# The Impact of the Japanese Banking Crisis on the Intraday FX Market*

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**Abstract**

Using the tick-by-tick yen/dollar exchange rate, this paper examines exchange rate dynamics for the period of the 1997 Japanese banking crisis. By high-frequency methodology, GARCH estimation and variance-ratio tests, the existence of a structural break in the foreign exchange market at the onset of the crisis is detected. We show a reversed pattern in return volatility after the series of bankruptcies. From the microstructure analysis, it is found that the change in exchange rate dynamics can be attributed to a change in strategic foreign exchange trade behavior. The result provides new insights into the trading activities of market makers at the onset of bank failures.

JEL classification: C32, F31, G14

Key words: Intraday exchange rate, Banking crisis, GARCH, Variance-ratio, Microstructure

# 1 Introduction

Many empirical investigations of high-frequency data, especially intraday exchange rate data, aim to shed light on market microstructure by focusing on spot rate revisions around some exogenous event. For example, the intraday return volatility pattern, such as the time of day effect and news impact, are analyzed in Goodhart, Ito, and Payne (1996), Peiers (1997) and Evans (2002), to name a few. Other studies have examined the transmission effect of volatility between markets: for example, Baillie and Bollerslev (1990) and Engle, Ito, and Lin (1990) examine a spillover effect between different market locations. These studies rely on Autoregressive Conditional Heteroscedasticity (ARCH)-type estimations and variance-ratio procedures. They unveil several features—for example, the impact of public announcements (e.g., regular news releases concerning macroeconomic fundamentals) on the foreign exchange (FX) market seems to be limited, while unexpected shocks have a greater and longer lasting effect.

Based on the existence of asymmetry in the FX market at the high-frequency level, this paper further examines the impact of the Japanese banking crisis on the FX market for the sample period August–December 1997.[1] This series of bankruptcies was unprecedented, despite the fact that massive bad debts have been plaguing the banking system—Japan had previously experienced almost no bank failures, at least in recent years.[2] The series of bank closures triggered an acceleration in the speed of depreciation of the yen, which at the time was

[1]In November 1997, two banks, Hokkaido Takushoku Bank (Japan's 10th largest bank) and Tokuyo City Bank (a regional Japanese bank) went bankrupt—the former on November 17 and the latter on November 26. There were also two failures of Japanese brokerages: Sanyo Securities (November 3) and Yamaichi Securities (November 24). Yamaichi was one of Japan's largest brokerages—the so-called Big Four.

[2]The Japanese financial system, including the management of banks, had been implicitly guaranteed by the Ministry of Finance. In the past, as when Yamaichi faced bankruptcy in the mid-1960s, the government poured public money in to keep it on its feet. As the crisis became evident in the 1990s, the ministry closed some of the lowest quality institutions and created a bridge bank to receive the remaining assets of failed smaller institutions. Some banks were encouraged to make large write-offs, and the government closed nonbank subsidiaries of financial institutions specializing in housings loans, known as "jusen companies". For an overview of the Japanese financial system and the Japanese banking crisis in the 1990s, see Cargill, Hutchison and Ito (1997, 2000), Hoshi and Kashyap (2000), Posen (2000), and Sakakibara (2000).

already on a downward trend, due to the changes in market participants' behavior in the FX market. By analyzing the tick-by-tick Japanese yen (JPY) to U.S. dollar (USD) exchange rate data, this paper estimates a significant difference in the FX market microstructure after November 1997.

[Figure 1 inserted here]

The evidence of the Japanese banking crisis in November 1997 is, for example, investigated from the viewpoint of the Japanese interbank market in Hayashi (2001), indicating the presence of liquidity effects before the Yamaichi Securities failure. There are however very few analyses of the effect of the crisis on the FX market. At this time, Japanese financial institutions were persistently short of dollars, and of short-term funds in particular. The series of bankruptcies resulted in a dramatic loss of credibility for Japanese institutions in the eyes of the market, a situation which not only touched off a depreciation of the yen, but also sparked an urgent demand for dollars on the part of dealers. The latter was in case of increased difficulty of borrowing in dollars, due to credit concerns held by the financial markets. The exchange rate, beginning at 115.85 yen against the dollar in August, exhibited continuous decline (depreciation of the yen), reaching 130.00 towards the end of the year, and 133.84 in early January 1998.

In testing the significance differences of exchange rate dynamics across months, we follow Ito, Lyons and Melvin (1998) and Martens (2000) among others in estimating a GARCH model and calculating the conditional variance-ratio. Thus, using the high-frequency methodology over the second half of 1997, we shed light on the impact of the Japanese banking crisis on the FX market. From the estimation results, it is shown that there exists a structural break in the foreign exchange market at the onset of the crisis; a reversed pattern in return volatility after the series of bankruptcies was found. Based on the assumption that dealers are perceived to be better informed about future changes in the exchange rate than some other agents, the sources of the reversed pattern are examined from a microstructure analysis of exchange rate trade behavior for the second half of 1997. We find that the change in exchange rate dynamics can be attributed to the change in strategic foreign exchange trade behavior. The result provides new insights into the trading activities of market makers at the onset of bank failures.

The rest of this paper is organized as follows. Section 2 provides a brief overview of the Japanese banking crisis in historical perspective. Section 3 describes the data used in this paper and briefly summarizes the spot FX market trading structure. Section 4 presents the estimation methodology. Section 5 summarizes the results, and Section 6 examines their implications from the microstructure point of view. Section 7 concludes the paper.

