrees of the day-of-the-week effects after the announcement and maturity effects have been controlled for. Morning intervals that show day-of-the-week effects are more likely to be driven by Mondays' low volatility/activity, whereas afternoon intervals that show day-of-the-week effects are more likely driven by Thursdays' or Fridays' high volatility/activity. The Canadian dollar, on the other hand, shows no day-of-the-week effect for about 80% of the intervals.[23] The remaining intervals show the day-of-the-week effects predominantly driven by Mondays' low volatility/intensity.

The results indicate that, in addition to public information, the intraweek volatility and intensity patterns are driven by factors such as private information, traders' pattern of information processing, and by the trading process itself. Anecdotal evidence from futures traders suggests an increase in their activity over the course of the week.[24] Traders report that the earlier part of the week is used to get a sense of the markets, whereas the later part of the week is used to trade in the markets. Private information accumulated over the weekend seems to get little usage, as indicated by the lower volatility in the beginning intervals on Mondays. This is perhaps a result of traders' preference of getting a feel for the market in the early part of the week before taking actions.

Announcement and Day-of-the-Week Effects

Three hypothesis tests comparable to those discussed above are performed regarding the interaction of the announcement and day-of-the-week effects. Briefly, they are:

Hypothesis $H_o(4)$: All days of the week have an equal announcement effect for a given interval.

[23]The small numbers of price changes for the Canadian dollar on Mondays (as can be seen in Table IIB) can affect the reliability of the calculated standard deviation and the test results. However, the same concern seems not applicable to other currencies and the Canadian dollar for other days of the week.

[24]The authors have firsthand accounts from traders in various types of commodities. More detailed information is available upon request.

$$\text{Test: } e_2 = e_3 = e_4 = e_5 = 0$$

Hypothesis $H_o(5)$: Tuesday through Friday have an equal announcement effect for a given interval.

$$\text{Test: } e_2 = e_3 = e_4 = e_5$$

Hypothesis $H_o(6)$: Monday through Wednesday have an equal announcement effect for a given interval.

$$\text{Test: } e_2 = e_3 = 0$$

Scenarios A through D are analogous to scenarios 1 through 4 discussed above. Scenario A holds if the hypothesis that the announcements do not alter the day-of-the-week effect cannot be rejected. Scenario B holds if the hypothesis that the announcements do not alter the day-of-the-week effect can be rejected and that Mondays' low volatility/intensity is the likely explanation; however, if the same hypothesis can be rejected for higher volatility/intensity on Thursdays or Fridays, it is scenario C. Scenario D includes all other combinations.

Table IV reports the test results. As shown, for all currencies and for both statistical measures, scenario A holds for almost all intervals; that is, the presence of the announcements does not alter the day-of-the-week effect. Using Figure 2 to illustrate, Harvey and Huang (1991) suggest implicitly that, in the absence of announcements, there should be no day-of-the-week effect—that is, the slope of line connecting the day-of-the-week coefficients should be zero. This study suggests that there are day-of-the-week effects in the absence of announcements (represented by the thin solid line in Figure 2) and that the announcements cause a parallel shift in volatility/intensity every day of the week (represented by the bold dotted line in Figure 2), thus leaving the day-of-the-week pattern unchanged. In other words, currency futures markets process public information the same way across the days of the week, which is opposite to the observation of Chang, Pinegar, and Ravichandran (1998) that the U.S. equity market processes information differently on Mondays than on other days of the week.

Intraday Patterns

Intraday patterns of currency futures have been documented by Harvey and Huang (1991) and Leng (1996), with the former controlling for days of the week and the latter controlling for announcements. This study controls for both while testing the equality of volatility and intensity at different times of a given day of the week.

