Are Currencies Coordinating?: The Coupling-Decoupling Behavior of Won-Dollar and Yen-Dollar Exchange Rates

Jae-Young Kim*, Yun-Jong Wang, and Woong-Yong Park

This paper studies dynamic relation, namely, two currencies of Korean won and Japanese yen, before and after the East Asian financial crisis of the late 1990s. We conjecture that there exists a long-run relation between won and yen, which is characterized by a band-reverting-type dynamic behavior. This band-reverting behavior of the two currencies implies that their relative values maintain a stable relation, keeping their discrepancy within a certain bound or band. Such band-reverting behavior is due to the arbitrage-seeking behavior of investors or the market intervention of monetary authorities. Our empirical analysis shows that the two currencies have a long-run equilibrium relation that implies a band-reverting-type dynamic relation. Our analysis also shows that this band-reverting relation becomes clearer in the post-crisis period.

Keywords: Band-reverting behavior, Threshold cointegration, Structural change, Financial crisis, Won-Yen exchange rate

JEL Classification: C1, C5, F31, G15

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I. Introduction

In the currency market, each currency is primarily rated in terms of the U.S. dollar. Often, however, a pair of currencies other than the U.S. dollar move together in the market, which implies that the relative value of those currencies maintains a certain dynamic stability. This co-movement behavior of the currencies of two economies may reflect the fact that the two economies are closely related. Dynamic relations of currencies also contain useful information for investors to profit in the international financial market. This paper investigates the dynamic relation between the Korean won and the Japanese yen before and after the East Asian financial crisis of the late 1990s.

The won-dollar and yen-dollar exchange rates are determined independently in the currency market. The monetary authorities of Japan and Korea have not officially committed to fixing or stabilizing their bilateral exchange rates. However, as the economies of Japan and Korea are closely related to each other, the two exchange rates are interdependent. Kwan (2001) and Ueda (1998), among many others, studied the relation between the Japanese economy and other East Asian economies and found that movements of the Japanese yen often had a strong impact on other East Asian currencies. Song (2006) hypothesized that the won and the yen are coupled and then studied the determinants of the won-yen coupling based on a fractional cointegration approach. Fukuda and Ohno (2003) analyzed the possibility of change in the correlations of several East Asian currencies with the Japanese yen and the U.S. dollar after the East Asian financial crisis.

In the current paper, we study the dynamic relation of the won and the yen in the following three aspects. First, we study whether the two currencies have a long-run relation characterized by cointegration as introduced by Engle and Granger (1987). The existence of a cointegration relation in a set of variables implies that the variables have an equilibrium relation.

Second, we investigate the possibility of change in the long-run relation between the won and the yen after the East Asian financial crisis of 1997. After the crisis, there was an important change in exchange rate policy in Korea, from a dollar pegging policy to a floating exchange rate system. Kim, Kim, and Wang (2001) as well as Kang, Kim, Kim, and Wang (2002) provided detailed explanations on such change and capital market liberalization in Korea after the financial crisis. This change in the policy regime has important effects on the relation of the two currencies. We conjecture that the won-dollar exchange rate became more responsive to changes in the yen-dollar rate after the change in the exchange rate regime. The test procedures in Andrews and Kim (2003) are applied to study the possibility of such change in the relation between the won and the yen after the 1997 East Asian financial crisis.

Third, we study whether a band-reverting type equilibrium relation exists between the won-dollar and yen-dollar rates. The two exchange rates have a long-run (cointegration) relation, and is thus not too far away from each other. In particular, we conjecture that the ratio of the two exchange rates stays inside a band most of the time. If for some reason the two dollar-based exchange rates deviate temporarily away from each other so that the won-yen ratio, is away from the band, then there operates a kind of restoring force to bring the ratio back to the band. This restoring force is related to the investor behavior in the currency market or the market intervention of monetary authorities. An extended version of Balke and Fomby's (1997) threshold study the band-reverting type behavior of the won-yen exchange rate.

Data from July 1, 1993, to June 30, 2004 are used for the empirical analysis. For the whole sample, we cannot reject the null of no cointegration between the two exchange rates at the 5% level by the type tests of Dickey and Fuller (1979) (augmented Dickey-Fuller tests) and Phillips and Perron (1988). On the other hand, for data without observations from the crisis period, we reject the null of no cointegration between the two exchange rates. Formal tests for the existence of partial sample cointegration breakdown by Andrews and Kim (2003) detect the location of such crisis period affecting the cointegration relation. The detected period of cointegration breakdown is November 15, 1997 to June 16, 1998.

To study the band-reverting behavior of the won-yen exchange rate, we set up an extended version of the threshold cointegration model of Balke and Fomby (1997). We adopt asymmetry in the upper and lower bounds of the equilibrium band of the two currencies in the threshold cointegration. The possibility of change in the band-reverting behavior of the two currencies after the currency crisis is also incorporated. We found that change occurred in the band-reverting properties of the won-yen rate after the East Asian crisis and that the band-reverting behavior became clearer in the post-crisis period. We also found that the band has asymmetric upper and lower bounds and that the two currencies exhibit different behaviors outside each of the two bounds.

The rest of the paper goes as follows. Section II explains some aspects of the dynamic relation between the won-dollar and yen-dollar rates. Section III discusses our model and the econometric methods used for our empirical analysis. Section IV presents the results of our empirical analysis and discusses their implications. Section V concludes the paper.

