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Short-term eurocurrency rate behavior and specifications of cointegrating processes

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Abstract

This article presents empirical evidence on short-term behavior based on seven Eurocurrency market rates. Empirical analysis suggests that there is two-dimensional cointegration. First, the domestic short-term interest rate is cointegrated with longer-term interest rates within a particular country. Second, the domestic short-term interest rate is cointegrated with the comparable foreign short-term interest rate adjusted for the foreign exchange forward premium (discount). The empirical evidence confirms that an error-correction model combining both dimensional market-correcting processes better explains short-term interest rate movements. © 2000 Elsevier Science Inc. All rights reserved.

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1. Introduction

Recent advances in time-series analysis and cointegration tests on interest rate series suggest that interest rates tend to follow some common stochastic factors (Choi & Wohar, 1991; Mougoue, 1992; Engsted & Tanggaard, 1994). Focusing on the term structure of interest rates, it has been shown that short- and long-term interest rates are cointegrated within a particular country (Arshanapalli & Doukas, 1994; Chiang & Chiang, 1995). An important implication of this finding is that the lagged error correction term obtained from the long-term equilibrium equation implied by the term-structure relationship can be used to predict the subsequent changes of the short-term interest rates.

However, evidence has been found that short-term interest rates with the same

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maturities across different countries are also cointegrated (Mougoue, 1992), especially for a small open economy. This means that the error-correcting term obtained from the lagged covered-arbitrage margin can be used to predict future changes of short-term interest rates.

An important message obtained from these cointegration analyses is that it would be more informative if interest rate behavior could be modeled in an error-correcting process since this representation contains both levels and differences of explanatory variables concerned. Kugler (1990), Choi and Wohar (1991), Bradley and Lumpkin (1992), Mougoue (1992), Arshanaplli and Doukas (1994), and Chiang and Chiang (1995) present evidence to support the specification of the error-correction model (ECM). Yet in examining these two dimensions of cointegration, it is natural to ask which dimension of the equilibrium relationship is more relevant in an integrated international market. Are these two error-correcting terms substitutable or complementary to each other? Concrete empirical evidence on this issue would provide more insight into the nature of cointegration. As a result, the findings could offer an empirical basis for specifying the error-correcting model in predicting interest rate movements.

In this article, we consider two theoretical frameworks—the term-structure relationship of interest rates and the international interest rate parity condition—for guiding the structural relationship between the short-term interest rate and its equilibrium level. As the model stands, the existence of these long-run structural relationships will translate into a framework of cointegrated processes. The article is organized as follows. Section 2 provides a general discussion of the properties of cointegration and a description of the error-correction representations. Section 3 discusses the data and the evidence of unit roots and cointegration tests. Section 4 reports and discusses the empirical results for different specifications of the error-correction models for the Euro-interest rates. Section 5 contains concluding remarks.

2. Cointegrating factors and error correction models

To illustrate the tenet of the error-correction model (Muscatelli & Jurn, 1992), let us consider two time series, $\{y_t\}$ and $\{z_t\}$, which are first-difference stationary, that is, integrated of order 1, $I(1)$. It is generally true that any linear combination of these two series is also $I(1)$. However, if there is a linear combination of these two series such that $u_t = y_t - b_0 - b_1 z_t$ is stationary, $I(0)$, then $\{y_t\}$ and $\{z_t\}$ are said to be cointegrated.

By applying this notion to describe short-term Eurocurrency rate (r_t) behavior, it is necessary to identify the equilibrium rate in which the cointegrating equation is being specified. Two candidate variables may be considered. The first is the long-term rate (R_t) within a given currency rate; the second is the effective foreign interest rate (r_t^*), which is defined as the Eurodollar deposit rate (r_t^*) with the same maturity plus the U.S. dollar forward premium (Boothe, 1991). In the following sections, we shall provide a brief economic justification for using these rates.

Empirical evidence shows that short-term interest rates fluctuate around the “normal” level of a given interest rate (Modigliani & Sutch, 1966). This normal rate is

usually referred to as the long-term interest rate. As stated by the expectations theory of the maturity structure of interest rates, the long-term interest rate is a weighted average of current and expected short-term interest rates. Thus, we can write a long-run relationship between short rate and long rate as

$$r_t = b_{10} + b_{11}R_t + u_{1,t}, \tag{1}$$

where b_{10} and b_{11} are estimated parameters, r_t is the short-term interest rate, R_t is the long-term interest rate, and $u_{1,t}$ is an error term. Expressing Eq. (1) in a short-run dynamic process, we write an error-correction model (ECM) as

$$\Delta r_t = C_1 + \sum_{j=0}^m \gamma_{1j} \Delta R_{t-j} + \sum_{j=1}^n \pi_{1j} \Delta r_{t-j} - \psi_1 u_{1,t-1} + \epsilon_{1,t}, \tag{2}$$

where C_1 , γ_1 , π_1 , and ψ_1 are estimated parameters, $\epsilon_{1,t}$ is an error term, Δ is a change operator, and $u_{1,t-1}$ is the error-correction term obtained from the long-run equilibrium equation. This term reflects the fact that the short-term interest rate is in a state of disequilibrium that would be revised, moving toward its long-run level. To differentiate our model specifications, we shall call Eq. (2) a domestic term-structure ECM specification (Hall, et al., 1992; Nourzad & Grennier, 1995).

Notice that the specification of Eq. (2) gives no consideration to the effect derived from foreign markets. It has been observed that, for a small open economy, the short-term interest rate cannot deviate significantly from the comparable global level of interest rates. Thus, it can be argued that the Canadian and other short-term Eurocurrency rates will maintain a close relationship with Eurodollar rates having the same level of maturity. This tight relationship may stem from institutional arrangements in a global setting or from monetary policy coordination among national central banks (Mougoue, 1992).

It should be noted that the interest rate differentials do not provide all the explanation to describe international capital movements. To compare short-run investment returns across national borders, it is necessary to take into account the exchange-rate factor. As described by the international interest rate parity condition, the domestic short-term interest rate (r_t) should not deviate significantly from the comparable foreign short-term interest rate adjusted by a forward premium or forward discount on the foreign currency (r_{ft}^*). Thus, we can write a long-run relationship between r_t and r_{ft}^* as

$$r_t = b_{20} + b_{21} r_{ft}^* + u_{2,t}, \tag{3}$$

where b_{20} and b_{21} are estimated parameters. The $u_{2,t}$ in Eq. (3) is an error term, which may capture the information in relation to deviations from covered interest rate parity (CIP) resulting from real world frictions, transactions costs, currency preference, or different speeds of market reaction (Abeysekera & Turtle, 1995; Atkins, 1993; Bhatti & Moosa, 1995; Cody, 1990; Committeri et al., 1993). This information plays an important role in explaining international arbitrages, which in turn affect short-term interest rate movements. A short-run ECM for describing the relationship between r_t and r_{ft}^* is given by

$$\Delta r_t = C_2 + \sum_{j=0}^m \gamma_{2j} \Delta r_{f,t-j}^* + \sum_{j=1}^n \pi_{2j} \Delta r_{t-j} - \psi_2 u_{2,t-1} + \epsilon_{2,t}, \quad (4)$$

where C_2 , γ_2 , π_2 , and ψ_2 are estimated parameters, r_{ft}^* is the effective foreign investment return (Eurodollar rate plus a forward exchange premium on the U.S. dollar); r_t is the domestic investment return (Canadian and other Eurocurrency rates) of a given maturity; and $\epsilon_{2,t}$ is an error term. Although no particular argument in Eq. (4) has been used to describe the source that causes deviations from CIP, the inclusion of the $u_{2,t-1}$ term allows us to use additional information to predict future short-term interest rate movements. Of course, this econometric treatment is subject to empirical verification.

3. Data and unit-root and cointegration tests

3.1. Data

In this study, we employ weekly data of Eurocurrency deposit rates and spot and forward exchange rates for the period from June 1, 1973, through August 2, 1996.¹ The Eurocurrency rate data set includes 1-, 3-, 6-, and 12-month rates for Eurocurrency deposits denominated in British pounds (BP), Canadian dollars (CD), German marks (GM), Italian lira (IL), Japanese yen (JY), Swiss francs (SF), and U.S. dollars. The Eurocurrency rates are bid rates at the close of trading in London. The foreign exchange rate data contain spot exchange rates and 1-, 3-, 6-, and 12-month forward exchange rates of BP, CD, GM, IL, JY, and SF. The foreign exchange rates are defined as units of foreign currencies per U.S. dollar. All Eurocurrency rate and foreign exchange rate data are measured at the end of the week, as obtained from Data Resources, Inc.