TABLE IV

Explanatory Scenarios for Announcement and Day-of-the-Week Effects

	British Pound							
	Scenarios STD				*Scenarios NP*			
Segment	*S1*	*S2*	*S3*	*S4*	*S1*	*S2*	*S3*	*S4*
1	8	0	0	0	8	0	0	0
2	7	0	1	0	7	0	1	0
3	7	0	1	0	7	0	1	0
4	6	0	2	0	6	0	2	0
5	7	0	1	0	7	0	1	0
6	6	0	2	0	6	0	2	0
7	7	1	0	0	7	1	0	0
8	8	0	0	0	8	0	0	0
9	8	0	0	0	8	0	0	0
10	8	0	0	0	8	0	0	0
Sum	72	1	7	0	72	1	7	0

	Canadian Dollar							
	Scenarios STD				*Scenarios NP*			
Segment	*S1*	*S2*	*S3*	*S4*	*S1*	*S2*	*S3*	*S4*
1	8	0	0	0	8	0	0	0
2	8	0	0	0	8	0	0	0
3	8	0	0	0	8	0	0	0
4	8	0	0	0	8	0	0	0
5	6	0	2	0	7	0	1	0
6	8	0	0	0	8	0	0	0
7	8	0	0	0	8	0	0	0
8	7	0	1	0	7	0	1	0
9	6	0	1	1	8	0	0	0
10	8	0	0	0	8	0	0	0
Sum	75	0	4	1	78	0	2	0

	Deutsche Mark							
	Scenarios STD				*Scenarios NP*			
Segment	*S1*	*S2*	*S3*	*S4*	*S1*	*S2*	*S3*	*S4*
1	8	0	0	0	8	0	0	0
2	8	0	0	0	8	0	0	0
3	8	0	0	0	8	0	0	0
4	8	0	0	0	8	0	0	0
5	8	0	0	0	8	0	0	0
6	7	0	1	0	7	0	1	0
7	8	0	0	0	7	1	0	0
8	8	0	0	0	8	0	0	0
9	7	0	1	0	7	0	1	0
10	8	0	0	0	8	0	0	0
Sum	78	0	2	0	77	1	2	0

	Japanese Yen							
	Scenarios STD				*Scenarios NP*			
Segment	*S1*	*S2*	*S3*	*S4*	*S1*	*S2*	*S3*	*S4*
1	8	0	0	0	8	0	0	0
2	8	0	0	0	8	0	0	0
3	8	0	0	0	8	0	0	0
4	8	0	0	0	8	0	0	0
5	8	0	0	0	8	0	0	0
6	8	0	0	0	8	0	0	0
7	7	0	1	0	7	0	1	0
8	8	0	0	0	8	0	0	0
9	8	0	0	0	8	0	0	0
10	8	0	0	0	8	0	0	0
Sum	79	0	1	0	79	0	1	0

For the model

$$STAT_{h,i,d} = \sum_{m=1}^{16} a_{h,i,m} D_{m,d} + b_{h,i} DTM_d + c_{h,i} ANN_d * DTM_d + \sum_{k=1}^{5} d_{h,i,k} DOW_{k,d} + \sum_{k=2,3,4,5} e_{h,i,k} ANN_d * DOW_{k,d} + u_{h,i,d}$$

The coefficients for $ANN_d * DOW_{k,d}$ are tested for the three hypotheses $H_0(1)$: $e_2 = e_3 = e_4 = e_5 = 0$, $H_0(2)$: $e_2 = e_3 = e_4 = e_5$, and $H_0(3)$: $e_1 = e_2 = 0$. The results are summarized in four scenarios: Scenario 1: Failure to reject $H_0(1)$ implies that there is not day-of-the-week effect. Scenario 2: Rejection of $H_0(1)$, failure to reject $H_0(2)$, and rejection of $H_0(3)$ indicates a Monday-driven day-of-the-week effect. Scenario 3: Rejection of $H_0(1)$ and $H_0(2)$, and failure to reject $H_0(3)$ indicates a Thursday/Friday-driven day-of-the-week effect. Scenario 4: Other combinations of $H_0(2)$ and $H_0(3)$ are not informative. For example, the number in the S1 column is the number of intervals satisfying the definition of scenario 1 in each segment. Note that announcements take place in segments 1, 2, 3, and 9.

