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The expectations hypothesis of the term structure: tests on US, German, French, and UK Euro-rates

Eric Jondeau *, Roland Ricart

Banque de France, 31 rue Croix des Petits Champs, 75049 Paris, France

Abstract

This paper tests the expectations hypothesis of the term structure on US, German, French, and UK Euro-rates. Three tests are examined: the first is based on forward rates and the other two are based on the interest rates spread. First, we show that the 'sign puzzle' highlighted by Campbell and Shiller (Campbell, J.Y., Shiller, R.J., 1991. Yield spreads and interest rate movements: a bird's eye view. Review of Economic Studies 58, 495–514) for US data does not arise in the cases of French and UK short-term rates. Second, we propose tests for the expectations hypothesis based on error-correction models. With these tests the sign puzzle disappears, but the 'country puzzle' remains.

JEL classification: E43

Keywords: Term structure of interest rates; Expectations hypothesis; Error-correction model

1. Introduction

The relationship between long-term and short-term interest rates has long been recognized as playing an important role for macroeconomic modelling and the conduct of monetary policy. A convenient way to deal with the term structure is the expectations hypothesis (EH), which states that the long-term interest rate is an average of expected future short-term rates, plus a time-independent risk premium. The EH has received a great deal of attention in the empirical literature, however the

* Corresponding author. Tel.: +33-142-92-49-89; fax: +33-142-92-27-66.
E-mail address: ejondeau@banque-france.fr (E. Jondeau)

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empirical evidence varies from one study to the next depending on the precise implication tested, the segment of the yield curve examined or the period under study.

If we focus first on US rates, the implications of the EH have long been contested by empirical work (see Shiller, 1990, for a survey). Three *standard* implications have been more specifically studied. The fist one states that the forward rate is an unbiased predictor of future spot rates (Fama, 1984; Fama and Bliss, 1987; Mishkin, 1988). In the second and third specifications, the term spread—the spread between the long-term rate and the short-term rate—is an unbiased predictor of future short-run changes in long-term rates as well as of future cumulative changes in short-term rates (Mankiw, 1986; Mankiw and Miron, 1986; Campbell and Shiller, 1991; Evans and Lewis, 1994; Campbell, 1995). Although forward rates seem to have some ability to forecast future spot rates, the results for term spreads are much more puzzling: the term spread is a good predictor of future cumulative changes in short-term rates (although these move by less than predicted by the EH), but a rise of the spread is generally followed by a subsequent decrease, rather than an increase, in the long-term rate. This 'sign puzzle' has been highlighted by Campbell and Shiller (1991) and more recently by Hardouvelis (1994).

The international evidence on the EH is also puzzling. Recent work on the short-end of the yield curve (for securities with a maturity of one year or less) shows that the EH is more often accepted when European data are studied. In an international comparison based on the ability of the spread to forecast cumulative changes in short-term rates, Gerlach and Smets (1997) conclude that the term structure of Euro-dollar rates is the least favorable to the EH, while for Belgium, France, Germany, Italy, and Spain they find more empirical support for the EH. Using the same approach, Hurn et al. (1995) also obtain results in favor of the EH from interest rates on the UK interbank market. Dahlquist and Jonsson (1995), using a test based on the forward rate, are unable to reject the EH from interest rates for Swedish Treasury bills. From this work, it appears that the rejection of the EH is less clear-cut for non-US countries.

Concerning the yield curve for maturities of more than one year, some studies also find that non-US data are, if anything, more supportive of the EH than US data. In their tests based on the forward rate for Germany, Switzerland, the UK, and the US, between 1973 and 1989, Jorion and Mishkin (1991) find some support for the EH: regressing the change in spot rate on the forward-spot spread yields coefficients which are not statistically significantly different from unity. For the US, however, these coefficients are negative, for the shortest maturity pairs. Moreover, using data on 3-month and 10-year rates for the G7 countries, Hardouvelis (1994) studies the ability of the term spread to forecast future changes in long-term rates. He shows that the EH is easily supported in all countries studied except the US.

The approach developed in this paper is based on the fact that interest rates are likely to be non-stationary. This property is implicitly taken into account in the formulation of the standard tests of the EH by using spreads and changes in interest rates. Nevertheless, the dynamics of interest rates should be specified in the form of an error-correction model (ECM), as shown by Engle and Granger (1987). This omission in the standard tests could lead to specification biases.[1]

[1] See Hakkio and Rush (1989) in the context of exchange rate modelling.

In this paper, we test the EH using end-of-month US, German, French, and UK Euro-rates between January 1975 and December 1997. The main empirical findings are as follows. Using the *standard approach*, we obtain the 'country puzzle': the EH is supported by the data for France and the UK, independently of the specification tested; however for the US and Germany it is rejected. For the latter two countries, we find the 'sign puzzle': the slope parameter is close to unity when the term spread is used to predict cumulative changes in the short-term rates; but it is negative when the spread is used to predict short-run changes in the long-term rates. Using the *ECM approach*, the sign puzzle disappears, and the estimated coefficients are generally close to the value predicted by the EH. However, the country puzzle remains.

The remainder of the paper is organized as follows. Section 2 presents the three standard tests of the EH and the empirical results obtained for the four countries studied. Section 3 deals with the tests of the EH in an ECM framework. In Section 4, we propose some interpretations of the results obtained with the standard approach and the ECMs. Our conclusions are summarized in Section 5.

2. The EH according to the standard approach

2.1. Definition of risk premia

The EH states that two investment strategies applied at t for the same horizon must have the same expected yield, up to a term premium, which is supposed constant over time but possibly maturity-dependent. Shiller (1990) defines three different time-independent term premia.

The *forward term premium* $\varphi_f^{(m,n)}$ is the difference between the yield on a forward investment at t in $n-m$ periods on a security maturing at $t+n$ and the expected yield at t on an investment at time $t+n-m$ on a security maturing at $t+n$:

$$\varphi_f^{(m,n)}=f_t^{(m,n)}-E_t r_{t+n-m}^{(m)},\ \ 0<m<n, \tag{1}$$

where E_t denotes the mathematical expectation conditional on information available at time t and $r_t^{(m)}$ is the yield at time t of a zero-coupon bond with a maturity of m. The forward rate is the yield at t on holding a zero-coupon bond with a maturity of m from $t+n-m$ to $t+n$. It is evaluated as:

$$f_t^{(m,n)}=\frac{1}{m}(nr_t^{(n)}-(n-m)r_t^{(n-m)}).$$

The *holding-period term premium* $\varphi_h^{(m,n)}$ is the difference between the expected yield at t from buying at t a security maturing at $t+n$, and selling it at $t+m$, and the yield on a spot purchase at t of a security maturing at $t+m$:

$$\varphi_h^{(m,n)}=E_t h_t^{(m,n)}-r_t^{(m)},\ \ 0<m<n, \tag{2}$$

where the holding-period return is the yield at t from the purchase of a zero-coupon bond with a remaining maturity of n that is sold at $t+m$. It is written as:

$$h_t^{(m,n)}=\frac{1}{m}(nr_t^{(n)}-(n-m)r_{t+m}^{(n-m)})$$

Lastly, the *roll-over term premium* $\varphi_k^{(m,n)}$ is the difference between the yield on the spot purchase at t of a security maturing at $t+n$, and the expected yield at t of a sequence of purchases at t, $t+m,\ldots,$ $t+n-m$ of securities with a remaining maturity of m:

$$\varphi_k^{(m,n)}=r_t^{(n)}-E_t k_t^{(m,n)},\ \ 0<m<n, \tag{3}$$

where $\frac{n}{m}$ is an integer. The roll-over return is the yield at t from successive purchases at t, $t+m,\ldots,$ $t+n-m$ of zero-coupon bonds with remaining maturities of m. It is written as:

$$k_t^{(m,n)}=\frac{m}{n}\sum_{i=0}^{\frac{n}{m}-1} r_{t+im}^{(m)}.$$

2.2. The specifications based on the standard approach

Three tests can be directly derived from Eqs. (1)–(3). In each case, the relationship is specified with a change in an interest rate on the LHS and a spread on the RHS. This is done to take account of the possible non-stationarity of interest rates.

The first equation is based on the relationship between the expected change in the spot rate and the forward-spot spread:

$$E_t r_{t+n-m}^{(m)}-r_t^{(m)}=(f_t^{(m,n)}-r_t^{(m)})-\varphi_f^{(m,n)} \tag{4}$$

The second equation is based on the relationship between the expected change in the yield of a long-term bond and the term spread:

$$E_t r_{t+m}^{(n-m)}-r_t^{(n)}=\frac{m}{n-m}(r_t^{(n)}-r_t^{(m)})-\frac{m}{n-m}\varphi_h^{(m,n)} \tag{5}$$

The third equation is based on the relationship between the average expected change in the future short-term rate over a long period of time and the term spread:

$$E_t k_t^{(m,n)}-r_t^{(m)}=(r_t^{(n)}-r_t^{(m)})-\varphi_k^{(m,n)} \tag{6}$$

with

$$E_t k_t^{(m,n)}-r_t^{(m)}=\frac{n}{m}\sum_{i=1}^{\frac{n}{m}-1}\sum_{j=1}^{im} E_t\Delta r_{t+j}^{(m)}.$$

Eq. (4) indicates that when the forward rate is greater than the spot rate, then agents expect an increase in the future spot rate. Eqs. (5) and (6) show that an increase in the term spread should be accompanied by a future increase in both long-term rates and short-term rates. The initial spread will decrease however, as the short-term rate should rise by more than the long-term rate (if $n>2m$).