3.2. Unit-Root Tests

To estimate short-run dynamic equations, researchers usually begin with testing the stationarity of the series under consideration. To this end, we employ the Dickey Fuller (DF) (1979) and augmented Dickey Fuller (ADF) (1981) tests to examine whether the time-series variables are stationary or not. Table 1A reports results of unit-root tests for 1-, 3-, 6-, and 12-month Eurocurrency deposit rates. The test statistics indicate that, with the exception of the 1-month rate for the SF, the null hypothesis of a unit-root cannot be rejected for the levels of Eurocurrency rates. However, the null hypothesis is rejected for all cases when Eurocurrency rates are first differenced. This means that, in general, the levels of Eurocurrency rates are nonstationary while the first differences are stationary. These results are consistent with the findings of Kugler (1990), Mougoue (1992), Arshanapalli and Doukas (1994), and Chiang and Chiang (1995).²

Table 1B reports the results of unit-root tests for 1-, 3-, 6-, and 12-month foreign investment returns, r_{ft}^* , which are defined as Eurodollar deposit rates (Euromark for U.S. investors) plus the forward premiums of various currencies on the U.S. dollar

Table 1
Unit-root and cointegration tests

Currency	Variables	Level		First Differencing	
		DF	ADF(Lags)	DF	ADF(Lags)
A. Eurocurrency rates and error-correction terms from the term-structure relation					
US	$r_t(1)$	-1.61	-2.39(2)	-27.10*	-19.00(1)*
	$r_t(3)$	-1.51	-2.52(5)	-25.34*	-12.96(4)*
	$r_t(6)$	-1.47	-2.30(4)	-25.53*	-15.02(3)*
	$R_t(12)$	-1.34	-2.31(4)	-24.62*	-12.95(4)*
	$u_{t,i}(1-3)$	-9.36*	-9.21(2)*		
	$u_{t,i}(3-6)$	-5.37*	-6.06(1)*		
	$u_{t,i}(6-12)$	-4.60*	-5.58(4)*		
BP	$r_t(1)$	-2.47	-2.61(7)	-30.81*	-12.54(6)*
	$r_t(3)$	-1.80	-2.21(3)	-28.25*	-19.48(2)*
	$r_t(6)$	-1.52	-2.18(1)	-26.90*	-26.90(0)*
	$R_t(12)$	-1.48	-2.09(1)	-26.10*	-26.10(0)*
	$u_{t,i}(1-3)$	-10.39*	-6.33(4)*		
	$u_{t,i}(3-6)$	-7.46*	-6.21(3)*		
	$u_{t,i}(6-12)$	-6.51*	-6.51(0)*		
CD	$r_t(1)$	-0.88	-1.31(1)	-23.30*	-23.30(0)*
	$r_t(3)$	-0.79	-1.29(1)	-22.69*	-22.69(0)*
	$r_t(6)$	-0.87	-1.34(1)	-23.26*	-23.26(0)*
	$R_t(12)$	-0.94	-1.44(1)	-22.83*	-22.83(0)*
	$u_{t,i}(1-3)$	-7.98*	-8.37(1)*		
	$u_{t,i}(3-6)$	-6.23*	-6.23(0)*		
	$u_{t,i}(6-12)$	-5.89*	-5.27(3)*		
GM	$r_t(1)$	-2.25	-1.86(8)	-29.18*	-14.37(7)*
	$r_t(3)$	-1.59	-1.63(3)	-27.87*	-16.05(3)*
	$r_t(6)$	-1.37	-1.53(3)	-25.71*	-18.81(2)*
	$R_t(12)$	-1.16	-1.61(3)	-24.57*	-17.09(2)*
	$u_{t,i}(1-3)$	-9.27*	-9.72(2)*		
	$u_{t,i}(3-6)$	-5.93*	-5.99(1)*		
	$u_{t,i}(6-12)$	-4.48*	-4.48(0)		
IL	$r_t(1)$	-3.13**	-2.51(2)	-26.43*	-26.41(1)*
	$r_t(3)$	-2.24	-2.08(2)	-24.32*	-22.98(1)*
	$r_t(6)$	-2.09	-1.81(3)	-23.08*	-16.55(2)*
	$R_t(12)$	-1.81	-1.73(2)	-23.08*	-20.01(1)*
	$u_{t,i}(1-3)$	-12.72*	-11.13(2)*		
	$u_{t,i}(3-6)$	-5.35*	-4.09(4)*		
	$u_{t,i}(6-12)$	-6.96*	-6.38(4)*		
JY	$r_t(1)$	-2.01	-1.01(7)	-27.91*	-14.22(6)*
	$r_t(3)$	-1.08	-1.15(6)	-22.93*	-13.89(5)*
	$r_t(6)$	-0.81	-1.08(5)	-22.61*	-14.16(4)*
	$R_t(12)$	-0.50	-1.26(3)	-21.51*	-14.89(2)*
	$u_{t,i}(1-3)$	-9.65*	-8.57(2)*		
	$u_{t,i}(3-6)$	-6.30*	-4.55(8)*		
	$u_{t,i}(6-12)$	-5.74*	-5.14(2)*		

(continued)

Table 1
(Continued)

Currency	Variables	Level		First Differencing	
		DF	ADF(Lags)	DF	ADF(Lags)
SF	$r_t(1)$	-2.98**	-2.87(5)**	-31.74*	-17.31(4)*
	$r_t(3)$	-2.01	-2.35(1)	-28.98*	-28.98(0)*
	$r_t(6)$	-1.67	-2.15(2)	-27.97*	-20.73(1)*
	$R_t(12)$	-1.45	-1.88(1)	-27.73*	-27.73(0)*
	$u_{1,t}(1-3)$	-10.51*	-12.05(1)*		
	$u_{1,t}(3-6)$	-6.28*	-6.28(0)*		
	$u_{1,t}(6-12)$	-6.15*	-6.15(0)*		
B. Effective foreign interest rates (Eurodollar deposit rate plus forward premium on U.S. dollar) and error-correction terms from the international interest-rate parity condition					
CD-US*	$r_{ft}^*(1)$	-2.12	-1.94(1)	-37.64*	-37.64(0)*
	$r_{ft}^*(3)$	-1.32	-1.89(2)	-28.80*	-28.80(0)*
	$r_{ft}^*(6)$	-1.51	-1.87(2)	-32.66*	-21.69(1)*
	$u_{2,t}(1)$	-13.45*	-5.68(4)*		
	$u_{2,t}(3)$	-10.39*	-4.14(4)*		
	$u_{2,t}(6)$	-15.03*	-4.93(5)*		
BP-US*	$r_{ft}^*(1)$	-3.46*	-2.51(4)	-36.10*	-20.47(3)*
	$r_{ft}^*(3)$	-2.10	-2.57(1)	-29.51*	-23.59(1)*
	$r_{ft}^*(6)$	-1.68	-2.26(1)	-27.78*	-27.78(0)*
	$u_{2,t}(1)$	-14.54*	-5.31(5)*		
	$u_{2,t}(3)$	-11.36*	-5.77(3)*		
	$u_{2,t}(6)$	-11.93*	-5.85(4)*		
GM-US*	$r_{ft}^*(1)$	-4.30*	-2.08(13)	-46.84*	-11.42(12)*
	$r_{ft}^*(3)$	-2.25	-2.01(4)	-38.56*	-16.47(3)*
	$r_{ft}^*(6)$	-1.68	-1.55(3)	-31.40*	-19.99(2)*
	$u_{2,t}(1)$	-10.95*	-5.22(6)*		
	$u_{2,t}(3)$	-9.79*	-4.16(3)*		
	$u_{2,t}(6)$	-9.48*	-4.13(4)*		
IL-US*	$r_{ft}^*(1)$	-6.54*	-6.96(1)*	-33.56*	-19.19(4)*
	$r_{ft}^*(3)$	-4.15*	-4.85(1)*	-30.40*	-25.71(1)*
	$r_{ft}^*(6)$	-2.86**	-3.25(2)**	-29.36*	-23.89(1)*
	$u_{2,t}(1)$	-6.57*	-6.57(0)*		
	$u_{2,t}(3)$	-6.10*	-5.36(6)*		
	$u_{2,t}(6)$	-7.94*	-6.68(1)*		
JY-US*	$r_{ft}^*(1)$	-9.26*	-6.26(7)*	-35.21*	-21.08(8)*
	$r_{ft}^*(3)$	-4.92*	-4.47(5)*	-35.65*	-16.12(5)*
	$r_{ft}^*(6)$	-3.63*	-4.07(4)*	-33.79*	-14.27(4)*
	$u_{2,t}(1)$	-17.94*	-7.80(3)*		
	$u_{2,t}(3)$	-3.77**	-1.63(1)		
	$u_{2,t}(6)$	-2.42	-0.93(1)		