## 2 Overview of the Japanese Banking Crisis in November 1997

Ever since the so-called "bubble economy" burst in 1990–92, Japan's economy has remained more or less stagnant. The stock market has been flat too, making it difficult for many financial institutions to generate profits. There have been persistent fears that Japan's financial institutions have so many bad loans on their books that the whole Japanese financial system may collapse. Nationwide, private estimates of bad loans have ranged from around 10 percent to 20 percent of gross domestic product at their peak in 1995.[3] The Japanese government has been struggling, with limited success, to deal with its financial problems.[4] The closings of Sanyo securities, Hokkaido Takushoku Bank, and Yamaichi Securities in November 1997 came as a signal that Japan's financial sector was deeply troubled. Under the weight of 'hidden debt,' Yamaichi Securities, the fourth largest brokerage in Japan, was allowed to file for bankruptcy—a significant departure from the past.

The first regional bank failure occurred in 1995 and was followed in 1996 by the officially assisted restructurings, which organized mergers with other regional banks after providing capital injections.[5]

[3]By 1995, a number of financial institutions had been found insolvent. The closure of the *jusen*, or housing loan companies, was a change of longstanding government policy—the traditional "convoy" system. It is argued that the strong reluctance to commit public funds, despite the shift in government policy, to liquidate insolvent institutions has been a major obstacle in resolving Japan's bank problems. The use of public monies was brought up by the government as part of the *jusen* resolution plan in late 1995. Although this legislation was eventually passed, it faced strong political opposition despite the fact that only about $5 billion in public funds were involved. This contrasts with the estimated $145 billion committed by the U.S. government to resolve the savings and loan crisis—a banking problem smaller in magnitude than that facing Japan.

[4]See Cargill, Hutchison, and Ito (1997, 2000).

[5]The banks in question were Hyogo bank, August 1995; Taiheiyo bank, March 1996; and Hanwa Bank, November 1996.

Japan's Sanyo Securities Co. filed for court protection with 373.6 billion yen (USD 3.1 billion) on November 3; a week before, several life insurance companies turned down Sanyo Securities' request for an extension of its loan repayments.[6]

On November 17, Hokkaido Takushoku Bank went bankrupt—the first closure of a large, nationwide commercial bank. Although the announcement came as a surprise, the financial health of the bank had long been suspect. Earlier in the year, Hokkaido Takushoku Bank's inaction vis-a-vis the bankruptcy of a large construction firm (Tokai Kogyo Co. Ltd., for which it served as the main bank) was seen as a sign of less-than-robust health. In September, the bank announced it would abandon a proposed merger with smaller regional rival Hokkaido Bank Ltd. It was reported that the merger talks had stalled over Hokkaido Bank's reluctance to take on the 935 billion yen (USD 7.5 billion) of bad loans Hokkaido Takushoku Bank said it had as of March 1997. Like other Japanese banks, however, Hokkaido Takushoku Bank was later found to have a relatively high percentage of its supposed assets that had turned into bad loans—roughly 1 trillion yen (USD 8.0 billion) worth in its case.

The news that one of Japan's biggest financial institutions, Yamaichi Securities, had gone bankrupt owing billions of dollars was officially announced early morning November 24.[7] It was the third major financial company to fail in the month, following the closures of Sanyo Securities and Hokkaido Takushoku Bank. Yamaichi Securities had hidden more than 200 billion yen (USD 1.6 billion) worth of debts, some of which may be from illegal stock trades. Earlier that year, in August, the eleven top management of the company had quit for allegedly paying USD 1.4 million to a gangster. The resignations and persistent speculation that Yamaichi was hiding debt pushed the stocks down more than three fourths. On November 21, Moody's Investor Service cut its rating of Yamaichi's debt to junk, making it harder and more expensive for Yamaichi to borrow and thereby roll over its debt.

[6] According to the news source Bloomberg, the rejection of Sanyo's request was because the brokerage hadn't submitted a restructuring proposal and hadn't reported that the deadline needed to be postponed.

[7] There was a series of news announcement that Bank of Japan would hold an emergency meeting on Yamaichi (6:00 (JST)) and that Yamaichi asked the Ministry of Finance to cease operations (7:39 (JST)). Before the formal closure on November 24, several Japanese media outlets had reported the confirmation of Yamaichi Securities' closure on November 23.

# 3 Data Description and Preliminary Testing

The exchange rate data used for the analysis in this paper is the tick-by-tick JPY/USD spot rate for five months, from August 1, 1997 to January 8, 1998, obtained from CQG.[8] The data set is unique in the sense that it is micro data—it provides information on trading between FX dealers around the world. Unlike the stock exchanges and securities markets, the FX market is virtually continuously active and traded in several different locations on the globe. That is, the FX market is an electronic market active 24 hours a day with no particular geographical location; however, it is natural to think of the trading as proceeding according to time zones.[9]

Two features of the data used in this paper are particularly noteworthy. First, it is micro data in that the exchange rates are tick-by-tick. It consists of the indicative bid- and asked-rates, and thereby provides the microstructure of the dealing as well as the FX market in depth.[10] Second, the analysis covers a relatively long time span of five months, compared with other previous studies based on micro data sets.[11] This span provides a vast number of minute-by-minute observations on trading activity across a wide variety of market states, which enables us to investigate the exchange rate dynamics in historical perspective.

CQG has recorded the value of the spot exchange rate for the Japanese yen vis-a-vis the U.S. dollar on the tick-by-tick bid and asked quotes. The database includes the date and time (hour and minute), at Central Standard Time (CST), the trade session code, and the bid and ask prices. The trade session code indicates either 0 (Asian trading time, 17:00-24:00), 1 (European trading time, 00:00-07:00), or 2 (US trading time, 07:00-17:00). The trading day comprises a full 24 hours from Monday to Friday.[12] In the following anal-

[8] The author thanks Sumisho Capital Management Co. for providing the data.

