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'Once-in-a-generation' yen volatility in 1998: fundamentals, intervention, and order flow

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Abstract

The dramatic yen/dollar volatility of 1998 has been popularly ascribed to order flow driven by changing tastes for risk and hedge-fund herding on unwinding yen 'carry trade' positions rather than fundamentals. High-frequency evidence of shifting fundamentals is provided by a comprehensive list of macroeconomic announcements. News is found to have significant effects on volatility, but order flow may play a more important role. Since portfolio shifts are revealed to the market through trading, the results are consistent with order flow playing a significant role in the revelation of private information and associated exchange rate shifts.

JEL classification: F31; G14; G15; C22

Keywords: Exchange rate volatility; Private information; Order flow; News announcements; Central bank intervention

1. Introduction

The yen/dollar exchange rate provided market participants with a year to remember in 1998. Not since the breakdown of the Bretton Woods system in the early 1970s has such volatility been witnessed. After many months of uneven yen depreciation, a surprise joint US–Japanese intervention on June 17 led to a yen appreciation of

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more than 6 yen per dollar. This first-ever yen intervention by the Clinton Administration followed the yen hitting an 8-yr low against the dollar earlier that week. Then, after several months of continued yen depreciation, a sudden reversal was experienced where, on October 7, the yen price of a dollar fell from about 134 to 120 in one day. On the next day, the yen traded in a remarkably large range between 111 and 123. For the remainder of the year, sporadic volatility occurred and investor uncertainty was reflected in the implied volatility in yen options trading between 15 and 23%. Near year's end, the premium for one-month dollar puts reached an all-time high of 3.6%.[1]

A search of the news reveals three sources being most frequently mentioned as the cause of yen–dollar volatility: announcements related to macroeconomic fundamentals; intervention by the Bank of Japan, the US Treasury, and the Federal Reserve; and portfolio position switches by large institutions. Most analysts blamed the wide swings of late 1998 on hedge funds and panic trading. For instance, in a review of recent yen performance a *Financial Times* article reported that the fluctuations in the value of the yen in late 1998 were "driven by temporary market panic, rather than any economic fundamentals."[2] The rapid appreciation of the yen has been most commonly associated with investors unwinding positions in the 'yen-carry' trade where funds had borrowed yen at interest rates near zero and then invested in higher-yielding securities denominated in dollars and other currencies. During the period of yen depreciation in early 1998, such short-yen positions were quite profitable. The standard belief is that a reassessment of the risk environment was associated with a liquidity crunch and was brought about by a convergence of negative outcomes such as hedge fund losses in emerging markets and the near-collapse of Long Term Capital Management. This changed environment caused funds to unwind their short yen positions and resulted in yen appreciation. Once the appreciation began, herd behavior is said to have occurred where there was a stampede of investors to cover their short yen positions.[3]

The notable events of 1998 provide an interesting laboratory to assess the role of economic fundamentals and test if there was an independent role for order-flow induced exchange rate volatility where investor position switches were revealed through their trades. In a broad sense, the sample provides insights into the role of public information in the form of macroeconomic announcements versus private information revealed through order flow in determining exchange rates. Microstructure theories provide a framework for understanding the learning that occurs when a large fund reveals its position switching through trades with counterparty banks. The world learns about the yen carry-trade unwinding not via public announcements

[1] A good overview of the environment in late 1998 is provided in the March 1999 Federal Reserve Bulletin.

[2] See Tett (1999).

[3] A useful non-technical discussion of the yen carry-trade and its potential effects on exchange rate volatility is provided in Beranger et al. (1999).

but via trades of the firms holding the short-yen positions.[4] Beyond the particular interest in understanding the causes of yen volatility in 1998, it is also worthwhile to consider the broader issue of exchange rate determination. It has long been known that empirical models of exchange rates have not performed well. In the high-frequency data setting, researchers have examined the impact of macroeconomic news and found that intra-daily exchange rate volatility systematically responds to public information announcements (see Andersen and Bollerslev (1998) for a mark/dollar example). However, researchers have recently suggested that the act of trading, apart from any fundamentals—related news, may be an important source of exchange rate dynamics.[5]

The foreign exchange market is a market with a relative lack of transparency and asymmetrically-informed traders so that order flow should be expected to contain independent information. This is a view that is widely supported by practitioners and documented in several market surveys. For instance, Menkhoff (1998) found that the overwhelming majority of 205 German FX professionals he surveyed agreed with the following statement: "Big market participants can 'make' exchange rates for a while via own position taking and customer orders." This is consistent with the findings of a survey of 142 U.S. market participants by Cheung and Chinn (2000). They find that "large players are perceived to have a better customer and market network, which, in turn, give them better information on order flow and the activity of other trading banks" (p. 8). Cheung and Wong (1999) surveyed almost 400 traders in Hong Kong, Tokyo, and Singapore and find that roughly 25% of respondents identify their trading style to be determined by customer order flow rather than technical trading, fundamentals, or jobbing (continuously buying and selling small amounts to earn the spread). Cheung et al. (1999) found that 97% of the 110 UK FX professionals they surveyed disagreed with the statement: "Intraday exchange rate movements accurately reflect changes in the fundamental value." Based on their survey results and the role that order flow may play in revealing 'speculative forces' leads Cheung et al. to state that "A model capable of explaining exchange rate movements needs to consider another factor, over and above the usual suspects." We believe that this 'other factor' is order flow and hope to demonstrate the importance empirically in a setting incorporating major news releases so that the effect of order flow, independent of announcement effects, may be identified.

The response of the yen–dollar exchange rate to regularly scheduled news releases has been studied by others. Ederington and Lee (1994), DeGennaro and Shrieves (1997), Leng (1996) and Chatrath and Song (1998) are among those who investigate

[4] Evans and Lyons (1999) provide a theoretical model of the role of foreign exchange market order flow in determining exchange rates. Using data on signed order flow (whether a purchase or sale) from the Reuters Dealing 2000–1 system, they find evidence that order flow is a significant determinant of the mark–dollar and yen–dollar exchange rates over 89 days in 1996. Unfortunately, such data are not available for our sample period as the Bank of England only collected the data for four months in 1996. In addition, the EBS system is known to provide better coverage of the yen/dollar market than Reuters so one may wonder how representative the Reuters system would be for yen/dollar trades.

[5] See, for example, Ito et al. (1998) and Evans and Lyons (1999).

high-frequency news effects on the yen. All but DeGennaro and Shrieves focus on macroeconomic announcements during US trading hours and futures markets, with their limited trading hours constraint.[6] Earlier studies tend to emphasize one of the following three components-time-of-day patterns (intraday calendar effects), macroeconomic announcements (public information effects), and intra- and inter-day volatility persistence (ARCH effects). Recent findings suggest that all three factors should be accounted for simultaneously in high frequency studies of volatility processes, or else distorted estimates for the individual components may arise.