(continued)

Table 1
(Continued)

Currency	Variables	Level		First Differencing	
		DF	ADF(Lags)	DF	ADF(Lags)
SF-US*	$r_{fi}^*(1)$	-5.69*	-3.03(5)**	-47.11*	-19.76(4)*
	$r_{fi}^*(3)$	-2.54	-2.54(0)	-34.95*	-34.95(0)
	$r_{fi}^*(6)$	-2.22	-2.22(0)	-35.08*	-35.08(0)*
	$u_{2,i}(1)$	-21.29*	-7.70(4)*		
	$u_{2,i}(3)$	-11.81*	-5.55(3)*		
	$u_{2,i}(6)$	-16.12*	-4.41(7)*		
US-GM*	$r_{fi}^*(1)$	-3.09**	-2.38(11)	-40.79*	-11.44(10)*
	$r_{fi}^*(3)$	-1.88	-2.48(3)	-30.62*	-17.22(2)*
	$r_{fi}^*(6)$	-1.61	-2.46(3)	-27.17*	-16.13(2)*
	$u_{2,i}(1)$	-16.54*	-8.84(3)*		
	$u_{2,i}(3)$	-16.96*	-5.86(4)*		
	$u_{2,i}(6)$	-14.67*	-4.23(7)*		

For domestic interest rates and effective foreign interest rates, the regression model for the Dickey-Fuller (DF) test is $\Delta x_t = \alpha + \rho x_{t-1} + \epsilon_t$, where x_t : $\{r_t$ and $R_t\}$ (domestic interest rates) or $\{r_t\}$ (effective foreign interest rates defined as Eurodollar rates plus forward exchange premium on U.S. dollar) for testing $H_0: \rho = 0$. The augmented Dickey-Fuller (ADF) test is given by $\Delta x_t = \alpha + \rho x_{t-1} + \sum_{i=1}^k \gamma_i \Delta x_{t-i} + \epsilon_t$. The numbers in the parentheses are the optimal lag lengths for the ADF test. The choice of optimal lag length (k) for the ADF test is determined by adding an additional lag until the joint significance (the Ljung-Box Q-test) of the residual autocorrelation up to the 8th order is rejected at a 5% significance level. The * and ** indicate statistical significance at the 1% and 5% levels, respectively. The critical values for the 1% and 5% significance levels are -3.43 and -2.86, respectively (Fuller, 1976).

Effective foreign interest rates, r_{fi}^* , which domestic investors can obtain from investment in Eurodollar deposit rates, plus currencies' forward premiums, $f_i - s_i$, on the U.S. dollar based on the covered Interest-Rate Parity. That is, $r_{fi}^* = r_i^* + (f_i - s_i)$, where r_{fi}^* = effective foreign interest rates Eurodollar (or Euromark) deposit rates; r_i^* = Eurodollar (or Euromark) rates; f_i = forward exchange rate in the natural log; and s_i = spot exchange rate in the natural log. In the cases of Canada, Japan, and European countries, we assume that the United States is the foreign country. For the United States, effective foreign interest rates are constructed as Euromark deposit rates plus forward premiums on the German mark. Germany is assumed to be the foreign country.

Error correction terms, $u_{1,t}$, are obtained from a cointegrating equation of $u_{1,t} = r_t - b_{10} - b_{11}R_t$, where r_t is the short rate and R_t is the adjacent longer rate. Error correction terms, $u_{2,t}$, are obtained from a cointegrating equation of $u_{2,t} = r_t - b_{20} - b_{21}r_{fi}^*$. The DF tests for cointegration are based on the regression equation of $\Delta u_{i,t} = \rho_i u_{i,t-1} + \epsilon_{i,t}$. The ADF tests for cointegration are based on the regression equation of $\Delta u_{i,t} = \rho_i u_{i,t-1} + \sum_{j=2}^k \gamma_{ij} u_{i,t-j} + \epsilon_{i,t}$. For DF and ADF tests for cointegration, the critical values are -4.07 (-3.77) and -3.37 (-3.17) at the 1% and 5% significance levels, respectively (Engle & Granger, 1987). The choice of optimal lag length (k) for the ADF test is determined by adding additional lag until the joint significance (Ljung-Box Q-test) of residual autocorrelation up to the 8th order is rejected at the 5% level of significance.

(forward premium on the German mark for U.S. investors). With the exceptions of the JY and IL, the evidence shows that the null hypothesis cannot be rejected for the interest rate levels. Yet, for the first differences of the r_{fi}^* series, the null hypothesis is rejected for all cases. In general, the majority of the foreign investment returns are nonstationary, while the first differences are stationary.

We also examine the results of the error terms on the long-run equilibrium Eqs. (1) and (3). Evidence shows that for virtually all of the residual series, the null hypothesis of unit roots is rejected. Specifically, the $u_{1,t}$'s shown in Table 1A indicate that these values are highly significant. This suggests that two adjacent interest rates are cointegrated across the entire term-structure spectrum.

To examine the international market cointegration hypothesis, we examine the relationship between the domestic interest rate (r_t) and the foreign interest rate adjusted by the exchange rate factor (r_t^*). The stationarity tests of the residuals derived from the cointegrating Eq. (3) are presented in Table 1B. For all cases except JY for 3-, 6-, and 12-month maturities, DF and ADF tests on the residuals from equilibrium regressions show that those residuals are stationary at the one percent significance level. This suggests that cointegration between domestic and foreign interest rates adjusted by a forward premium (discount) is confirmed by the data.³

4. Estimation of error-correction models

Having performed the cointegration tests, we are ready to apply the two-step procedure proposed by Engle and Granger (1987). In the first step, the long-run relationship (the level of the variables) is estimated by OLS regressions. In the second step, the short-run dynamic (the change of the variables) is estimated by including a lagged error term from the long-run relationship regression. This two-step procedure requires that all the variables in the error correction model regressions are stationary, otherwise OLS estimates are inappropriate (West, 1988; Mehra, 1993). To estimate the error-correction model, the optimal lag length of independent variables has to be determined. Because most Eurocurrency rates and exchange rates are highly sensitive and efficient and also for the purpose of comparison across countries and maturities, we employ the first-order lag for independent variables. The estimated results for these two specifications of ECM representations (Eqs. [2] and [4]) are presented in Tables 2 and 3.^{4,5}

4.1. Evidence from domestic term-structure ECM

The findings shown in Table 2 on the relationship between short rates and long rates for a given currency are consistent with those presented by Chiang and Chiang (1995), who used monthly short-end Eurocurrency rates. First, all estimated equations have a relatively high R^2 , ranging from 0.65 to 0.93. The DW statistics indicate the absence of first-order serial correlation.

Second, all the error-correction terms have negative signs and are highly significant at the one percent level. The negative sign is consistent with the error-correction process in that when the short rate deviates from the long rate, there is a tendency to revert to the long-run level. In particular, as the short rate falls below the long rate, the short rate is expected to rise in proportion to the error-correction term (this may be viewed as a proxy of the slope of the yield curve), moving toward long-run equilibrium. The reverse movement also holds true when the short rate rises above

Table 2

Regression estimates of ECM based on domestic term-structure relations

$$\Delta r_t = \alpha_1 + \beta_{10}\Delta R_t + \beta_{11}\Delta R_{t-1} + \gamma_{11}\Delta r_{t-1} + \epsilon_{1,t}$$

