Partial price adjustment and autocorrelation in foreign exchange markets

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Abstract

This paper studies autocorrelation in the won/dollar Foreign Exchange (FX) market. In contrast to FX markets in developed countries, we find significant positive autocorrelation until quite recently, with partial price adjustment the only plausible explanation. We find that the autocorrelation was eliminated as the FX market was gradually liberalized. The informational efficiency of the market was significantly improved, with the time required for new information to be fully incorporated into the exchange rate diminishing from eight trading days to less than one day. We study the determinants of the autocorrelation from a market microstructure point of view, finding that the autocorrelation was not related to volatility, and was related to trading volume only after the final stage of the FX liberalization. While the liberalization allowed greater freedom to make speculative trades, our results suggest that the bulk of the trade was for hedging rather than speculative purposes

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1. Introduction

Studies of major foreign exchange (FX) rates have not found autocorrelation in daily returns.[1] In this paper, we examine whether these findings extend to non-reserve currency FX returns. Surprisingly, we find significant positive autocorrelation in returns on a non-reserve currency exchange rate until quite recently. This autocorrelation can only be plausibly explained by partial adjustment, in which trades are occurring at prices that do *not* correctly reflect the information available to traders. We find that the autocorrelation was reduced and ultimately eliminated as the foreign exchange market was gradually liberalized. We investigate the determinants of this autocorrelation using a market microstructure approach.

We study the Korean won-U.S. dollar (won/dollar) exchange rate. Although the won is not a reserve currency like the dollar, yen, euro or pound, the won/dollar volume is still quite high, since the Korean economy, the 12th largest in the world by GDP, is heavily dependent on trade. Moreover, there is reliable data on the *total* won/dollar trading volume, in contrast to the situation in most FX markets, where trading is very decentralized, and analyses have relied on data on the transactions of one or a few dealers.[2] These volume data allow us to do a thorough market microstructure analysis.

The partial price adjustment hypothesis has been very controversial, with a large number of papers arguing for and against it based on evidence in other types of financial markets. The regime shifts from a managed system to a liberalized system in the Korea FX market during our sample period provide a clean experiment that enables us to study the partial price adjustment hypothesis; we find compelling evidence in favor of it in the won/dollar market.

While previous work has not found autocorrelation in foreign exchange returns, there is an extensive literature concerning autocorrelation in stock returns. Individual stock returns exhibit negative, but statistically weakly significant, autocorrelation (see Lo and MacKinlay (1990)). By contrast, returns on stock portfolios have a statistically very significant and positive autocorrelation. Three hypotheses have been advanced to explain the positive autocorrelation of portfolio returns (see Boudoukh, Richardson, and Whitelaw (1994)): (1) market microstructure biases including the nonsynchronous trading effect and bid-ask bounce, (2) time-varying risk premium, and (3) partial price adjustment.

The nonsynchronous trading effect seems clearly inapplicable to FX markets. Nonsynchronous trading causes positive autocorrelation in stock *portfolios* because, after some news is released, some stocks within the portfolio will trade before the daily close, while other stocks will not. The won/dollar rate is a single security, not a portfolio[3], trading is essentially continuous, and many FX dealers close their balances (inventories) to zero at the end of every trading day.[4] Similarly, bid-ask bounce seems inapplicable because foreign exchange transactions are priced on an exceedingly fine grid[5]; in any case, bid-ask bounce should result in negative first-order autocorrelation, whereas we find positive first-order autocorrelation in won/dollar rates. The time-varying risk premium hypothesis is not a phenomenon of daily data; "asset pricing models link expected returns with changing investment opportunities, which, by nature, are low-frequency events" (Ahn, Boudoukh, Richardson, and Whitelaw (2002), page 656). Thus, we are left only with partial price adjustment as a plausible source of autocorrelation in the won/dollar exchange rate.

Partial price adjustment models allow for the possibility that the market price at a given time does *not* correctly reflect all the available information. This could result from asymmetric information, with the better-informed traders exercising their informational advantage slowly to maximize the value of the information. In this setting, we would expect to see uninformed traders use technical strategies, such as positive-feedback trading, which allow them to appropriate some of the value of the private information possessed by the informed traders. Positive-feedback trading will tend to speed up the adjustment of prices by amplifying the demands of the informed traders, but it may also result in short-run overshooting.[6] We find that the signs of the autocorrelation coefficients alternate within a time span of a few days. This short-run overshooting is distinct from the longer-run overshooting in the Dornbusch Overshooting Model, which is derived from the lag (measured in months) between a monetary shock and the resultant change in prices.

There is evidence of asymmetric information in the won/dollar FX market. Korean firms engaged in trade are grouped into large conglomerates (*chaebols*); each *chaebol* has a General Trading Corporation (GTC) that handles the bulk of the *chaebol*'s foreign trade and foreign exchange transactions. The GTCs of the largest *chaebols*, such as Samsung and Hyundai, are each responsible for a large fraction of Korea's total trade, so that their own foreign exchange needs constitute a substantial part of the FX trade; in other words, each large *chaebol*'s own foreign exchange needs are significantly correlated with the trade fundamentals underlying the won/dollar rate. In the early part of our data period, Koreans were prohibited from investing in foreign currency bonds, and foreign investors were prohibited from investing in Korean bonds; these restrictions were practically eliminated in July, 1998, during the Asian financial crisis, but foreign investors still constitute less than one per cent of the trade in Korean government bonds. Thus, trade has a much larger influence on the won/dollar exchange rate than portfolio-balance considerations that are important in other FX markets.

There is also evidence of positive-feedback trading in the won/dollar market: Ahn, Lee, and Suh (2002) report that positive-feedback trading was common in the won/dollar market in 2001.[7] The regime shifts in the Korea FX market allow us to test the importance of asymmetric information, and the use of positive-feedback trading by uninformed traders seeking to capitalize on others' superior information.

In our empirical analysis, we examine the daily returns, return volatility, and trading volume in the won/dollar market for the period September 2, 1991 ~ August 11, 2003. We exclude the period of the Asian financial crisis, October 1, 1997 to March 31, 1999, from our sample period.[8] We divide our data into three periods: the period before October 1997 (before the liberalization); the period between April 1999 and December 2000 (First-Stage FX Liberalization); and the period from January 2001 to August 2003 (Second-Stage FX

Liberalization), which leads our sample period to exactly correspond to the regime shits in the Korea FX market.

Here are our main findings:

- The first-order autocorrelation coefficient of won/dollar returns is strongly positive and highly significant before the liberalization and during the First-Stage FX Liberalization period, whereas it is slightly negative and statistically insignificant after the Second-Stage FX Liberalization. The higher-order partial autocorrelation coefficients before the liberalization show the characteristic pattern of a damped harmonic oscillator, alternating in sign and gradually decreasing; this pattern disappears for the First-Stage FX Liberalization. Partial price adjustment is the only plausible explanation for the existence of positive autocorrelation. The disappearance of the autocorrelation indicates that the informational efficiency of the won/dollar FX market improved as the market was liberalized.
- The relationship between volatility and autocorrelation is statistically insignificant in each of the three data periods; indeed the coefficient does not even exhibit a consistent sign. This contrasts with the situation in the stock market, where volatility and autocorrelation are negatively related. We provide a simple

theoretical analysis of the relationship between volatility and autocorrelation that is consistent with our empirical findings. This analysis indicates that the increase in volatility provides further evidence that the market became informationally more efficient over the period of our study.