Building on the methodology in Andersen and Bollerslev (1997, 1998), this paper offers a comprehensive study of the intraday patterns in the volatility of the yen–dollar spot exchange rate that explicitly incorporates the different volatility components in a coherent framework. Our analysis is based on a one-year sample of five-minute returns in 1998. The impact of 32 US and 33 Japanese regularly released macroeconomic announcements is examined. The sample of macroeconomic news is more comprehensive than that used in any existing study on the yen–dollar exchange rate. From the US side, ten announcements are found to be significant. These include the employment report, the consumer price index (CPI), the Gross Domestic Product (GDP), the producer price index (PPI), the merchandise trade balance, consumer installment credit, real earnings, employment costs, reserve assets, and personal income. The six significant Japanese announcements include the Tankan report,[7] the unemployment rate, vehicle sales, the consumer sentiment index, electricity usage, and vehicle production. Dummy variables for central bank intervention are also found to have a significant effect on volatility. Order flow is proxied by yen positions held by major market participants such as commercial and investment banks. We find that yen volatility is positively associated with purchases of yen spot, forward, and futures contracts and negatively associated with sales. The results indicate that there is a significant role for order flow in understanding the yen volatility of 1998 apart from announcements regarding fundamentals or central-bank intervention.

Despite the extraordinary yen–dollar exchange rate volatility in 1998, we are able to capture a distinct intraday volatility pattern over different regional segments. The significant calendar effects include holiday, weekend, Tokyo opening, Tokyo and European lunch breaks, Monday morning, late Friday, and Daylight Saving Time. In contrast to previous studies, the day-of-the-week effects remain highly significant even after accounting for the clustering of regularly scheduled macroeconomic news releases on Thursdays and Fridays during the sample period.

The remainder of the paper is organized as follows. Section 2 describes the data, summarizes the intraday volatility patterns, and estimates various intraday calendar effects. Section 3 examines the implications of major macroeconomic announcements, intervention, and order flow. Section 4 assesses the overall importance of

[6] Hardouvelis (1984), Hakkio and Pearce (1985), Thornton (1989) and Ito and Roley (1987) examine announcement effects on the yen–dollar exchange rate using lower-frequency data. See Andersen and Bollerslev (1998) for a more detailed review of earlier studies on the impact of macroeconomic news on major currencies.

[7] The BOJ conducts a quarterly short-term economic survey (Tankan) of about 7500 companies.

different volatility components at the intraday and daily level. Finally, Section 5 provides a concluding discussion of results and implications.

2. Modeling the intraday patterns

2.1. Data

The Japanese yen–US dollar spot exchange rate quotes for 1998 are provided by Olsen and Associates Limited. Each quote contains a bid and ask price along with the time to the nearest second. At the end of each five-minute interval, we use the immediately preceding and following quotes to construct the relevant price. The log-price is first calculated as the midpoint of the logarithmic bid and ask. The log-prices are then weighted by their inverse relative distance to the endpoint. On weekdays, all 288 intervals during the 24-hour trading cycle are used. On weekends, however, all returns from 21:00 Greenwich Mean Time (GMT) Friday through 21:00 GMT Sunday are excluded. To maintain a fixed number of observations over the span of a week, returns during worldwide or country-specific holidays are not removed, although the holiday effects are explicitly accounted for by dummy variables. There are 260 trading days during the sample period so this leaves us with a total of 74,880 observations on returns, $R_{t,n}$, where n=1,2,…,288, and t=1,2,…,260.

To provide a sense of the range of fluctuations that occurred in 1998, daily data are plotted in Fig. 1.[8] The incredible range of prices is clearly illustrated in the figure

Fig. 1. Japanese yen–US dollar spot exchange rate in 1998.

[8] Daily observations on the yen–dollar spot rate are taken from Datastream. These are the midpoints of the bid and ask quotes in London from Barclays Bank International at 16:30 GMT.

and reflects the wild events of the year, which include spillovers from the Asian crisis, a Russian bond default, currency market interventions, and the near-collapse of a very large hedge fund, Long Term Capital Management.

2.2. Intradaily patterns

Although there is little evidence of a systematic pattern in the raw five-minute yen–dollar returns across the day, there is a pronounced pattern in intraday volatility. Fig. 2 depicts the average absolute return for each five-minute interval across 145

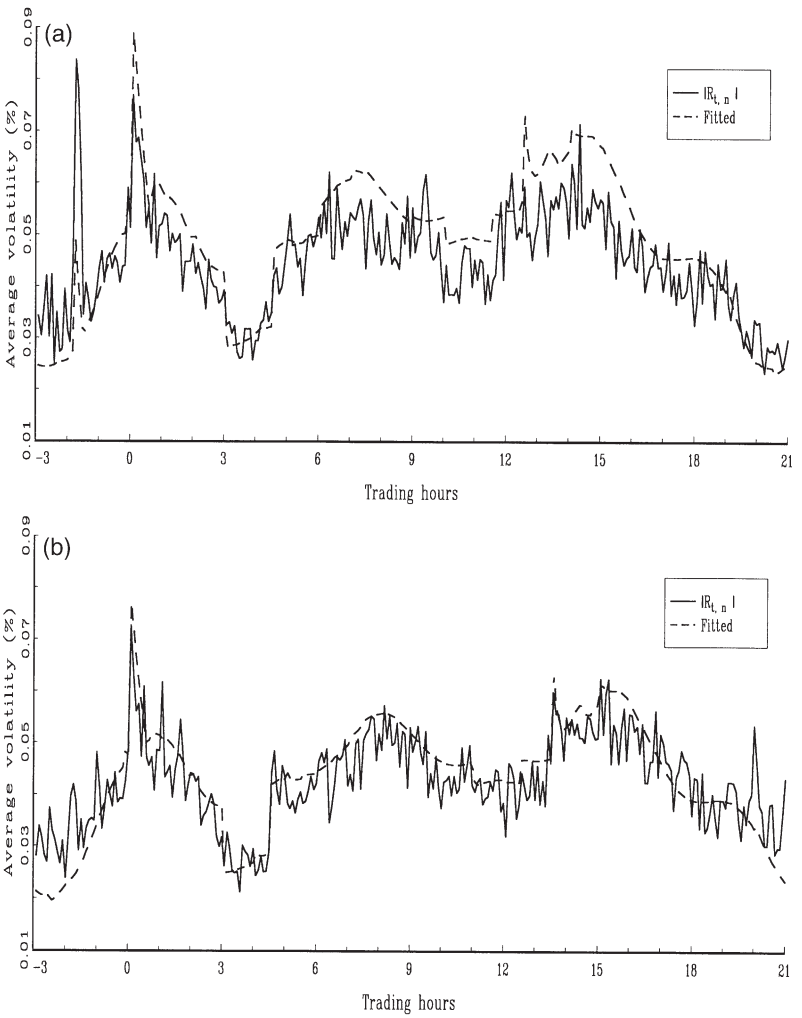

Fig. 2. (a) Japanese yen–US dollar summer time intraday five-minute average$|R_{t,n}|$; (b) Japanese yen–US dollar winter time intraday five-munite average $|R_{t,n}|$.