Currency	Constant	Δr_{t-1}	ΔR_t	ΔR_{t-1}	$u_{1,t-1}$	R^2	SEE	DW
A. $r_t = 1$ -month rate and $R_t = 3$ -month rate								
US	-0.000004 (0.09)	-0.042 (0.68)	0.940* (33.59)	0.050 (0.90)	-0.132* (5.37)	0.80	0.0014	1.99
CD	-0.000008 (0.15)	0.094** (2.27)	0.905* (29.13)	-0.123*** (1.88)	-0.165* (7.58)	0.77	0.0014	2.00
BP	-0.000003 (0.06)	-0.079 (1.46)	1.078* (20.26)	0.005 (0.07)	-0.150* (5.29)	0.79	0.0019	2.04
GM	0.000003 (0.11)	-0.236* (6.20)	1.096* (26.68)	-0.277* (5.12)	-0.160* (7.47)	0.80	0.0010	1.95
JY	-0.000003 (0.07)	-0.055 (0.51)	1.037* (15.69)	-0.083 (0.72)	-0.147* (7.44)	0.65	0.0015	1.73
IL	000009 (0.54)	0.153** (1.99)	1.404* (15.21)	-0.171*** (1.87)	-0.315* (5.64)	0.83	0.0040	1.95
SF	000004 (0.06)	0.171* (4.53)	1.204* (21.77)	-0.252* (5.15)	-0.195* (8.70)	0.73	0.0020	1.97
B. $r_t = 3$ -month rate and $R_t = 6$ -month rate								
US	-0.0000007 (0.03)	0.136* (3.17)	0.996* (44.48)	-0.105* (2.65)	-0.054* (4.03)	0.93	0.0008	1.99
CD	-0.000008 (0.21)	0.109** (2.08)	0.881* (35.07)	-0.070*** (1.65)	-0.089* (7.87)	0.83	0.0011	2.02
BP	-0.00001 (0.27)	0.004 (0.08)	1.056* (29.66)	-0.074 (1.40)	-0.087* (5.23)	0.85	0.0014	2.01
GM	-0.000005 (0.23)	0.055 (1.37)	1.023* (22.46)	-0.102** (2.46)	-0.060* (4.98)	0.84	0.0007	2.00
JY	000005 (0.18)	0.011 (0.18)	0.987* (24.98)	-0.047 (0.66)	-0.074* (3.85)	0.80	0.0009	1.99
IL	00005 (0.57)	-0.039 (0.78)	1.284* (11.37)	0.055 (0.85)	-0.053* (2.60)	0.80	0.0027	1.99
SF	000003 (0.10)	-0.102* (3.03)	1.082* (37.37)	0.119* (3.08)	-0.061* (4.48)	0.83	0.0010	2.01
C. $r_t = 6$ -month rate and $R_t = 12$ -month rate								
US	-0.0000006 (0.02)	0.002 (0.03)	1.109* (43.04)	-0.004 (0.06)	-0.036* (3.11)	0.91	0.0009	1.99
CD	-0.00001 (0.34)	-0.112** (2.41)	0.957* (38.85)	0.114** (2.35)	-0.063* (4.34)	0.86	0.0010	2.02
BP	-0.00001 (0.32)	-0.095* (2.67)	1.071* (39.85)	0.055 (1.33)	-0.061* (4.53)	0.86	0.0012	2.02
GM	-0.000003 (0.16)	0.003 (0.09)	1.006* (31.83)	0.010 (0.28)	-0.034* (3.85)	0.82	0.0007	1.99
JY	0.000007 (0.27)	0.033 (0.55)	1.059* (22.39)	-0.049 (0.73)	-0.069* (3.48)	0.78	0.0009	1.96
IL	-0.000009 (0.11)	0.095*** (1.67)	0.906* (15.89)	0.001 (0.01)	-0.116* (3.04)	0.67	0.0023	1.93
SF	-0.000002 (0.08)	-0.008 (0.19)	1.072* (38.58)	0.022 (0.41)	-0.062* (4.34)	0.83	0.0009	2.00

* indicates statistically significant differences from 0 at the 1% level; ** indicates statistically significant differences from 0 at the 5% level; *** indicates statistically significant differences from 0 at the 10% level. Numbers in parentheses are absolute values of t statistics. DW is Durbin-Watson statistic; SEE is standard error of estimate.

Table 3
Regression estimates of ECM based on international interest-rate parity

$$\Delta r_t = \alpha_2 + \beta_{20}\Delta r_{jt}^* + \beta_{21}\Delta r_{jt-1}^* + \gamma_{21}\Delta r_{t-1} - \psi_2 u_{2,t-1} + \epsilon_{2,t}$$

Currencies	Constant	Δr_{t-1}	Δr_{jt}^*	Δr_{jt-1}^*	$u_{2,t-1}$	R ²	SEE	DW
A. 1-month maturity								
CD-US	-0.00002 (0.37)	-0.157 (2.94)	0.580* (11.09)	0.267 (6.26)	-0.082* (3.06)	0.66	0.0016	2.14
BP-US*	-0.00003 (0.52)	-0.185* (2.70)	0.608* (14.41)	0.215* (3.04)	-0.147* (4.11)	0.72	0.0023	2.12
GM-US*	-0.00002 (0.42)	0.016 (1.48)	0.449* (7.94)	0.164* (7.94)	-0.056* (3.84)	0.56	0.0015	2.02
JY-US*	0.00001 (0.07)	0.015 (0.18)	0.231** (2.28)	0.071*** (1.67)	-0.099* (3.24)	0.26	0.0022	2.01
IL-US*	-0.00002 (0.12)	0.022 (0.28)	0.515* (9.62)	0.005 (0.08)	-0.072*** (1.68)	0.59	0.0062	1.99
SF-US*	-0.00003 (0.39)	-0.132 (0.15)	0.332* (2.75)	0.098*** (1.72)	-0.146* (4.11)	0.36	0.0030	2.05
US-GM*	-0.00001 (0.28)	-0.151* (4.48)	0.614* (13.21)	0.147* (6.38)	-0.219* (9.34)	0.70	0.0017	2.02
B. 3-month maturity								
CD-US*	-0.00001 (0.24)	-0.235* (6.86)	0.829* (16.76)	0.276* (8.88)	-0.117* (4.27)	0.84	0.0011	2.16
BP-US*	-0.00001 (0.23)	-0.321** (12.75)	0.759* (33.46)	0.340* (13.77)	-0.102* (4.13)	0.83	0.0014	2.18
GM-US*	-0.00001 (0.43)	-0.136* (2.89)	0.589* (9.79)	0.271* (10.07)	-0.043* (3.07)	0.66	0.0010	2.11
JY-US*	-0.00003 (0.74)	0.029 (0.28)	0.377* (3.55)	0.199** (2.34)	-0.004 (0.51)	0.46	0.0016	2.06
IL-US*	-0.00003 (0.25)	0.163*** (2.42)	0.463* (9.52)	-0.019 (0.39)	-0.069*** (1.66)	0.47	0.0043	1.98
SF-US*	-0.00002 (0.35)	-0.209* (3.38)	0.634* (7.27)	0.268* (7.04)	-0.074* (3.21)	0.65	0.0016	2.12
SF-US*	-0.00001 (0.26)	-0.279* (6.55)	0.780* (23.61)	0.268* (8.13)	-0.230* (6.77)	0.86	0.0011	2.13
C. 6-month maturity								
CD-US*	-0.00001 (0.19)	-0.273* (5.38)	0.829* (19.67)	0.330* (6.32)	-0.226* (4.40)	0.82	0.0011	2.15
BP-US*	0.00000 (0.01)	-0.301* (7.42)	0.818* (51.47)	0.348* (9.05)	-0.122* (5.59)	0.88	0.0011	2.15
GM-US*	-0.00001 (0.27)	-0.018** (2.34)	0.711* (18.56)	0.237* (6.47)	-0.067* (3.92)	0.76	0.0008	2.10
JY-US*	-0.00003 (0.91)	479 (0.38)	0.406* (3.23)	0.174*** (1.75)	-0.003 (0.45)	0.45	0.0014	2.03
IL-US*	-0.00003 (0.40)	069 (0.81)	0.476* (10.14)	0.055 (1.07)	-0.098** (2.32)	0.50	0.0029	1.97
SF-US*	-0.00002 (0.36)	-0.098 (1.64)	0.583* (8.05)	0.215* (5.45)	-0.138* (5.12)	0.62	0.0014	2.09
US-GM*	-0.00001 (0.25)	-0.205* (4.17)	0.864* (49.84)	0.207* (4.75)	-0.227* (5.66)	0.92	0.0008	2.09

* indicates statistically significant differences from 0 at the 1% level; ** indicates statistically significant differences from 0 at the 5% level; *** indicates statistically significant differences from 0 at the 10% level. Numbers in parentheses are absolute values of *t* statistics. DW is Durbin-Watson statistic; SEE is standard error of estimate.

the long rate. In addition, the coefficients of the error-correction term in the ECM for shorter maturities are, in general, larger than those derived from longer maturities. This means that the adjustment speed is faster in the 1- and 3-month equations than in the 3- and 6-month equations, and it is faster in the 3- and 6-month equations than in the 6- and 12-month equations.⁶

Third, all the contemporaneous terms of the change of the longer-term interest rates have a positive sign and are significantly different from 0 at the one percent level. This finding suggests that the short rate and the long rate are cointegrated in the short-run as well as in the long-run relationship. In addition, lagged long-term rates have an effect on the changes in short rates in some cases, even though the explanatory power is relatively weaker than the contemporaneous term. Thus, the evidence suggests that the long rate plays an important role in explaining the movements of the short-term interest rate.