- Volume is negatively related to autocorrelation in each of three sample periods, but statistically significant only for the Second-Stage FX Liberalization, when the autocorrelation of the won/dollar returns disappears. This indicates that, in the final sample period, there is positive autocorrelation on days of low volume, and negative autocorrelation on days of high volume, and that these effects largely cancel, resulting in net autocorrelation which is not statistically different from zero. Following the market microstructure literature on stocks, this indicates that upward blips in volume resulted more from blips in concrete FX exchange needs than from upward blips in speculation.

This paper is organized as follows. In the next section, we briefly describe the regime shifts in the won/dollar FX market. Then, section 3 reports the data, their descriptive statistics, and the autocorrelation of returns on daily won/dollar rates. In section 4, we report the determinants of autocorrelation in the won/dollar rates in three subsections; first, we describe the basic specification of our models and then estimate the relationship between the autocorrelation of returns and the volatility. Second, we present estimates of the relationship between the autocorrelation of returns and the trading volume. Third, we estimate the relationship between autocorrelation, volatility and trading volume simultaneously, as a robustness test. Section 5 provides a summary of our results and some suggestions for further research.

2. Regime changes in the won/dollar FX market

Prior to the Asian financial crisis, the won/dollar FX market was governed by the Market Average Exchange Rate (MAR) system. Under the MAR system, there were limits on the daily movement of the won/dollar rate. At the beginning of our data sample, the limit was relatively tight: ±0.6% daily. These limits were gradually relaxed, and were ±2.25% from December 1995 until the onset of the crisis. In addition, the MAR system included restrictions making it hard to do currency exchanges other than those needed immediately to facilitate merchandise trade. Our first data period coincides with the MAR regime, and ends with the onset of the crisis in the fall of 1997.

The First-Stage FX Liberalization occurred on April 1, 1999, the start of our second data period. The limits on daily movement of the won/dollar rate were abolished.[9] Currency exchanges were permitted to facilitate current account and capital transactions, rather than being restricted to facilitating merchandise trade. The Korea Futures Exchange (KOFEX) opened, and immediately began trading won/dollar futures; this permitted traders to engage in a limited set of speculative and hedge trades.

The Second-Stage FX Liberalization occurred on January 1, 2001, the start of our third data period. After this liberalization, the rules governing the won/dollar FX market were essentially the same as those prevailing in developed country FX markets. Certain specified transactions (for example, money laundering) were prohibited; all transactions not expressly prohibited were legalized. In particular, there were no restrictions on the types of won/dollar FX derivatives that could be traded.

Under the MAR system, the limits on daily movement of the won/dollar rate would be expected to generate positive autocorrelation; on any day on which the limit was binding, whatever movement could not be accommodated under the limit would occur the following day. Remarkably, during the MAR system, the daily limit on trade was never hit. The only plausible explanation of this fact is that the government intervened in the won/dollar markets every time the exchange rate approached the daily limit.[10] Thus, the limits appeared to function as announcements of how much daily volatility the government would allow before intervening. The effect of this intervention policy would also be to generate positive autocorrelation, just as if there were a tight daily limit in an FX market with little government intervention.

However, the government intervention would have had a major effect on traders' strategic incentives. In the absence of intervention, an informed trader would tend to spread out trades so as to avoid generating adverse price movements. If the government stands willing to buy or sell unlimited quantities of dollars in order to keep the price within the daily limit, then the optimal strategy for an unconstrained informed trader would be to make his/her entire desired trade on a single day. By limiting the price movement, the government intervention not only shields the informed trader from adverse price movements but also helps the informed trader obscure his/her information. On the other hand, the government had some ability to limit informed traders. The government closely regulated all banks, and owned some of them, so it may have been in a position to persuade banks to support, or at least not undermine, its intervention through their own trades. It probably had some influence over the *chaebols*, although these were all privately owned and were less tightly regulated than the banks. If a given *chaebol* regularly made very large transactions on single days, forcing a major government intervention to keep the exchange rate within the daily limit and leaving the government with foreign exchange losses, the *chaebol* might have been concerned about receiving additional regulatory scrutiny in retaliation. Thus, the strategic considerations of traders in the MAR period were very complicated.

As noted above, the limits on foreign investment in Korean bonds and Korean investment in foreign bonds during the MAR period meant that real trade was the main driving factor in a portfolio balance analysis. Because the larger *chaebols*' GTCs each constituted a significant fraction of total Korean trade, simply knowing their own FX needs provided them with a significant informational advantage in the won/dollar market throughout all three data periods. In the first data period, the GTCs' role as the trading entities for their respective *chaebols* could potentially have allowed them to disguise certain speculative or hedging FX trades as being related to immediate real trade needs. There was little room for other entities to engage in speculative trading, including attempting to appropriate a portion of the value of the GTCs' private information through the use of positive-feedback strategies. In the absence of government intervention, we would anticipate that the GTCs would attempt to exploit the value of their private information by spreading trades over several days. Given the complexity of the strategic situation, there is no clear theoretical prediction of how the GTCs would exploit their informational advantage. However, regardless of the GTCs' strategies, the MAR system would be expected to have produced positive autocorrelation in the won/dollar rate in the first data period.

The First-Stage FX Liberalization removed some of the restrictions on the FX market, and the Second-Stage FX Liberalization finished the job. The two-stage elimination of restrictions on speculative trades might be expected to improve the efficiency of the won/dollar market. Our three data periods were chosen to study the effect of the liberalization on the functioning of the FX market.

3. Basic characteristics of the data

For the analyses in this paper, we use the daily won/dollar closing rate and trading volume from September 2, 1991 to August 11, 2003. The return (r_t) of exchange rates (S_t) is defined as the log first difference of the daily FX rate series multiplied by 100, $r_t = 100 \times (\ln S_t - \ln S_{t-1})$. We use the daily trading volume data of won/dollar exchange after detrending, "to discriminate between increases in trading volume due to information arrivals and increases due to more traders in the markets (see Gallant, Rossi, and Tauchen (1993) and Fong and Lab-Sane (2003))." Following Andersen (1996) and Fong and Lab-Sane (2003), we detrend using an equally weighted moving average of length one year centered on each day. The trading volume used in this paper is centralized data, the total trading volume transacted for each day excluding only transactions on offshore markets; by contrast, previous studies of other currencies have depended on reports of a small, non-random, sample of the total transactions.[11]

As described above, we consider three data periods, corresponding to successive liberalization of the won/dollar FX market, and we exclude the period of the Asian financial crisis. Since our analysis concerns the relationship among daily variables, there is ample time for traders to form rational expectations of those relationships within each of our data periods. We do not have to address the relationship between long-term expectations and the true distribution of long-run events, for example the so-called "peso problem," because we do not analyze any long-run relationships among variables. We exclude the period of the crisis because the extreme turmoil of that period prevents us from drawing meaningful conclusions from that period. The purpose of this paper is to analyze the relationship between regime shifts (liberalization) of the Korea FX market and existence of autocorrelation (partial price adjustment hypothesis), and to draw conclusions about market microstructure aspects of foreign exchange markets during relatively normal periods.

Table 1 shows the descriptive statistics for daily rates of return and detrended trading volume of the won/dollar exchange for our sample period. It also shows those for daily rates of return of the yen/dollar exchange. Figures 1-4 show plots of daily rates (level and return), volatility, and trading volume (level and detrended series) of the won/dollar exchange, and daily rates (level and return) of the yen/dollar exchange, respectively. Table 1 and Figures 1-3 show that, for our first data period, the volatility increased slowly; however, the trading volume rapidly increased until late 1993, but then stays relatively stable until the onset of the Asian financial crisis. In the second and third data periods, however, both volatility and volume increase.