Since the Eqs. (4)–(6) are directly derived from the EH, if one of them holds for any m and any n, then the other two should also hold for any m and any n. Nevertheless, these different specifications have been extensively studied in the empirical literature, because they enable one to focus on different aspects of the EH. Each of them can be useful for examining a different aspect of the EH.

2.3. The empirical results

We consider Euro-rates at four maturities (one month, three months, six months, and one year) and for four countries (the US, Germany, France, and the UK). The sample covers the period from January 1975 to December 1997. The data are end-of-month averages of bid and ask quotes, giving us 276 observations. The data come from Datastream. Interest rates are expressed as continuously compounded zero-coupon rates, as recommended by McCulloch (1993) and Shea (1992).[2] The choice of Euro-rates stems from a concern for homogeneity between the markets under study, which allows international comparisons of the results.

In Table 1, we report the results of ADF tests for the different data series. It appears that zero-coupon rates, which are the basis for defining all of the other yields, are all integrated of order one at a 5% significance level in all countries and for all maturities. In most of the cases (except for (m,n)=(3,12) and (6,12) months in the US), the term spreads and the forward-spot spreads can be considered as stationary. This implies that for almost all pairs of maturities, the standard regressions are well balanced: the LHS variable as well as the RHS variable are stationary.

Eqs. (4)–(6) are then used to test the EH. Their estimation requires a further assumption of rational expectations. Indeed, under this additional assumption, Eqs. (4)–(6) can be rewritten in regression form as:

$$r_{t+n-m}^{(m)}-r_t^{(m)}=\alpha_f+\beta_f(f_t^{(m,n)}-r_t^{(m)})+u_{f,t+n-m}, \tag{7}$$

$$r_{t+m}^{(n-m)}-r_t^{(n)}=\alpha_h+\beta_h\frac{m}{n-m}(r_t^{(n)}-r_t^{(m)})+u_{h,t+m}, \tag{8}$$

$$k_t^{(m,n)}-r_t^{(m)}=\alpha_k+\beta_k(r_t^{(n)}-r_t^{(m)})+u_{k,t+n-m}, \tag{9}$$

where $u_{i,t}$, $i=f, h, k$, is an error term.

[2] Interest rates for intermediate maturities (used to compute some forward rates and holding rates) are not available for the whole period, so they are obtained by linear interpolation. This technique is admittedly imperfect, but it provides uniform data and avoids the inherent estimation problems in complex interpolation procedures.

Table 1
Unit root tests[d]

m,n	The US	Germany	France	The UK
Interest Rate				
1	−1.599	−2.437	−1.836	−1.886
3	−1.370	−2.839[c]	−1.500	−1.963
6	−1.628	−2.577[c]	−1.542	−1.980
12	−1.432	−2.648[c]	−1.145	−2.291
Term spread				
1,3	−8.121[a]	−3.131[b]	−8.747[a]	−3.844[a]
1,6	−3.282[b]	−3.466[a]	−7.530[a]	−4.647[a]
1,12	−3.480[a]	−3.337[b]	−6.617[a]	−4.380[a]
3,6	−3.588[a]	−3.382[b]	−3.396[b]	−5.064[a]
3,12	−2.485	−3.472[a]	−4.568[a]	−3.889[a]
6,12	−2.580[c]	−3.674[a]	−4.199[a]	−3.571[a]
Forward-spot spread				
1,3	−8.121[a]	−3.313[b]	−8.747[a]	−3.844[a]
1,6	−3.392[b]	−3.242[b]	−7.106[a]	−5.145[a]
1,12	−3.076[b]	−3.530[a]	−4.383[a]	−3.413[b]
3,6	−3.588[a]	−3.382[b]	−3.396[b]	−5.064[a]
3,12	−1.988	−3.763[a]	−6.876[a]	−3.365[b]
6,12	−2.580[c]	−3.674[a]	−4.199[a]	−3.571[a]
Ex-post forward term premium				
1,3	−5.014[a]	−5.766[a]	−5.610[a]	−5.497[a]
1,6	−4.127[a]	−3.391[b]	−3.623[a]	−4.986[a]
1,12	−3.491[a]	−3.427[b]	−3.748[a]	−4.163[a]
3,6	−4.339[a]	−3.846[a]	−9.330[a]	−4.696[a]
3,12	−2.511	−3.013[b]	−5.971[a]	−3.034[b]
6,12	−3.042[b]	−3.870[a]	−5.516[a]	−3.604[a]
Ex-post holding term premium				
1,3	−5.484[a]	−6.180[a]	−8.793[a]	−5.758[a]
1,6	−5.344[a]	−4.217[a]	−11.430[a]	−5.586[a]
1,12	−6.487[a]	−3.829[a]	−8.340[a]	−7.365[a]
3,6	−4.339[a]	−3.846[a]	−9.330[a]	−4.696[a]
3,13	−4.139[a]	−3.545[a]	−8.172[a]	−5.066[a]
6,12	−3.042[b]	−3.870[a]	−5.516[a]	−3.604[a]
Ex-post rollover term premium				
1,3	−4.893[a]	−5.654[a]	−9.040[a]	−5.895[a]
1,6	−5.213[a]	−4.061[a]	−4.222[a]	−5.277[a]
1,12	−3.913[a]	−3.179[b]	−4.252[a]	−4.817[a]
3,6	−4.339[a]	−3.846[a]	−9.330[a]	−4.696[a]
3,12	−2.632[c]	−3.261[b]	−4.783[a]	−4.586[a]
6,12	−3.042[b]	−3.870[a]	−5.516[a]	−3.604[a]

[a] Statistics are significant at the 1% significance level.
[b] Statistics are significant at the 5% significance level.
[c] Statistics are significant at the 10% significance level.
[d] The Table presents augmented Dickey and Fuller *t*-statistics of the hypothesis H_0:φ=0 in the following regression: $\Delta x_t = \mu + \varphi x_{t-1} + \Sigma^{l}_{i=1} \theta_i \Delta x_{t-i} + u_t$, where x_t is the interest rate and u_t is the error term. The order of the autoregressive process, *l*, is selected in order to whiten the residuals. The critical values are from Fuller (1976).

In its 'pure' form, the EH implies that α_i=0 and β_i=1, but, in empirical work, the null premium hypothesis (α_i=0) is often neglected to concentrate on parameter β_i being equal to one. This is consistent with risk premia that are constant over time, but maturity dependent.

Table 2 shows the estimates of β_i, i=f, h, k, the asymptotic standard deviations,

Table 2
Estimate of standard specifications[a]

m,n	Eq. (7)		Eq. (8)		Eq. (9)	
	β_f (s.e)	$\bar{R}^2$ (p-val)	β_h (s.e)	$\bar{R}^2$ (p-val)	β_k (s.e)	$\bar{R}^2$ (p-val)
The US						
1,3	0.447	0.049	−0.322	0.001	0.525	0.062
	(0.17)	(0.00)	(0.30)	(0.00)	(0.19)	(0.03)
1,6	0.395	0.043	−0.818	0.010	0.505	0.064
	(0.20)	(0.02)	(0.42)	(0.00)	(0.17)	(0.03)
1,12	0.368	0.067	−0.505	0.001	0.465	0.090
	(0.19)	(0.03)	(0.47)	(0.01)	(0.16)	(0.02)
3,6	0.308	0.013	−0.381	0.003	0.308	0.013
	(0.29)	(0.03)	(0.57)	(0.06)	(0.29)	(0.08)
3,12	0.241	0.024	−0.470	0.004	0.349	0.041
	(0.17)	(0.01)	(0.84)	(0.28)	(0.20)	(0.04)
6,12	0.337	0.029	−0.326	0.004	0.337	0.029
	(0.25)	(0.08)	(0.51)	(0.11)	(0.25)	(0.07)
Germany						
1,3	0.581	0.131	0.255	0.000	0.702	0.166
	(0.09)	(0.00)	(0.26)	(0.01)	(0.10)	(0.02)
1,6	0.454	0.095	−0.179	−0.003	0.568	0.137
	(0.15)	(0.03)	(0.34)	(0.01)	(0.12)	(0.01)
1,12	0.538	0.134	−0.528	0.003	0.558	0.139
	(0.21)	(0.28)	(0.41)	(0.00)	(0.20)	(0.19)
3,6	0.335	0.034	−0.329	0.006	0.335	0.034
	(0.13)	(0.01)	(0.26)	(0.00)	(0.13)	(0.02)
3,12	0.484	0.093	−0.525	0.012	0.459	0.080
	(0.22)	(0.28)	(0.34)	(0.01)	(0.22)	(0.25)
6,12	0.367	0.039	−0.265	0.002	0.367	0.039
	(0.20)	(0.09)	(0.40)	(0.11)	(0.20)	(0.08)
France						
1,3	0.761	0.205	1.090	0.054	0.978	0.276
	(0.23)	(0.35)	(0.27)	(0.72)	(0.24)	(0.89)
1,6	0.912	0.383	0.854	0.034	1.018	0.436
	(0.13)	(0.53)	(0.26)	(0.57)	(0.15)	(0.90)
1,12	0.718	0.320	0.619	0.016	0.893	0.495
	(0.08)	(0.01)	(0.27)	(0.16)	(0.08)	(0.24)
3,6	0.982	0.293	0.948	0.087	0.982	0.293
	(0.22)	(0.99)	(0.44)	(0.88)	(0.22)	(0.92)
3,12	0.649	0.246	0.633	0.036	0.859	0.397
	(0.14)	(0.04)	(0.45)	(0.52)	(0.11)	(0.28)
6,12	0.757	0.214	0.514	0.027	0.757	0.214
	(0.12)	(0.09)	(0.23)	(0.12)	(0.12)	(0.09)