[9] Lyons (2001) is a good reference on microstructure of the FX market and dealing system.

[10] The bid and ask rate (FX quote) are shown on the screens of specialist information providers, such as Reuters Telerate, and Minex. These quotes represent indicative prices at which a dealer will be willing to buy (bid) or sell (ask) a particular currency. See Lyons (2001).

[11] For example, the work by Bollerslev and Domowitz (1993) covers April 9 to June 30, 1989; Goodhart, Ito, and Payne (1996) examine trade activity over seven hours on June 16, 1993.

[12] Many previous analyses, such as Andersen and Bollerslev (1998) and Martens (2001), exclude data on Saturday and Sunday from their analysis in order to eliminate weekend

ysis, the date is converted to Japanese Standard Time (JST). The bids and asks are the dealers' indicative buying and selling prices for the US dollar, respectively. Since the original data set records every bid- and asked quote, it includes several "quote revisions"—either the bid or the asked price is successively quoted. These can be interpreted as the dealer's revision of prices in the midst of bid/ask offer for whatever reason. The bids/asks in bold in Table 1, an extract of the CQG data set, are revised quotes.

[Table 1 inserted here]

Although the CQG data has greater coverage and span, it does not provide information on the identity of the counterparties involved in each trade for confidentiality reasons.[13] It also lacks information on the size of each trade, although this may not represent a significant loss of information on trading patterns across the market, as seen in Jones, Kaul and Lipson (1994) and Evans (2002).

Our analysis below is based on the logarithmic middle price of the exchange rate, $p_t$, which is defined to be the log average of bid- and asked-prices, as in Goodhart et al. (1993) and Martens (2001). Each of the bid- and asked-rates used in our analysis is the last arrival for every 10-minute interval. The choice of price interval varies across authors: Ito and Roley (1987), Ederington and Lee (1993), and Bollerslev, Cai and Song (2000), for example, use 5-minute intervals. Baillie and Bollerslev (1990) averages the last 5 bid rates in an hour; Martens (2001) uses the last quote of a half-hour interval; Evans (2002) uses hourly exchange rates. In this paper we follow De Gennaro and Shrieves (1997) with the 10-minute interval price. The exchange rate return, $r_t$, is given as

$$r_t = p_t - p_{t-1}.$$

Table 2 reports the summary statistics of $r_t(\times 100)$ for each month. The mean of the return is significantly negative in September and October, implying that the Japanese yen showed a temporary recovery at that time, while the JPY/USD exchange rate tended to depreciate over the period as a whole. Although the maximum and minimum values of the return, $r_t$, vary across months, the monthly variance of the return does not show significant change.

effect. See Bollerslev and Domowitz (1993) for details of the weekend definition.

[13]Micro FX data sets such as Reuters, which very many previous studies have relied on, have limited access in providing information on individual parties participating in the market, the actual transaction prices, the size of trade, and so on. See Lyons (2001) for details.

[Table 2 inserted here]

Under the null hypothesis of normality, both $\sqrt{6/T} \times skewness$ and $\sqrt{24/T} \times kurtosis$ have asymptotic standard normal distributions, where T is the number of observations. As shown in the table, severe skewness and excess kurtosis are present in all the residual series. The kurtosis of the return exceeds 3.0; the return has a fat-tailed distribution. It is also skewed to the left at significance 1%. Both the skewness and kurtosis are far from normally distributed for the sample of August, September, October, and December, implying that the existence of volatility clustering, *except* in November.

The table also presents the standard Ljung/Box test statistics, LB(12) and LB(24), for up to 12th- and 24th-order serial correlation, respectively.[14] The null of no serial correlation follows an asymptotically chi-squared distribution with 12 (24) of degree of freedom as $T \to \infty$. The critical value of the chi-squared distribution (d.f.= 12) at the 1% significance level is 26.2. The high values of these statistics strongly suggest the presence of serial correlation. Since the return is at 10 minute intervals, 12 lags and 24 lags correspond to 2 hours and 4 hours respectively. An exogenous shock is found to have a long-lasting effect in the JPY/USD FX market.

# 4 Analysis Methodology

On the basis of the preliminary data analysis in the preceding section, the variance of the generalized autoregressive conditional heteroskedasticity (GARCH) model was estimated for each of the 10-minute first differences of the logarithmic exchange rates.

## 4.1 GARCH model

Following Baillie and Bollerslev (1990), Engle, Ito, and Lin (1990), Goodhart, Ito, and Payne (1996), Peiers (1997), Ito, Lyons and Melvin (1998) and Martens (2001), innovations in the JPY/USD FX market are allowed to influence the exchange rate return through the error term. For high-frequency financial data that exhibit ARCH-type dynamics in the residuals, the GARCH model is commonly applied in estimation.[15]

[14]The statistics are heteroskedasticity adjusted. See Dielbold (1988).

[15]See Bollerslev (1986) and Goodhart and O'Hara (1997) for details of GARCH.

In the presence of well-known characteristics of high-frequency returns such as volatility clustering, however, the GARCH estimate is likely to be biased: GARCH assumes symmetry in volatility. As shown in the preliminary test in the previous section, the exchange rate used in the analysis has an asymmetry in its return. In order to obtain the consistent estimate, then, we apply an Exponential GARCH (EGARCH) model and a Threshold GARCH (TGARCH) model by controlling the asymmetry in volatility.[16] The asymmetry is often referred to as the leverage effect in the context of stock price returns.[17]

In the context of market efficiency, one explanation of the existence of volatility clustering is that different investors either observe different news or interpret the same news differently. Even though the market is efficient and the exchange rate follows a martingale process, if the information (news) comes as clustering, this could create as a result a process of price adjustment where the price bounces forth and back between centers with different information: the exchange rate follows an ARCH process.