Fourth, the coefficients on the lagged short-term interest rates appear to have mixed signs, depending on the country or maturity. The evidence did not indicate whether the interest rate series on the weekly base is in the nature of an extrapolative or a distributed lag process. Since the explanatory power is dominated by the change of the long rate and by the error-correction term, the lagged change in the short rate appear to be less significant.

4.2. Evidence from international interest rate parity ECM

The estimates of dynamic adjustments for international integrated capital markets are presented in Table 3. The findings are summarized as follows. First, the model appears to have good explanatory power. The R^2 for the estimated equations ranges from 0.26 to 0.88, although these values are lower than in the previous model. The DW statistics indicate no first-order serial correlation.

Second, consistent with our earlier cointegration tests, all the error correction terms, with the exceptions of JY rates in the 3-, 6-, and 12-month cases, are highly significant. The negative sign of the error-correcting term implies that when there is a discrepancy between domestic and effective foreign returns, international arbitrage takes place, forcing Eurocurrency rates to revert to their long-run equilibrium level.

Third, changes in the effective Eurodollar rates have a positive sign and are highly significant. This finding suggests that Eurocurrency rates and effective Eurodollar rates have a tendency of co-movement, both in the short-run dynamic relationship as well as in the long-run equilibrium relationship. However, the significance of the lagged effective Eurodollar rates and the error-correcting terms suggests that the international interest rate parity condition does not necessarily hold true in an instantaneous case.

Fourth, the coefficients on the lagged short-term interest rates are statistically significant only for several instances, and the majority of them show a negative sign. The negative AR(1) process suggests that the underlying interest rates are self-correcting and appear to maintain stability.

5. Specification tests

Estimates of ECM indicate that both longer-term Eurocurrency rates of a given currency and effective foreign interest rates (Eurodollar rate plus a forward premium) for a given maturity have significant explanatory power. Moreover, both error-correcting terms contain significant information, which can be used to predict the short-end Eurocurrency rates. Apparently, the Eurocurrency market undergoes two-dimensional market arbitrage: intertemporal and spatial. Therefore, it is very important to ask which dimension of market arbitrage appears to be more dominant. As a result, it is of interest to find out whether both pieces of information can be used to describe short-term interest rate movements. To resolve these issues, we conduct the J-test.

The J-test proposed by Davidson and MacKinnon (1981) is designed to test non-nested models. To conduct this test, it is convenient to rewrite Eq. (2) as

$$\Delta r = x\beta + \epsilon, \tag{5}$$

where $x = (I, \Delta R_t, \Delta R_{t-1}, \Delta r_{t-1}, u_{1,t-1})$ and $\beta = (\beta_0, \beta_1, \beta_2, \beta_3, \beta_4)'$. Likewise, we rewrite Eq. (4) as

$$\Delta r = z\gamma + \epsilon, \tag{6}$$

where $z = (I, \Delta r_{it}^*, \Delta r_{it-1}^*, \Delta r_{t-1}, u_{2,t-1})$ and $\gamma = (\gamma_0, \gamma_1, \gamma_2, \gamma_3, \gamma_4)'$.

An integrated model can be expressed as a weighted average of arguments in Eqs. (5) and (6), which is given by

$$\Delta r = (1 - \alpha)x\beta + \alpha z\gamma + \epsilon. \tag{7}$$

The problem we encounter here is that the coefficient α cannot be estimated by using Eq. (7). Thus, to perform the J-test, we must first generate γ by estimating Eq. (6) and then substituting $\hat{\gamma}$ into Eq. (7), which yields

$$\Delta r = x\beta^* + \alpha z\hat{\gamma} + \epsilon, \tag{8}$$

where $\beta^* = (1 - \alpha)\beta$, and $\hat{\gamma}$ is the estimated parameter obtained from Eq. (6). Now we can set up the null hypothesis that $\alpha = 0$. If the null is true, that *plim* $\hat{\alpha} = 0$. Asymptotically, the ratio $\hat{\alpha}/s.e.(\hat{\alpha})$ (i.e., the *t* ratio) is distributed as standard normal. Particularly, if the null is rejected by a *t* test, it means that the international integration hypothesis is significant in explaining the change of short-rate movements.

By the same token, we can test the significance of the domestic short-long spread. In this way, we write Eqs. (9) and (10):

$$\Delta r = (1 - \lambda)z\gamma + \lambda x\beta + \epsilon, \text{ and} \tag{9}$$

$$\Delta r = z\gamma^* + \lambda x\hat{\beta} + \epsilon, \tag{10}$$

where $\gamma^* = (1 - \lambda)\gamma$ and $\hat{\beta}$ is a vector of estimated parameters obtained from Eq. (5).

The hypothesis testing involves examining whether $\lambda = 0$. The rejection of the null suggests the significance of domestic ECM. However, if both null hypotheses are rejected, it means the arguments in both models are significant in explaining the

Table 4

Davidson and MacKinnon's J-tests for two non-nested ECMs

Currency	1-month rate ($R_t = 3\text{-month rate}$)	3-month rate ($R_t = 6\text{-month rate}$)	6-month rate ($R_t = 12\text{-month rate}$)
A. Test for the significance of the international interest parity condition $\Delta r = X\beta^* + \alpha Z\hat{\gamma} + \epsilon$, $H_0: \alpha = 0$			
CD	0.498* (5.58)	0.562* (8.88)	0.470* (6.80)
BP	0.492* (8.30)	0.528* (10.81)	0.568* (12.87)
GM	0.362* (5.71)	0.355* (5.34)	0.484* (7.32)
JY	0.460** (2.13)	0.334** (2.36)	0.328** (2.09)
IL	0.430* (3.43)	0.146 (0.93)	0.561* (4.13)
SF	0.401** (2.21)	0.336* (3.13)	0.342* (3.99)
US	0.445* (5.62)	0.348* (4.92)	0.543* (9.05)
B. Test for the significance of the domestic term-structure relation $\Delta r = Z\gamma^* + \lambda X\hat{\beta} + \epsilon$, $H_0: \lambda = 0$			
CD-US*	0.703* (14.99)	0.537* (12.61)	0.612* (9.81)
BP-US*	0.647* (14.64)	0.565* (14.73)	0.503* (11.00)
GM-US*	0.810* (21.75)	0.774* (20.17)	0.648* (13.65)
JY-US*	0.899* (12.58)	0.866* (12.87)	0.870* (14.17)
IL-US*	0.785* (14.03)	0.933* (6.26)	0.771* (9.41)
SF-US*	0.869* (12.60)	0.789* (11.65)	0.795* (16.15)
US-GM*	0.692* (11.30)	0.707* (13.22)	0.508* (9.02)

*Indicates statistically significant differences from 0 at 1%.

**Indicates statistically significant differences from 0 at 5%.

***Indicates statistically significant differences from 0 at 10%.

Numbers in parentheses are t statistics.Null hypothesis of $\alpha = 0$ is used for testing significance of international interest rate parity condition.Null hypothesis of $\lambda = 0$ is used for testing significance of domestic term-structure element.

behavior of short-term Eurocurrency rates. The results of the J-test are presented in Table 4. For all cases of testing $\lambda = 0$, the t statistics are highly significant, rejecting the null. This suggests that the arguments involved in the term-structure relationship possess significant information to explain the changes of short rates. Similarly, the evidence for testing $\alpha = 0$ indicates that the null hypothesis should be rejected. The

test results support the argument that the international interest rate parity theory is valid for predicting short-rate movements, thus concurring the international integration hypothesis. Evidently, there is a complementary relationship between two-dimensional market arbitrage: intertemporal and international spatial.