<Insert Table 1>

<Insert Fig. 1>

<Insert Fig. 2>

<Insert Fig. 3>

<Insert Fig. 4>

In order to validate our specification, we carried out unit root tests for three variables: daily returns of won/dollar and yen/dollar rates, and daily detrended won/dollar trading volume. We used three popular unit root tests with a drift term: the Phillips Z(*t*) test, the ADF (Augmented Dickey-Fuller) test, and the G(*p*,*q*) test of VAT (Variable Addition Test). While the first two tests take the existence of the unit root as the null hypothesis, the third one takes the stationarity of the time series as the null hypothesis. The results are reported in Table 2. The results for the Phillips *Z*(*t*) test and the ADF test for both periods and all three variables are all well below the common 1% critical value (–3.43) for these tests, so the presence of a unit root is resoundingly rejected. For the G(*p*,*q*) test of VAT, we take q = 3 as the order of superfluously added time polynomial trends since we maintain only the drift term as a deterministic term for all three variables (see Park (1990)). Under the null hypothesis of stationarity, the asymptotic distribution of G(*p*,*q*) is χ^2 with q degree of freedom; since the results are all very close to zero, far below the critical values, we conclude that all three variables can be considered stationary.

<Insert Table 2>

Table 3 presents the first-order to tenth-order partial autocorrelation coefficients and the tenth-order Q-statistics for the Ljung-Box test of daily returns of the won/dollar and yen/dollar rates.[12] The first-order autocorrelation coefficient is positive and highly significant in the first data period, before the liberalization. By contrast, the autocorrelation in the yen/dollar rate is insignificant up to tenth order in our whole data sample. This is true despite the fact that the yen/dollar rate is a statistically significant determinant of the won/dollar rate (see section 4). The only plausible explanation of this positive autocorrelation is partial price adjustment; trades are occurring systematically at prices that do *not* correctly reflect the information available to traders.

<Insert Table 3>

In the first data period (before the liberalization), the higher order partial autocorrelation coefficients have the characteristic pattern of a damped harmonic oscillator. This indicates that (short-run) overshooting is occurring, and suggests that some speculative positive-feedback trades, using a moving-average criterion, are taking place. This is perhaps surprising, given the restrictions on speculative trading; it suggests that each GTC was able to engage in some degree of positive-feedback trading to take advantage of the information possessed by the other GTCs. The partial autocorrelations indicate that it takes up to eight trading days for private information to be fully and correctly incorporated into the FX rate.

In the second data period (First-Stage FX Liberalization), the first-order autocorrelation in the won/dollar rate is larger than in the first data period and is highly significant.[13] The damped harmonic oscillator pattern of the higher-order autocorrelations that was evident in the first data period disappears: eight of the first nine partial autocorrelations are positive, and the remaining one is virtually zero. This indicates that the (short-run) overshooting that occurred in the first data period has disappeared. Of the first nine partial autocorrelation coefficients, only the first- and fourth-order coefficients are significant and both of these are positive; this suggests that inside information that is received on a given day is incorporated into the won/dollar rate to a substantial extent by the following day, with the balance incorporated within a week.

In the third data period (Second-Stage FX Liberalization), the first-order autocorrelation in the won/dollar rate is slightly negative and not statistically significant.[14] In effect, the autocorrelation has disappeared. We argue below that the speculators significantly improved the informational efficiency of the market.

The disappearance of the first-order autocorrelation after the Second-Stage FX Liberalization indicates that the market became more efficient, in the sense that it became harder to make money using a simple rule such as positive-feedback trading.[15] However, more is true: the data show that the informational efficiency of the market increased. In other words, the data show that the FX rate adjusted more rapidly to the correct rate, so that the difference between the market and correct rates was reduced.

In the first data period, the partial autocorrelations have a sign pattern indicating overshooting; the first-, third-, fifth- and eighth-order autocorrelations are highly significant and vary in sign. In the second data period, only the first- and fourth-order are significant, and the autocorrelations do not vary in sign, indicating that overshooting has been essentially eliminated. Whereas it took eight trading days for information to be incorporated before the First-Stage FX Liberalization, it took only four trading days after.

The first-order autocorrelation increases after the First-Stage FX Liberalization. At first sight, this might be taken as an indication of decreased informational efficiency, but it actually indicates the opposite, for two reasons.

First, the overshooting that is evident in the first data period would reduce the measured first-order autocorrelation; on some days, overshooting leads to negative autocorrelation, canceling out to some degree the positive effect present from the slow incorporation of information. Elimination of this overshooting in the second data period indicates increased informational efficiency, and it results in an increase of the measured first-order autocorrelation because some of the cancellation generated by the overshooting has been eliminated.

Second, if information is incorporated into price in a shorter time, where the time is measured in days, the first-order (daily) autocorrelation would be expected to increase. For example, if adjustment that had been occurring over a five-day period were now compressed into a three-day period, one would expect to see the autocorrelations increase. It is only when adjustment speeds up to periods of less than a day that one would expect the first-order autocorrelation to be reduced or disappear entirely.

In the third data period, the first-order autocorrelation is not statistically different from zero, indicating that information is now being incorporated into the price in less than one day.

4. Determinants of autocorrelation

4.1. Autocorrelation and volatility

According to the literature on positive-feedback trading in the stock markets, higher return volatility decreases the autocorrelation of stock returns. Our model specification modifies the Koutmos (1997) specification for the autocorrelation of stock returns:[16]

$$r_t = \alpha + f\left(\sigma_t^2\right) r_{t-1} + \gamma s_{t-1} + \varepsilon_t$$

$$f\left(\sigma_t^2\right) = \delta_0 + \delta_1 \ln\left(\sigma_t^2\right)$$

$$\ln\left(\sigma_t^2\right) = \omega + \beta \ln\left(\sigma_{t-1}^2\right) + \theta_1 \varepsilon_{t-1} + \theta_2 \left(\left|\varepsilon_{t-1}\right| - E\left|\varepsilon_{t-1}\right|\right) \tag{1}$$

$$\varepsilon_t = \sigma_t z_t$$

where r_t and s_t denote the returns of won/dollar and yen/dollar rates respectively, and σ_t^2 denotes the time-varying conditional variance of the return. We assume that the distribution of z_t, $f(\cdot)$, follows the Generalized Error Distribution (GED). The AR(1) coefficient of return that shows the extent of the autocorrelation has a linear relation to the conditional variance. Unlike Koutmos (1997), we take Nelson's (1991) EGARCH(1,1) model for time-varying conditional volatility, allowing us to consider the asymmetry of the FX rate volatility. Thus, the parameter θ_1 reflects the asymmetric effect of the previous error term on the volatility. If $\theta_1 = 0$, then the effect of the positive previous error term on the volatility equals that of the negative previous error term. If $\theta_1 < 0$, however, then the effect of the previous error term on the volatility is greater if that term is negative than if it is positive. Many studies using high frequency data of stock returns report that θ_1 is negative. We analyze the yen/dollar rates along with the won/dollar rates yen/dollar rates since the former have significant explanatory power for the latter. We use the first-order lagged yen/dollar variable for our estimation, indicating that this variable is a proxy for public information that affects both Korea and Japan.[17]

Table 4 presents the estimation results for the equation (1). We use the method of Maximum Likelihood Estimation (MLE) with the BHHH algorithm. In all three data periods, the autocorrelation of won/dollar returns is not statistically significantly related to the volatility; the coefficients, δ_1, are negative in the first and third periods, positive in the second. The standard deviation of the daily percentage return on the won/dollar rate is 0.18 in the first period, 0.39 in the second period, and 0.45 in the third period (see Table 1). The volatility increases following each stage of the FX liberalization. However, the volatility remains below that of the daily return on the yen/dollar rate. We argue below that the increase in volatility results from the greater informational efficiency of the market.