The exchange rate return, $r_t$, is specified as GARCH(1,1) as follows:

$$r_t = constant + a_1 r_{t-1} + \epsilon_t. \tag{1}$$

The error process, or the innovation, $\epsilon_t$, is such that $\epsilon_t = h_t z_t$, $h_t > 0$. Here $\{z_t\}$ is a white-noise process with $E(z_t) = 0$ and $\mathrm{Var}(z_t) = 1$, independent of all $\epsilon_{t-i}$, $i \geq 1$. The conditional and unconditional means of $\epsilon_t$ are equal to 0. As a result, the conditional variance of $\epsilon_t$ at time $t$, $h_t^2$, is normally distributed with zero mean. That is,

$$\epsilon_t | I_t \sim N(0, h_t^2). \tag{2}$$

The dependent variable in the EGARCH model is the logarithm of volatility, in order to maintain nonnegativity of volatility. The conditional variance $h_t^2$ in EGARCH specifications takes the form

$$log(h_t^2) = \alpha_0 + \alpha_1 |\epsilon_{t-1}/h_{t-1}| + \alpha_2 log(h_{t-1}^2) + \theta \epsilon_{t-1}/h_{t-1}. \tag{3}$$

Note that the left hand side of this equation is the log of the conditional variance. This means that the asymmetric (leverage) effect is exponential and therefore the forecasts of conditional variance are nonnegative.

[16] See Nelson (1991) for EGARCH and Rabemananjara and Zakoian (1993) for TGARCH.

[17] The commonly observed fact that a negative return in the previous period has a larger effect on the current stock price than a positive return does is often called the "leverage effect".

The asymmetric effect is described as parameter $\theta$ in the EGARCH model. This effect implies commonly observed evidence of asymmetry in stock price behavior; negative surprises ($\epsilon_t < 0$) tend to decrease the rate of return $r_t$ and to increase the volatility more than the positive surprises ($\epsilon_t > 0$). In the EGARCH specification $\theta$ allows this effect to be asymmetric. If $\theta = 0$, then a positive surprise has the same effect on volatility as a negative surprise of the same magnitude. If $-1 < \theta < 0$, a positive surprise increases volatility less than a negative surprise. If $\theta < -1$, a positive surprise actually reduces volatility while a negative surprise increases volatility. Therefore, $\theta \neq 0$ corresponds to asymmetry in the volatility.

In applying EGARCH estimation to the exchange rate model, the interpretation of $\theta$ requires caution. In the EGARCH system, a negative shock ($\epsilon_t < 0$) to reduce the "numeric" exchange rate return, $r_t$, is equivalent to appreciation of the yen vis-a-vis the dollar, while a positive shock ($\epsilon_t > 0$) is equivalent to depreciation of the yen. Therefore, an estimated value $\theta \neq 0$ is interpreted as an appreciation shock increasing volatility more than a depreciation shock, and vice versa.

Similar to the idea behind the EGARCH specification, the TGARCH model also assumes an asymmetric impact on volatility. The conditional variance in the TGARCH specification takes the form

$$h_t^2 = \beta_0 + \beta_1 \epsilon_{t-1}^2 + \beta_2 h_{t-1}^2 + \gamma \epsilon_{t-1}^2 d_{t-1}, \tag{4}$$

where $d_t = 1$ if $\epsilon_t < 0$, and 0 otherwise.

Asymmetry is captured by parameter $\gamma$ in the TGARCH model. In this specification, good news (positive surprises, $\epsilon_t > 0$) has an impact of $\beta_1$ on volatility while bad news (negative surprises, $\epsilon_t < 0$) has impact $\beta_1 + \gamma$. If $\gamma = 0$, there exists no asymmetric impact between the two. If $0 < \gamma$, bad news has a larger effect on volatility than good news does. Again, the interpretation of $\gamma$ requires caution. In the TGARCH system, a depreciation shock ($\epsilon_t > 0$) has impact $\beta_1$ on volatility, while an appreciation shock ($\epsilon_t < 0$) has impact $\beta_1 + \gamma$.

## 4.2 Variance Ratio Test

Based on GARCH estimation, we conduct a month-to-month variance-ratio test. Variance-ratio statistics are routinely employed in empirical work to assess the structural change in high-frequency returns over time. In testing the difference of return volatility over a specific interval, a test for equality of variances is conducted. The null hypothesis of no difference is stated in terms of the variance-ratio as

$$\frac{V^1}{V^2} = 1,$$

where $V^1$ and $V^2$ denote the return variance for the two sample groups, respectively. If the returns are i.i.d. normally distributed and the null hypothesis is valid, the variance-ratio represents a realization of an $F_{n_1,n_2}$-distributed random variable, where $n_1$ and $n_2$ are the number of observations. When the sample size is large enough, the F-distribution is approximately normal. The associated F value of the conditional variance ratio for the two sub-samples is calculated as

$$F = \frac{n_1 S_1^2/(n_1 - 1)}{n_2 S_2^2/(n_2 - 1)}, \tag{5}$$

where $S_1^2$ and $S_2^2$ are the unbiased estimates of variances—in this case the conditional variances $h_t^2$ estimated from EGARCH—while $n_1$ and $n_2$ are the number of observations. The subscript refers to the sub-sample.

# 5 Results

First, the EGARCH and TGARCH estimations are conducted for August 1, 1997–January 8, 1998.[18] Based on the monthly estimation results, the existence of asymmetry in return volatility is examined. Next, the variance-ratio test is employed to test whether there is a significant difference in the behavior of the exchange rate across months.