(continued on next page)

Table 2
continued

m,n	Eq. (7)		Eq. (8)		Eq. (9)	
	β_f (s.e)	$\bar{R}^2$ (p-val)	β_h (s.e)	$\bar{R}^2$ (p-val)	β_k (s.e)	$\bar{R}^2$ (p-val)
The UK						
1,3	0.696	0.148	0.070	−0.004	0.726	0.142
	(0.14)	(0.07)	(0.30)	(0.00)	(0.14)	(0.08)
1,6	0.639	0.164	0.174	−0.003	0.722	0.194
	(0.15)	(0.10)	(0.35)	(0.02)	(0.16)	(0.19)
1,12	0.840	0.261	0.339	−0.001	0.834	0.260
	(0.19)	(0.55)	(0.43)	(0.14)	(0.20)	(0.61)
3,6	0.690	0.120	0.380	0.007	0.690	0.120
	(0.18)	(0.21)	(0.36)	(0.19)	(0.18)	(0.24)
3,12	0.825	0.208	0.474	0.006	0.813	0.202
	(0.22)	(0.60)	(0.49)	(0.40)	(0.23)	(0.62)
6,12	0.811	0.134	0.618	0.019	0.811	0.134
	(0.24)	(0.56)	(0.49)	(0.59)	(0.24)	(0.59)

[a] The Table reports the estimates of Eqs. (7)–(9). The estimates relate to the period 1975–97. The estimates of the constant are not shown. Asymptotic standard deviations, shown in parentheses, are corrected for overlapping (Hansen and Hodrick, 1980) and for heteroscedasticity (White, 1980). The variance-covariance matrix is estimated as suggested by Newey and West (1987). p-value is the significance level for the test of the hypothesis β_i=1, based on bootstrapping simulations (1000 simulated samples).

the corrected R^2 and lastly the p-value for the test for β_i=1. Asymptotic standard deviations are corrected for overlapping forecast horizons (Hansen and Hodrick, 1980)[3] and for heteroskedasticity (White, 1980), while the variance-covariance matrix is estimated as suggested by Newey and West (1987). The *p*-values are computed from bootstrapping simulations.[4]

The standard specifications Eqs. (7)–(9) are estimated for all pairs of maturities on US, German, French and UK rates. We obtain substantially different results as far as the EH is concerned. The results for US rates are very similar to those obtained in previous studies: for Eqs. (7) and (9), β_f and β_k are estimated to be significantly less than one (between 0.3 and 0.6), and for Eq. (8) β_h is negative (between −0.3 and −0.8). The EH is thus generally rejected, since we are unable to reject the hypothesis that β_i=1 in only 6 of 18 cases. Moreover, in all cases, the $\bar{R}^2$s are close

[3] Although expectations errors are supposed to be uncorrelated over time, residual terms in Eqs. (7)–(9) are not white noise. They rather follow MA($n-m-1$), MA($m-1$) and MA($n-m-1$) processes respectively.

[4] They are obtained as follows: in a first step, the two variables of the standard specifications are estimated as an AR model (in which the lag length is obtained from the HQ criterion); a large number of samples of the AR model is then obtained from simulations of the residuals (generated from the observed distribution of the residuals); lastly, the standard specifications are estimated and the p-values are the proportion of these samples for which the null β_i=1 is not rejected. In Table 3, the p-values for the test of the EH from the ECMs are computed in a similar way.

to zero. In the same way, the EH is generally rejected for German rates, whatever the specification (we accept the null hypothesis in only 7 of 18 cases). The estimates of β_f and β_k are significantly less than one (between 0.3 and 0.7) and the estimates of β_h are negative in most cases (between 0.3 and -0.6). The $\bar{R}^2$s are again very low (less than 0.17).

In contrast, for French rates, the EH is almost never rejected: we reject the β_i=1, i=f, h, k, in only two cases ((m,n,)=(1,12) and (3,12) months for the forward rate relation). It is worth noting that the estimates of β_i are quite close to each other: the estimates of β_h (which reflects the link between the term spread and the change in the yield of a long-term bond) are close to one, between 0.5 and 1.1 (and not negative, as with the US and German rates); moreover, for Eqs. (7) and (9), the spreads contain some information about the change in the future rates (the $\bar{R}^2$s range from 0.2 to 0.5). As far as UK rates are concerned, the EH is also supported by the data for almost all pairs of maturities. It is rejected only for the (1,3) and (1,6) combinations for Eq. (8). For Eqs. (7) and (9), the spreads are informative about the change in future rates (the $\bar{R}^2$s range from 0.1 to 0.3), but for Eq. (8) the $\bar{R}^2$s are close to zero.

Thus we conclude that, as far as the standard approach is concerned, the EH is generally supported by the French and UK data, whereas it is rejected for the US and German data. Moreover, a sign puzzle arises: the estimates of β_f and β_k, are positive but less than 1, whereas the estimates of β_h are generally negative.

Broadly speaking, these results are consistent with previous empirical evidence. For the US, we find results that are similar to those obtained, e.g., by Evans and Lewis (1994) using US Treasury bills or by Campbell (1995) using McCulloch (1990) pure discount bond yields on US government securities. For Germany we find less empirical support for the EH than Gerlach and Smets (1997), who use end-of-month Euro-mark rates: we reject the null hypothesis β_k=1 for (m, n)=(1,3) and (1,6) months, whereas they reject the EH for the (1,3) maturity pair only. This slight difference between the two studies seems to be mainly explained by the use of different samples. Indeed the sample used by Gerlach and Smets ranges from 1972 to 1993. But during the 1973–74 oil crisis, we observe a large but temporary increase in the short-term rate. This led to a large decrease in the term spread as well as in the roll-over spread, and thus to a higher correlation between the two series. But it is noteworthy that our rejection of the EH using the standard approach is essentially based on results of Eqs. (7) and (8), which to our knowledge have not been estimated on these data.

Gerlach and Smets (1997) find a strong empirical support for the EH using Euro-franc rates between 1977 and 1993 (essentially the same sample as ours), since they do not reject the hypothesis β_k=1 for the (m,n)=(1,3), (1,6) and (1,12) months. Lastly concerning UK rates, some recent work (Hurn et al., 1995; Cuthbertson, 1996 using LIBOR rates, Cuthbertson et al., 1996 using CD rates) generally do not reject β_k=1.

The contrast between the empirical evidence in various countries has already been noted by Hardouvelis (1994) for the long end of the yield curve. Here for the short end of the curve we obtain a similar puzzle, in which the EH is rejected for both the US and Germany, but accepted for France and the UK.

Many explanations of the rejection of the EH have been advanced (e.g., Campbell and Shiller, 1991; or Hardouvelis, 1994 for an overview). The most popular explanations are measurement error in long-term rate, the 'overreaction' hypothesis and the 'variable risk premium' hypothesis. The first hypothesis aims to explain why we obtain a bias toward -1 in regression Eq. (8) and a bias toward 0 only in regression Eq. (9) (Mankiw, 1986; or Campbell, 1995). According to the second explanation, long-term rates overreact to future short-term rates, thus raising questions with regard to rational expectations hypothesis since agents make systematic expectations errors (Mankiw and Summers, 1984; Hardouvelis, 1994). The variable risk premium hypothesis states that the long-term rate not only contains information about future short-term rates, but also about a time-varying risk premium (Mankiw and Miron, 1986). The main result obtained by Hardouvelis (1994) is that the measurement error in long-term rates is sufficient to explain the rejection of the EH for most of the G7 countries (in particular Germany). But in the US case, empirical results can be explained only by the overreaction hypothesis.

We consider in the next section another explanation of the sign puzzle, related to the choice of the variables entering the standard specifications. This argument is largely related to one proposed by Hakkio and Rush (1989), who state that the forward rate relation is not well behaved enough to test the EH.

3. The EH in an ECM approach

3.1. Cointegration and the standard approach

Most empirical work on the EH has taken account of the non-stationarity of interest rates. Indeed, Eqs. (7)–(9) are specified only with stationary variables (changes in interest rates, forward-spot spread, term spread). But a cointegrating relationship between two series implies some restrictions in the specification of the dynamics of the series. More precisely, if two variables are non-stationary and cointegrated, then the full dynamics of the system can be written in an ECM form (Engle and Granger, 1987).

The implications for the EH of the potential non-stationarity of interest rates have been extensively studied (Campbell and Shiller 1987, 1988; Shea, 1992). Some tests of the EH have been proposed in a restricted VAR framework, in which the variables are the change in the short-term rate and the spread. The most commonly used test is based on the significance of past and current spreads in the equation for changes in short-term rates. This test explicitly takes account of the properties of the series, since it is derived from a restricted VAR (equivalent to the ECM representation).