In the literature on stocks, volatility is found (both theoretically and empirically) to have a statistically significant and negative effect on autocorrelation (Sentana and Wadhwani (1992), Koutmos (1997), and Säfvenblad (2000) among many others). Thus, our result that volatility has no effect on autocorrelation in this FX market is surprising. In order to motivate our empirical result, we sketch a theoretical analysis that is consistent with our finding. Consider a random walk process, representing the "correct" daily FX rate, i.e. the rate that would occur in the market if all information were public. The random walk may well have a drift term representing uncovered interest parity (UIP). If informed traders know the correct FX rate, but choose to utilize their information over a period of n days, the market FX rate would be a smoothed version of the "correct" rate; it would adjust each day by $1/n$ of the difference between the previous day's market rate and the current day's correct rate. If $n=1$, the resulting market-rate process would equal the "correct" rate random walk; if $n>1$, the resulting market-rate process has lower volatility, and the volatility decreases with n. Thus, if market rates adjust more quickly to the "correct" rate, we should expect the volatility of the market rate to rise. The effect of positive-feedback strategies depends primarily on whether there is a lag between the informed trades and the resulting positive-feedback trades. If there were no lag, the effect of the positive-feedback traders would simply be to make the market price adjust more quickly to the "correct" price, with no (short-run) overshooting; the market would become more informationally efficient.[18] The volatility of the market rate would increase, but only due to the reduction in the smoothing effect. However, if there were a lag between the informed trade and the resulting positive-feedback trade, we would expect to see overshooting in addition to more rapid adjustment.[19] The reduction in smoothing from the more rapid adjustment and the overshooting both increase volatility; the more rapid adjustment increases informational efficiency, while the overshooting decreases it. Assuming that n does not depend on the volatility of the "correct" process, and the positions taken by positive-feedback traders are linear in the change in price, an increase in the volatility of the underlying "correct" process has no effect on the autocorrelation of the market-rate process.

Our finding that volatility and autocorrelation are statistically unrelated in each of the three data periods is consistent with this theoretical analysis, provided that, within each of the three data periods, the period of time over which informed traders exercise their informational advantage is independent of the volatility, and the positions taken by positive-feedback traders are linear in the change in price. Moreover, it also confirms our finding, based on the changes in the partial autocorrelations, that the successive stages of the FX liberalization speeded up the process by which informed traders' information is incorporated into the market price. In our theoretical analysis, more rapid incorporation of information should lead to higher market volatility, and this is just what the volatility data show.

As described above, the partial autocorrelations clearly indicate that (short-run) overshooting is essentially eliminated in the second and third data periods, following the First-Stage FX Liberalization. In the theoretical analysis, this indicates that positive-feedback strategies were employed with a lag measured in days in the first data period, while the lag in using positive-feedback strategies was reduced to less than a day in the second and third data periods. It also indicates that the increase in volatility between the first and second data periods resulted from two effects: more rapid price adjustment, which increased volatility, and elimination of overshooting, which decreased volatility. The total increase in volatility thus understates the impact of more rapid price adjustment.

It is instructive to compare the won/dollar volatility to the yen/dollar volatility in our three data periods. The won/dollar volatilities steadily increase (0.18, 0.39 and 0.45), while the yen/dollar volatilities (0.71, 0.70, 0.62) are relatively stable and, if anything, declining. Even in the third data period, however, the won/dollar rate remains less volatile than the yen/dollar rate. This could indicate that information is still being incorporated more slowly in the won/dollar rate than in the yen/dollar market, but this seems unlikely given the absence of autocorrelation in the won/dollar returns in the third period. Perhaps the role of the yen as a reserve currency within Asia makes it inherently somewhat more volatile than the won. Or perhaps the lack of centralized data in the yen/dollar market makes volatility measures incomparable with those obtained from the centralized data on the won/dollar market.

<Insert Table 4>

Table 4 reports that γ is statistically significant in the first and third data periods, indicating that the yen/dollar rate affects the won/dollar rate. However, γ is quite small in the first data period, so the economic significance of the effect of the yen on the won is small in both the first two data periods.[20] We conjecture that the autocorrelation that we see in the first two data periods camouflages the effect of the yen/dollar rate on the won/dollar rate; once this autocorrelation is eliminated by the completion of the FX Liberalization, the strong effect of the yen on the won shows clearly. Table 4 also shows that θ_1 in the conditional variance equation is positive and statistically significant for the first data period. The positive sign is to be expected, because we are considering the won/dollar rate, i.e. the number of won required to buy one dollar. Thus, an increase in the won/dollar rate represents a decline in value of the won, and this is associated with a greater increase in future volatility than an increase in the value of the won (i.e. a decrease in the won/dollar rate). This asymmetric effect is not statistically significant in the second and third data periods.

4.2. Autocorrelation and trading volume

Now, we turn to the relationship between trading volume and autocorrelation. We use the following model specification:

$$f\left(vol_{t-1}\right)=\delta_0+\delta_2 vol_{t-1} \tag{2}$$

where vol_{t-1} denotes the detrended daily trading volume of won/dollar exchange at $t-1$. The other equations are the same as those in (1). Campbell, Grossman, and Wang (1993) report that daily trading volume affects the autocorrelation of stock returns with a one-day lag, so we use the trading volume data at $t-1$ instead of at t.

Table 5 reports that δ_2 is negative: an increase in trading volume decreases the autocorrelation of the return. However, the relationship is statistically insignificant for the first and second data periods, while it is statistically significant at the 5% level for the third data period.[21] The literature on autocorrelation of stock returns has focused, naturally, on the situation in which speculative trades are allowed, and thus should only be compared to the second and third data periods. Campbell, Grossman, and Wang (1993) argue that if an uninformed trader sells for exogenous reasons and the smart money takes it, then the stock price falls today but the fall tends to be reversed on subsequent days. Hence, an increase in the trading volume decreases the autocorrelation of stock returns. Llorente, Michaely, Saar, and Wang (2002) argue that the relationship between volume and autocorrelation depends on the relative importance of hedge trading and speculative trading: if hedge trading is predominant, then volume should be negatively correlated with the autocorrelation, while if speculative trading is predominant, volume should be positively correlated with autocorrelation. Our results thus suggest that in the period after the completion of the FX market liberalization, upward blips in FX volume result more from blips in concrete FX needs than from blips in speculation.

<Insert Table 5>

4.3. A robustness test: Autocorrelation, volatility, and trading volume

To test the robustness of our findings relating autocorrelation to volatility and to trading volume, we estimate the relationship of autocorrelation to both variables simultaneously, in equation (3).

$$f\left(\sigma_{t-1}^{2}, vol_{t-1}\right)=\delta_0+\delta_1 \ln\left(\sigma_{t-1}^{2}\right)+\delta_2 vol_{t-1} \tag{3}$$

The other equations are the same as those in equation (1). We also use the previous time, *t-1*, for both the volatility and the trading volume, whereas the analysis in section 4.1 used volatility at time *t*.[22] The results in Table 6 are qualitatively similar to those in Table 4 and Table 5.