[Table 3 inserted here]

The estimates of volatility asymmetry are presented in Table 3. In the table, $\theta$ and $\gamma$ show the asymmetric impact for EGARCH(1,1) and TGARCH(1,1) respectively. Estimated $\theta$ is significantly negative during August–October, while significantly positive in December, and insignificant in November, implying the existence of asymmetry in volatility in August-October, but insignificant impact in November and December. Estimated $\gamma$ gives the same

[18] In an earlier version of this paper, four GARCH-type regressions—GARCH(1,1), MA(1)-GARCH(1,1), EGARCH(1,1) and TGARCH(1,1)—were conducted, the results of which are not reported here. They can be obtained from the author upon request. All estimations have consistency in results.

implication: estimated parameters are significantly positive during August–October, while significantly negative in November and December. In sum, return volatility in the JPY/USD FX market shows the usual clustering and asymmetry *before* the crisis. However, it behaves "exceptionally" after November 1997. This result can potentially be attributed to change in dealer behavior: in the wake of bank failures, traders became cautious in terms of their response to news, including issues related to the banking systems.

[Table 4 inserted here]

The month-to-month variance-ratio test results are summarized in Table 4. The associated F value of the conditional variance ratio for the two sub-samples is calculated based on the results of EGARCH (1,1) estimations.

The validity of the assumption of constant variance is tested at 0.02 and 0.1 of the F distributed critical values. As the table shows, the null hypothesis of no difference between two sub-samples is rejected at the 2% significance level for pairs September–October and December–August, and 10% for pairs December–October and December–November. On the other hand, pairs November–August, November–September, November–October and August–September do not show marked difference. The large structural breaks in the high-frequency volatility pattern in FX market occurred in November 1997, in the wake of the banking crisis.

The GARCH estimation and the variance-ratio results provide strong evidence that the banking crisis did indeed change the behavior of exchange rate volatility. In contrast to the "normally" observed asymmetric news impact on high-frequency return for the pre-crisis period, the post-crisis return showed no time-varying conditional volatility or non-normally distributed residual. Inferences are that the increasing difficulty in forecasting the exchange rate prices in the wake of the bank failures led dealers to quote in a wider range of prices. Also, they were more likely to revise the price of the yen down. These results support the hypothesis that bank failures in November 1997 dramatically changed FX market dealers' behavior.

# 6 Microstructure of FX market

As shown in the previous section, we find a reversed volatility pattern at the onset of the banking crisis. The change in the exchange rate dynamics was due to a change in trading patterns following an extreme event: the bankruptcy of three major Japanese financial institutions within one month.

In this section, we investigate exchange rate trading in detail over the period—the microstructure of the spot FX market for the period around the Japanese banking crisis of November 1997. Specifically, by examining the trade activity of exchange rates through frequency of quote revision and width of price change, we identify a change in FX trade patterns after the crisis. The results provide new insights into the trading activities of market makers at the onset of bank failures.

## 6.1 Quote Entry

First, we examine the frequency of quote entry. Table 5 gives the average frequency of quote entry over an interval of 4 hours. The time is expressed in Japanese Standard Time (JST). The first two columns provide the averaged frequency of both bids and asks for the sample period from August to October 1997; the second two columns provided the frequency from November to December of the same year. The last two columns provide the frequency sample average.

[Table 5 inserted here]

On the whole, the difference in frequency sample average between bids and asks is not particularly large at each time interval. The frequency of quote entry is extremely large, approximately 930 instances, when both the European and US markets are active, which is 16:00 to 24:00 (JST). Quote entry decreases a little, but the market is still active and the frequency exceeds 570, between 0:00 and 4:00 (JST). In the period after the US market closes and before the Tokyo market opens—4:00 to 8:00 (JST)—trading activity is relatively small and calm.

The frequency of both the bid- and asked-quote entry increased after the onset of the banking crisis between 20:00 and 8:00 (JST). In particular, the frequency almost doubled between 4:00 and 8:00 (JST), when the exchange rate is usually least active (between the New York market closure and Tokyo market opening). The averaged frequency of bid quotes at this time increased dramatically, from 122 before the crisis to 204 after the crisis. There was also a large increase in frequency between 0:00 and 4:00 (JST), the US trading time, from 461–470 instances to 728–735 instances. On the other hand, the frequency decreased between 8:00 and 20:00 (JST), which is the Asian trading time. For example, the frequency of bid quotes from 12:00 to 16:00 (JST), when the Tokyo market was at its most active time, decreased from 498 before the crisis to 412 after the crisis. It is apparent from the table that in the wake of Japan's banking crisis, FX trading activity became less active during the Asian trading time, including at Tokyo—one of the three major markets.

## 6.2 Quote Revision and Price Change

Table 6 shows the hourly average of frequency of quote revision and the associated absolute price change. In the table, "positive" price change is quotes revised on depreciation of the yen, while "negative" change is those on appreciation of the yen. For each time interval, the frequency and the price change of both bids and asks for the sample period from August to October, from November to December, and the sample average are shown.

[Table 6 inserted here]

Regarding quote revision, the frequency sample average varies across the time interval. The bids and asks frequency with either positive or negative price change ranges from 1.7 to 3.5 between 4:00 and 8:00 (JST): the least of all time intervals. The frequency of quote revisions increases as the market moves from Asia to Europe and then to the US. During the Asian trading time, the frequency centers around 15–16. When the trade shifts to the European market, the average frequency reaches 18–21 instances for bids and 29–30 instances for asks. This active quote revision remains when the US market opens. As the European market closes and the US market comes to an end, the frequency of quote revisions decreases to 12 instances.