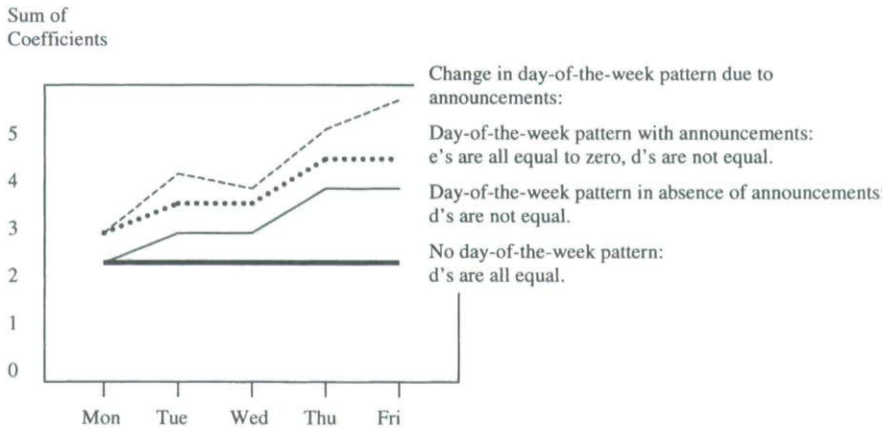


FIGURE 2

Illustration of interaction of announcement and day-of-the-week effects. The pattern of the sum of the coefficients d, a and k in the model

$$STAT_{h,i,d} = \sum_{m=1}^{16} a_{h,i,m} D_{m,d} + b_{h,i} DTM_d + c_{h,i} ANN_d * DTM_d + \sum_{k=1\text{ to }5} d_{h,i,k} DOW_{k,d} + \sum_{k=2,3,4,5} e_{h,i,k} ANN_d * DOW_{k,d} + u_{h,i,d}$$

depends on the volatility/intensity in the absence of announcements (d), the marginal effect of individual announcements (a), and the announcement effect on the volatility/intensity (e). This study indicates a pattern represented by the thin solid line (in the absence of announcements) and the bold dotted line (with the announcement effect).

TABLE V

Generalized Method of Moments χ^2 Tests for Intraday Patterns

		Monday		*Tuesday*		*Wednesday*		*Thursday*		*Friday*	
Currency	*Statistic*	*Coeff*	*PV*	*Coeff*	*PV*	*Coeff*	*PV*	*Coeff*	*PV*	*Coeff*	*PV*
B. Pound	NP	62.5	0.00	57.8	0.00	66.4	0.00	66.1	0.00	69.8	0.00
	STD	48.9	0.00	45.6	0.00	46.0	0.00	53.9	0.00	51.8	0.00
C. Dollar	NP	41.7	0.00	44.1	0.00	45.2	0.00	32.8	0.00	45.0	0.00
	STD	72.4	0.00	80.7	0.00	91.1	0.00	98.7	0.00	0.0	1.00
D. Mark	NP	76.2	0.00	76.2	0.00	82.5	0.00	83.1	0.00	88.6	0.00
	STD	73.3	0.00	65.6	0.00	72.9	0.00	76.5	0.00	97.2	0.00
J. Yen	NP	76.0	0.00	77.2	0.00	82.3	0.00	80.3	0.00	84.9	0.00
	STD	70.3	0.00	67.0	0.00	66.9	0.00	63.3	0.00	80.1	0.00

Notes: The intraday equality of the coefficients d in the model

$$STAT_{h,i,d} = \sum_{m=1}^{16} a_{h,i,m} D_{m,d} + b_{h,i} DTM_d + c_{h,i} ANN_d * DTM_d + \sum_{k=1\text{to}5}^{5} d_{h,i,k} DOW_{k,d} + \sum_{k=2,3,4,5} e_{h,i,k} ANN_d * DOW_{k,d} + u_{h,i,d}$$

is tested by applying GMM separately to the equations $d_{h,6,k} = d_{h,20,k} = d_{h,34,k} = d_{h,48,k} = d_{h,62,k} = d_{h,76,k}$, for k = 1 to 5. The covariance matrix is estimated using Newey-West (1987) with ten lags to correct for possible serial correlation. Hansen's χ^2 $(r - a)$ test is used to test the equality conditions.