II. Dynamic Relation of Two Currencies

Let x_t and y_t be the logarithms of exchange rates of two currencies. If the economies of these currencies are related to each other, then the values of the currencies will exhibit a specific co-movement pattern. If x_t and y_t are integrated series, then the co-movement can be characterized by the cointegration introduced by Engle and Granger (1987). That is, there exists a constant α such that

$$y_t + \alpha x_t = u_t \quad \text{where} \quad u_t \sim I(0) \tag{1}$$

for x_t, $y_t \sim I(1)$, where $I(i)$ refers to the "integrated of order i." A cointegration relation is often interpreted as a long-run equilibrium relation. In Section IV, we explore whether the won and the yen have such an equilibrium relation and whether the relation, if any, is stable in a long time horizon.

We also study whether there is a band-reverting type equilibrium relation between the won-dollar and yen-dollar rates. The two exchange rates have a long-run relation and are thus not too far away from each other. In particular, we conjecture that the ratio of the two exchange rates stays inside a band most of the time. This conjecture implies that u_t in (1) has a restoring property. That is, if for some reason the two exchange rates deviate temporarily away from each other, so that u_t for a given β deviates from some equilibrium band of u_t, then there operates a kind of restoring force that brings the exchange rates back to the band. This restoring force is related to the investors' arbitrage behavior in the currency market or the market intervention of monetary authorities. In Section III.*B*, a vector error correction model incorporating threshold cointegration relation(s) is used to study the band-reverting type behavior of the won-yen exchange rate.

Why do the won-dollar and yen-dollar rates move together? Kwan (2001) and Kang, Kim, and Wang (2004) explained why a movement in the yen-dollar rate affects the won-dollar rate. First, when the yen de-

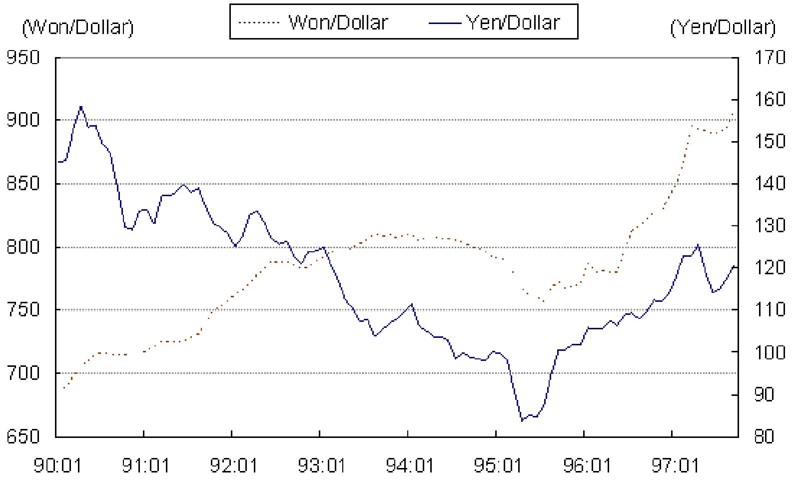

FIGURE 1

YEN/DOLLAR AND WON/DOLLAR EXCHANGE RATES (1990:01-1997:09)

preciates, capital flow to Korea is affected, which, in turn, causes the won-dollar rate to change. For example, when the yen depreciates, the dollar prices of assets in Japan become relatively cheaper, which causes investment funds to flow from Korea to Japan. Capital flow from Korea to Japan is achieved by selling the won and buying the yen, such that the won depreciates as well. Moreover, when the yen depreciates, production costs in Japan become lower relative to those in Korea, which makes investment money flow from Korea to Japan. Second, a change in the yen-dollar rate affects the competitiveness of Japanese products. A weaker yen makes Japanese products relatively cheaper than the products of other countries. Thus, a weaker yen causes a decline in the price competitiveness of Korean products against Japanese products. To restore the price competitiveness of Korean products, the won has to depreciate as well.

On the other hand, the impact of yen depreciation/appreciation on won may depend on the exchange rate regime. This is because the responsiveness of the won to a change in yen will be different depending on the regime. The exchange rate regime in Korea changed after the 1997 East Asian financial crisis. After the financial crisis, the Korean government adopted a floating exchange rate regime similar to Japan [see Kim, Kim, and Wang (2001) and Kang, Kim, Kim, and Wang (2002)]. Thus,

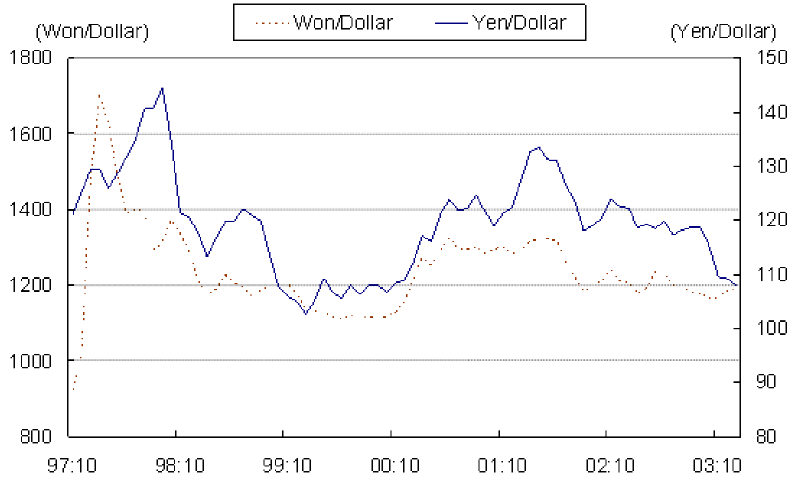

Figure 2

Yen/Dollar and Won/Dollar Exchange Rates (1997:10-2003:12)

we expect that the two currencies of won and yen move in a more synchronized fashion in the post-crisis period. Figures 1 and 2 show the movement of the won-dollar and yen-dollar rates, respectively. In the first half of the 1990s the two exchange rates hardly seem to move together. The Japanese yen steadily appreciated in this period while the Korean won experienced depreciation. However, the two currencies seem to have moved together since the mid-1990s, when the Korean government adopted a floating exchange rate regime.