On the basis of these findings, we re-estimate the short-term interest rate equations by combining the arguments in both the domestic term structure of interest rates and international interest rate parity ECMs. Two alternative approaches are considered for the model estimations. In the first approach, we combine the information involving two-dimensional market cointegration. In this way, the error-correcting term, u_t , is obtained from Eq. (11), a regression equation:

$$r_t = b_0 + b_1 R_t + b_2 r_{ft}^* + u_t. \quad (11)$$

This equation assumes that r_t is cointegrated with R_t and r_{ft}^* simultaneously. To verify this presumption, we perform Johansen tests (1988, 1991) on the vector of $[r_t \ R_t \ r_{ft}^*]$. As shown in Table 5, both the trace test and the maximum eigenvalue test produce very similar results. The evidence shows that the hypothesis of no cointegrating vector is rejected. The only exception is the 6-month rate for the JY, where the null cannot be rejected. Next, we examine the hypothesis that the number of the cointegrating vectors is at most equal to 1. The null is also rejected. These test results thus suggest that, with the exception of the JY, there are two cointegrating vectors for the system. This means these three variables have a meaningful long-run relationship and do not tend to move too far away from each other. Having derived the error correcting term, we can write the ECM as follows:

$$\begin{aligned} \Delta r_t = & \alpha + \beta_{10} \Delta R_t + \beta_{11} \Delta R_{t-1} + \beta_{20} \Delta r_{ft}^* + \beta_{21} \Delta r_{ft-1}^* + \gamma_1 \Delta r_{t-1} \\ & - \psi u_{t-1} + \epsilon_t \end{aligned} \quad (12)$$

In the second approach to combine term-structure and interest rate parity information, we include both error-correcting terms derived from the long-run equilibrium Eqs. (1) and (3), respectively, into the ECM specification. Specifically, we write

$$\begin{aligned} \Delta r_t = & \alpha + \beta_{10} \Delta R_t + \beta_{11} \Delta R_{t-1} + \beta_{20} \Delta r_{ft}^* + \beta_{21} \Delta r_{ft-1}^* + \gamma_1 \Delta r_{t-1} \\ & - \psi_1 u_{1,t-1} - \psi_2 u_{2,t-1} + \epsilon_t \end{aligned} \quad (13)$$

This specification allows us to detect the relative effect of two alternative adjustment processes. The estimates of Eqs. (12) and (13) are reported in Tables 6 and 7, respectively. The evidence shows that all of the estimated regressions have a relatively high R^2 , ranging from 0.70 to 0.95. These R^2 s derived from the combined error-adjustment effect are higher than those derived from either the domestic term-structure model or the interest rate parity condition. Several empirical findings are worth noting.

First, let us inspect the error-correcting terms. As may be seen in Table 6, all the error-correcting terms have the expected sign, and the coefficients are significant at the one percent level. The absolute values of the coefficients are higher than those we obtained in either the domestic term-structure model or the interest rate parity condition. Next, let us look at the error terms in Table 7. With the exceptions of the

Table 5
Multivariate Johansen cointegration tests on the short and long domestic rates and effective foreign rate

Trace Tests (Tr)				Maximum Eigenvalue Tests (λ_{max})			
H_0	1 & 3-M	3 & 6-M	6 & 12-M	H_0	1 & 3-M	3 & 6-M	6 & 12-M
A. BP-US*							
$r = 0$	113.30*	82.45*	80.92*	$r = 0$	56.51*	51.82*	52.93*
$r \leq 1$	56.79*	30.63*	27.99*	$r = 1$	49.20*	25.12*	22.75*
$r \leq 2$	7.59	5.52	5.24	$r = 2$	7.59	5.52	5.24
B. CD-US*							
$r = 0$	153.52*	95.11*	78.50*	$r = 0$	87.04*	50.12*	46.26*
$r \leq 1$	66.48*	44.99*	32.23*	$r = 1$	62.33*	40.49*	28.85*
$r \leq 2$	4.15	4.50	3.38	$r = 2$	4.15	4.50	3.38
C. GM-US*							
$r \leq 0$	158.55*	65.15*	49.57*	$r = 0$	110.88*	36.04*	29.85*
$r \leq 1$	47.67*	29.11*	19.72	$r = 1$	42.98*	24.21*	15.39
$r \leq 2$	4.69	4.90	4.33	$r = 2$	4.69	4.90	4.33
D. IL-US*							
$r = 0$	155.41*	74.26*	71.49*	$r = 0$	116.30*	46.49*	40.68*
$r \leq 1$	39.11*	27.77*	30.81*	$r = 1$	34.65*	23.50*	27.40*
$r \leq 2$	4.46	4.27	3.41	$r = 2$	4.46	4.27	3.41
E. JY-US*							
$r = 0$	183.33*	70.34*	28.78	$r = 0$	123.01*	62.97*	21.84
$r \leq 1$	60.33*	7.37	6.93	$r = 1$	57.06*	6.39	6.31
$r \leq 2$	3.26	0.99	0.63	$r = 2$	3.26	0.99	0.63
F. SF-US*							
$r = 0$	228.13*	86.36*	102.67*	$r = 0$	132.76*	51.95*	58.83*
$r \leq 1$	95.36*	34.41*	43.84*	$r = 1$	87.66*	27.42*	36.88*
$r \leq 2$	7.70	6.99	6.96	$r = 2$	7.70	6.99	6.96
G. US-GM*							
$t = 0$	174.66*	96.90*	94.35*	$r = 0$	96.06*	62.79*	64.51*
$r \leq 1$	78.60*	34.12*	29.84*	$r = 1$	73.55*	28.92*	25.04*
$r \leq 2$	5.05	5.20	4.80	$r = 2$	5.05	5.20	4.80

*indicates statistically significant at the 5% level. Trace (0.95) and λ_{max} (0.95) are critical values for trace tests and maximum eigenvalue tests at the 95% quartile of the distribution. These critical values were taken from Osterwald-Lenum (1992).

Trace (0.95)		λ_{max} (0.95)	
$r = 0$	34.91	$r = 0$	22.00
$r \leq 1$	19.96	$r = 1$	15.67
$r \leq 2$	9.24	$r = 2$	9.24

3- and 6-month JY rates and the 3-month IL rate, both error-correction terms have negative signs and are highly significant. This finding suggests that there are two-dimensional adjustment processes that operate in a complementary manner, moving toward long-run levels of equilibrium at the same time. Yet, the estimated values of

Table 6
Regression estimates on integrated ECM

$$\Delta r_t = \alpha + \beta_{10}\Delta R_t + \beta_{11}\Delta R_{t-1} + \beta_{20}\Delta r_{t-1}^* + \beta_{21}\Delta r_{t-1}^* + \gamma_1\Delta r_{t-1} - \psi u_{t-1} + \epsilon_t$$

Currency	Constant	ΔR_{t-1}	ΔR_t	ΔR_{t-1}	Δr_{t-1}^*	Δr_{t-1}^*	u_{t-1}	R^2	SEE	DW
A. 1-month rate										
BP-US*	-0.00001 (0.17)	-0.172* (3.35)	0.695* (14.76)	0.004 (0.09)	0.295* (8.80)	0.121* (2.78)	-0.192* (6.86)	0.86	0.0016	2.07
CD-US*	-0.00000 (0.07)	-0.026 (0.35)	0.632* (15.88)	-0.075 (1.61)	0.301* (6.47)	0.099*** (1.88)	-0.230* (4.10)	0.85	0.0011	2.08
GM-US*	0.00000 (0.17)	0.160* (4.33)	0.879* (21.35)	-0.201* (4.26)	0.165* (6.08)	0.046* (3.41)	-0.195* (8.79)	0.84	0.0009	1.96
IL-US*	0.00010 (0.76)	-0.080*** (1.84)	1.072* (15.21)	0.129*** (1.65)	0.233* (3.96)	0.028 (1.13)	0.188* (5.52)	0.89	0.0032	2.02
JY-US*	-0.00000 (0.06)	-0.043 (0.43)	0.916* (12.03)	-0.101 (1.02)	0.103*** (2.46)	0.017 (0.79)	-0.256* (8.14)	0.70	0.0014	1.75
SF-US*	0.00000 (0.09)	0.117** (2.42)	1.043* (12.74)	-0.201* (4.67)	0.135*** (2.50)	0.021 (0.81)	-0.271* (9.11)	0.77	0.0018	1.98
US-GM*	-0.00001 (0.17)	-0.142* (3.13)	0.655* (12.16)	0.037 (0.97)	0.268* (5.94)	0.075* (4.23)	-0.198* (9.12)	0.85	0.0012	2.00
B. 3-month rate										
BP-US*	-0.00000 (0.12)	-0.242* (4.98)	0.593* (15.20)	0.010 (0.26)	0.403* (10.91)	0.196* (9.21)	-0.093* (4.96)	0.91	0.0010	2.11
CD-US*	-0.00000 (0.12)	-0.099** (1.95)	0.465* (12.54)	-0.031 (1.04)	0.476* (9.22)	0.150* (4.78)	-0.147* (5.73)	0.91	0.0008	2.09
GM-US*	-0.00000 (0.15)	-0.051 (1.13)	0.788* (20.08)	-0.068*** (1.87)	0.211* (5.39)	0.102* (5.21)	-0.079* (5.87)	0.88	0.0006	2.05
IL-US*	0.00005 (0.60)	-0.004 (0.13)	1.204* (6.28)	0.091 (0.92)	0.058 (0.82)	-0.049 (1.26)	-0.052* (2.68)	0.80	0.0026	1.96
JY-US*	-0.00000 (0.14)	-0.029 (0.51)	0.855* (12.90)	-0.048 (0.78)	0.127*** (2.45)	0.060 (1.51)	-0.076* (4.02)	0.83	0.0009	2.00
SF-US*	0.00000 (0.15)	-0.187* (4.48)	0.851* (11.55)	0.124* (3.51)	0.213* (3.22)	0.084* (3.01)	-0.108* (5.26)	0.88	0.0009	2.04
US-GM*	-0.00000 (0.14)	-0.069 (1.23)	0.700* (13.52)	-0.026 (0.77)	0.272* (5.09)	0.100* (3.10)	-0.107* (6.11)	0.95	0.0007	2.04