Examining the absolute price change of quote revisions, both positive and negative price changes are concentrated around 0.031 between 0:00 and 3:59; 0.022 between 4:00 and 7:59; 0.04 between 8:00 and 11:59; 0.045 between 12:00 and 15:59; 0.037 between 16:00 and 19:59; and 0.035 between 20:00 and 23:59. As a whole, the width of price change is larger as the market is more active.

Comparing the price changes before and after the crisis, price width for both bids and asks changes become larger between 8:00 and 19:59 (JST) after the crisis. For example, the bid rate width with positive price change before the crisis was 0.0403, compared to 0.433 after, for the period from 8:00 to 11:59. In particular, from 8:00 to 15:59 when the Tokyo market was the most active, the price change of bids was wider than that of asks. Between 12:00

and 15:59, the bid rate width for positive price change widened from 0.0389 to 0.0481, and the bid rate width for negative price change also widened from 00418 to 0.0527. This fact reflects dealers' urgent demand for dollars with the series of bankruptcies. The majority of Tokyo market participants are Japanese financial and non-financial institutions, which were heavily in need of US dollars, and therefore likely to raise the buying price of US dollars in order to procure them.

In contrast, for the time intervals from 20:00 to 3:59 (JST), during opening of the European and US markets, price change with only ask rate revision become larger after the crisis. It is also noteworthy that the width of ask price change is larger than that of bids during this time interval. The majority of participants at these time intervals are US and European banks and other institutions, which *provide*, rather than buy, dollars. Thus, the value of the dollar rose in response to increased demand from Japanese banks and institutions.

In sum, the trading patterns, including frequency of quote entry and quote revisions, show marked changes at the onset of the banking crisis. The frequency of quote entry indicates that the Tokyo market became less active after the bank failures. Although the frequency of quote revisions remained relatively stable compared to the pre-crisis period, the width of price change associated with quote revision widened after its onset. In particular, the bids price change became larger during Tokyo trading time, whereas the asks price change became larger during the European and US market trading times. This is consistent with the fact that in the wake of the crisis, Japanese financial and non-financial institutions were heavily in need of dollars. The buying price of dollars therefore soared when Japanese firms are active in market, while the selling price of dollars rose when dealers in Europe and the US were active.

# 7 Concluding remarks

In this paper, we apply GARCH estimation and the variance-ratio test to the tick-by-tick quoted JPY/USD exchange rate data and reveal several interesting findings. First, there is a structural break in FX market volatility patterns at the onset of the Japanese banking crisis in November 1997. This appears due to changes in FX dealers' strategic trading behavior. Specifically, our results shows that the trading patterns, including the frequency of the quote revisions and the number of quotes, as well as the price change of revisions, show marked difference before and after the bank failures. In the wake of these unexpected failures, the difficulty of forecasting the market encouraged dealers to refrain from frequent quote entry as well as quote revisions. At the same time, dealers quoted with a wider price width, resulting in rapid increase in the buying price of dollars while the Tokyo market was open, and similarly for the selling price while European and US markets were open. These changes in dealing patterns contributed to the downward trend of the Japanese yen.

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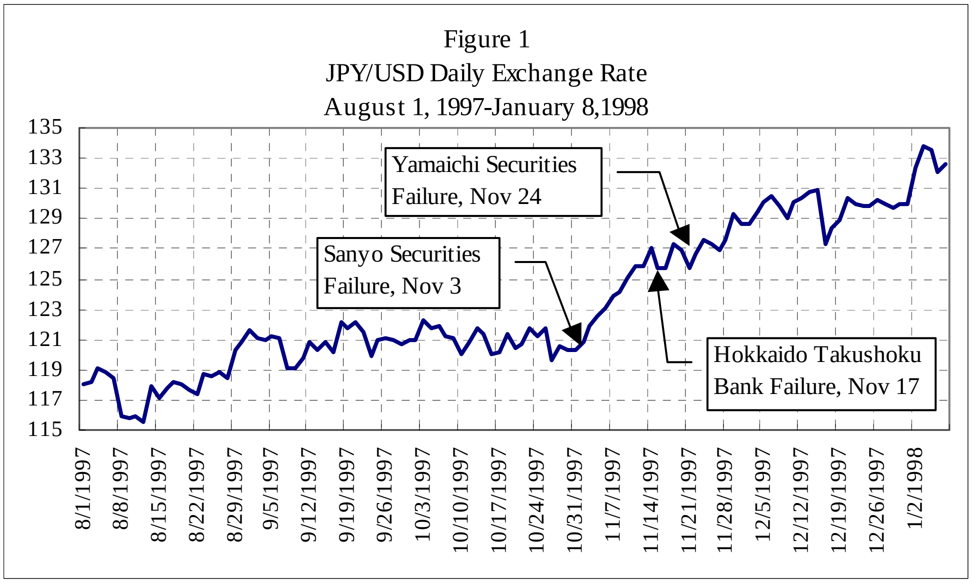
Figure 1
JPY/USD Daily Exchange Rate
August 1, 1997-January 8,1998
135
133
131
129
127
125
123
121
119
117
115
Yamaichi Securities
Failure, Nov 24
Sanyo Securities
Failure, Nov 3
Hokkaido Takushoku
Bank Failure, Nov 17
8/1/1997
8/8/1997
8/15/1997
8/22/1997
8/29/1997
9/5/1997
9/12/1997
9/19/1997
9/26/1997
10/3/1997
10/10/1997
10/17/1997
10/24/1997
10/31/1997
11/7/1997
11/14/1997
11/21/1997
11/28/1997
12/5/1997
12/12/1997
12/19/1997
12/26/1997
1/2/1998