III. Methodology

Our empirical investigation proceeds in the following manner: First, we study whether the won-dollar and yen-dollar exchange rates have a dynamic long-run relation characterized by the cointegration relation (1). More specifically, we explore whether the logarithm of the won-dollar rate and of the yen-dollar rate follow a cointegration relation with the cointegration vector (1, -1), that is, $\alpha=-1$ in (1). That is, we test whether the logarithm of the won-yen ratio follows a stationary process.

Second, we study the possibility of a change occurring in a cointegration relation, if any, between the won-dollar and yen-dollar rates. For this analysis, we apply the test procedures in Andrews and Kim (2003), which are explained in Section III.*A* and in the Appendix. Third, we investigate whether there is a band-reverting-type equilibrium relation between the won-dollar and yen-dollar rates based on a threshold vector error correction model (TVECM), which is explained in Section III.*B*.

A. Partial Sample Cointegration Breakdown Tests

Cointegration breakdown may occur at the end or in the middle of sample. First, consider the case of the end-of-sample cointegration breakdown. Suppose that x_t on y_t has a cointegration relation, which possibly undergoes breakdown at some period T_0:

$$y_t = \begin{cases} x_t'\beta_0 + u_t & \text{for} \quad t = 1, \dots, T_0 \\ x_t'\beta_t + u_t & \text{for} \quad t = T_0 + 1, \dots, T_0 + m \end{cases} \tag{2}$$

for $T_0 > 1$ and $m \geq 1$, where y_t, $u_t \in \mathbb{R}$, and x_t may be a vector, that is, x_t, β_0, $\beta_t \in \mathbb{R}^k$. The errors for the first T_0 periods, $\{u_t : t=1, \dots, T_0\}$, are mean zero stationary and ergodic processes. x_t may be a vector consisting of stationary and nonstationary variables. The model (1) is a special case of (2) with $k=1$ and $\beta=-\alpha$, where $\beta=\beta_0=\beta_t$ for $t=1, \dots, T_0+m$.

The situation in (2) can be described by the following null and alternative hypotheses:

$$H_0 = \begin{cases} \beta_t = \beta_0 \text{ for all } t = T_0+1, \dots, T_0+m, \text{ and} \\ \{u_t : t=1, \dots, T_0+m\} \text{ are stationary and ergodic.} \end{cases}$$
$$H_1 = \begin{cases} \beta_t \neq \beta_0 \text{ for some } t = T_0+1, \dots, T_0+m, \text{ and/or} \\ \text{the distribution of } \{u_{T_0+1}, \dots, u_{T_0+m}\} \text{ differs from} \\ \text{the distribution of } \{u_1, \dots, u_{T_0+m}\}. \end{cases} \tag{3}$$

Under the null hypothesis, the model is a well-specified cointegrating regression model for all $t=1, \dots, T_0+m$. Under the alternative hypothesis, the cointegrating relationship breaks down after $t=T_0$. The breakdown may be due to (i) a shift in the cointegrating vector from β_0 to β_t, (ii) a shift in the distribution of u_t from being stationary to a unit root, (iii) some other shift in the distribution of $\{u_{T_0+1}, \dots, u_{T_0+m}\}$ from that of $\{u_1, \dots, u_m\}$, or (iv) any combination of the above shifts.

Our analysis for the possibility of the end-of-sample cointegration breakdown is based on the following p-values obtained from the P_a, P_b,

P_c and R_a, R_b, R_c tests studied in Andrews and Kim (2003) and explained in the Appendix:

$$pv_{P_i} = (T_0 - m + 1)^{-1} \sum_{j=1}^{T_0 - m + 1} 1(P_i \leq P_{i,j}) \tag{4}$$

$$pv_{R_i} = (T_0 - m + 1)^{-1} \sum_{j=1}^{T_0 - m + 1} 1(R_i \leq R_{i,j}) \tag{5}$$

for $i = a,\ b,\ c$, where P_i, $P_{i,j}$ and R_i, $R_{i,j}$ are explained in the Appendix.

Simulations in Andrews and Kim (2003) indicate that pv_{P_a} has down-sized distortion, implying that the P_a test over-rejects the null hypothesis in many scenarios, distorting the test size. The P_b and P_c tests are better in terms of size distortion than the P_a test. The R-tests, on the other hand, are designed to consider the locally best invariant (LBI) test for the presence of unit root errors. This type of test is asymptotically valid under more general conditions on the errors and regressors [see Andrews and Kim (2003)].

The p-values of the above tests, (4) and (5), for detecting cointegration breakdown at the end of the sample can be altered to detect breakdown that occurs at the beginning or in the middle of the sample. Thus, consider testing for cointegration breakdown for the m observations indexed by $t = t_0,\ \ldots,\ t_0 + m - 1$ when the total number of observations is $T_0 + m$. The corresponding null and alternative hypotheses are given by

$$H_0 = \begin{cases} y_t = x_t'\beta_0 + u_t \text{ for all } t = 1,\ \ldots,\ T_0 + m, \text{ and} \\ \{u_t : t \geq 1\} \text{ are stationary and ergodic,} \end{cases}$$

$$H_1 = \begin{cases} y_t = x_t'\beta_0 + u_t \text{ for all } t = 1,\ \ldots,\ t_0 - 1,\ t_0 + m,\ \ldots,\ T_0 + m, \text{ and} \\ y_t = x_t'\beta_t + u_t \text{ with } \beta_t \neq \beta_0 \text{ for some } t = t_0,\ \ldots,\ t_0 + m - 1, \text{ and/or} \\ \text{the distribution of } \{u_{t_0},\ \ldots,\ u_{t_0 + m - 1}\} \text{ differs from that of} \\ \text{error sequences } \{u_t,\ \ldots,\ u_{t+m-s}\} \text{ that do not overlap with it.} \end{cases} \tag{6}$$