Abbreviations: Number of price changes (NP), standard deviation (STD), coefficient values (Coeff), probability values (PV).

As noted above, Hansen's GMM is performed on a system of equations representing the selected intervals. To limit the time needed for computing a system of equations with nonlinear restrictions, only six intervals are used for testing. The results from testing intervals 6, 20, 34, 48, 62, and 76 are shown. The six intervals are selected because they are equally spaced, and because none of the intervals are announcement intervals.[25] As shown in Figures 1A and 1B, the announcement intervals tend to have higher volatility and intensity even on the nonannouncement days. Because this study cannot control for all economic indicators, it could be that some days are treated as nonannouncement days when, on the contrary, they are actually announcement days. If the equality is rejected for these six nonannouncement intervals, it is extremely likely that the equality would be rejected for all intervals. Therefore, the selection of intervals for testing intraday homogeneity errs toward the acceptance of the null hypothesis. The results reported in Table V clearly indicate intraday patterns (or inequalities) for all days of the week, after controlling for announcement and maturity effects.

Intraday and Intraweek Patterns

Joint tests of the equality of selected intervals across the days of the week are also performed. Again, Hansen's GMM is applied to a system of equations representing the selected intervals restricted by eq. (5). As expected, the null hypothesis is rejected for all currencies, as shown in Table VI. In other words, both the standard deviation of returns and number of price changes of all four currency futures show statistically significantly intraday and intraweek differences.

Maturity Effect

The model set up in eq. (3) also allows for testing the presence of a maturity effect and the effect of announcements on the maturity effect. The probability values of the coefficient associated with *DTM* indicate that there is virtually no maturity effect for both statistical measures and for all currencies. Also, the announcements do not alter the lack of maturity effect in any way. Table VII reports the number of significant intervals by segment. All coefficients for significant intervals have positive signs, contrary to Samuelson's (1965) prediction. The result of no maturity effect is thus consistent with Galloway and Kolb (1996).

[25]Using other patterns of equally-spaced intervals yields similar outcomes, indicating that the results are robust with respect to the intervals used.

TABLE VI

Generalized Method of Moments χ^2 Tests for Intraday and Intraweek Patterns

	Number of Price Changes		*Standard Deviation*	
Currency	*Coefficient*	*Probability Value*	*Coefficient*	*Probability Value*
British Pound	83.7	0.00	70.5	0.00
Canadian Dollar	54.3	0.01	65.2	0.00
Deutsche Mark	98.5	0.00	103.6	0.00
Japanese Yen	83.7	0.00	70.5	0.00

Notes: The intraday and intraweek equality of the coefficients d in the model

$$STAT_{h,i,d} = \sum_{m=1}^{16} a_{h,i,m} D_{m,d} + b_{h,i} DTM_d + c_{h,i} ANN_d * DTM_d + \sum_{k=1\text{ to }5}^{5} d_{h,i,k} DOW_{k,d} + \sum_{k=2,3,4,5} e_{h,i,k} ANN_d * DOW_{k,d} + u_{h,i,d}$$

is tested by applying GMM to the system described in equation (5). The covariance matrix is estimated using Newey-West (1987) with ten lags to correct for possible serial correlation. Hansen's χ^2 $(r - a)$ test is used to test the equality conditions.