However the three standard specifications described in Section 2 are not directly based on such a framework. Hakkio and Rush (1989) point out this problem in connection with Eq. (7). They study the consistency between the ECM and the standard equations in the test of the efficiency hypothesis on the foreign exchange market. They show that when a spot rate and a forward rate are cointegrated, then the ECM is the appropriate framework for testing efficiency. In this case, carrying out the test with the standard equation can lead to a specification error. More precisely, they show that under the alternative hypothesis the standard equations imply too restrictive constraints. Hakkio and Rush (1989) and Dahlquist and Jonsson (1995) then propose an alternative ECM to Eq. (7). In this representation, the ex-post term premium, that is the spread between the current spot rate and the past forward rate, is the error-correction term in the dynamics of the change in the spot rate.

It is possible to show that Eqs. (8) and (9) are not compatible with any ECM or restricted VAR framework. Indeed, using the term spread as an error-correction term would mean introducing either the change in long-term rates or the change in short-term rates as one of the variables of the system. But Eq. (8) is based on the change in the yield of a long-term bond (not the change in the long-term rate, except in the case of a consol bond, as in Campbell and Shiller, 1987); and Eq. (9) is based on the cumulative change in current and future short-term rates (not the change in the short-term rate). So none of these specifications can be regarded as part of an ECM or a restricted VAR. This result does not imply that the standard approach is invalid, since under the EH the specifications are consistent with the ECMs. But they can be rather weak against some alternative hypotheses. Additional details are given in Section 4.

3.2. Long-term relationships

As in Hakkio and Rush (1989) and Dahlquist and Jonsson (1995), we estimate univariate ECMs in which the ex-post holding premium and the ex-post roll-over premium (obtained by using the actual series in Eqs. (2) and (3)) act as error-correction terms. As shown in Section 2, if interest rates are non-stationary, the EH implies that the three premia are constant over time. So the ex-post premia are stationary, since expectations errors are stationary under rationality.

Thus we can deduce from Eqs. (1)–(3) the following three cointegration relationships:

$$r_{t+n-m}^{(m)}=\delta_f f_t^{(m,n)}-\mu_f+z_{f,t+n-m}, \tag{10}$$

$$h_t^{(m,n)}=\delta_h r_t^{(m)}+\mu_h+z_{h,t+m}, \tag{11}$$

$$k_t^{(m,n)}=\delta_k r_t^{(n)}-\mu_k+z_{k,t+n-m}, \tag{12}$$

where $z_{i,t}$, for $i=f, h, k$, is the sum of the expectations error and, possibly, the expected (stationary) variable component of the risk premium. Under the EH, we directly obtain that $\delta_i=1$ and $\mu_i=\varphi_i^{(m,n)}$. These conditions are necessary but not sufficient for the EH to hold, since the expectations have also to be rational. The errors associated with the Eqs. (10)–(12) are defined under the EH as follows:

$$z_{f,t+n-m}=r_{t+n-m}^{(m)}-E_t r_{t+n-m}^{(m)}, \tag{13}$$

$$z_{h,t+m}=h_t^{(m,n)}-E_t h_t^{(m,n)}=-\frac{n-m}{m}(r_{t+m}^{(n-m)}-E_t r_{t+m}^{(n-m)}), \tag{14}$$

$$z_{k,t+n-m}=k_t^{(m,n)}-E_t k_t^{(m,n)}=\frac{m}{n}\sum_{i=0}^{\frac{n}{m}-1}(r_{t+im}^{(m)}-E_t r_{t+im}^{(m)}), \tag{15}$$

It is clear that these errors are expressed as a direct function of the expectations errors, which in turn should be white noise under rational expectations. Moreover, the error terms defined Eqs. (13)–(15) are observed at different dates: in Eqs. (13) and (14), the errors stem from expectations at t about $t+n-m$ and $t+m$ respectively; in Eq. (15), the error term refers to expectations at t about $t+m$, $t+2m,\ldots$, $t+n-m$. Thus even under rationality, the error terms $z_{i,t}$ in Eqs. (13)–(15) will not generally be a white noise processes, because of the standard overlapping forecast horizons problem.[5] It follows that the cointegration framework is not well adapted to test all the implications of the EH. Indeed cointegration (or, in other words, stationarity of ex-post premia) is an implication of most of the models of the term structure, and not specifically of the EH. For example, the overreaction hypothesis or the variable premium hypothesis are both consistent with the stationarity of ex-post premia. To be complete, cointegration holds as long as both term premia and expectations errors are stationary.

Some authors (Hall et al., 1992; Shea, 1992; Engsted and Tanggaard, 1994) have used the ECM framework to study some 'long-run implications' of the EH when more than two interest rates are considered: in a system of N different interest rates, Hall et al. show that the EH implies $N-1$ cointegration relationships, each of them being expressed as a spread between any interest rate and the shortest rate. Note however that they aim to test implications on the long-run dynamics—not on the full dynamics since they do not derive all the constraints implied by the EH on the ECM parameters (especially on short-run parameters). In the following section, we derive all the constraints of the EH.

3.3. Error-correction models

The existence of the cointegrating relationships Eqs. (10)–(12) implies a slightly more complicated writing of the ECMs than is usually the case. The Eqs. (10)–(12) reflect that the risk-adjusted expected returns of alternative investments over the same horizon are not different. Yet at time t only one of the yields is perfectly known (the forward rate in Eq. (10) and the zero-coupon rates in Eqs. (11) and (12)), the other yield being known after $n-m$, m and $n-m$ lags respectively. Thus, the orders of differentiation must be compatible with the number of periods required for the error-correction term to be known at time t, and therefore to be uncorrelated with the error term under rational expectations. The ECMs associated with Eqs. (10) to (12) are then respectively, with no lagged terms:

$$r_{t+n-m}^{(m)}-r_t^{(m)}=a_f(r_t^{(m)}+\mu_f-\delta_f f_{t-n+m}^{(m,n)})+b_f(f_t^{(m,n)}-f_{t-n+m}^{(m,n)})+\varepsilon_{f,t+n-m}, \tag{16}$$

$$h_t^{(m,n)}-h_{t-m}^{(m,n)}=a_h(h_{t-m}^{(m,n)}-\mu_h-\delta_h r_{t-m}^{(m)})+b_h(r_t^{(m)}-r_{t-m}^{(m)})+\varepsilon_{h,t+m}, \tag{17}$$

$$k_t^{(m,n)}-k_{t-n+m}^{(m,n)}=a_k(k_{t-n+m}^{(m,n)}+\mu_k-\delta_k r_{t-n+m}^{(n)})+b_k(r_t^{(n)}-r_{t-n+m}^{(n)})+\varepsilon_{k,t+n-m}, \tag{18}$$

[5] For Eqs. (13) and (15), the errors will have a $(n-m-1)$ MA component as soon as $n-m>1$; for Eq. (14), the errors will have a $(m-1)$ MA component as soon as $m>1$.

where $\varepsilon_{i,t}$, i=f, h, k, denotes the error term. The LHS variable and the second term on the RHS are stationary if interest rate levels are $I(1)$. Moreover if the EH is valid, the error-correction term, which is the first term on the RHS, is stationary. Thus, if δ_i is assumed to be known, standard techniques can be used to estimate Eqs. (16)–(18) and they give consistent estimates of a_i and b_i, i=f, h, k.

It is easy to check that standard specifications and ECMs are all consistent when the EH holds, since it implies β_i=1 in Eqs. (7)–(9) and $-a_i=\delta_i=b_i=1$ in Eqs. (16)–(18). However, the situation is more complicated under the alternative. Starting with the ECM for the forward rate (Eq. (16)), it is clear that, after a simple reorganization of the variables, the standard specification Eq. (7) is included in the ECM under the single assumption that δ_f=1. Indeed if δ_f=1, Eq. (16) can be written as:

$$r_{t+n-m}^{(m)}-r_t^{(m)}=a_f(r_t^{(m)}-f_t^{(n-m,n)})+(a_f+b_f)(f_t^{(n-m,n)}-f_{t-n+m}^{(n-m,n)})+\alpha_f\mu_f+\varepsilon_{f,t+n-m}, \tag{19}$$

and the additional restriction $b_f=-a_f$ is imposed by the standard specification Eq. (7). So if spot rate and forward rate are cointegrated, i.e., if the ECM is the true model, imposing the constraint $b_f=-a_f$ when estimating the standard relationship can lead to a missing-variable bias in estimating β_f (Hakkio and Rush, 1989). That is to say, under the alternative, Eq. (7) is too restrictive, since it implies that the forward rate has the same effect on the spot rate in the short run and in the long run. The bias is linked to the correlation between the spread (spot rate-forward rate), which is present in Eq. (7), and the change in the forward rate, which is missing.

For the two other tests (based on the change in the long-term rate and the short-term rate), the standard specifications cannot be directly written as special cases of the ECMs. Nevertheless, when the yields are cointegrated, the dynamics of the systems composed of the different yields should be written as ECMs and there is a potential specification bias for the tests based on the standard approach.