trading days during the US summer time and 115 trading days during the US winter time, respectively.[9] The initial observation corresponds to the interval beginning at 21:00 GMT, and the last observation represents the interval ending at 21:00 GMT. Thus, trading originates every morning in the Pacific segment where banks located in Wellington and Sydney dominate the market. Trading volume and return volatility are rather subdued at this hour. Fig. 2(a) shows a significant spike in volatility in the early Asian morning in summer. In both seasons, there is a significant jump in volatility at 00:00 GMT, or 9 a.m. Tokyo time, corresponding to the opening of the Tokyo foreign exchange interbank market, in which yen–dollar dealings comprise the largest portion of the trading volume.[10] The market slows down significantly during the Tokyo lunch time, 3:00–4:30 GMT. Volatility then picks up again at 6:00 GMT during summer time (7:00 GMT during Winter Time) when the European market begins to trade. The overlap of the European and North American market between 12:00 and 15:00 GMT constitutes another notable segment of high volatility. With the observance of daylight saving time in both Europe and North America, the volatility pattern appears to shift leftward between 6:00 and 21:00 GMT. In particular, the two peaks corresponding to the scheduled US macroeconomic announcements at 8:30 and 10:00 Eastern Standard Time (EST), or 13:30 and 15:00 GMT in Fig. 2(b) are shifted to the left by exactly one hour in Fig. 2(a). The overall pattern is consistent with those found in Baillie and Bollerslev (1991), Harvey and Huang (1991), Dacorogna et al. (1993), Andersen and Bollerslev (1998) and Melvin and Yin (2000) for major currencies.

2.3. Flexible Fourier form estimates

In order to explicitly model the periodic volatility component in the high-frequency returns, we apply the general framework developed by Andersen and Bollerslev (1997). Specifically, on decomposing the demeaned five-minute returns as,

$$R_{t,n}-E(R_{t,n})=s_{t,n}\cdot\sigma_{t,n}\cdot Z_{t,n} \tag{1}$$

where $\sigma_{t,n}$ denotes a daily volatility factor and $Z_{t,n}$ is an i.i.d. mean zero unit variance innovation term, the logarithmic seasonal component, $\ln(s_{t,n}^2)$, may be conveniently estimated from the following flexible Fourier form (FFF) regression,

$$2\ln\frac{|R_{t,n}-\bar{R}|}{\hat{\sigma}_t/N^{1/2}}=c+\beta O_{t,n}+\sum_{k=1}^{D}\lambda_k\cdot I_k(t,n)+\delta_{0,1}\frac{n}{N_1}+\delta_{0,2}\frac{n^2}{N_2}+\sum_{p=1}^{P}\left(\delta_{c,p}\cdot\cos\frac{2\pi p}{N}n+\delta_{s,p}\cdot\sin\frac{2\pi p}{N}n\right)+\varepsilon_{t,n}, \tag{2}$$

where $\bar{R}$ denotes the sample mean of the five-minute returns, $\hat{\sigma}_t$ is an a priori estimate

[9] Summer time, or daylight saving time, is defined as the period from April 5 to October 25.

[10] According to the Japan Economic Almanac (Anon, 1999), yen–dollar dealings account for 72% of the total trading volume in Japan during the first 11 months of 1998.

of the daily volatility component.[11] $N_1=(N+1)/2$ and $N_2=(N+1)(N+2)/6$ are normalizing constants. N refers to the number of return intervals per day, and the tuning parameter P determines the order of the expansion. $O_{t,n}$ is the order flow of large market participants. The $I_k(t,n)$ indicator variable for event k during interval n on day t allows for the inclusion of specific calendar and news announcement effects that will be discussed in the following sections.[12]

2.4. Calendar effects and their estimates

We now briefly outline the treatment of a number of distinct calendar features in the absolute five-minute yen–dollar spot exchange rate returns. First, we observe a significant slow down in market activity over worldwide and regional holidays. The worldwide holidays include January 1, December 24–26, and December 31, during which a dummy variable is assigned to each of the 288 five-minute intervals. The regional holidays are from the following eight countries: New Zealand, Australia, Japan, Hong Kong, Singapore, Germany, France, Great Britain, and the United States. Regional holidays affect the corresponding trading segment only.[13] The volatility burst following the Tokyo opening is captured by a single coefficient that allows for a linear decay between 00:00 and 00:30 GMT. Volatility slows down significantly in the morning on Asian Monday (21:00–22:30 GMT) in winter, and late Friday afternoon (16:00–21:00 summer time and 17:00–21:00 winter time) in the North America segment. We model these periods by constrained second-order polynomials over the corresponding intervals, resulting in two regression coefficients for each period. During the US summer time, the sinusoid regressors are shifted leftward by one hour, resulting in lower volatility in the late afternoon between 19:00 and 21:00 GMT. This is adjusted by a restricted second-order polynomial with one free parameter. In order to compensate for the one-hour shift, we elongate the intraday pattern via sinusoid regressors between 20:00 and 22:00 GMT. We also add dummy variables to control for the lunch breaks in Tokyo (3:00–4:30 GMT) and Europe (10:00–11:30 GMT summer time and 11:00–12:30 GMT winter time). Finally, we incorporate day-of-the-week dummies for all weekdays except Monday.

After some experimentation we found that P=6 in Eq. (2) was sufficient to capture

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[11] Following Andersen and Bollerslev (1998), the daily volatility component is calculated in two ways: a time varying $\hat{\sigma}_{t,n}=\hat{\sigma}_t/N^{1/2}$ where $\hat{\sigma}_t$ is the estimated daily volatility from a MA(1)-FIGARCH(1,d,1) model fitted over 3652 daily returns from January 2, 1985 to December 31, 1998, and a constant $\hat{\sigma}_{t,n}=\bar{\sigma}/N^{1/2}$, where $\bar{\sigma}$ is the sample mean of $\hat{\sigma}_t$.

[12] The actual estimation involves a two-step procedure, see Andersen and Bollerslev (1997) for more details.

[13] Holidays in the US include Martin Luther King Day (19/1), President's Day (16/2), Easter (12/4–13/4), Memorial Day (25/5), Independence Day (4/7), Labor Day (7/9), Columbus Day (12/10), Veteran's Day (11/11), and Thanksgiving Day (26/11). Holidays in Japan include Coming of Age Day (15/1), National Foundation (11/2), Vernal Equinox (21/3), Green Day (29/4), Constitution Memorial and National Holiday (3/5–4/5), Children's Day (5/5), Sea Day (20/7), Respect for the Aged Day (15/9), Autumn Equinox (23/9), Health and Sports Day (10/10), National Culture Day (3/11), Labor Thanksgiving Day (23/11), and Emperor's Birthday (23/12).

the basic shape. It is clear from the corresponding dashed lines plotted in Fig. 2(a,b) that the fitted values provide a close approximation to the general intradaily volatility pattern in the yen–dollar foreign exchange market.