(continued)

Table 6
(Continued)

$$\Delta r_t = \alpha + \beta_{10}\Delta R_t + \beta_{11}\Delta R_{t-1} + \beta_{20}\Delta r_{t-1}^* + \beta_{21}\Delta r_{t-1}^{**} + \gamma_1\Delta r_{t-1} + \psi u_{t-1} + \epsilon_t$$

Currency	Constant	Δr_{t-1}	ΔR_t	ΔR_{t-1}	Δr_{t-1}^*	Δr_{t-1}^{**}	u_{t-1}	R^2	SEE	DW
C. 6-month rate										
BP-US*	-0.00000 (0.02)	-0.286* (7.68)	0.537* (11.30)	0.055*** (1.78)	0.461* (13.07)	0.227* (7.44)	-0.091* (5.15)	0.92	0.0009	2.12
CD-US*	-0.00001 (0.23)	-0.228* (5.89)	0.580* (9.73)	0.068** (2.25)	0.392* (6.80)	0.170* (5.41)	-0.162* (4.20)	0.91	0.0008	2.11
GM-US*	0.00000 (0.01)	-0.147* (4.22)	0.649* (13.78)	0.035 (1.34)	0.341* (7.54)	0.147* (4.82)	-0.066* (5.13)	0.89	0.0005	2.09
IL-US*	0.00001 (0.20)	-0.013 (0.21)	0.688* (9.38)	0.084 (1.17)	0.268* (4.12)	0.025 (0.97)	-0.147* (3.07)	0.78	0.0019	1.97
JY-US*	-0.00000 (0.06)	-0.012 (0.19)	0.919* (14.06)	-0.031 (0.54)	0.137** (2.27)	0.040 (0.94)	-0.067* (3.81)	0.80	0.0008	1.98
SF-US*	-0.00000 (0.02)	-0.100** (2.36)	0.846* (16.20)	0.049 (1.14)	0.203* (4.11)	0.077* (3.04)	-0.090* (5.70)	0.86	0.0008	2.02
US-GM*	-0.00000 (0.16)	-0.149* (2.79)	0.564* (9.18)	-0.024 (0.59)	0.464* (9.23)	0.152* (4.12)	-0.136* (5.38)	0.95	0.0006	2.07

See Table 2 for legend.

Table 7
Regression estimates on two-dimensional ECM

$$\Delta r_t = \alpha + \beta_{10}\Delta R_t + \beta_{11}\Delta R_{t-1} + \beta_{20}\Delta r_{t-1}^* + \beta_{21}\Delta r_{t-1}^{**} + \gamma_1\Delta r_{t-1} + \gamma_2\Delta r_{t-1}^* - \psi_1u_{1,t-1} - \psi_2u_{2,t-1} + \epsilon_t$$

Currencies	Constant	Δr_{t-1}	ΔR_t	ΔR_{t-1}	Δr_{t-1}^*	Δr_{t-1}^{**}	$u_{1,t-1}$	$u_{2,t-1}$	R^2	SEE	DW
A. 1-month rate											
CD-US*	-0.00000 (0.09)	-0.027 (0.37)	0.633* (15.75)	-0.084*** (1.82)	0.296* (6.22)	0.106** (2.03)	-0.130* (6.22)	-0.094* (3.09)	0.85	0.0011	2.09
BP-US*	-0.00001 (0.17)	-0.173* (3.39)	0.695* (14.51)	0.005 (0.11)	0.295* (8.52)	0.123* (2.87)	-0.108* (5.25)	-0.081* (4.56)	0.86	0.0016	2.37
GM-US*	0.00000 (0.17)	0.160* (4.30)	0.880* (21.04)	-0.204* (4.29)	0.162* (5.71)	0.049* (3.92)	-0.150* (8.75)	-0.041* (3.93)	0.84	0.0009	1.96
IL-US*	0.00010 (0.81)	-0.077*** (1.76)	1.087* (13.70)	0.121 (1.54)	0.221* (3.48)	0.038 (1.63)	-0.192* (6.43)	-0.002* (0.16)	0.89	0.0032	2.02
JY-US*	-0.00000 (0.06)	-0.048 (0.48)	0.914* (11.56)	-0.088 (0.87)	0.105** (2.27)	0.016 (0.87)	-0.165* (7.24)	-0.082* (4.37)	0.70	0.0014	1.75
SF-US*	0.00000 (0.09)	0.114** (2.30)	1.042* (12.31)	-0.199* (4.38)	0.133** (2.29)	0.023 (1.03)	-0.181* (7.57)	-0.083* (4.25)	0.77	0.0018	1.98
US-GM*	-0.00001 (0.18)	-0.144* (3.19)	0.651* (11.08)	0.042 (1.06)	0.272* (5.55)	0.072* (4.36)	-0.089* (4.85)	-0.109* (5.07)	0.85	0.0012	2.00
B. 3-month rate											
BP-US*	-0.00000 (0.12)	-0.242* (4.91)	0.597* (14.85)	0.007 (0.18)	0.399* (10.43)	0.198* (9.46)	-0.046* (4.54)	-0.045* (2.99)	0.91	0.0010	2.11
CD-US*	-0.00000 (0.13)	-0.102** (2.01)	0.470* (12.66)	-0.039 (1.36)	0.466* (9.08)	0.159* (4.77)	-0.066* (6.20)	-0.077* (3.97)	0.91	0.0008	2.10
GM-US*	-0.00000 (0.15)	-0.051 (1.13)	0.790* (20.03)	-0.071*** (1.95)	0.209* (5.27)	0.104* (5.47)	-0.054* (5.44)	-0.024* (3.47)	0.88	0.0006	2.05
IL-US*	0.00005 (0.58)	-0.004 (0.12)	1.197* (6.23)	0.093 (0.93)	0.062 (0.89)	-0.053 (1.28)	-0.049** (2.32)	-0.003 (0.26)	0.81	0.0026	1.95
JY-US*	-0.00000 (0.16)	-0.030 (0.53)	0.855* (12.86)	-0.050 (0.82)	0.126*** (2.40)	0.064*** (1.71)	-0.067* (3.90)	0.006 (1.13)	0.83	0.0009	2.00
SF-US*	0.00000 (0.15)	-0.187* (4.48)	0.851* (11.47)	0.124* (3.50)	0.213* (3.19)	0.084* (3.08)	-0.060* (4.29)	-0.048* (4.87)	0.88	0.0009	2.04
US-GM*	-0.00000 (0.14)	-0.069 (1.21)	0.701* (13.17)	-0.027 (0.77)	0.271* (4.95)	0.101* (3.16)	-0.027** (2.50)	-0.079* (4.35)	0.95	0.0007	2.04

(continued)

Table 7
(Continued)

$$\Delta r_t = \alpha + \beta_{10}\Delta R_t + \beta_{11}\Delta R_{t-1} + \beta_{20}\Delta r_{t-1}^* + \beta_{21}\Delta r_{t-1}^{**} + \gamma_1\Delta r_{t-1} + \gamma_2\Delta r_{t-1} - \psi_1 u_{1,t-1} - \psi_2 u_{2,t-1} + \epsilon_t$$