**Table 1**

The following is the listing of CQG data reports.
Since the bids and asks are put in at separate times, and there are cases where consecutive bid/ask quote are put, the revised quotes (in Bold) are omitted from the analysis.

| date | session | time | price | B/A |
|---|---|---|---|---|
| 19970909 | 2 | 1028 | 11895 | B |
| 19970909 | 2 | 1028 | 11905 | A |
| 19970909 | 2 | 1028 | 11896 | B |
| **19970909** | **2** | **1028** | **11904** | **A** |
| **19970909** | **2** | **1028** | **11901** | **A** |
| **19970909** | **2** | **1028** | **11906** | **A** |
| 19970909 | 2 | 1028 | 11899 | A |
| 19970909 | 2 | 1029 | 11896 | B |
| 19970909 | 2 | 1029 | 11899 | A |
| 19970909 | 2 | 1029 | 11883 | B |
| 19970909 | 2 | 1029 | 11893 | A |
| **19970909** | **2** | **1029** | **11895** | **B** |
| **19970909** | **2** | **1029** | **11896** | **B** |
| 19970909 | 2 | 1029 | 11885 | B |
| 19970909 | 2 | 1029 | 11890 | A |

**Table 2**
**Summary Statistics**

| | August | | September | | October | | November | | December | |
|---|---|---|---|---|---|---|---|---|---|---|
| Mean | 6.54E-04 | | -1.40E-04 | | -1.27E-06 | | 2.13E-03 | | 8.43E-04 | |
| (s.e.) | 2.62E-05 | | 2.49E-05 | | 2.22E-05 | | 2.55E-05 | | 2.18E-05 | |
| Minimum | -1.132 | | -1.640 | | -0.911 | | -0.580 | | -1.283 | |
| Maximum | 0.500 | | 0.647 | | 0.783 | | 0.418 | | 0.581 | |
| Variance | 5.98E-03 | | 6.00E-03 | | 5.23E-03 | | 5.22E-03 | | 7.33E-03 | |
| Skewness | -1.091 | * | -2.941 | * | -0.876 | * | -0.567 | * | -1.771 | * |
| (s.e.) | 4.51E-02 | | 4.39E-02 | | 4.29E-02 | | 4.60E-02 | | 3.91E-02 | |
| Kurtosis | 19.497 | * | 68.456 | * | 24.461 | * | 6.432 | * | 26.758 | * |
| (s.e.) | 9.01E-02 | | 8.79E-02 | | 8.59E-02 | | 9.21E-02 | | 7.82E-02 | |
| LB(12) | 27.5 | | 73.7 | | 76.7 | | 42.7 | | 83.5 | |
| LB(24) | 48.1 | | 90.4 | | 102 | | 71.7 | | 102 | |
| nobs | 2954 | | 3108 | | 3255 | | 2832 | | 3923 | |

*Note:* * indicates significance at a 1 % level against null of normal distribution.

**Table 3**
**Estimate of asymmetry in return volatility**

| | August | September | October | November | December |
|---|---|---|---|---|---|
| | Panel A: EGARCH(1,3) | | | | |
| theta | -5.38E-02 | -9.73E-02 | -6.75E-02 | 2.83E-03 | 5.07E-02 |
| (s.e.) | 6.99E-03 | 7.40E-03 | 1.04E-02 | 7.18E-03 | 7.51E-03 |
| | Panel B: TGARCH(1,3) | | | | |
| gamma | 0.065 | 0.175 | 0.098 | -0.012 | -0.109 |
| (s.e.) | 1.07E-02 | 1.48E-02 | 1.81E-02 | 8.47E-03 | 1.45E-02 |

**Table 4**

**Comparison of conditional variance between sub-periods**

The table repots the ratio between the mean of conditional variances estimated for two sub-periods. The null hypothesis of no difference between the two sub-sample is based on the F-test. Conditional variances are calculated based on EGARCH(1,1).

| month pair | F-value | |
|---|---|---|
| September-August | 1.155 | |
| October-August | 1.200 | |
| October-September | 1.386 | * |
| November-August | 1.117 | |
| November-September | 1.290 | |
| November-October | 1.074 | |
| December-August | 1.391 | * |
| December-September | 1.204 | |
| December-October | 1.669 | ** |
| December-November | 1.554 | ** |

** and *: significantly different from 1 at the 2% level and 9% level, respectively.

**Table 5**

Frequency of quote entry

The numbers are hourly average of quot entry for six 4-hour intervals.

The time is Japanese Standard Time (JST).

| | August-October | | November-December | | Sample Average | |
|---|---|---|---|---|---|---|
| Time interval | bid | ask | bid | ask | bid | ask |
| 0:00-3:59 | 470.26 | 461.21 | 728.07 | 735.83 | 573.38 | 571.05 |
| 4:00-7:59 | 121.89 | 124.11 | 204.47 | 205.73 | 154.92 | 156.76 |
| 8:00-11:59 | 445.26 | 453.53 | 438.69 | 438.57 | 442.63 | 447.54 |
| 12:00-15:59 | 498.04 | 506.38 | 412.24 | 417.18 | 463.72 | 470.70 |
| 16:00-19:59 | 937.15 | 962.33 | 898.99 | 912.32 | 921.89 | 942.33 |
| 20:00-23:59 | 911.90 | 908.56 | 948.63 | 962.33 | 926.59 | 930.07 |

**Table 6**
**Summary of Quote Revisions and associated Absolute Price Change**
The numbers are hourly average for each time interval. The time is at Japanese Standard Time (JST).