3. Macroeconomic announcement, intervention, and order flow effects

3.1. Important announcements

In order to formally analyze the actual impact of the news announcements, we collected data on the dates and release times of 32 US macroeconomic news releases from Reuters and 33 Japanese macroeconomic news announcements from Bloomberg.[14] All US announcements are monthly except for quarterly announcements of GDP, employment costs and the current account deficit, weekly announcements of initial jobless claims and the money supply (M2), and irregular announcements of FOMC meeting minutes, productivity and costs, the Beige book, and auto sales. For Japan, except for the quarterly announcements of the Tankan report, consumer sentiment index, GDP, and Tokyo office vacancy rate, all macroeconomic announcements are released on a monthly basis. The US announcements are released widely and virtually instantaneously at a precise scheduled time. For the Japanese announcements, we cross-checked the scheduled release time with reports from Reuters. The release times are essentially the same. Our sample of macroeconomic news from the two countries is the most comprehensive set employed to study yen–dollar exchange rate volatility.

In addition to the regularly scheduled macroeconomic news, we also include dummy variables for two days when large-scale intervention in the yen–dollar market occurred. The Bank of Japan intervened in support of the yen on April 10. The *Financial Times* reported that Tokyo currency dealers estimated the magnitude of the intervention to be around $5 billion. On June 17, the Clinton Administration's first-ever intervention aimed at supporting a weak yen was carried out in tandem with the BOJ. The *Financial Times* estimated the magnitude of the intervention to be $2 billion. Despite rumors of intervention later in the year, there was no intervention in the fourth quarter.

3.2. Order flow

Data on foreign exchange market order flow are not made public. Historically, this was due to the bilateral nature of direct-dealing trades where only the two participants to the trade knew the quantity traded and price. More recently with the advent of electronic brokerages, it is feasible to provide data representing a large cross-

[14] US non-farm payrolls and employment reports are always released at the same time, as are industrial production and capacity utilization. Simultaneous releases of news in Japan include the unemployment report and job-to-applicant ratio, housing starts and construction orders, and CPI nationwide and in the Tokyo area.

section of the market, but the firms providing the major platforms (EBS and Reuters) do not make such data public in order to preserve the confidentiality of the trading parties. In the past, the only view of order flow has been through individual traders (Lyons, 1995; Yao, 1998). Recently, Evans (1997) obtained four months of data in 1996 from the Reuters direct-dealing 2000–1 system that contains transaction prices and whether a trade was a purchase or sale (Reuters would not provide the quantities traded).

Note that there exists no way to capture the order flow of the entire market at the high frequency level across the spectrum of telephone and electronic trading venues. Obtaining the trading records over a short sample period from one trading venue, like the Reuters 2000–1 system, is the best one can hope for. However, at a lower frequency level there exist time-series data on quantities in the form of positions held by major market participants. For our study of 1998 yen volatility, we employ these data. The data source is the US Treasury. Market participants with positions greater than $50 billion in foreign exchange contracts on the last business day of any quarter must file weekly reports on their purchases and sales. The Treasury does not reveal the participants identities and only provides aggregated data. However, the size threshold for required reporting suggests that these major market participants are essentially the largest commercial and investment banks. We use the weekly data on purchases and sales of spot, forward, and futures contracts on the yen as our proxy for order flow.[15] It is the order flow that reveals the private information regarding position changes as there are no public announcements when a large fund switches from long to short or vice versa. In the context of the yen in 1998, the financial press frequently reported that a liquidity crunch associated with losses in emerging markets like Southeast Asia and Russia and the tightening of credit following the losses of Long Term Capital Management led to unwinding the yen carry-trade positions. In fact, a search of Reuters news associated with the 25 largest 5-min absolute returns in our sample reveals that many of these intervals are associated with the yen carry trade. The increased dollar selling and yen buying associated with unwinding positions was reported to be the force behind the dramatic periods of yen appreciation.

When a hedge fund initiates a trade aimed at unwinding its short yen position, this trade is not known to anyone other than the counterparty to the trade. As the magnitude of such trading grew and the yen rose in value, rumors regarding the scale of the position switches were common. The important point is that it is the order flow related to the position switching that results in the exchange rate changing and this order flow may be orthogonal to public information associated with current fundamentals. In the context of the 'portfolio shifts' model presented in Evans and Lyons (1999), this result requires that (1) portfolio shifts are not common knowledge as they occur and (2) they are large enough that clearing the market requires adjust-

[15] Wei and Kim (1997) use these data to establish that the major market participants' positions Granger-cause exchange rate volatility for the UK pound, Swiss franc, yen, mark, and Canadian dollar over the 1994–1996 period.

ment of the spot exchange rate.[16] In the case under study, the first condition is correct at the time trades are initiated. Furthermore, in the case of the yen in 1998, the second condition is fulfilled to such a degree that news services quickly search for a causal factor. This results in news reports of major hedge fund yen purchases with a short lag (within the day) after the trades.

Some additional comments on order flow in the context of our model are needed. First, since the measure of order flow, O, is only available weekly, O will not enter into the determination of the intradaily volatility patterns. Instead, O may be thought of as shifting the intercept term to account for shifts in average weekly volatility. As will be seen below, there are significant shifts in average weekly volatility that would be missed in the absence of the O variable. Second, the time aggregation embodied in O creates a potential simultaneity problem. As a result, we utilize an instrumental variable estimation procedure where the instruments are two lags of order flow and two lags of the absolute weekly exchange rate returns (a volatility proxy). It should be kept in mind that our measure of O is the only market-wide proxy for order flow available and our study is the first to incorporate such a measure in an intradaily model of exchange rate dynamics.

3.3. Initial estimation results

We begin our analysis with the announcement effects. Given the limited number of occurrences of each type of news announcement and the inherent noise in the return process, it is not possible to simultaneously estimate separate coefficients for each event and time interval following the news releases. Instead, we impose a reasonable decay structure on the volatility response pattern and estimate the degree to which the event 'loads onto' this pattern. Following Andersen and Bollerslev (1998), we choose the dynamic response pattern to be of the form $\lambda(k,i)=\lambda_k \cdot \gamma(i), i=0,1,2,\ldots,12$, where the pre-specified $\gamma(i)$ coefficients are determined by a third-order polynomial, the general shape of which is given in Fig. 3.[17] This approach restricts the response horizon to be one hour.

Table 1 summarizes the estimates of the full system in Eq. (2) including the intradaily calendar effects, time-varying daily volatility factor, intervention effects, holiday and day-of-the-week dummies, order flow, and macroeconomic data announcements. For the latter, the table just includes those announcements that were found to have a statistically significant effect on volatility. Significant announcements were identified by estimating a version of Eq. (2) for each specific announcement, where

[16] Evans and Lyons develop a model of daily exchange rate returns depending upon macroeconomic news and order flow. They use daily interest differential changes as their proxy for macro news and the number of purchases minus sales per day as their measure of order flow. While their model is aimed at estimating returns, one can derive their model in absolute value terms to address volatility.

[17] We calibrate this pattern by fitting all three parameters for a set of announcements of about equal significance, without the λ_k coefficient. This uniquely identifies the three parameters. For the rest of the announcement effects, we fix the response pattern and estimate the λ_k coefficient that loads onto the pattern. Details are available upon request.