3.4. The empirical results

We have derived the implications of the EH in an ECM framework, supposing that the ex-post premia are all stationary. Table 1 shows the results of the ADF test statistics for stationarity of ex-post risk premia. For German, French, and UK rates, the premia are all stationary whatever the maturities. In the case of US rates the null of non-stationarity is not rejected only for the (3,12)-month ex-post forward premium and ex-post holding premium. Thus ex-post premia can generally be used as error-correction terms in the ECMs Eqs. (16)–(18).

We then estimate the three ECMs Eqs. (16)–(18) for each pair of maturities. Table 3 shows the estimate of a_i and b_i, which should equal -1 and 1 respectively under the EH, and the significance level of the F-test of the joint hypothesis $-a_i=b_i=1$. As in the case of standard specifications, p-values are computed with bootstrapping simulations.

Note first that the parameter estimates are much more close to each other across specifications and countries than with standard specifications: for i=f, h, k, a_i is between -1.21 and -0.24 and b_i is between 0.07 and 1.48, whatever the pair of maturities. We thus can conclude that the sign puzzle highlighted by Campbell and

Table 3
Estimate of the error-correction models[a]

m,n	Eq. (16)			Eq. (17)			Eq. (18)		
	a_f (s.e)	b_f (s.e)	$\bar{R}^2$ (p-val)	a_h (s.e)	b_h (s.e)	$\bar{R}^2$ (p-val)	a_k (s.e)	b_k (s.e)	$\bar{R}^2$ (p-val)
The US									
1,3	−0.462	0.453	0.047	−0.921	0.732	0.623	−0.914	0.971	0.518
	(0.20)	(0.16)	(0.00)	(0.11)	(0.22)	(0.02)	(0.23)	(0.13)	(0.84)
1,6	−0.392	0.115	0.092	−0.953	0.372	0.515	−0.738	0.742	0.345
	(0.22)	(0.28)	(0.00)	(0.10)	(0.48)	(0.04)	(0.22)	(0.15)	(0.05)
1,12	−0.421	0.551	0.086	−0.780	1.413	0.459	−0.656	0.910	0.459
	(0.19)	(0.24)	(0.08)	(0.09)	(0.74)	(0.02)	(0.34)	(0.21)	(0.26)
3,6	−0.269	0.075	0.040	−0.665	1.392	0.799	−0.243	0.546	0.381
	(0.26)	(0.23)	(0.00)	(0.35)	(0.34)	(0.28)	(0.34)	(0.16)	(0.01)
3,12	−0.283	0.351	0.029	−0.859	1.411	0.644	−0.499	0.783	0.411
	(0.18)	(0.24)	(0.01)	(0.29)	(0.71)	(0.67)	(0.29)	(0.21)	(0.12)
6,12	−0.304	0.218	0.029	−0.429	1.465	0.776	−0.246	0.617	0.422
	(0.26)	(0.33)	(0.04)	(0.27)	(0.32)	(0.08)	(0.32)	(0.20)	(0.02)
Germany									
1,3	−0.549	0.559	0.130	−0.940	1.090	0.693	−0.707	0.820	0.517
	(0.11)	(0.08)	(0.00)	(0.11)	(0.19)	(0.82)	(0.10)	(0.06)	(0.04)
1,6	−0.407	0.632	0.172	−0.861	1.385	0.569	−0.574	0.905	0.656
	(0.14)	(0.13)	(0.00)	(0.09)	(0.38)	(0.29)	(0.18)	(0.08)	(0.02)
1,12	−0.616	0.913	0.248	−0.908	1.479	0.514	−0.848	1.100	0.711
	(0.24)	(0.21)	(0.19)	(0.08)	(0.64)	(0.47)	(0.26)	(0.11)	(0.19)
3,6	−0.286	0.479	0.086	−0.620	1.140	0.758	−0.382	0.789	0.627
	(0.13)	(0.11)	(0.00)	(0.15)	(0.14)	(0.02)	(0.15)	(0.07)	(0.00)
3,12	−0.579	0.868	0.917	−0.857	0.651	0.538	−0.774	1.051	0.677
	(0.24)	(0.24)	(0.14)	(0.14)	(0.35)	(0.05)	(0.25)	(0.12)	(0.17)
6,12	−0.386	0.610	0.093	−0.718	0.961	0.747	−0.523	0.897	0.627
	(0.19)	(0.20)	(0.03)	(0.22)	(0.21)	(0.07)	(0.25)	(0.13)	(0.06)
France									
1,3	−0.771	0.716	0.208	−0.941	1.256	0.748	−0.878	0.928	0.471
	(0.23)	(0.23)	(0.11)	(0.12)	(0.19)	(0.25)	(0.29)	(0.29)	(0.66)
1,6	−0.921	0.820	0.385	−0.887	1.168	0.622	−0.867	0.818	0.374
	(0.12)	(0.17)	(0.63)	(0.09)	(0.23)	(0.44)	(0.15)	(0.16)	(0.22)
1,12	−0.713	0.720	0.314	−0.856	1.169	0.550	−0.888	1.005	0.442
	(0.08)	(0.12)	(0.14)	(0.08)	(0.28)	(0.13)	(0.19)	(0.14)	(0.79)
3,6	−0.960	0.852	0.294	−1.047	0.984	0.818	−0.993	0.974	0.450
	(0.21)	(0.21)	(0.75)	(0.20)	(0.19)	(0.92)	(0.24)	(0.11)	(0.68)
3,12	−0.654	0.622	0.247	−0.956	0.935	0.671	−0.866	0.990	0.468
	(0.14)	(0.14)	(0.05)	(0.13)	(0.18)	(0.62)	(0.23)	(0.14)	(0.68)
6,12	−0.785	0.847	0.223	−0.879	0.980	0.783	−0.818	0.969	0.500
	(0.13)	(0.21)	(0.42)	(0.18)	(0.18)	(0.45)	(0.20)	(0.13)	(0.50)

(continued on next page)

continued

m,n	Eq. (16)			Eq. (17)			Eq. (18)		
	a_f (s.e)	b_f (s.e)	$\bar{R}^2$ (p-val)	a_h (s.e)	b_h (s.e)	$\bar{R}^2$ (p-val)	a_k (s.e)	b_k (s.e)	$\bar{R}^2$ (p-val)
The UK									
1,3	−0.666	0.713	0.148	−1.212	0.722	0.710	−0.750	0.879	0.557
	(0.15)	(0.15)	(0.04)	(0.12)	(0.23)	(0.25)	(0.13)	(0.07)	(0.16)
1,6	−0.663	0.710	0.176	−1.109	0.713	0.605	−0.831	0.966	0.607
	(0.17)	(0.14)	(0.13)	(0.10)	(0.40)	(0.48)	(0.17)	(0.09)	(0.49)
1,12	−0.845	0.769	0.268	−0.994	1.033	0.539	−1.086	1.015	0.572
	(0.19)	(0.20)	(0.76)	(0.09)	(0.69)	(0.99)	(0.17)	(0.11)	(0.88)
3,6	−0.674	0.740	0.120	−0.670	1.237	0.791	−0.614	0.842	0.571
	(0.20)	(0.18)	(0.14)	(0.17)	(0.16)	(0.16)	(0.20)	(0.10)	(0.10)
3,12	−0.852	0.739	0.224	−0.889	1.102	0.626	−1.022	1.007	0.544
	(0.21)	(0.22)	(0.75)	(0.15)	(0.42)	(0.72)	(0.19)	(0.11)	(0.99)
6,12	−0.823	0.828	0.133	−0.978	0.966	0.793	−0.895	0.970	0.521
	(0.24)	(0.23)	(0.79)	(0.23)	(0.24)	(0.90)	(0.25)	(0.13)	(0.90)

[a] The Table reports the estimates of Eqs. (16)–(18). The estimates relate to the period 1975-97. The estimates of the constant are not shown. Asymptotic standard deviations, shown in parentheses, are corrected for overlapping (Hansen and Hodrick, 1980) and for heteroscedasticity (White, 1980). The variance-covariance matrix is estimated as suggested by Newey and West (1987). p-value is the significance level for the test of the joint hypothesis $-a_i = b_i = 1$, based on bootstrapping simulations (1000 simulated samples).

Shiller (1991) disappears. Second, the EH is more often supported by the data when the tests are based on ECMs rather than on the standard approach. Nevertheless, US rates and German rates are still poorly explained by the EH: we are unable to reject the EH in 8 of 18 cases for the US rates and in 9 of 18 cases for the German rates. It is interesting to note that the worst results are obtained for the forward rate relation Eq. (16). This result is consistent with the tests based on the standard specification, which is nested in the ECM. Moreover we observe that the EH is generally supported for the holding rate relation Eq. (17): the estimates of a_h and b_h are quite close to -1 and 1 respectively.

For French and UK rates, the parameters are very close to the values implied by the EH: a_i is between -0.6 and -1.2 and b_i is between 0.6 and 1.3. For French rates, the EH is never rejected, whereas for UK rates the EH is rejected in only one case (the (1,3) combination for the forward rate relation). These estimates are thus supportive of the EH.

Even when the EH is rejected, moreover, the estimates are not very far from those predicted by the theory. The main exception to this overall claim is the test based on forward rates for US rates and, to a lesser extent, for German rates. In the US case, a_1 is between -0.26 and -0.46 and b_1 is between 0.07 and 0.45; in the German case, a_1 is between -0.28 and -0.62 and b_1 is between 0.47 and 0.91.