One can construct tests for these hypotheses by moving the observations $\{(y_t,\ x_t) : t = t_0,\ \ldots,\ t_0 + m - 1\}$ to the end of the sample and moving the observations after $t = T_0 + m - 1$ to fill up the gap. The observations originally indexed by $t = t_0,\ \ldots,\ t_0 + m - 1$ are subsequently indexed by $t = T_0,\ \ldots,\ T_0 + m$, and the tests defined above can be used to test the hypotheses in (6).

B. Threshold Vector Error-Correction Model

Let $\{y_t : t = -p, \ldots, 0, 1, \ldots, T\}$ and $\{x_t : t = -p, \ldots, 0, 1, \ldots, T\}$ be the logarithms of the won-dollar and yen-dollar exchange rates, respectively. y_t and x_t are assumed to be $I(1)$ processes. If the won-dollar and yen-dollar rates are perfectly synchronized, the logarithm of the won-yen ratio, $z_t = y_t - x_t$, is constant. If the coupling is strong, though not perfect, we can expect that won-yen exchange rate to have a long-run equilibrium relation. That is, the won-yen exchange rate, $z_t = y_t - x_t$, is a stationary process, and the two exchange rates x_t and y_t are cointegrated with a known cointegrating vector, $(1, -1)$.

When y_t and x_t are cointegrated, their dynamic behavior can be described by the following vector error-correction model (VECM):

$$\begin{pmatrix} \Delta y_t \\ \Delta x_t \end{pmatrix} = \alpha + \sum_{s=1}^{p-1} \Psi_s \begin{pmatrix} \Delta y_{t-s} \\ \Delta x_{t-s} \end{pmatrix} + \beta z_{t-1} + u_t, \text{ for } t = 1, \ldots, T, \tag{7}$$

where $\alpha = (\alpha^y, \alpha^x)'$ is a vector of two constants, Ψ_s is a 2×2 matrix of coefficients, and $\beta = (\beta^y, \beta^x)'$ is a 2×1 vector of coefficients. The disturbance u_t is assumed to be an *iid* normal process with the finite covariance matrix $\Sigma = E(u_t u_t')$.

In general, the won-yen rate z_t fluctuates around some equilibrium values. We assume that there exists a band of z_t values to which z_t returns when it deviates away from the band. That is, when z_t deviates temporarily away from the band, there operates a kind of restoring force to bring the exchange rate back to the band. This restoring force operates due to the investors' arbitrage behavior in the market or to the market intervention of monetary authorities.

Suppose that the restoring force operates when the won-yen exchange rate is away from a range (γ_1, γ_2), where $\gamma_1 < \gamma_2$. Consider a TVECM with three regimes, where the regime is classified according to the value of the won-yen rate z_{t-1}:

$$\begin{pmatrix}\Delta y_t\\ \Delta x_t\end{pmatrix}=\begin{cases}\alpha_1+\sum_{s=1}^{p-1}\Psi_s^1\begin{pmatrix}\Delta y_{t-s}\\ \Delta x_{t-s}\end{pmatrix}+\beta^1 z_{t-1}+u_t, \text{ if } z_{t-1}\le\gamma_1,\\ \alpha_2+\sum_{s=1}^{p-1}\Psi_s^2\begin{pmatrix}\Delta y_{t-s}\\ \Delta x_{t-s}\end{pmatrix}+\beta^2 z_{t-1}+u_t, \text{ if } \gamma_1< z_{t-1}\le\gamma_2\\ \alpha_3+\sum_{s=1}^{p-1}\Psi_s^3\begin{pmatrix}\Delta y_{t-s}\\ \Delta x_{t-s}\end{pmatrix}+\beta^3 z_{t-1}+u_t, \text{ if } z_{t-1}>\gamma_2,\end{cases} \tag{8}$$

where $\alpha^i=(\alpha^{i,\, y},\ \alpha^{i,\, x})'$, Ψ_s^i and $\beta^i=(\beta^{i,\, y},\ \beta^{i,\, x})'$ for the three regimes, $i(=1,\ 2,\ 3)$.

Write the model (8) as in the following:

$$\Delta w_t=A'_1 W_{1,\, t-1}+A'_2 W_{2,\, t-1}+A'_3 W_{3,\, t-1}+u_t, \tag{9}$$

where $\Delta w_t=(\Delta y_t,\ \Delta x_t)'$ and $A_i=(\alpha^{i\prime},\ \Psi_1^i,\ \dots,\ \Psi_{p-1}^i,\ \beta^{i\prime})'$ for $i=1,\ 2,\ 3$, and $W_{i,\, t-1}=(1,\ \Delta w'_{t-1},\ \dots,\ \Delta w'_{t-p+1},\ z_{t-1})'\cdot 1(z_{t-1}$ is in regime $i)$ is the $(2p\times 1)$ vector of regressors in each regime, where $1(\cdot)$ is an indicator function.