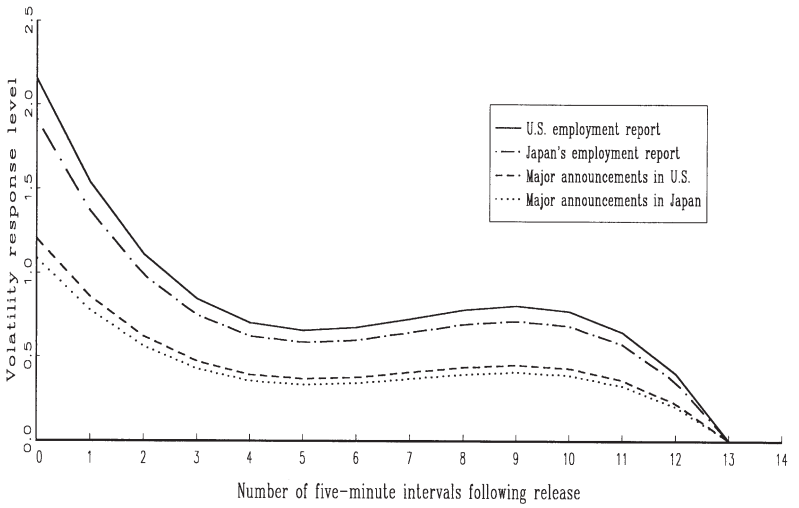

Fig. 3. Estimated announcement response patterns.

each announcement is, in turn, entered into the equation separately while other announcements are entered jointly with a separate 'all other announcements' coefficient. Appendix A provides details on the individual announcement effects. Of the 32 US and 33 Japanese announcements analyzed, the following announcements were employed in the estimates reported in Table 1: US employment report, CPI, GDP, PPI, merchandise trade balance, consumer installment credit, real earnings, employment costs, reserve assets, and personal income; Japanese employment report, Tankan report, unemployment rate, vehicle sales, consumer sentiment index, electricity usage, and vehicle production. Given the importance of the two employment reports, their coefficients are estimated separately. The remaining announcements are aggregated into the 'major announcement' variable.

Table 1a reports results using the time-varying daily volatility-scaling factor $\hat{\sigma}$. Table 1b contains the results based on the constant daily volatility-scaling factor $\bar{\sigma}$. Column 2 of Table 1a reports estimates of the complete model. The coefficients associated with the intraday patterns are significant except for the US afternoon summer slowdown and the second-order term on winter Monday morning. Andersen and Bollerslev (1998) found day-of-the-week effects to be insignificant for the dollar–mark exchange rate once the other calendar effects and announcements were included. However, the coefficients reported in column 2 indicate that the daily dummies are significant. Column 3 reports estimates for the yen–dollar with the day-of-the-week dummies excluded. A chi-square test of the exclusion restriction indicates that the day-of-the-week dummies are highly significant. Whether this difference between the results found by Andersen and Bollerslev and our results reflects a systematic difference between the mark and yen volatility dynamics or is due to the special nature of the year we study is open to further analysis.

Focusing on the separate sources of volatility, we see that both intervention

Table 1a
Using time-varying daily volatility factor

Parameter	Full system	Day-of-the-week dummies excluded	Intervention dummies excluded	Macro-announcements excluded	Order flow variables excluded
Constant intercept	−4.65 (−4.32)	−4.43 (−4.11)	−4.63 (−4.29)	−4.20 (−3.90)	−6.08 (−5.66)
Holiday	−0.91 (−18.48)	−0.93 (−18.98)	−0.91 (−18.53)	−0.91 (−18.38)	−0.89 (−18.05)
Tokyo open	1.52 (6.77)	1.52 (6.74)	1.52 (6.77)	1.47 (6.54)	1.53 (6.80)
US afternoon summer slowdown	−0.01 (−0.25)	−0.01 (−0.43)	−0.01 (−0.24)	−0.01 (−0.18)	−0.03 (−1.69)
Winter Asian Monday morning	−2.01 (−2.98)	−2.13 (−3.15)	−2.01 (−2.98)	−2.01 (−2.98)	−1.95 (−2.88)
	0.12 (0.49)	0.09 (0.35)	0.12 (0.49)	0.12 (0.49)	0.14 (0.57)
Friday late	−0.04 (−5.06)	−0.03 (−4.32)	−0.04 (−5.12)	−0.04 (−5.19)	−0.04 (−4.96)
	0.06×10^{-2} (3.57)	0.05×10^{-2} (3.04)	0.06×10^{-2} (3.60)	0.07×10^{-2} (3.66)	0.06×10^{-2} (3.47)
Tokyo lunch break	−0.81 (−11.15)	−0.81 (−11.13)	−0.81 (−11.15)	−0.81 (−11.21)	−0.79 (−10.88)
European lunch break	−0.21 (−3.18)	−0.21 (−3.17)	−0.21 (−3.20)	−0.19 (−2.86)	−0.21 (−3.24)
Summer high volatility at 2210–2225 GMT	1.47 (5.45)	1.51 (5.62)	1.47 (5.45)	1.46 (5.44)	1.36 (5.04)
Tuesday	0.12 (3.84)		0.12 (3.84)	0.13 (4.10)	0.12 (3.95)
Wednesday	0.17 (5.51)		0.17 (5.60)	0.17 (5.57)	0.17 (5.59)
Thursday	0.26 (8.49)		0.26 (8.49)	0.27 (8.80)	0.26 (8.58)
Friday	0.23 (7.10)		0.24 (7.29)	0.26 (7.99)	0.24 (7.13)
FED and BOJ intervention on June 17	2.65 (2.75)	2.67 (2.77)		2.58 (2.67)	2.68 (2.77)
BOJ intervention on April 10	1.09 (2.92)	1.16 (3.13)		1.05 (2.82)	1.23 (3.30)
US employment reports	2.00 (5.60)	2.16 (6.06)	1.98 (5.54)		2.01 (5.62)
Japan's employment reports	1.78 (5.06)	1.88 (5.36)	1.77 (5.02)		1.80 (5.08)
Major announcements in US	1.14 (8.13)	1.21 (8.58)	1.13 (8.06)		1.15 (8.12)
Major announcements in Japan	1.01 (5.54)	1.03 (5.65)	1.00 (5.50)		1.02 (5.60)
Spot, forward purchased	3.21×10^{-2} (8.18)	3.26×10^{-2} (8.29)	3.20×10^{-2} (8.14)	3.24×10^{-2} (8.25)	
Spot, forward sold	-3.82×10^{-2} (−9.62)	-3.86×10^{-2} (−9.73)	-3.81×10^{-2} (−9.60)	-3.85×10^{-2} (−9.69)	
Log-likelihood	−179,444.33	−179,488.04	−179,458.73	−179,496.30	−179,577.42