Currencies	Constant	Δr_{t-1}	ΔR_t	ΔR_{t-1}	Δr_{t-1}^*	Δr_{t-1}^{**}	$u_{1,t-1}$	$u_{2,t-1}$	R ²	SEE	DW
C. 6-month rate											
BP-US*	-0.00000 (0.02)	-0.287* (7.72)	0.538* (11.05)	0.055*** (1.81)	0.460* (12.76)	0.228* (7.59)	-0.027* (3.35)	-0.063* (3.93)	0.92	0.0009	2.12
CD-US*	-0.00001 (0.23)	-0.229* (5.91)	0.584* (9.68)	0.065*** (2.05)	0.387* (6.63)	0.175* (5.55)	-0.052* (4.33)	-0.107* (3.38)	0.91	0.0008	2.11
GM-US*	0.00000 (0.01)	-0.147* (4.22)	0.649* (13.64)	0.034 (1.30)	0.340* (7.43)	0.148* (4.90)	-0.025* (4.36)	-0.040* (4.06)	0.89	0.0005	2.09
IL-US*	0.00001 (0.20)	-0.014 (0.23)	0.668* (9.15)	0.086 (1.19)	0.267* (4.11)	0.026 (1.05)	-0.090* (3.63)	-0.054** (2.36)	0.78	0.0019	1.97
JY-US*	-0.00000 (0.08)	-0.014 (0.22)	0.919* (14.13)	-0.033 (0.55)	0.136** (2.24)	0.045 (1.12)	-0.062* (3.54)	-0.003 (0.63)	0.80	0.0008	1.98
SF-US*	-0.00000 (0.02)	-0.100** (2.36)	0.851* (16.08)	0.045 (1.03)	0.198* (3.99)	0.082* (3.23)	-0.050* (4.28)	-0.037* (2.79)	0.86	0.0008	2.03
US-GM*	-0.00000 (0.16)	-0.149* (2.79)	0.563* (9.02)	-0.023 (0.56)	0.465* (9.10)	0.151* (4.14)	-0.009 (1.31)	-0.128* (5.01)	0.95	0.0006	2.07

See Table 2 for legend.

the coefficients for $u_{1,t-1}$ in general are higher than those of $u_{2,t-1}$, indicating that the domestic term-structure force carries more weight in the adjustment process.

It is important to point out that the estimated coefficients of the error-correcting terms from Eq. (12), ψ , are approximately equal to the sum of the values of two error-correcting terms, $\psi_1 + \psi_2$, based on Eq. (13). This suggests that the information of the combined error-correcting term, u_{t-1} , summarizes the effects that come from domestic, $u_{1,t-1}$, and international, $u_{2,t-1}$, adjustment processes.

Second, all the contemporaneous terms of the change in the long rates and the change of the effective foreign short rates (Eurodollar rates plus forward premium on U.S. dollar) shown in both Tables 6 and 7 have a positive sign and are highly statistically significant. In addition, the one-period lagged rates are also significant in about half the cases, although they are much weaker. In terms of magnitude, the current change in long rates is, in general, larger than that of effective foreign short rates. Thus, the evidence favors the elements involved in utilizing the domestic term structure of interest rates to describe the short-rate movements.

6. Conclusion

This paper investigates short-term interest rate behavior, applying the data from seven Eurocurrency rates. Unit-root tests suggest that both levels of short-end Eurocurrency deposit rates and effective foreign interest rates (Eurodollar deposit rates plus forward premiums) are nonstationary. We find evidence for two-dimensional cointegration: the domestic short rate cointegrated with the long rate of the same currency and the domestic short rate cointegrated with the effective foreign short rate having the same maturity.

By building on established evidence that the short-term interest rate is more appropriate for specification in an error-correction model based on the domestic term-structure relationship (Chiang & Chiang, 1995), this paper adds a new element to the model: the international interest rate parity ECM. Our empirical evidence indicates that both error-correcting terms, derived from the domestic term-structure relationship and the interest rate parity condition, are highly significant. Thus, these two error-correcting terms can be used simultaneously to predict subsequent short-rate movements. Yet, when the estimations are based on the combined error-correcting term, by regressing the domestic short rate on both the domestic long rate and the effective foreign short rate, the estimated value of this coefficient in the ECM is approximately equal to the sum of two individual error-correcting terms, producing a combined effect in predicting short rates.

This finding has an important policy implication, because our evidence indicates that market adjustments react not only to the deviations of the current short rate from its long-run level, but also to the divergences of international interest rates. To make monetary policy effective and at the same time maintain a stable financial market system, a closer coordination between international monetary authorities is necessary.

Our evidence also suggests that the domestic long rate and the comparable effective

foreign short rate are highly significant in explaining short-term interest rate behavior. We conclude that both arguments shown in the domestic term structure of interest rates as well as the international interest rate parity equation are relevant for predicting short-term interest rates. Although these two market arbitrages are complementary, the domestic term-structure elements appear to have more significant explanatory power than does the international dimension.

Notes

1. The sample period spans June 1, 1973, to August 2, 1996. This period applies to the data for the U.S. dollar, GM, and SF. However, with the same ending period, the starting periods for the data series vary across the other currencies and maturities. For the case of BP, the starting period is June 1, 1973, for the 1-, 3-, and 6-month rates and September 21, 1973, for the 12-month rate. In the case of CD, the sample period starts from August 17, 1979, for 1-, 3-, and 6-month rates and September 21, 1973, for the 12-month rate. In the case of JY, the sample period starts from January 6, 1978, for the 3-, 6-, and 12-month rates and January 5, 1979, for the 1-month rate. For the IL, all the data start from October 3, 1980. For the foreign exchange rates, with the exceptions of 12-month forward exchange rates for JY and IL, all sample periods start from June 1, 1973. The data for the 12-month forward exchange rate starts from December 28, 1973, for IL and January 18, 1974, for JY. French franc rates were excluded from our study because their failure to satisfy the necessary condition of the cointegration tests.
2. Similar results were obtained from the Phillips and Perron test (1998).
3. Johansen (1988, 1991) and Johansen and Juselius (1990) provide an alternative approach for investigating cointegration relations on the multivariate approach. According to Johansen's approach, the cointegrating vectors are determined by the ranks in the cointegrating matrix, suggesting two likelihood-ratio statistics to determine the number of cointegrating vectors. These two statistics are trace statistics and maximum eigenvalue statistics. The trace statistic is defined as: $-2\ln(Q) = -T \sum_{i=r+1}^p \ln(1 - \hat{\lambda}_i)$, where $\hat{\lambda}_{r+1}, \dots, \hat{\lambda}_p$ are the $p - r$ smallest eigenvalues. The trace statistic tests the null hypothesis that the number of distinct cointegrating vectors is less than or equal to r against a general alternative. Next, the maximum eigenvalue statistic is given by $-2\ln(Q) = -T\ln(1 - \lambda_{r+1})$. The null hypothesis tested by the maximum eigenvalue statistic is that the number of cointegrating vectors is r against the alternative, $r + 1$ cointegrating vectors. Consistent with the results presented in the text, the Johansen tests indicate that the null hypothesis of no cointegrating vector between two joint Eurocurrency rates within a given country is rejected for all maturities. The results hold true for testing the cointegration between the domestic short rate and effective foreign rate for the 3- and 6-month maturities. However, the null cannot be rejected for the 6- and 12-month rates. This implies that the

international adjustment is more sensitive and effective for the short-end horizons. To save space, the Johansen test results are not reported here.

4. To achieve a consistent estimator, the White (1980) and Newey and West (1985) procedure has been used to obtain the estimates in Tables 2, 3, and 5. The White-Newey-West estimate of the variance–covariance matrix allowing for conditional heteroskedasticity is given by $\hat{V}(\hat{\beta}) = (X'X)^{-1}\hat{W}(X'X)^{-1}$, where X denotes the right-hand side variables. The matrix \hat{W} is calculated by

$$\hat{W} = \sum_{k=-L}^L \{1 - [|k|/(L + 1)]\}^{\theta} \sum_{t=1}^T \hat{u}_t x_t x'_{t-k} \hat{u}'_{t-k}.$$

When θ is equal to 0, the weight becomes unity and \hat{W} reduces to Hansen and Hodrick's specification (1980). A special case occurs when $\theta = 1$, which is the smallest value that guarantees a positive definite matrix (Doan, 1991).

5. Our testing results (not reported) indicate that both $[b_{10} \ b_{11}]' = [0 \ 1]'$ and $[b_{20} \ b_{21}]' = [0 \ 1]'$ are rejected in most cases. This evidence means that $u_{1,t}$ and $u_{2,t}$ are not necessarily equal to $(r_t - R_t)$ and $(r_t - r_t^*)$, respectively. However, $u_{1,t}$ and $u_{2,t}$ do summarize some information about return spreads, imperfect substitutability, and different preferences toward different instruments. From the econometric point of view, the error-correcting terms, such as $u_{1,t}$ and $u_{2,t}$, possess useful informational content for predicting future interest rate movements.
6. Note that the magnitudes of the coefficients of the error-correction terms in this study are consistently smaller than those of Chiang and Chiang (1995). This result comes from the use of a different frequency of the data. Chiang and Chiang (1995) use monthly data, while we use weekly data; thus, the coefficients of the error-correction terms represent a weekly adjustment rather than a monthly adjustment.

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