We can estimate the model (8) by the maximum likelihood method. The maximum likelihood estimates (MLE) for the parameters $(A_1,\ A_2,\ A_3,\ \Sigma,\ \gamma_1,\ \gamma_2)$ are obtained by

$$\begin{aligned}(\hat{A}_1,\ \hat{A}_2,\ \hat{A}_3,\ \hat{\Sigma},\ \hat{\gamma}_1,\ \hat{\gamma}_2)&=\text{argmax } l_T(A_1,\ A_2,\ A_3,\ \Sigma,\ \gamma_1,\ \gamma_2)\\ &=\text{argmax}\left(-\frac{T}{2}\log|\Sigma|-\frac{1}{2}\sum_{t=1}^{T}u'_t\Sigma^{-1}u_t\right)\end{aligned} \tag{10}$$

where $l_T(\cdot)$ denotes the log-likelihood function. The usual maximization method does not apply for (10) because the likelihood function is not differentiable due to the threshold effect. Instead a grid search method is applied to get the MLEs of parameters including $(\gamma_1,\ \gamma_2)$.

IV. Empirical Results

We use daily data for the won-dollar and yen-dollar exchange rates from July 1, 1993 to June 30, 2004. All data are obtained from the Datastream service. Unless otherwise mentioned, variables described below are logged ones. For example, "won-dollar rate" (or won) is for the logarithm of the won-dollar rate.

TABLE 1
RESULTS OF UNIT ROOT TESTS FOR THE LOG OF WON/USD EXCHANGE RATE

	ADF		PP	
	Z_{ADF}	*OLS t*	Z_a	Z_t
Entire period 1	-5.68	-1.77	-3.18	-1.41
Entire period 2	-9.81	-2.18	-7.3	-1.94
Pre-crisis period	6.47	3.21	6.64	3.91
Crisis period	-2.31	-1.28	-12.88	-3.21
Post-crisis period	-9.17	-2.18	-10.25	-2.63

Note: 1) ADF: Augmented Dickey-Fuller test, PP: Phillips-Perron test, Z_{ADF}: coefficient test of ADF, ADF t-test is just *OLS t*; Z_a: Phillip-Perron's coefficient test, Z_t: Phillip-Perron's t-test.

2) Entire period 1: from July 1, 1993 to June 30, 2004. Entire period 2: from July 1, 1993 to June 30, 2004, where observations in the crisis period from November 19, 1997 to June 16, 1998 is omitted. Pre-crisis period: from July 1, 1993 to November 18, 1997. Crisis period: from November 19, 1997 to June 16, 1998. Post-crisis period: from June 17, 1998 to June 30, 2004.

3) Critical values for Z_{DF} and Z_a are -13.73 at 5% significance level and -19.83 at 1% significance level. The critical values for *OLS t* and Z_t are -2.87 at 5% significance level and -3.46 at 1% significance level.

4) When we include a time trend in the cointegrating regression with known cointegrating vector, critical values are -21.22 for Z_{DF} and Z_a at 5% significance level and -3.43 for *OLS t* and Z_t at 5% significance level.

A. Results of Cointegration Tests

First, we conduct a cointegration test for the data of the whole sample period. We apply the tests of Phillips and Perron (1988) (PP) and Augmented Dickey-Fuller (ADF) to test a unit root. The results in Tables 1 and 2 for the whole sample ("Entire Period 1" in the first row) show that for each of the won-dollar and yen-dollar exchange rates, the null of a unit root is not rejected at 5%. In addition, for the won-yen exchange rate (log of the won-yen ratio), we do not reject the null of a unit root (Table 3) for the whole sample.

The sample period for the Asian financial crisis lasts from November 19, 1997 to June 16, 1998, which is then divided into three subperiods: pre-crisis, crisis, and post-crisis. The null hypothesis of a unit root is not rejected for the won-dollar and yen-dollar exchange rates for most cases under consideration. On the other hand, for the won-yen exchange

TABLE 2
RESULTS OF UNIT ROOT TESTS FOR THE LOG OF YEN/USD EXCHANGE RATE

	ADF		PP	
	Z_{DF}	OLS t	Z_a	Z_t
Entire period 1	-7.25	-1.90	-7.21	-1.91
Entire period 2	-9.84	-2.15	-9.22	-2.12
Pre-crisis period	-2.82	-0.87	-1.18	-0.49
Crisis period	0.14	0.06	-5.08	-1.54
Post-crisis period	-10.39	-2.62	-9.13	-2.40

Note: See Notes in Table 1.

TABLE 3
RESULTS OF UNIT ROOT TESTS FOR THE LOG OF WON/YEN EXCHANGE RATE

	ADF		PP	
	Z_{DF}	OLS t	Z_a	Z_t
Entire period 1	-10.73	-2.29	-8.48	-2.13
Entire period 2	-25.81**	-3.44*	-24.15**	-3.5**
Pre-crisis period	-7.83	-1.89	-7.77	-1.97
Crisis period	-0.57	-0.43	-10.49	-2.75
Post-crisis period	-27.83**	-3.79**	-22.04**	-3.34*

Note: See Notes in Table 1. *: Significant at 5%, **: Significant at 1%.

rate, the null of a unit root is rejected for the sample without observations of the crisis period (entire period 2 in Table 3). Thus, we can say that for the sample without observations in the crisis period, the won-dollar exchange rate y_t and the yen-dollar exchange rate x_t are cointegrated with the cointegration vector $(1, -1)$.

B. Results of Cointegration Breakdown Tests

We apply the partial sample cointegration breakdown tests of Andrews and Kim (2003) for $m=25$. Figures 3 and 4 show the p-values in (4) and (5) of the tests for a series of hypothetical breakdown periods. The horizontal line is the 5% line. Thus, a date with the p-value below the 5% line is the starting date of a period of cointegration breakdown.