Table 1b
Using constant daily volatility factor

Parameter	Full system	Day-of-the-week dummies excluded	Intervention dummies excluded	Macro-announcements excluded	Order flow variables excluded
Constant intercept	−8.63 (−7.96)	−8.40 (−7.75)	−8.60 (−7.94)	−8.19 (−7.57)	−6.28 (−5.79)
Holiday	−0.91 (−18.33)	−0.93 (−18.80)	−0.92 (−18.39)	−0.91 (−18.24)	−0.90 (−17.97)
Tokyo open	1.51 (6.67)	1.50 (6.63)	1.51 (6.67)	1.47 (6.45)	1.52 (6.67)
US afternoon summer slowdown	0.01 (0.37)	0.01 (0.19)	0.01 (0.38)	0.01 (0.43)	−0.01 (−0.37)
Winter Asian Monday morning	−2.03 (−2.96)	−2.15 (−3.14)	−2.03 (−2.96)	−2.03 (−2.97)	−1.98 (−2.94)
	0.11 (0.44)	0.07 (0.30)	0.11 (0.44)	0.11 (0.44)	0.13 (0.52)
Friday late	−0.04 (−5.07)	−0.03 (−4.31)	−0.04 (−5.14)	−0.04 (−5.20)	−0.04 (−5.11)
	0.06×10^{-2} (3.62)	0.05×10^{-2} (3.08)	0.07×10^{-2} (3.66)	0.07×10^{-2} (3.71)	0.07×10^{-2} (3.67)
Tokyo lunch break	−0.82 (−11.17)	−0.82 (−11.14)	−0.82 (−11.16)	−0.82 (−11.23)	−0.81 (−10.95)
European lunch break	−0.21 (−3.11)	−0.21 (−3.10)	−0.21 (−3.13)	−0.18 (−2.80)	−0.21 (−3.13)
Summer high volatility at 2210–2225 GMT	1.50 (5.60)	1.55 (5.76)	1.50 (5.60)	1.50 (5.59)	1.46 (5.46)
Tuesday	0.10 (3.28)		0.10 (3.27)	0.11 (3.52)	0.10 (3.33)
Wednesday	0.16 (5.36)		0.17 (5.46)	0.17 (5.42)	0.17 (5.40)
Thursday	0.29 (9.32)		0.29 (9.32)	0.30 (9.62)	0.30 (9.46)
Friday	0.24 (7.16)		0.25 (7.40)	0.27 (8.04)	0.24 (7.20)
Fed and BOJ intervention on June 17	2.76 (2.86)	2.77 (2.88)		2.69 (2.79)	2.57 (2.67)
BOJ intervention on April 10	1.36 (3.66)	1.44 (3.88)		1.33 (3.56)	1.05 (2.82)
US employment reports	2.02 (5.68)	2.18 (6.16)	1.99 (5.61)		1.99 (5.61)
Japan's employment reports	1.65 (4.59)	1.73 (4.88)	1.63 (4.54)		1.63 (4.68)
Major announcements in US	1.12 (7.87)	1.19 (8.34)	1.11 (7.80)		1.16 (8.22)
Major announcements in Japan	1.00 (5.41)	1.03 (5.54)	0.99 (5.35)		0.98 (5.23)
Spot, forward purchased	5.28×10^{-2} (13.40)	5.33×10^{-2} (13.51)	5.26×10^{-2} (13.36)	5.31×10^{-2} (13.47)	
Spot, forward sold	-4.09×10^{-2} (−10.27)	-4.14×10^{-2} (−10.38)	-4.08×10^{-2} (−10.25)	-4.12×10^{-2} (−10.34)	
Log-likelihood	−179,909.25	−179,961.42	−179,927.55	−179,958.42	−180,414.24

dummy variables are positive and significant, indicating that volatility was higher on the intervention days. Column 4 of Table 1a reports estimates of the model with the intervention dummies omitted. A likelihood ratio test of the exclusion restriction indicates that the intervention dummies are jointly significant. Among macroeconomic announcements, the employment reports have the largest effect on yen–dollar volatility similar to the mark–dollar findings of Andersen and Bollerslev (1998). The other major announcements also have positive and significant effects on volatility. Column 5 of Table 1a reports estimates of the model with the macroeconomic announcements variables excluded. A likelihood ratio test of the exclusion restriction indicates they are jointly highly significant. Finally, order flow, as proxied by purchases and sales of spot, forward, and futures contracts by major market participants, is seen to have a significant effect on volatility. Purchases are associated with higher volatility and sales with lower volatility. The positive and significant effect of purchases is consistent with volatility being caused by the unwinding of yen carry-trade positions. Periods with large yen sales by major participants are associated with lower yen volatility. This suggests that the establishment of short yen positions was consistent with a tranquil market. Column 6 of Table 1a reports model estimates with the order flow variables excluded. A likelihood ratio test of the exclusion restriction indicates that the order flow variables are also jointly highly significant.

The estimates reported in Table 1b, using the constant daily volatility-scaling factor are generally quite similar to those reported in Table 1a. The variables that were found to be insignificant determinants of yen/dollar volatility in Table 1a are also the variables with insignificant coefficients in Table 1b. The qualitative results of Table 1a all carry over to Table 1b. The greatest difference between the two tables is with regard to the order-flow variables. There appears to be collinearity between the time-varying daily volatility factor used in Table 1a and order flow. When the constant daily volatility factor is used in Table 1b, we find order flow to have larger coefficients and a greater level of statistical significance. The likelihood-ratio statistic on the joint significance of the order flow variables implied by the results reported in the last column of each table increases from 266 in Table 1a to 1010 in Table 1b. It seems likely that the generated time-varying daily volatility-scaling variable $\hat{\sigma}$ is, at least partially, reflecting shifts in order flow over time.

The results of Tables 1a and 1b indicate that each of the major factors we examine has a statistically significant role in explaining volatility. Now we would like to have an idea of the relative contributions of each to understanding yen–dollar volatility in 1998. The next section will provide a measure of the marginal predictive power of each individual component.

4. The relative importance of different volatility components

In this section we provide a direct assessment of the joint and marginal predictive power of each of the four volatility components—intraday calendar effects, announcement effects, intervention effects, and order flow. The basic idea is to construct a series of five-minute volatility forecasts $v(\mathrm{I}{:}t,n)$ that in turn omits or includes

only the contribution from each of the four components. The day-of-the-week and holiday effects are always included in the regressions. The joint and marginal contribution of the four volatility components at the daily and intraday frequencies are then measured by the coefficient of explained variation, R^2, from the regressions of the realized daily cumulative absolute returns, $\Sigma^{N}_{n=1}|R_{t,n}-\bar{R}|$, and the realized five-minute absolute returns, $|R_{t,n}-\bar{R}|$, on the corresponding volatility forecasts, $\Sigma^{N}_{n=1}v(I{:}t,n)$ and $v(I{:}t,n)$, respectively.