| | Frequency of revisions | | Absolute Price Change | |
|---|---|---|---|---|
| | Bid | Ask | Bid | Ask |
| 0:00-3:59 | | | | |
| **August-October** | | | | |
| positive price change | 14.0972 | 11.5556 | 0.0343 | 0.0306 |
| zero price change | 1.5833 | 0.0417 | 0.0000 | 0.0000 |
| negative price change | 11.9028 | 10.7500 | 0.0318 | 0.0286 |
| **November-December** | | | | |
| positive price change | 10.9583 | 13.9583 | 0.0328 | 0.0337 |
| zero price change | 1.3125 | 0.0208 | 0.0000 | 0.0000 |
| negative price change | 10.7708 | 14.9792 | 0.0316 | 0.0344 |
| **Sample Average** | | | | |
| positive price change | 12.8417 | 12.5167 | 0.0337 | 0.0318 |
| zero price change | 1.4750 | 0.0333 | 0.0000 | 0.0000 |
| negative price change | 11.4500 | 12.4417 | 0.0317 | 0.0309 |
| 4:00-7:59 | | | | |
| **August-October** | | | | |
| positive price change | 1.7500 | 4.0833 | 0.0225 | 0.0274 |
| zero price change | 0.8194 | 0.0000 | 0.0000 | 0.0000 |
| negative price change | 1.6944 | 3.4861 | 0.0199 | 0.0228 |
| **November-December** | | | | |
| positive price change | 1.5833 | 2.7500 | 0.0204 | 0.0260 |
| zero price change | 0.5625 | 0.0000 | 0.0000 | 0.0000 |
| negative price change | 1.8125 | 1.9792 | 0.0231 | 0.0233 |
| **Sample Average** | | | | |
| positive price change | 1.6833 | 3.5500 | 0.0216 | 0.0269 |
| zero price change | 0.7167 | 0.0000 | 0.0000 | 0.0000 |
| negative price change | 1.7417 | 2.8833 | 0.0212 | 0.0230 |
| 8:00-11:59 | | | | |
| **August-October** | | | | |
| positive price change | 15.1111 | 22.8194 | 0.0403 | 0.0362 |
| zero price change | 4.0417 | 0.0139 | 0.0000 | 0.0000 |
| negative price change | 14.7639 | 20.8194 | 0.0400 | 0.0346 |
| **November-December** | | | | |
| positive price change | 12.7708 | 13.9375 | 0.0433 | 0.0394 |
| zero price change | 3.1875 | 0.0208 | 0.0000 | 0.0000 |
| negative price change | 11.3542 | 14.2500 | 0.0448 | 0.0430 |
| **Sample Average** | | | | |
| positive price change | 14.1750 | 19.2667 | 0.0415 | 0.0375 |
| zero price change | 3.7000 | 0.0167 | 0.0000 | 0.0000 |
| negative price change | 13.4000 | 18.1917 | 0.0419 | 0.0380 |

**Table 6 (cont'd)**
**Summary of Quote Revisions and associated Absolute Price Change**

| | Frequency of revisions | | Absolute Price Change | |
|---|---|---|---|---|
| | Bid | Ask | Bid | Ask |
| 12:00-15:59 | | | | |
| **August-October** | | | | |
| positive price change | 13.7917 | 19.0278 | 0.0389 | 0.0403 |
| zero price change | 2.9861 | 0.0000 | 0.0000 | 0.0000 |
| negative price change | 12.4444 | 18.2917 | 0.0418 | 0.0399 |
| **November-December** | | | | |
| positive price change | 9.1250 | 12.2708 | 0.0481 | 0.0465 |
| zero price change | 2.5833 | 0.0208 | 0.0000 | 0.0000 |
| negative price change | 9.7083 | 13.5000 | 0.0522 | 0.0497 |
| **Sample Average** | | | | |
| positive price change | 11.9250 | 16.3250 | 0.0426 | 0.0428 |
| zero price change | 2.8250 | 0.0083 | 0.0000 | 0.0000 |
| negative price change | 11.3500 | 16.3750 | 0.0460 | 0.0439 |
| 16:00-19:59 | | | | |
| **August-October** | | | | |
| positive price change | 22.0694 | 32.1528 | 0.0360 | 0.0383 |
| zero price change | 3.1250 | 0.0000 | 0.0000 | 0.0000 |
| negative price change | 18.5139 | 30.2222 | 0.0363 | 0.0367 |
| **November-December** | | | | |
| positive price change | 20.3958 | 26.9375 | 0.0367 | 0.0401 |
| zero price change | 2.9375 | 0.0208 | 0.0000 | 0.0000 |
| negative price change | 18.4583 | 27.5208 | 0.0380 | 0.0414 |
| **Sample Average** | | | | |
| positive price change | 21.4000 | 30.0667 | 0.0363 | 0.0390 |
| zero price change | 3.0500 | 0.0083 | 0.0000 | 0.0000 |
| negative price change | 18.4917 | 29.1417 | 0.0370 | 0.0386 |
| 20:00-23:59 | | | | |
| **August-October** | | | | |
| positive price change | 31.1944 | 29.3194 | 0.0367 | 0.0357 |
| zero price change | 3.5139 | 0.0556 | 0.0000 | 0.0000 |
| negative price change | 28.8889 | 28.4861 | 0.0362 | 0.0346 |
| **November-December** | | | | |
| positive price change | 21.1042 | 27.4167 | 0.0332 | 0.0374 |
| zero price change | 2.0833 | 0.0000 | 0.0000 | 0.0000 |
| negative price change | 19.6875 | 28.2292 | 0.0320 | 0.0360 |
| **Sample Average** | | | | |
| positive price change | 27.1583 | 28.5583 | 0.0353 | 0.0364 |
| zero price change | 2.9417 | 0.0333 | 0.0000 | 0.0000 |
| negative price change | 25.2083 | 28.3833 | 0.0345 | 0.0352 |