4. Interpreting the results

4.1. Comparison between the standard approach and the ECMs

In comparing the standard approach and the ECMs, it is notable that the sign puzzle broadly disappears with the latter approach. In this case, the estimates are similar for the holding return equation and for the roll-over return equation. This result is interesting, since explaining the sign puzzle has long been an open question. Our results enable us to give an interpretation of the puzzle.

As already indicated, the comparison of the standard approach and the ECMs shows that the equation based on forward rates Eq. (7) is the only one nested in an ECM (namely, Eq. (16)). However, Eqs. (8) and (9) based on the term spread cannot be viewed as special cases of Eqs. (17) and (18). This implies that a strict comparison between the models is only possible in the case of forward rates. Tables 2 and 3 show very similar results for both the standard approach and the ECMs when the EH is tested from the forward rate equation. Such a result is not surprising, since the null appears as a special case of both approaches.

In order to identify the links between the standard approach and the ECMs more precisely, suppose that $-a_i = b_i$ in the ECMs Eqs. (17) and (18).[6] Thus we can write the standard specifications Eqs. (8) and (9), ignoring constant terms:

$$h_t^{(m,n)} - r_t^{(n)} = \beta_h (r_t^{(m)} - r_t^{(n)}) + u_{h,t+m}, \tag{20}$$

$$k_t^{(m,n)} - r_t^{(m)} = \beta_k (r_t^{(n)} - r_t^{(m)}) + u_{k,t+n-m}, \tag{21}$$

while the ECMs Eqs. (17) and (18) can be rewritten as:

$$h_t^{(m,n)} - h_{t-m}^{(m,n)} = b_h (r_t^{(m)} - h_{t-m}^{(m,n)}) + \varepsilon_{h,t+m}, \tag{22}$$

$$k_t^{(m,n)} - k_{t-n+m}^{(m,n)} = b_k (r_t^{(n)} - k_{t-n+m}^{(m,n)}) + \varepsilon_{k,t+n-m}. \tag{23}$$

From these equations, it appears that the main difference between the two approaches (if one supposes $-a_i = b_i$ in the ECMs) lies in the variable used to render both sides of the equations stationary. In Eqs. (20) and (21), stationarity is achieved by using the long-term rate and the short-term rate respectively, which allow to introduce the spread on the RHS of the equation, As a result, the LHS variable is no longer defined as a change in a yield. On the contrary, the RHS of Eqs. (22) and (23) contains an ad-hoc variable (similar to the current forward-spot spread in Eq. (7)), but the variables on the LHS are clearly defined as changes in a yield.

The main empirical difference between these two approaches is to dramatically change the signal-to-noise ratio, that is the ratio of standard deviation of the LHS variable to the standard deviation of the RHS variable, when Eqs. (22) and (20) are

[6] It is clear that, when $-a_f = b_f$, Eqs. (7) and (16) are the same equation.

considered. Table 4 reports the signal-to-noise ratios for Eqs. (20)–(23). As far as Eq. (20) is concerned, this ratio is the lowest for France (between 2.9 and 4.6, depending on the maturities) and the largest for the US (between 3.7 and 7.8). For Eq. (22), this ratio is far lower, between 0.97 and 1.36 for all countries. On the contrary the signal-to-noise ratios for Eqs. (21) and (23) remain almost unchanged: they are between 1.2 and 2.4 for Eq. (21) and between 1.2 and 1.5 for Eq. (23).

The low variability of the spread compared to the change in the yield of the long-term securities Eq. (20) enables to explain both the large standard deviation of β_h and the very low $\bar{R}^2$ (as shown in Table 2). These characteristics of the standard test based on the long-term rate disappear when the test is based on the holding-period return Table 3.

Table 4
Signal-to-noise ratios[a]

m,*n*	Standard specifications		ECMS	
	Eq. (20)	Eq. (21)	Eq. (22)	Eq. (23)
The US				
1,3	4.96	2.05	1.09	1.39
1,6	7.00	1.95	1.20	1.26
1,12	7.84	1.52	1.23	1.42
3,6	4.83	2.43	1.15	1.32
3,12	5.34	1.65	1.25	1.41
6,12	3.71	1.87	1.07	1.40
Germany				
1,3	4.23	1.71	1.19	1.21
1,6	5.58	1.52	1.26	1.26
1,12	6.72	1.48	1.32	1.38
3,6	3.39	1.72	1.00	1.31
3,12	4.25	1.59	1.10	1.40
6,12	3.50	1.78	0.97	1.44
France				
1,3	4.54	1.85	1.23	1.36
1,6	4.38	1.53	1.22	1.34
1,12	4.44	1.24	1.23	1.47
3,6	3.16	1.79	1.12	1.43
3,12	3.19	1.36	1.16	1.46
6,12	2.93	1.63	1.05	1.48
The UK				
1,3	4.88	1.90	1.24	1.25
1,6	5.73	1.63	1.34	1.28
1,12	7.18	1.63	1.36	1.34
3,6	3.70	1.97	1.08	1.29
3,12	4.77	1.79	1.20	1.36
6,12	4.10	2.18	1.09	1.41

[a] The Table reports the signal-to-noise ratios, that is the ratio of the standard deviation of the LHS variable to the standard deviation of the RHS variable, for Eqs. (20)–(23).

4.2. Comparison between countries

Explaining the country puzzle still remains an important question. When the results obtained from the standard specifications are compared with those from ECMs, we find that two groups of countries can be distinguished. In the first group (France and the UK), the EH is not rejected by either approach. In the second group (the US and Germany), the EH is generally rejected under both approaches, even if testing the EH with ECMs gives results that are more favorable to the theory.

Gerlach and Smets (1997) suggest that the failure of standard tests for some countries on Euro-rates may be due to the lack of predictability of short-term interest rates coupled with a time-varying risk premium. They show that the countries for which the slope parameters are the larger are the countries which have quasi-fixed exchange rate regimes and have experienced speculative attacks in the foreign exchange market. The rationale is that currency turmoils generally imply large and negative term spread and cumulative changes in short-term rates, giving estimates of β_k close to unity. This hypothesis could be a good candidate to explain our findings on French and UK data, since both countries experienced speculative attacks during the period under study.

To examine this argument, we check the stability of the parameters of both the standard specifications and the ECMs. The estimates should be closer to unity during subperiods with speculative attacks. This is done using rolling regressions over 5-year subperiods, following Dahlquist and Jonsson (1995). Figs. 1 and 2 display the estimates of the coefficients and 95 percent confidence bands in all countries for $(m, n)=(3,6)$ months. Our main result is that the difference between the two groups of countries seems to be independent from monetary policy shocks. Indeed in the US and Germany, the slope estimates are generally well below unity: in the US case, the change in the monetary operating procedures of the Fed during the 1979–82 subperiod has basically no effect on the estimates, whereas estimates are closer to unity at the end of the sample. For Germany we observe the same general pattern but with much smaller standard deviations. This is the reason why the EH is not rejected for the US (3,6) combination for the two specifications based on the term spread (Eqs. (8) and (9)).

Concerning the second group of countries, we also find that currency turmoils generally imply a decrease in the slope parameters, rather than an increase as argued by Gerlach and Smets (1997). Indeed, the estimates are almost always close to unity except in 1981 (that is over the 1977–81 subperiod) and in 1992 for France and from 1993 to 1997 for the UK. In the French case, the speculative attacks associated with large increase in short-term rates imply rejection of the EH over these periods of time only; the dramatic decrease in the UK short-term rates between 1990 and 1993 leads to a persistent rejection of the EH.

This result does not necessarily refute the argument of Gerlach and Smets, but the link between quasi-fixed exchange-rate regime and non-rejection of the EH may not be directly connected with speculative attacks. In the case of France for example, participating to the EMS may imply a stronger predictability of short-term rates, whose movements are restrained by currency agreements. This argument is similar

Fig. 1. Rolling regressions—standard approach: point estimates and 95% confidence bands.

to the one developed by Mankiw and Miron (1986). They show that the rejection of the EH could be due to the very low predictability of short-term rates, which is implied by the credibility of the monetary policy of the central bank. Conversely, quasi-fixed exchange-rate regimes imply some predictability of short-term rates,