Table 2 summarizes the results for the different model configurations. Columns 2 and 3 contain results for models based upon the time-varying daily volatility-scaling factor while results reported in columns 4 and 5 are for models using the constant daily volatility-scaling factor. The numbers in the second and fourth columns refer to the degree of explained variation in the daily cumulative absolute returns. The complete model using the time-varying daily volatility-scaling factor $\hat{\sigma}$ accounts for 49.7% of the cumulative daily volatility.[18] The complete model with the constant daily volatility-scaling factor $\bar{\sigma}$ explains 23.7% of the total variation. The explanatory power is similar when the calendar effects are removed from the forecast. The R^2 drops slightly when the announcement variables are deleted. It drops

Table 2
Explained variation (R^2) from regressions of Japanese yen–US dollar daily cumulative absolute returns or five-minute absolute returns on absolute return forecasts[a]

Model	Time-varying daily volatility		Constant daily volatility	
	Daily cumulative absolute return	Five-minute absolute return	Daily cumulative absolute return	Five-minute absolute return
Complete model	0.497	0.072	0.237	0.046
No intraday calendar effects	0.497	0.053	0.237	0.028
No announcements	0.490	0.071	0.228	0.045
No intervention dummies	0.482	0.069	0.218	0.043
No order flow	0.477	0.073	0.031	0.027
Intraday calendar effects only	0.469	0.069	0.024	0.022
Announcements only	0.470	0.050	0.029	0.007
Intervention dummies only	0.478	0.052	0.034	0.007
Order flow only	0.489	0.049	0.228	0.024

[a] The table reports the explained variation (R^2) from regressing $\Sigma^{N}_{n=1}|R_{t,n}-\bar{R}|$ on $\Sigma^{N}_{n=1}v(I{:}t,n)$,$t$=1,2,...$T$ for daily cumulative absolute returns and from regressing $|R_{t,n}-\bar{R}|$ on $v(I{:}t,n)$,t=1,2,...T,n=1,2,...N, for five-minute absolute returns. $v(I{:}t,n)$ is the five-minute volatility forecast that in turn leaves out or includes only the contribution from each of the following components, the intraday calendar effects, the announcement effects, the intervention dummies, and predicted order flow by big market participants. The first two columns report estimates for the complete model using the time-varying daily volatility factor $\hat{\sigma}$. The remaining columns report estimates using the constant daily volatility factor $\bar{\sigma}$. The day-of-the-week dummies and holiday effects are included in all regressions.

[18] Explanatory power may be increased for the cumulative absolute returns when some components are deleted since the forecasts at this horizon involve a nonlinear transformation of the components.

somewhat more without the intervention dummies. The biggest drop in explanatory power for the daily cumulative absolute returns occurs when order flow is omitted.

As one would expect, the models estimated for five-minute absolute returns reveal significant explanatory power for the intraday calendar effects. Five-minute absolute return models based on $\hat{\sigma}$ find that the deletion of announcements, intervention dummies, or order flow all have about the same minor effect on explanatory power. The five-minute absolute return models based on $\bar{\sigma}$ find the same results for announcements or intervention, but now we see the omission of order flow cutting explanatory power roughly in half. This different inference on order flow effects between models based on $\hat{\sigma}$ or $\bar{\sigma}$ is due to the collinearity that exists between order flow and $\hat{\sigma}$.

Examining the explanatory power when each source of volatility is used by itself to forecast, provides the R^2 results reported in the last four rows of Table 2. Standing alone, the R^2 estimates for daily cumulative absolute returns are listed in ascending order as calendar, announcement, intervention, and order flow effects; with time-varying (constant) daily volatility values ranging from 46.9 (2.4) to 48.9 (22.8)%. For the five-minute absolute returns, results using time-varying daily volatility indicate calendar effects have the highest R^2 of 6.9% while the other three components have approximately the same values of 5%. With constant daily volatility, the five-minute absolute returns range from a low of 0.7% for announcements and intervention to 2.4% for order flow. The evidence presented in Table 2 suggests that, compared to the effect of order flow, the announcement and intervention effects are of secondary importance in understanding yen–dollar volatility in 1998.

5. Discussion and conclusion

This paper provides a detailed characterization of the Japanese yen–US dollar spot exchange rate return volatility over 1998. The yen–dollar exchange rate was extraordinarily volatile during the year with periods of both rapid yen depreciation and rapid yen appreciation. A review of the news during the year suggests the following candidates as sources of the dramatic volatility: foreign exchange market intervention by the Bank of Japan, the US Treasury and the Federal Reserve; shifting fundamentals related to US and Japanese macroeconomic conditions; and spillover from the Asian and Russian financial crises and Long Term Capital Management losses resulting in a liquidity crunch that caused large investment funds to unwind short yen positions. Our analysis is focused on identifying the relative contributions of these various factors in understanding the yen–dollar volatility of 1998.

In order to obtain meaningful estimates of the effects of intervention, macroeconomic announcements, and big-trader order flow, a model capturing the typical intradaily volatility pattern over a 24-h trading day must be employed. The resulting model incorporates intradaily calendar effects to account for the regular daily pattern of activity in the yen–dollar market. Our analysis also details the impact of a comprehensive list of 32 US and 33 Japanese regularly released macroeconomic announcements. Most of the ten significant US announcements and six significant Japanese

announcements are associated with the real side of the economies, with employment reports from both countries on top of the list. In contrast to previous studies, the day-of-the-week effects cannot be attributed to the clustering of scheduled macroeconomic news releases on Thursdays and Fridays during the morning session of US trading hours.

Comparing the alternative sources of volatility, we find that order flow is most important. The significance of order flow by itself could simply reflect the effect of some underlying true causal factor like macroeconomic announcements or intervention. However, even accounting for a lengthy list of announcements and the actual interventions that occurred during 1998, we find an independent role for order flow in explaining yen–dollar volatility. This finding lends support to the assertion that portfolio shifts were responsible for much of the volatility. The popular story is that early in the year there was a large-scale shift into short yen positions associated with the yen 'carry trade' of borrowing yen at extremely low interest rates and then investing in higher-yielding assets denominated in other currencies. Later in the year, following losses in Asian and Russian markets and credit constraints associated with new perceptions of risk following Long Term Capital Management's problems, there was a large-scale unwinding of the short-yen positions. The market learns about such portfolio shifts through order flow rather than public announcements. Our results lend support to the effect of order flow being an important determinant of yen–dollar volatility in 1998.

In a broader context than our particular yen–dollar application, are the implications for understanding the structure of the foreign exchange market. It has long been known that empirical exchange rate models based on fundamentals perform poorly. This has led to an ongoing search for better approaches to modeling exchange rate dynamics. Recently, some studies have provided suggestive evidence that the act of trading, apart from any news regarding fundamentals, may be an important source of exchange rate movements. As a market with a relative lack of transparency and asymmetrically informed traders, it should not be surprising to find that order flow contains independent information. Just as news regarding macro announcements can affect volatility by providing information to the market, so does large order flow convey new information. While we might expect order flow to reflect macro news, what else could drive position changes? In general, order flow that is orthogonal to current macro news may reflect expectations of future changes in fundamentals or revised expectations due to institutional changes. In the most dramatic period of yen volatility in 1998, it is likely that changing risk perceptions and associated credit constraints associated with the Russian bond default, losses in Asian markets, and the LTCM debacle contributed to the order flow associated with unwinding the yen carry trade. Such an effect will not be revealed by macroeconomic announcements. As discussed in the introduction, practitioners have long argued that order flow is a major source of price movements. However, only now is the evidence accumulating to support this view. It is in this sense that our findings have implications beyond the yen–dollar application studied. We provide new evidence in support of the role of order flow and its associated information as a determinant of exchange rate dynamics.