<Insert Table 6>

5. Concluding remarks

Our results show that there was significant autocorrelation of return on the won/dollar exchange rates until quite recently. The only plausible explanation is partial price adjustment: the won/dollar rates did not correctly reflect the full information. The autocorrelation gradually diminished as the Korean FX market was liberalized, and disappeared after the liberalization was complete. The length of time required to fully and accurately incorporate information into the exchange rate was reduced from eight trading days, when the market was subject to stringent regulation, to less than one day after the liberalization was complete. We found substantial evidence that the liberalization of the market significantly improved its informational efficiency.

We found that volatility is not a significant determinant of autocorrelation in the Korea FX market. We found this to be consistent with a simple theoretical analysis, provided that the period over which informed traders exercise their informational advantage is independent of the volatility and the positions taken by positive-feedback traders are linear in the price change. The fact that volatility *is* a significant determinant of autocorrelation in equity markets suggests that one or both of these assumptions is violated in equity markets.

We found that trading volume became a significant determinant of the autocorrelation only recently, after the Second-Stage FX liberalization. Since the literature on equity markets associates the link between volume and autocorrelation to the prevalence of hedging and speculative activity, we conclude that the absence of the relationship prior to the liberalization reflects the relative lack of hedging and speculative trades during the MAR and First-Stage FX Liberalization periods, and that after the Second-Stage FX Liberalization, upward blips in FX volume resulted from blips in hedging needs, rather than blips in purely speculative activity.

Further research is needed to determine whether other countries' currencies show, or have recently shown, significant autocorrelation. A cross-country study relating the autocorrelation patterns to the FX regulatory regime would validate or refute our finding that liberalization significantly improved the market's informational efficiency.

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Footnotes

[1] Hsieh (1988) and LeBaron (1999) found no autocorrelation in *daily* FX rates of major industrial countries. However, their findings are limited because they reported autocorrelations only as part of their descriptive statistics without further analysis. In contrast, the recent market microstructure FX research tends to use *intra-day* data rather than daily data. The empirical findings on autocorrelation of intra-day FX data do not present a uniform picture; they depend on the choice of data variables ("strong positive in trades data; *perhaps* weak positive, after taking account of the [bid-ask] bounce, in returns; and negative in quotes" (Goodhart and O'Hara (1997))).

[2] In Korea, most interbank transactions are traded through brokers. FX brokers intermediate between banks without holding any position. At present, there are two FX brokers, Seoul Money Brokerage Services (SMBS) and Korea Money Broker Corporation (KMBC) (see Bank of Korea (2002)). The investors and banks have ready access to the real time data provided by the two brokers.

[3] It is true that the won/dollar exchange rate reflects the fortunes of the Korean economy and Korean firms, so it may be viewed as a portfolio in a certain sense. However, the nonsynchronous trading effect in stock portfolios arises because the closing portfolio value is computed from the closing prices of the individual stocks in the portfolio, and some of these individual stocks will not have traded for a considerable period prior to the market close. If one chooses to view the won as a portfolio, it is more like a Standard & Poor's

Depository Receipt (SPDR), which trades, than an index. Indices exhibit positive autocorrelation, while SPDRs do not (see Eom, Hahn, and Park (2004)).

[4] Nonsynchronous trading remains an important factor in the study of autocorrelation in the stock market. This issue was studied actively in the late 1980s and the early 1990s, but the fraction of the autocorrelation that can be explained by nonsynchronous trading remains very controversial. Atchison, Butler, and Simonds (1987) and Lo and MacKinlay (1990) state that nonsynchronous trading explains only a small part (16% for daily autocorrelation in Atchison, Butler, and Simonds, 0.07, a small part of the total autocorrelation, for weekly autocorrelation in Lo and MacKinlay). However, Boudoukh, Richardson, and Whitelaw (1994) show that the weekly autocorrelation can come from the nonsynchronous trading as high as 0.20, or 56% of the total autocorrelation**.** The use of intra-day data has produced a recent resurgence of interest in this issue. However, the results have remained controversial (see Kadlec and Patterson (1999), Ahn, Boudoukh, Richardson, and Whitelaw (2002), Eom, Hahn, and Park (2004), and others).

[5] Goodhart, Love, Payne, and Rime (2002) argue that price discreteness matters in the US dollar/euro market, causing percentage spreads as a percentage of mid-quote to rise from the levels in the previous US dollar/Deutsche mark market. They attribute the increased percentage spread to an increase in the size of the pips (all trade must be at an integral number of pips) to 0.0112% of the exchange rate at the time the euro

replaced the mark. However, our won/dollar rates range from 736.60 to 1,365.20 (excluding the period of the Asian financial crisis); the corresponding pip size, 2 digits below the decimal point, is at most 0.0013% of the exchange rate. Goodhart, et al. also report that the price discreteness did not matter in Japanese yen/US dollar rates (p. 545).

[6] The terminology is perhaps confusing, since overshooting might be considered "excessive" price adjustment rather than "partial" price adjustment. In the literature, both types of incorrect pricing are included within the term "partial price adjustment."

[7] The importance of asymmetric information and positive-feedback trading in FX markets is documented in Ito, Lyons, and Melvin (1998), Lyons (1995, 1996, 2001), Menkhoff (1998), and Payne (1999), among many others.

[8] In section 3, we discuss the reasons for excluding the crisis period from our analysis.

[9] Just prior to the abolition of the MAR system, the daily limit on movement in the won/dollar exchange rate had been increased to ±10%.

[10] Since FX trading volume was relatively small during the MAR period, it was feasible for the government to intervene in this way. There appears to have been a political motive for the intervention, namely that hitting

the limit would generate intensive news coverage unfavorable to the government and the senior civil servants in charge of managing the exchange rate.

[11] To our knowledge, there is only one exception. Galati (2000) analyzed the relationship among volume, volatility, and bid-ask spread, using the centralized data of 7 emerging markets: Brazil, Colombia, India, Indonesia, Israel, Mexico, and South Africa.

[12] We also estimated the ARMA(1,1) model for won/dollar rate. The *p*-value of the MA(1) coefficient is greater than 15.0, showing that it is not statistically significant even at the 15% significance level.

[13] It is somewhat less significant than the first-order autocorrelation in the first data period; we attribute this to the fact that the second period is much shorter than the first.

[14] Of the first twenty partial autocorrelation coefficients (we report only the first ten in our table), only one (the ninth) is statistically significant; it is hard to construct a plausible story to explain why the ninth coefficient should be significant, and we are inclined to disregard it as a statistical aberration.

[15] It appears that there remained some money to be made using a more complicated rule involving volume-dependent feedback trading.

[16] To check the robustness of our model specification, we also use the LeBaron (1992) model that considers the nonlinear structure between the autocorrelation and the volatility. The estimation results are qualitatively the same as those of Table 4. The results are available on request.

[17] Korean export goods in the global market are in many cases substitutes for Japanese goods. In the short-run, with no changes in productivity or preferences in the global market for these substitute goods, this establishes a correlation between the Japanese and Korean currencies. Foreign exchange traders anticipate this correlation and take it into account in choosing their strategies.

[18] In equilibrium, informed traders will respond to the presence of positive-feedback traders, with further effects on the speed of price adjustment.