The p-values of P-tests and the R-tests, pv_{P_i} and pv_{R_i} yield similar

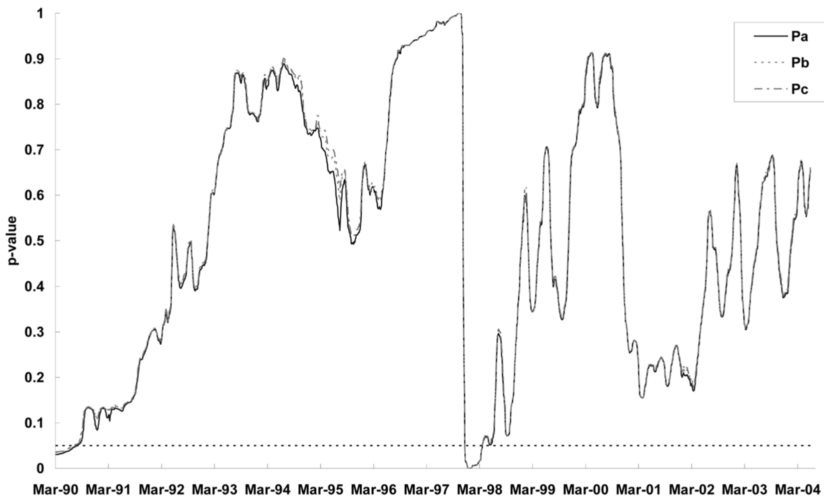

FIGURE 3
p-VALUES OF P STATISTICS

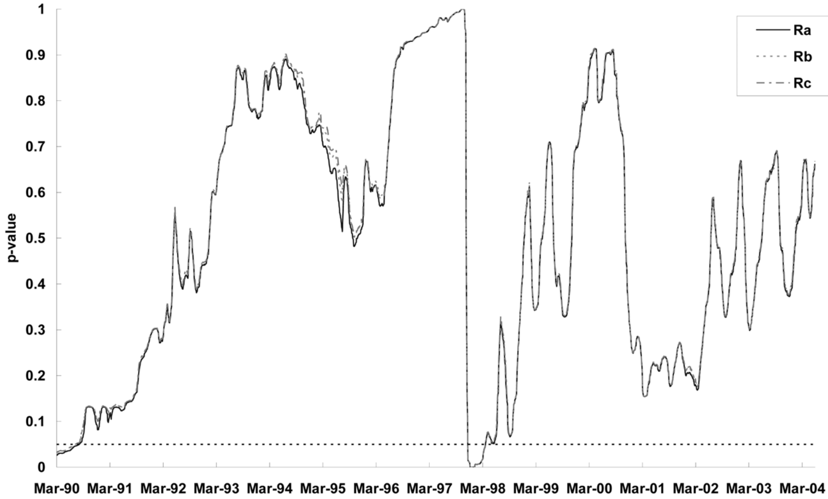

FIGURE 4
p-VALUES OF R STATISTICS

results. The *p*-values of *P*-tests, pv_{P_i}, detect two sets of periods of cointegration breakdown at the 5% level: one begins on March 1, 1990 and

TABLE 4
ESTIMATION RESULTS OF TVECM: BEFORE AND AFTER THE CRISIS

		Before crisis		After crisis	
γ		2.0635, 2.0812		2.2577, 2.4165	
exp(γ)		7.8735, 8.0141		9.5611, 11.2066	
Case 1	β^y	-0.0018	(0.0041)	-0.1228*	(0.0586)
	β^x	0.018	(0.0102)	-0.0097	(0.0291)
Case 2	β^y	-0.1097	(0.2721)	-0.0036	(0.0039)
	β^x	0.4328	(0.3374)	0.0143**	(0.0052)
Case 3	β^y	0.0346	(0.0981)	-0.041**	(0.0038)
	β^x	0.1315	(0.1463)	0.2591*	(0.1452)

Note: 1) The crisis period begins on November 15, 1997 and ends on June 16, 1998.
2) Numbers in parentheses are standard errors. *: Significant at 5%, **: Significant at 1%.

ends on August 7, 1990, and the other begins on November 19, 1997 and ends on April 22, 1998. The pv_{R_i} of R-tests also detect two such sets of periods of cointegration breakdown: one begins on March 1, 1990 and ends on August 10, 1990, and the other begins on November 19, 1997 and ends on April 21, 1998. Thus, the long-run relation between the won-dollar and yen-dollar exchange rates broke in the early 1990 and in the period of the Asian financial crisis.

C. Analysis by the TVECM

We estimate the model (8) in the pre-crisis period and in the post-crisis period separately because a long-run relation between the won and the yen undergoes change after the East Asian crisis, as evidenced by the analysis of the previous subsection. The estimates are presented in Table 4. The threshold bands are estimated as (7.8735, 8.0141) in the pre-crisis period and (9.5611, 11.2066) in the post-crisis period.

Before the crisis, the estimates of the coefficient of the error term, β, are all statistically insignificant. After the crisis, however, estimates of β are statistically significant in most cases, except β^x in Case 1 and β^y in Case 2. Notice that the movements of the exchange rates in Case 2 are within the band, which may be allowed to exist by the arbitrage seeking investors and the monetary authorities. Thus, we focus our attention to the other two cases in the post-crisis period.

When $z_{t-1} \leq \gamma_1$ (Case 1), the estimates of β, the coefficient of the error-correction term, are -0.1228 (significant at 5%) and -0.0097 (insignificant at 5%), respectively, for the won-dollar and yen-dollar exchange rates. This result implies that when the won-yen exchange rate falls below a proper level as the Korean won appreciates relative to the Japanese yen, the won-dollar rate plays the major role in the adjustment process to return to the band. On the other hand, when $z_{t-1} > \gamma_1$ (Case 3), the coefficient estimates for the error-correction term are -0.041 (significant at 1%) for the won-dollar exchange rate and 0.2591 (significant at 5%) for the yen-dollar exchange rate. These estimates indicate that both the won-dollar and yen-dollar rates adjust so that the won-yen exchange rate returns to the band.