CONCLUSIONS

Using standard deviations and numbers of price changes calculated from tick data for currency futures, this study finds strong day-of-the-week effects for both the Deutsche mark and Japanese yen, mild effects for the British pound, and no effects for the Canadian dollar after controlling for the announcement effect and the maturity effect. This result suggests that the day-of-the-week effects in currency futures are not driven by the announcements of macroeconomic indicators as suggested by Harvey and Huang (1991) and tested by Ederington and Lee (1993). Our contradiction of the statistical evidence of Ederington and Lee (1993) is possibly led by the observation that the day-of-the-week effects are tested by interval in this study, whereas the effects are tested with all intervals pooled in their study. This study further shows that Mondays' low volatility drives the day-of-the-week effects for about half of the intervals showing such effects; Thursdays' or Fridays' high volatility drives the remaining half. This research also finds that information is processed equally across the days of the week for all four currency futures, as opposed to the findings of Chang, Pinegar, and Ravichandran (1998) that the U.S. equity market processes information on Mondays differently than on other days of the week.

This study documents strong intraday inequalities for both standard deviation and number of price changes for intervals other than the opening and closing intervals, while controlling for the announcement and maturity effects. Confirming the findings of Galloway and Kolb (1996), this study also finds no maturity effect with respect to both standard deviation and number of price changes.

TABLE VII

Days-to-maturity Effect

	British Pound					*Canadian Dollar*			
	STD		*NP*			*STD*		*NP*	
Segment	*DTM*	*ANN*DTM*	*DTM*	*ANN*DTM*	*Segment*	*DTM*	*ANN*DTM*	*DTM*	*ANN*DTM*
1	0	0	1	0	1	0	0	0	0
2	0	0	0	1	2	0	0	0	0
3	0	0	0	0	3	0	0	0	0
4	0	1	0	0	4	0	0	0	0
5	0	0	1	0	5	0	0	0	0
6	0	1	0	0	6	0	0	1	0
7	0	0	0	2	7	0	0	0	0
8	0	1	0	0	8	0	1	0	0
9	1	0	1	0	9	0	1	0	0
10	0	0	0	0	10	0	0	0	1
Sum	1	3	3	3	Sum	0	2	1	1
	Deutsche Mark					*Japanese yen*			
	STD		*NP*			*STD*		*NP*	
Segment	*DTM*	*ANN*DTM*	*DTM*	*ANN*DTM*	*Segment*	*DTM*	*ANN*DTM*	*DTM*	*ANN*DTM*
1	1	0	0	0	1	1	0	0	0
2	1	0	2	0	2	3	0	0	0
3	1	0	0	0	3	3	0	0	0
4	0	0	0	0	4	0	0	0	5
5	0	0	0	0	5	1	0	0	0
6	0	1	2	1	6	4	0	1	0
7	0	0	1	0	7	0	0	0	0
8	0	0	0	0	8	3	0	4	0
9	3	0	0	1	9	3	0	2	0
10	0	0	0	0	10	0	1	0	1
Sum	6	1	5	2	Sum	18	1	7	6

The trading day starting 7:20 and ending 14:00 is divided into ten segments lasting 40 minutes each the number of five-minute intervals with statistically significant coefficients *b* and *c* within each segment is counted for the model

$$STAT_{h,i,d} = \sum_{m=1}^{16} a_{h,i,m}D_{m,d} + b_{h,i}DTM_d + c_{h,i}ANN_d * DTM_d + \sum_{k=1\text{to}5} d_{h,i,k}DOW_{k,d} + \sum_{k=2,3,4,5} e_{h,i,k}ANN_d * DOW_{k,d} + u_{h,i,d}$$

These results strongly suggest that currency futures are moved by factors other than the scheduled announcements of macroeconomic indicators, such as private information–based trading and microstructure of the markets. Although it is impossible to test directly whether the observed intraday and intraweek patterns are caused by private information–based trading or by the market microstructure, the similarity of the intraday pattern across the days of the week suggests that the market microstructure and the trading process may be more important factors shaping the volatility and intensity patterns than private information–based trading, unless there is evidence to indicate that market participants always act on private information at certain times.

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