[19] In addition, in equilibrium, the presence of lagged positive-feedback traders will induce the informed traders to trade more rapidly, to minimize the portion of the value of their information that is lost to the positive-feedback traders.

[20] In the first period, γ is one-seventeenth as large as it is in the third data period. While it is statistically significant in the first data period, it is only twice as large as the statistically insignificant value in the second data period.

[21] The Mixture of Distributions Hypothesis (MDH) in market microstructure research on stock returns asserts that volatility and trading volume both reflect a common unobserved process, the arrival of information (see Tauchen and Pitts (1983), Andersen (1996), Bollerslev and Jubinski (1999) among many others; for the won/dollar case, see Eom and Hahn (2004)). We find that volume is related to autocorrelation, while volatility is not. This does not provide support for MDH, but neither does it directly contradict MDH. It indicates that the relationship between volume and autocorrelation comes from some determinant(s) of volume separate from the information flow.

[22] We could also use $\ln\left(\sigma_t^2\right)$ as an explanatory variable since the return volatility of won/dollar rates at *t*, σ_t^2, is estimated from information up to *t-1*. However, the results are not significantly different. Campbell, Grossman, and Wang (1993) use σ_{t-1}^2 for the corresponding estimation.

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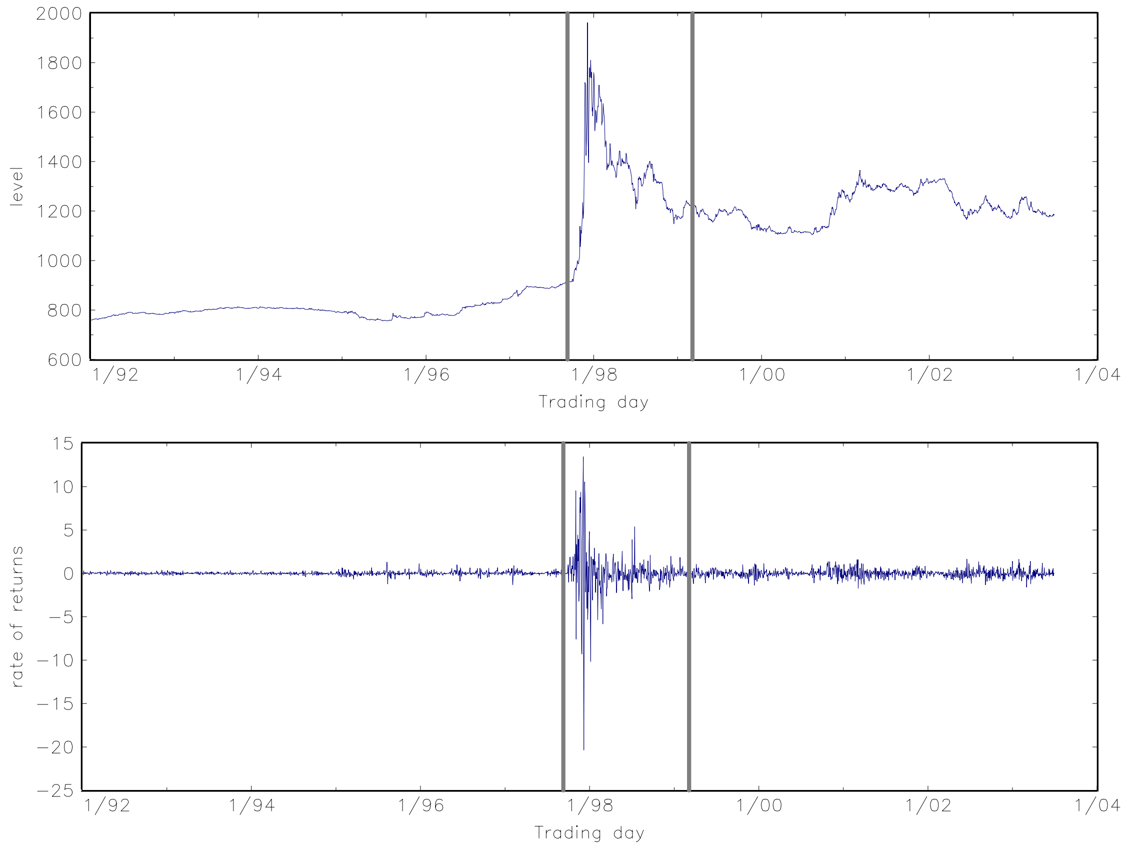

Fig. 1. Daily won/dollar rate and its rate of return (Jan 01, 1992 ~ Aug 11, 2003)

1) "Level" and "rate of return" denote daily won/dollar rate, S_t, and its rate of return, r_t, respectively. r_t is calculated as follows: $100 \cdot (\ln S_t - \ln S_{t-1})$.

2) The grey vertical lines denote the period of the Asian financial crisis.

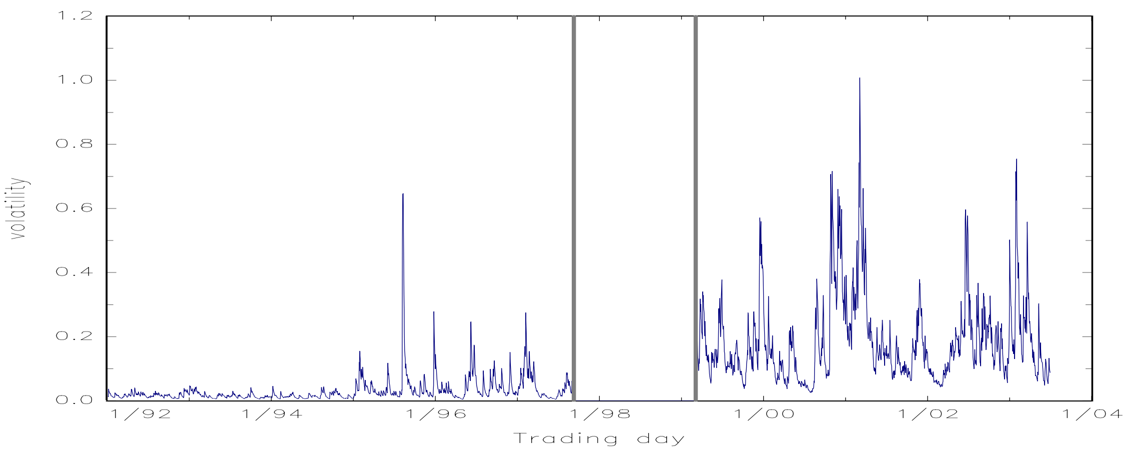

Fig. 2. Daily volatility of the won/dollar rate (Jan 01, 1992 ~ Aug 11, 2003)
1) The grey vertical lines denote the period of the Asian financial crisis.
2) We exclude the period of the Asian financial crisis, when the volatility was about 150 times larger than during our data periods.