Remark (a) The coupling or decoupling behavior of the two currencies studied in this paper may be due to the investors' behavior and/or the intervention of monetary authorities in the market, among other reasons. This paper aims to find whether there is evidence of such behavior in the data from July 1, 1993 to June 30, 2004. Our results show clear evidence of the coupling behavior in the won and the yen in the post-crisis period.

(b) It is not clear whether the coupling behavior evidenced in our analysis is mainly due to the market intervention, if any, of the Bank of Korea (BOK). It may be interesting to study how and to what extend the market intervention of BOK contributes to the coupling behavior of the won and the yen. However, this subject is beyond the scope of this paper and is thus left for future research.

(c) In general, the value of a currency is affected by many economic factors. For example, the monetary theory of exchange rate determination argues that economic variables such as national outputs, interest rates, money supplies, and price levels of the involved economies determine the relative value of a currency. The movements of these variables are closely related to the business cycles of the involved economies. Therefore, the exchange rates depend on the business cycles of the involved economies. It would be interesting to study how the coupling-decoupling behavior of two currencies depends on these factors in the involved economies. However, this subject is also beyond the scope of this paper and is thus left for future research.[1]

[1] The points in Remarks (b) and (c) are raised by one of the referees. The author appreciates the points of the referee.

V. Concluding Remarks

Although each of the won-dollar and yen-dollar exchange rates is determined independently of the other in the currency market, the two currencies have a close relationship because the two economies of Japan and Korea do so. We conjectured that such a relationship is stronger when the two currencies are allowed to adjust freely in the market. Our empirical investigation confirmed this conjecture. In particular, our empirical study shows that the band-reverting-type of equilibrium relationship between the Korean won and the Japanese yen became clearer after the Korean won was allowed to move more freely.

It would be interesting to build a structural model that corresponds to the empirical results of this paper, in which one can incorporate the investors' behavior and the intervention of monetary authorities in the market. Additionally, it would be useful to extend our analysis to the case of other currencies.

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Appendix

The following explanations for the cointegration breakdown tests are from Andrews and Kim (2003). For more detailed explanations, see Andrews and Kim (2003).

A1. P_a, P_b, and P_c Tests

For any $1 \leq r \leq s \leq T_0 + m$, let

$$\mathbf{Y}_{r-s} = (y_r, \ldots, y_s)', \ \mathbf{X}_{r-s} = (x_r, \ldots, x_s)', \text{ and } \mathbf{U}_{r-s} = (u_r, \ldots, u_s)'. \tag{A.1}$$

Moreover, let

$$\begin{aligned} &P_j(\beta, \Omega) = (\mathbf{Y}_{j-(j+m-1)} - \mathbf{X}_{j-(j+m-1)}\beta)' \Omega (\mathbf{Y}_{j-(j+m-1)} - \mathbf{X}_{j-(j+m-1)}\beta), \text{ and} \\ &P_j(\beta) = P_j(\beta, \mathbf{I}_m) \end{aligned} \tag{A.2}$$

for $j = 1, \ldots, T_0 + 1$, where Ω is some nonsingular $m \times m$ matrix and $\mathbf{I}_m$ denotes the m dimensional identity matrix.

Let $\hat{\beta}_{r-s}$ denote an estimator of β_0 based on observations $t = r, \ldots, s$

for $1 \leq r \leq s \leq T_0 + m$. For example, for the LS estimator,

$$\hat{\beta}_{r-s} = (\mathbf{X}'_{r-s}\mathbf{X}_{r-s})^{-1}\mathbf{X}'_{r-s}\mathbf{Y}_{r-s}. \tag{A.3}$$

The test statistic P_a is defined as

$$\begin{aligned} P_a = \; & P_{T_0+1}(\hat{\beta}_{1-T_0}) \\ & \sum_{t=T_0+1}^{T_0+m} (y_t - x'_t\hat{\beta}_{1-T_0})^2 \end{aligned} \tag{A.4}$$

P_a is the post-breakdown sum of squared residuals. The statistic P_a is often referred to as a predictive statistic.

Now, for $j = 1, \ldots, T_0 - m + 1$, define

$$\hat{\beta}_{(j)} = \text{estimator of } \beta \text{ using observations indexed by } t = 1, \ldots, T_0 \text{ with } t \neq j, \ldots, j + m - 1. \tag{A.5}$$

The estimator $\hat{\beta}_{(j)}$ is consistent for β_0 (uniformly over j) under suitable assumptions. Furthermore, define

$$P_{a,j} = P_j(\hat{\beta}_{(j)}) \text{ for } j = 1, \ldots, T_0 - m + 1 \tag{A.6}$$

The empirical distribution function of $\{P_{a,j} : j = 1, \ldots, T_0 - m + 1\}$ is

$$\hat{F}_{P_a,T_0}(x) = \frac{1}{T_0 - m + 1} \sum_{t=1}^{T_0-m+1} 1(P_{a,j} \leq x). \tag{A.7}$$

This empirical distribution converges in probability (and almost surely) to the df of $P_1(\beta_0)$ under suitable assumptions. Notice that the random variables $\{P_j(\beta_0) : j = 1, \ldots, T_0 - m + 1\}$ are stationary and ergodic under H_0 and H_1, so that the empirical distribution function of $\{P_j(\beta_0) : j = 1, \ldots, T_0 - m + 1\}$ is a consistent estimator of the df of $P_1(\beta_0)$.