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Appendix A. Individual macroeconomic news announcement effects

The dependent variables are based on raw five-minute returns on the Japanese yen–US dollar spot exchange rate. The sample period is from January 1998 to December 1998 for a total of 74,880 observations. The regression takes the form as in Table 1. The volatility response pattern following announcements is approximated by a third-order polynomial restricted to reach zero at the end of the response horizon of one hour, or the 13th five-minute interval. The reported coefficients measure the extent to which the absolute returns load onto this pattern following the announcement. The sample of macroeconomic news includes 32 announcements from the US and 33 announcements from Japan. The instantaneous jump in volatility measures the estimated increase in the five-minute absolute return for the interval when the announcement is made. The estimated total cumulative absolute return induced by the announcement over the assumed horizon is measured relative to the median cumulative absolute return over the sample period of 11.7% per day.

Table 3 only summarizes the results for the significant announcements from both the US and Japan. In descending order based on the estimated volatility jump, the insignificant US announcements include construction spending, FOMC meeting minutes, factory inventories, housing starts, new single-family home sales, housing completion, NAPM survey, industrial production, productivity and costs, initial jobless claims, existing home sales, beige book, federal budget, durable goods orders, import prices, leading indicators, money supply (M2), consumer confidence, retail sales, business inventories, current account deficit, and auto sales. The insignificant Japanese announcements in descending order include the current account, vehicle exports, foreign currency reserves, housing starts, GDP, merchandise trade balance, Tokyo new condo sales, vehicle imports, money supply (M2+CD), leading indicators, Tokyo department store sales, large scale retail sales, bank lending, bankruptcies, average lending rate, wholesale price index, nationwide department store sales, corporate service price, Tokyo office vacancy rate, steel production, machine tool orders, household spending, industrial production, machinery orders, international securities investment, crude oil imports, and consumer price index.

Table 3
Important annnouncement effects

Announcement	OBS	GMT	Coefficient	Robust *t*-statistic	Instantaneous jump in volatility (%)	Impact on daily cum absolute return (%)
US						
Employment report	12	1330	2.01	5.59	188	3.2
CPI	12	1330	1.63	4.03	136	2.4
GDP	4	1330	1.40	3.70	110	2.0
PPI	12	1330	1.26	2.84	94	1.8
Merchandise trade balance	12	1330	1.24	3.00	92	1.7
Consumer instalment credit	12	2000	1.17	2.54	85	1.0
Real earnings	12	1500	0.93	2.96	63	1.3
Employment costs	4	1330	0.91	1.73	61	1.2
Reserve assets	12	2000	0.84	1.80	56	0.7
Personal income	12	1330	0.71	2.10	46	0.9
Japan						
Tankan report	4	2350	2.71	5.66	317	5.0
Unemployment report	12	30	1.75	4.81	151	2.4
Vehicle sales	12	500	1.09	3.37	78	1.2
Consumer sentiment index	4	500	0.85	1.75	57	0.9
Electricity usage	12	200	0.82	2.75	54	0.8
Vehicle production	12	400	0.75	1.77	49	0.7

References

Anon, 1999. Japan Economic Almanac. Nihon Keizai Shimbun Inc.

Andersen, T., Bollerslev, T., 1997. Intraday periodicity and volatility persistence in financial markets. Journal of Empirical Finance 4, 115–158.

Andersen, T., Bollerslev, T., 1998. Deutsche mark–dollar volatility: intraday activity patterns, macroeconomic announcements, and longer-run dependencies. Journal of Finance 1, 219–265.

Baillie, R., Bollerslev, T., 1991. Intra-day and inter-market volatility in foreign exchange rates. Review of Economic Studies 58, 565–585.

Beranger, F., Galati, G., Tsatsaronis, K., von Kleist, K., 1999. The yen carry trade and recent foreign exchange market volatility. International Banking and Financial Market Developments, Bank for International Settlements, 33–38.

Chatrath, A., Song, F., 1998. Information and volatility in futures and spot markets: the case of the Japanese yen. Journal of Futures Markets 18, 201–223.

Cheung, Y., Wong, C., 1999. Foreign exchange traders in Hong Kong, Tokyo, and Singapore: a survey study. Advances in Pacific Basin Financial Markets 5, 111–134.

Cheung, Y., Chinn, M., 2000. Currency traders and exchange rate dynamics: a survey of the U.S. market. Journal of International Money and Finance, in press.

Cheung, Y., Chinn, M., Marsh, I., 1999. How do U.K.-based foreign exchange dealers think their market operates? CEPR Working Paper no. 2230.

Dacorogna, M., Müller, U., Nagler, R., Olsen, R., Pictet, O., 1993. A geographical model for the daily and weekly seasonal volatility in the FX market. Journal of International Money and Finance 12, 413–438.

DeGennaro, R., Shrieves, R., 1997. Public information releases, private information arrival, and volatility in the foreign exchange market. Journal of Empirical Finance 4, 295–315.

Ederington, L., Lee, J., 1994. The response of the dollar–yen exchange rate to economic announcements. Financial Engineering and the Japanese Markets 1, 111–128.

Evans, M., 1997. The microstructure of foreign exchange dynamics, Working Paper, Georgetown University.

Evans, M., Lyons, R., 1999. Order flow and exchange rate dynamics, Working Paper, University of California at Berkeley.

Hakkio, C., Pearce, D., 1985. The reaction of exchange rates to economic news. Economic Inquiry 23, 621–636.

Hardouvelis, G., 1984. Market perceptions of Federal Reserve policy and the weekly monetary announcements. Journal of Monetary Economics 14, 225–240.

Harvey, C., Huang, R., 1991. Volatility in the foreign currency futures market. Review of Financial Studies 4, 543–569.

Ito, T., Lyons, R., Melvin, M., 1998. Is there private information in the FX market? The Tokyo experiment. Journal of Finance 53, 1111–1130.

Ito, T., Roley, V., 1987. News from the U. S. and Japan: which moves the yen/dollar exchange rate? Journal of Monetary Economics 19, 255–277.

Leng, H., 1996. Announcement versus nonannouncement: a study of intraday transaction price paths of Deutsche mark and Japanese yen futures. Journal of Futures Markets 16, 829–857.

Lyons, R., 1995. Tests of microstructural hypotheses in the foreign exchange market. Journal of Financial Economics 39, 321–351.

Melvin, M., Yin, X., 2000. Public information arrival, exchange rate volatility, and quote frequency. The Economic Journal 110, 644–661.

Menkhoff, L., 1998. The noise trading approach—questionnaire evidence from foreign exchange. Journal of International Money and Finance 17, 547–564.

Tett, G., 1999. Bruised investors wait for rising yen bubble to burst, Financial Times, June 25, p. V.

Thornton, D., 1989. The effect of unanticipated money on the money and foreign exchange markets. Journal of International Money and Finance 8, 573–587.

Yao, J., 1998. Market making in the interbank foreign exchange market. New York University Salomon Center Working Paper no. 5-98-3.

Wei, S.-J., Kim, J. 1997. The big players in the foreign exchange market: do they trade on information or noise? NBER Working Paper 6256.