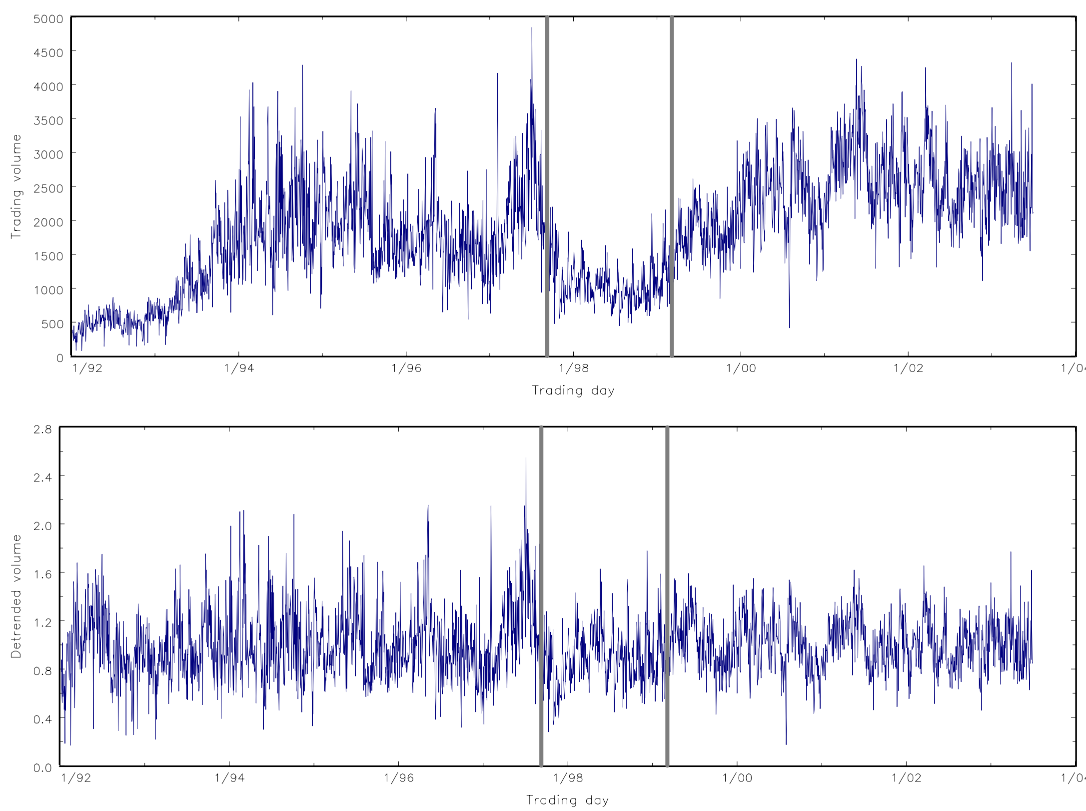

Fig. 3. Daily trading volume and detrended volume of won/dollar trading (Jan 01, 1992 ~ Aug 11, 2003)
1) “Trading volume” is a level variable.
2) The grey vertical lines denote the period of the Asian financial crisis.

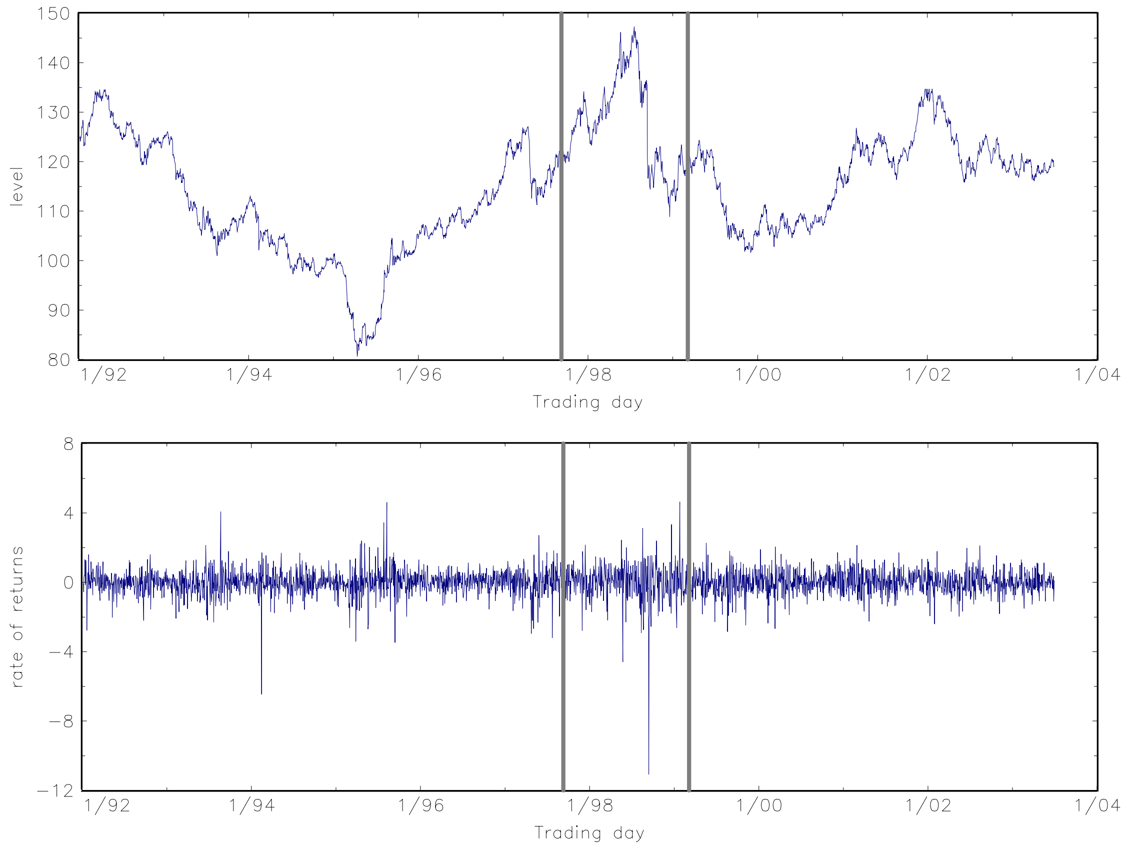

Fig. 4. Daily yen/dollar rate and its rate of return (Jan 01, 1992 ~ Aug 11, 2003)

1) "Level" and "rate of return" denote the daily won/dollar rate, S_t , and its rate of return, s_t, respectively. s_t is calculated as follows: $100 \cdot (\ln S_t - \ln S_{t-1})$.

2) The grey vertical lines denote the period of the Asian financial crisis.

Table 1
Descriptive statistics of daily rate of return on FX rates and volume

	No. of Obs.	Mean	Minimum	Maximum	Std. Dev.	Skewness	Kurtosis
Daily rate of return on won/dollar exchange rate							
91.9.2~97.9.30	1504	0.014	-1.33	1.29	0.18	0.34	14.13
99.4.1~00.12.31	437	0.009	-1.37	1.36	0.39	0.33	4.77
01.1.2~03.8.11	643	-0.012	-1.71	1.65	0.45	0.27	4.46
Daily detrended trading volume in won/dollar exchange							
91.9.2~97.9.30	1504	1.001	0.15	2.55	0.30	0.73	4.39
99.4.1~00.12.31	437	1.016	0.17	1.59	0.23	-0.03	3.08
01.1.2~03.8.11	643	1.004	0.46	1.77	0.21	0.27	3.05
Daily rate of return on yen/dollar exchange rate							
91.9.2~03.8.11	2955	-0.005	-11.07	4.64	0.76	-1.37	22.96

1) Daily rates of return on won/dollar and yen/dollar rates (S_t) are calculated as follows: $100\cdot(\ln S_t - \ln S_{t-1})$.
2) The standard deviations of yen/dollar rates of return for the same sample periods are 0.71, 0.70, and 0.62, respectively.