In consequence, to obtain a test with asymptotic significance level α, we take the critical value of the test statistic P_a to be the $1 - \alpha$ sample quantile, $\hat{q}_{P_a, 1-\alpha}$ of $\{P_{a,j} j = 1, \ldots, T_0 - m + 1\}$. By definition,

$$\hat{q}_{P_a, 1-\alpha} = \inf\{x \in \mathbb{R} : \hat{F}_{P_a, T_0}(x) \geq 1 - \alpha\} \tag{A.8}$$

We reject H_0 if $P_a > \hat{q}_{P_a, 1-\alpha}$. Equivalently, we reject H_0 if P_a exceeds $100(1-\alpha)\%$ of the values, that is, if

$$(T_0 - m + 1)^{-1} \sum_{j=1}^{T_0-m+1} 1(P_a > P_{a,j}) \geq 1 - \alpha. \tag{A.9}$$

In addition the p-value for the P_a test is

$$pv_{P_a} = (T_0 - m + 1)^{-1} \sum_{j=1}^{T_0-m+1} 1(P_a \leq P_{a,j}) \tag{A.10}$$

Simulations in Andrews and Kim (2003) indicate that the P_a test over-rejects the null hypothesis in many scenarios. In consequence, two variants of the P_a, P_b, P_c tests are designed to have better finite-sample properties. First, the P_b test is based on

$$\begin{aligned} &P_b = P_{T+1}(\hat{\beta}_{1-(T_0+[m/2])}), \text{ and} \\ &P_{b,j} = P_j(\hat{\beta}_{(j)}) \text{ for } j=1, \ldots, T_0-m+1, \end{aligned} \tag{A.11}$$

where $[m/2]$ denotes the smallest integer that is greater than or equal to $m/2$. The estimator $\hat{\beta}_{1-(T_0+[m/2])}$ uses the observations $t=1, \ldots, T_0+[m/2]$. Critical values and p-values for P_b are obtained using $\{P_{b,j} : j=1, ,,,, T_0-m+1\}$ as in (A.9)-(A.10) with a replaced by b. The P_b statistic is somewhat less variable than the P_a statistic because the estimator $\hat{\beta}_{1-(T_0+[m/2])}$ depends on the observations indexed by $t=T_0+1, \ldots, T_0+[m/2]$. Hence, the residuals indexed by $t=T_0+1, \ldots, T_0+[m/2]$ (upon which $P_{T_0+1}(\cdot)$ depends) are less variable when computed using $\hat{\beta}_{1-(T_0+[m/2])}$ than when computed using $\hat{\beta}_{1-T_0}$. The critical values for P_b are based on the same statistics $P_j(\hat{\beta}_{(j)})$ as for the P_a statistic. In consequence, the test P_b rejects less frequently under H_0 than the P_a test does.

Next, the P_c test is based on a statistic that depends on the complete sample estimator $\hat{\beta}_{1-(T_0+m)}$:

$$P_c = P_{T_0+1}(\hat{\beta}_{1-(T_0+m)}) \tag{A.12}$$

and the $P_{c,j}$ statistic is defined as follows:

$$P_{c,j} = P_j(\hat{\beta}_{2(j)}) \text{ for } j=1, \ldots, T_0-m+1 \tag{A.13}$$

where

$$\hat{\beta}_{2(j)} = \text{estimator of } \beta \text{ using observations indexed by } t=1, \ldots, T_0 \text{ with } t \neq j, \ldots, j+[m/2]-1 \tag{A.14}$$

for $j=1, \ldots, T_0-m+1$. The critical values and p-values for P_c are obtained using $\{P_{c,j} : j=1, \ldots, T_0-m+1\}$ as in (A.9)-(A.10) with a replaced by c. The test based on P_c and $P_{c,j}$ rejects noticeably less frequently under the null hypothesis than the P_a test and somewhat less frequently than the P_b test.

A2. $R_a - R_c$ Tests

R-tests are designed to consider the locally best invariant (LBI) test for the presence of unit root errors. This type of test is asymptotically valid under more general conditions on the errors and regressors. R-tests have the form of

$$\sum_{t=T_0+1}^{T_0+m}\left(\sum_{s=t}^{T_0+m}\hat{u}_s\right)^2 \tag{A.15}$$

where u_s is the residual. Similar the P-tests, there are three different types of R-test statistics, R_a, R_b, R_c. The size and power properties of the tests are analogous to those of the P-tests. The three tests are defined as follows:

$$\begin{aligned}
R_a &= \sum_{t=T_0+1}^{T_0+m}\left(\sum_{s=t}^{T_0+m}(y_s - x_s'\hat{\beta}_{1-T_0})\right)^2, \; R_{a,j} = \sum_{t=j}^{j+m-1}\left(\sum_{s=t}^{j+m-1}(y_s - x_s'\hat{\beta}_{(j)})\right)^2, \\
R_b &= \sum_{t=T_0+1}^{T_0+m}\left(\sum_{s=t}^{T_0+m}(y_s - x_s'\hat{\beta}_{1-(T_0+[m/2])})\right)^2, \; R_{b,j} = \sum_{t=j}^{j+m-1}\left(\sum_{s=t}^{j+m-1}(y_s - x_s'\hat{\beta}_{(j)})\right)^2, \\
R_c &= \sum_{t=T_0+1}^{T_0+m}\left(\sum_{s=t}^{T_0+m}(y_s - x_s'\hat{\beta}_{1-(T_0+m)})\right)^2, \; R_{c,j} = \sum_{t=j}^{j+m-1}\left(\sum_{s=t}^{j+m-1}(y_s - x_s'\hat{\beta}_{2(j)})\right)^2.
\end{aligned} \tag{A.16}$$

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