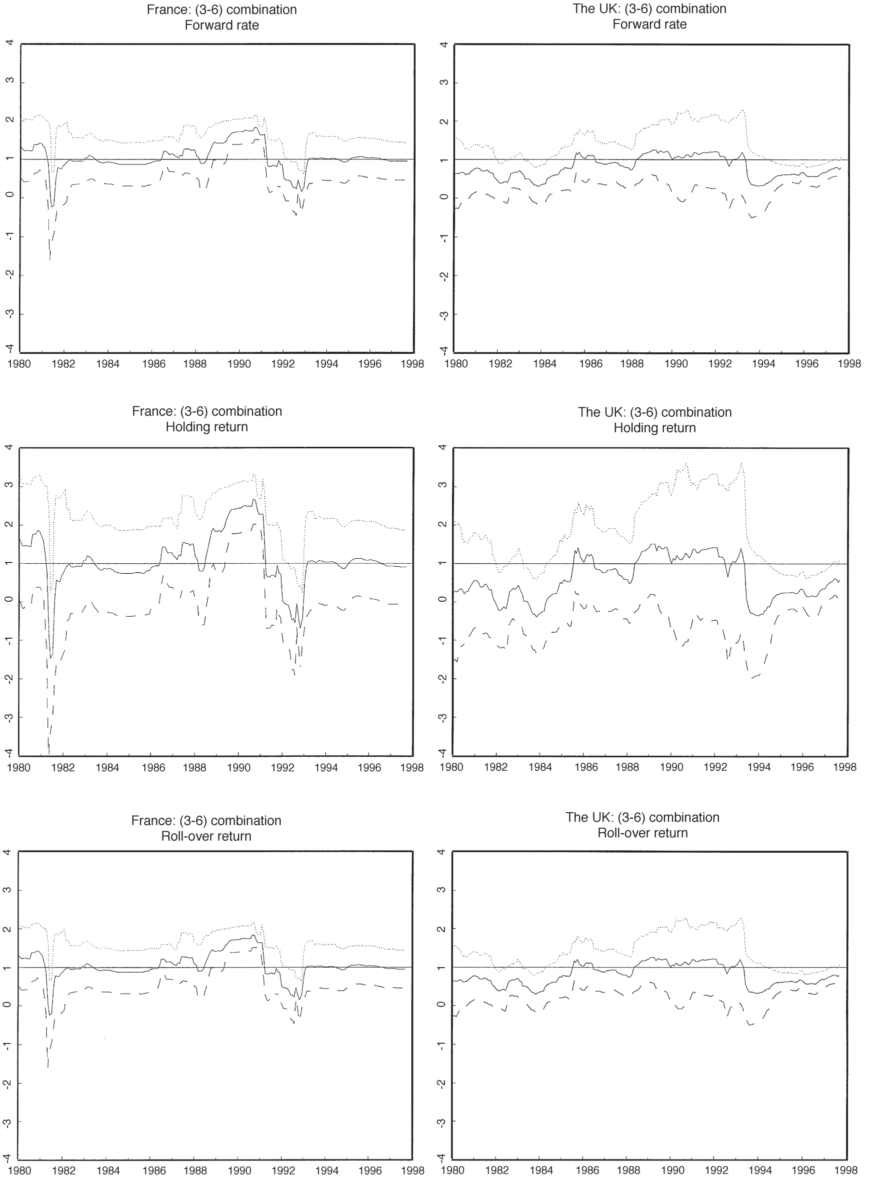

Fig. 1. (*continued*)

when exchange rates come close to bounds, since market participants expect that the central bank will be obliged to intervene on the foreign exchange market and on the money market. Germany has not been in such a situation because of the leader role of the mark.

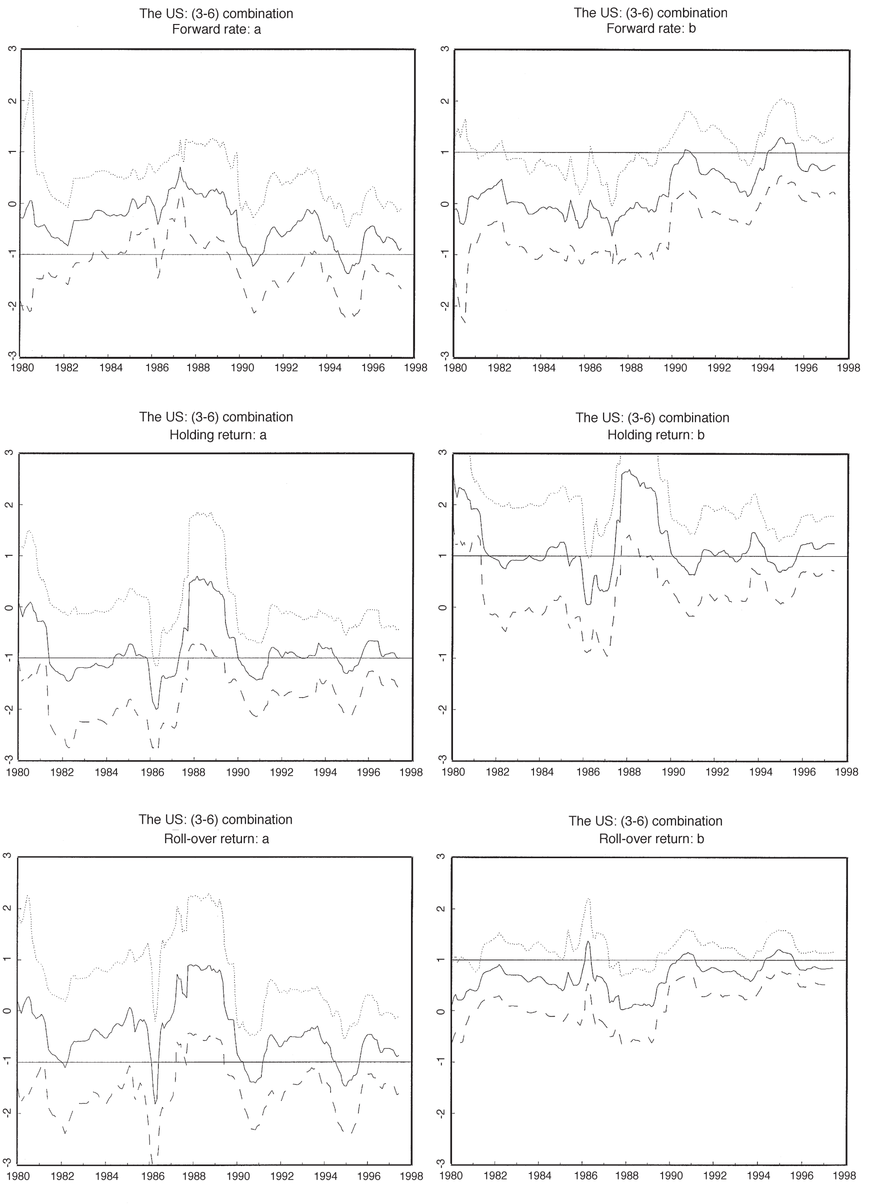

Fig. 2. Rolling regressions—ECM approach: point estimates and 95% confidence bands.

5. Conclusion

The aim of the paper was twofold. First, we proposed an alternative approach to testing the EH, which takes account of the potential non-stationarity of interest rates

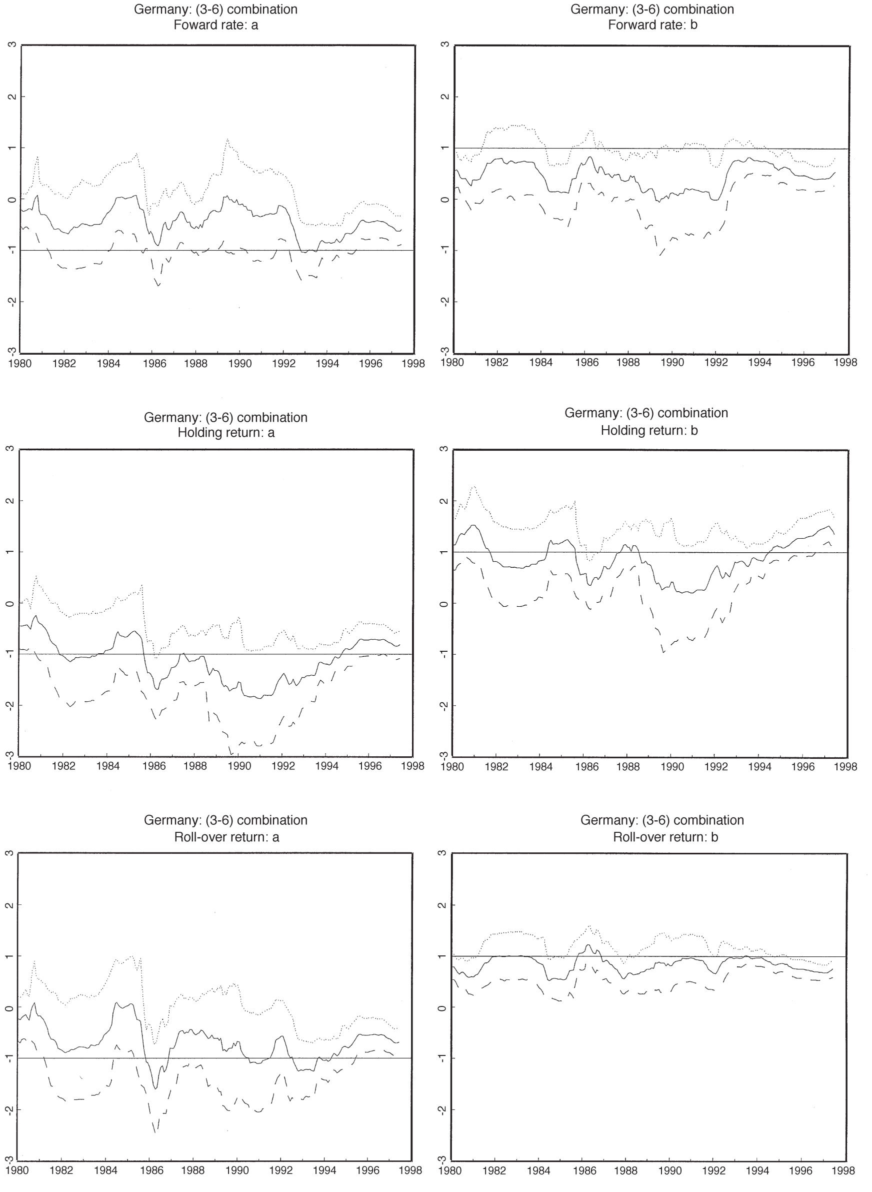

Fig. 2. (*continued*)

in an ECM framework. Such a procedure has already been developed to test the ability of the forward rate to forecast future spot rates (Hakkio and Rush, 1989 or Dahlquist and Jonsson, 1995), but not to study the ability of the term spread to forecast future changes in interest rates. The ECM approach seems more suited to