Table 2
Unit root tests

Test Statistics	Period	Phillips Z(*t*) test	ADF test	G(*p*,*q*) test of VAT
Daily rate of return on won/dollar exchange rate				
	91.9.2~97.9.30	-34.82¶	-14.51¶	0.011
	99.4.1~00.12.31	-17.26¶	-6.32¶	0.064
	01.1.2~03.8.11	-26.02¶	-9.16¶	0.001
Daily detrended trading volume in won/dollar exchange				
	91.9.2~97.9.30	-40.16¶	-24.14¶	0.003
	99.4.1~00.12.31	-10.84¶	-4.52¶	0.071
	01.1.2~03.8.11	-15.23¶	-5.49¶	0.010
Daily rate of return on yen/dollar exchange rate				
	91.9.2~97.9.30	-40.16¶	-14.98¶	0.003
	01.1.2~03.8.11	-35.44¶	-11.97¶	0.002

1) ¶ denotes significance at the 1% level.
2) With a drift term, the Phillips Z(*t*) test and the ADF (Augmented Dickey-Fuller) test have the same 1% critical value of -3.43.
3) For the G(*p*,*q*) test of VAT (Variable Addition Test), the 1% critical value of the G(0,3) is 11.34.
4) For the Phillips Z(*t*) test and the G(*p*,*q*) test of VAT, we use the automatic bandwidth selection method using a quadratic spectral (QS) kernel function as in Andrews (1991).
5) We obtain the results of the ADF test using six lags. However, using more lags does not change the results.

Table 3

Autocorrelation coefficients and Ljung-Box test for autocorrelations

Period	Auto-correlation coefficient 1st-order	2nd-order	3rd-order	4th-order	5th-order	6th-order	7th-order	8th-order	9th-order	10th-order	Q(10)
Daily rate of return on won/dollar exchange rate											
91.9.2	0.11	-0.04	-0.10	0.02	0.08	0.01	-0.02	0.07	-0.00	0.05	57.71
~97.9.30	(4.19)¶	(1.69)	(3.72)¶	(0.65)	(3.21)¶	(0.31)	(0.96)	(2.87)¶	(0.09)	(1.89)*	(0.00)¶
99.4.1	0.17	0.00	0.03	0.15	0.03	0.04	-0.00	0.03	0.04	-0.03	30.11
~00.12.31	(3.61)¶	(0.00)	(0.70)	(3.09)¶	(0.59)	(0.75)	(0.00)	(0.67)	(0.75)	(0.62)	(0.00)¶
01.1.2	-0.03	0.01	0.07	0.04	0.01	-0.01	-0.00	-0.03	0.10	-0.05	13.71
~03.8.11	(0.75)	(0.24)	(1.82)*	(0.94)	(0.28)	(0.17)	(0.10)	(0.81)	(2.56)¶	(1.32)	(0.19)
Daily rate of return on yen/dollar exchange rate											
91.9.2	-0.01	-0.01	-0.03	-0.01	0.02	-0.01	0.01	0.00	0.03	0.01	6.60
~03.8.11	(0.45)	(0.50)	(1.49)	(0.55)	(0.87)	(0.53)	(0.32)	(0.25)	(1.38)	(0.67)	(0.76)

1) *, §, and ¶ denote significance at the 10%, 5%, and 1% level, respectively.

2) Parentheses for autocorrelation coefficients (1st~10th-order) denote *t*-values.

3) Parentheses for Ljung-Box test (Q(10)) denote *p*-values.

Table 4
Autocorrelation and volatility

Period	α	γ	δ_0	δ_1	ω	β	θ_1	θ_2	ν
91.9.2 ~97.9.30	0.0075	0.0124	-0.1080	-0.0542	-0.2453	0.9385	0.1448	0.2734	1.0720
	(0.0065)¶	(0.0045)¶	(0.5047)	(0.2144)	(0.0009)¶	(0.0000)¶	(0.0000)¶	(0.0000)¶	(0.0000)¶
99.4.1 ~00.12.31	-0.0148	0.0061	0.1384	0.0195	-0.1218	0.9386	0.0222	0.4018	1.1940
	(0.1668)	(0.7257)	(0.1536)	(0.7161)	(0.0917)*	(0.0000)¶	(0.6219)	(0.0001)¶	(0.0000)¶
01.1.2 ~03.8.11	-0.0181	0.2088	-0.2121	-0.0429	-0.0911	0.9511	0.0361	0.2057	1.3896
	(0.2194)	(0.0000)¶	(0.1102)	(0.5889)	(0.0632)*	(0.0000)¶	(0.1858)	(0.0004)¶	(0.0000)¶

1) *, §, and ¶ denote significance at the 10%, 5% and 1% level, respectively.
2) *p*-values are in parentheses.

Table 5
Autocorrelation and trading volume

Period	α	γ	δ_0	δ_2	ω	β	θ_1	θ_2	ν
91.9.2 ~97.9.30	0.0072	0.0120	0.1219	-0.0346	-0.2349	0.9412	0.1464	0.2679	1.0747
	(0.0112)§	(0.0042)¶	(0.2143)	(0.7128)	(0.0009)¶	(0.0000)¶	(0.0000)¶	(0.0000)¶	(0.0000)¶
99.4.1 ~00.12.31	-0.0116	0.0042	0.2492	-0.1289	-0.1258	0.9370	0.0256	0.4052	1.2066
	(0.3522)	(0.7874)	(0.3709)	(0.5833)	(0.0841)*	(0.0000)¶	(0.5768)	(0.0001)¶	(0.0000)¶
01.1.2 ~03.8.11	-0.0185	0.2096	0.2179	-0.3359	-0.0869	0.9535	0.0298	0.2031	1.3658
	(0.2181)	(0.0000)¶	(0.2135)	(0.0384)§	(0.0691)*	(0.0000)¶	(0.2656)	(0.0004)¶	(0.0000)¶

1) *, §, and ¶ denote significance at the 10%, 5%, and 1% level, respectively.
2) *p*-values are in parentheses.

Table 6

A robustness test: Autocorrelation, volatility, and trading volume

	α	γ	δ_0	δ_1	δ_2	ω	β	θ_1	θ_2	ν
91.9.2 ~97.9.30	0.0071 (0.0094)¶	0.0126 (0.0045)¶	-0.0474 (0.7734)	-0.0554 (0.1938)	-0.0695 (0.5185)	-0.2332 (0.0009)¶	0.9415 (0.0000)¶	0.1443 (0.0000)¶	0.2708 (0.0000)¶	1.0684 (0.0000)¶
99.4.1 ~00.12.31	α	γ	δ_0	δ_1	δ_2	ω	β	θ_1	θ_2	ν
	-0.0120 (0.3133)	0.0046 (0.7873)	0.2802 (0.3572)	0.0237 (0.7012)	-0.1049 (0.6684)	-0.1219 (0.0873)*	0.9390 (0.0000)¶	0.0271 (0.5526)	0.3971 (0.0001)¶	1.1966 (0.0000)¶
01.1.2 ~03.8.11	α	γ	δ_0	δ_1	δ_2	ω	β	θ_1	θ_2	ν
	-0.0190 (0.1785)	0.2100 (0.0000)¶	0.1641 (0.3419)	-0.0393 (0.5982)	-0.3554 (0.0143)§	-0.0850 (0.0667)*	0.9546 (0.0000)¶	0.0300 (0.2597)	0.1986 (0.0004)¶	1.3645 (0.0000)¶

1) *, §, and ¶ denote significance at the 10%, 5%, and 1% level, respectively.

2) *p*-values are in parentheses.