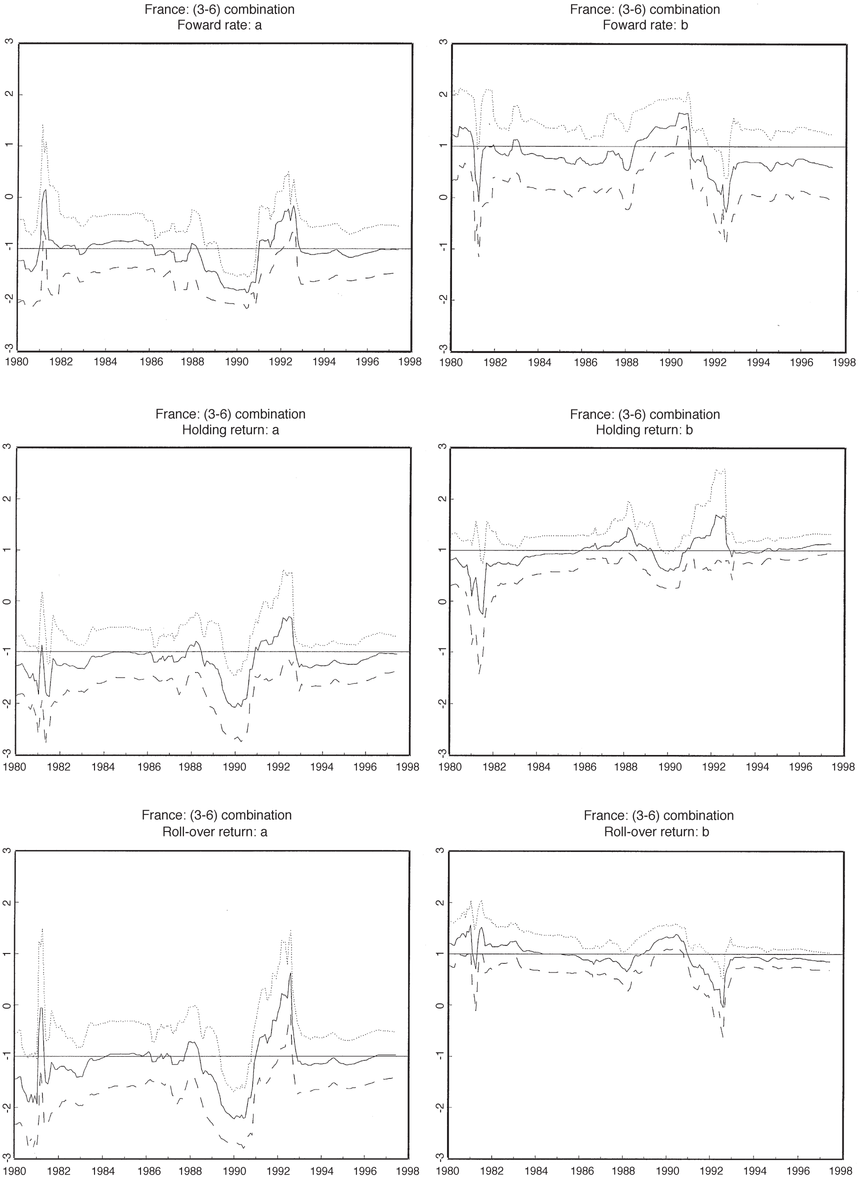

Fig. 2. (*continued*)

test the EH, since it deals with the cointegration relationships between interest rates. These long-run links have been explicitly used for example by Campbell and Shiller (1987, 1988) in a restricted VAR framework or by Hall et al. (1992) in an ECM, but not to study single regressions. We show that these ECMs are not directly comparable to the standard specifications proposed by Campbell and Shiller (1991). More

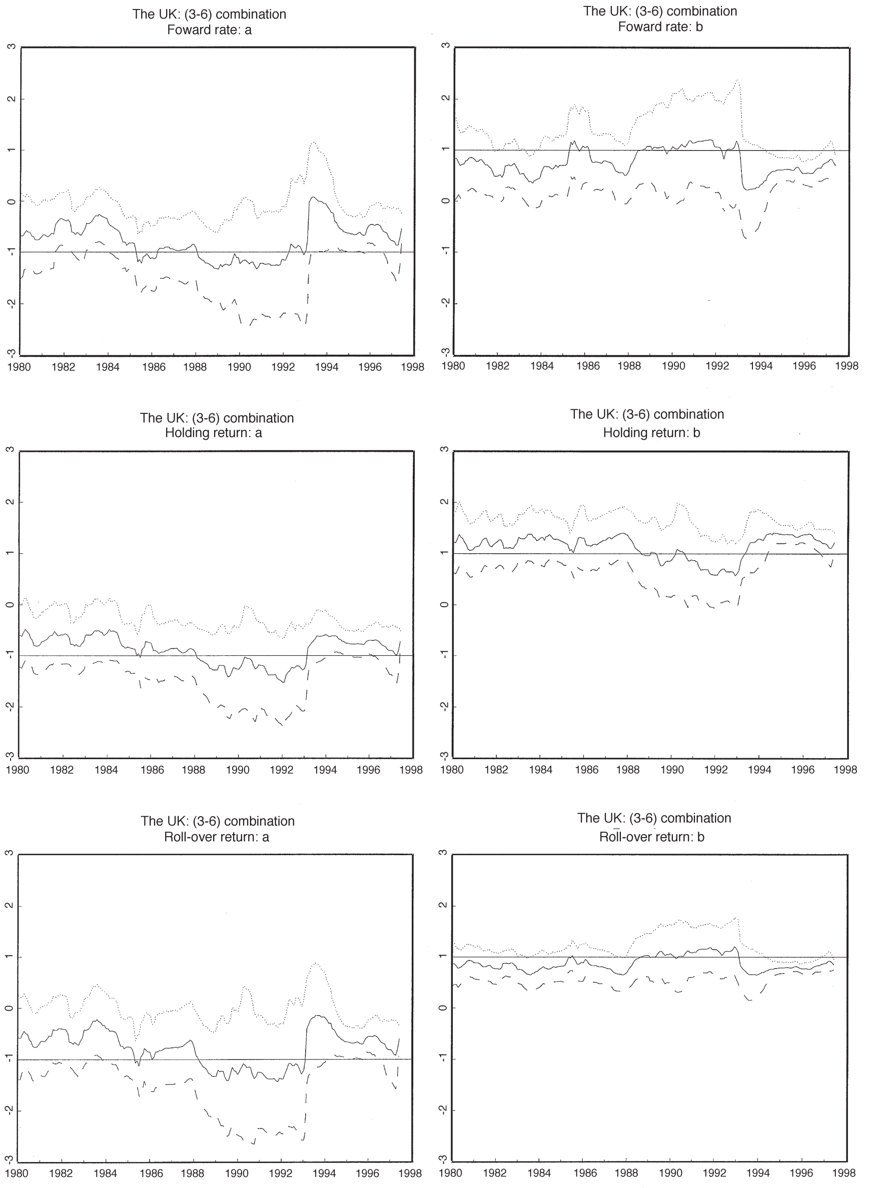

Fig. 2. (*continued*)

precisely, the difference between the two approaches is related to the variable chosen to render yields in the regression stationary.

Second, we tested the EH for US, German, French and UK Euro-rates over the period from 1975 to 1997. Concerning the standard approach, we almost never reject the theory for French and UK rates, whereas we generally reject the theory for US and German rates. Moreover, for a given country, the different specifications tested generally lead to the same conclusion. But for the US and German rates, we obtain the sign puzzle highlighted by Campbell and Shiller (1991).

The ECMs give much more similar results for the three different tests than the standard specifications and the sign puzzle disappears. However the country puzzle is not solved, since the EH is still rejected for the US and Germany. Gerlach and Smets (1997) suggest that participating in a quasi-fixed exchange rate regime (as France) may explain this result, A recursive analysis of the estimated parameters shows that this interpretation may hold, but not directly because of the special role played by speculative attacks. Indeed large changes in short-term interest rates due to currency turmoils (in France and in the UK) generally imply a decrease in the coefficient estimates. Participating in a quasi-fixed exchange-rate regime may reinforce the predictability of short-term rates and thus explain why the EH is not rejected for France, whereas it is rejected for Germany, whose monetary policy has not been constrained by currency agreements in practice. It is noteworthy however that this argument helps to explain why the EH is not rejected for some countries, but not why it is rejected for the others.

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