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Can forward rates be used to improve interest rate forecasts?

EMILIO DOMÍNGUEZ and ALFONSO NOVALES‡

Departamento de Análisis Económico, Universidad Pública de Navarra, Pamplona, Spain and ‡*Departamento de Economía Cuantitativa, Universidad Complutense, Madrid, Spain*

This paper evaluates the extent to which the explanatory power detected in the term structure in different markets and countries can actually be used to produce sensible forecasts of future short-term interest rates. Specifically, in spite of the forecasting connotation of the unbiasedness property of forward rates, actual evaluation of their forecasting performance has received scant attention in the literature on the term structure. This study uses monthly data for 1978–1998 on interest rates on Euro-deposits on the US dollar, yen, Deutsche mark, British pound, Spanish peseta, French franc, Italian lira and Swiss franc, comparing forecasts obtained from forward rates to those obtained from univariate autoregressions. By themselves, forward rates produce better one-step ahead forecasts, as well as better once-and-for all forecasts of 1-month interest rates over a full year horizon than those obtained from the own past of interest rates. The gain in one-step ahead forecasting disappears for longer maturities, although forward rates still produce better once-and-for all predictions of 3- and 6-month interest rates than univariate autoregressions for a number of currencies.

I. INTRODUCTION

The essence of the *Expectations Hypothesis* (EH) of the term structure is that long-term rates are an average of current and expected future shorter-term interest rates. As an implication, there is a close link between short- and long-term rates, and their spread contains all relevant information on future changes in short-term rates. That is of utmost interest to market participants, who could otherwise hope to design profitable investment strategies using information currently available.

The ability of the EH to explain the behaviour of interest rates over the term structure has been controversial for a long time (see Hamburger and Platt, 1975; Fama and Bliss, 1983; Shiller *et al.*, 1983; Fama, 1984; Mankiw and Summers, 1984; Mankiw and Miron, 1986; Fama and Bliss, 1987; Mishkin, 1988; Shiller, 1990; Fama, 1990; Campbell and Shiller, 1987, 1991; Jorion and Mishkin, 1991; Jorion, 1992 and Gerlach and Smets, 1997, among many others). Much of this work consistently rejected the restrictions implied by the EH, although providing evidence of explanatory power in the short/long-term interest rate spread on future short-term rates. By and large, changes predicted in future short-term rates by these models are small, suggesting a possible time varying risk or term premium. This may have also produced an impression that the forecasting ability of forward rates is not very high.

Most tests of the EH have been implemented either as regressions of future short-term interest rates on current forward rates, or as regressions of future changes in short-term rates on the current spread between long- and short-term interest rates. Since these regressions explain future returns as functions of current information, they are usually referred to as capturing the fact that, if the EH holds, then the current term structure contains information useful to *predict* future interest rates. Usually, if the mentioned regressions produce significant coefficients and

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* Corresponding author.

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a high R-squared, the researcher will maintain the ability of the term structure *to forecast* future rates. This has been a standard practice since Fama (1976). That conclusion will have been reached on the basis of a good fit in the regressions, but not on their actual ability to forecast future interest rates. If, in addition, the slope of the forward rate in the projection of future interest rates has a unit slope, the forward rate is said to be an *unbiased predictor* of future interest rates.

However, in spite of the forecasting connotation of the unbiasedness property of forward rates, actual evaluation of the forecasting performance of forward rates has received scant attention in the literature on the term structure, may be due to skepticism on its possibilities (for an actual exercise on forecasting, see Deaves, 1996). For forecasting conclusions based on goodness of fit, without actual forecasting, see Park and Switzer, 1997; Wahab, 1997, among many others).

This paper evaluates the extent to which the explanatory power detected in the term structure in the literature on different markets and countries can actually be used to produce sensible forecasts of future short-term interest rates. Interest rates on Eurodeposits, known as Eurorates, provide an interesting data set on which to test these issues. These deposits share important characteristics, not being distorted by differences in the fiscal treatment of returns or in the timing of interest payments, and not being affected by possible capital controls or other government regulations. That makes their returns more comparable than domestic rates. To the best of our knowledge, this is the first systematic attempt to measure the actual predictive power of the term structure under the restrictions of the Expectations Hypothesis on international data. After providing evidence on the relationships between interest rates and lagged forward rates, we analyse whether the estimated projections can in fact be used to produce improved short-term interest rate forecasts.

Section II reviews some concepts relating to the EH. Section III describes the goodness of fit of a variety of models capturing the restrictions of the EH, estimated with Eurocurrency interest rates. Section IV describes the forecasting exercises and discuss their results. The paper closes with some conclusions.

II. FORWARD RATES AS PREDICTORS OF FUTURE SPOT RATES

According to the EH, the return on an n-period investment, r_t^n, should be the average expected return on a roll-over strategy over that period, plus possibly a time invariant term or risk premium $\pi^{n,1}$,

$$r_t^n = \frac{1}{n}\sum_{j=0}^{n-1} E_t r_{t+j}^1 + \pi^{n,1} \tag{1}$$

$E_t r_{t+j}^1$ being the current expectation, based on information available at time t, of the one-period interest rate prevailing in the market at time $t+j$. This study works with annualized, continuously compounded rates of return, for which Equation 1 is an exact expression. Under risk neutrality, the risk premium would be zero, although $\pi^{n,1}$ might still represent some constant term premium. The stronger version of the EH implies that there is no premium of any kind, long-term rates being just the average of current and expected future short-term rates, while the weaker version of the EH would allow for a significant constant in Equation 1.

This expression can be generalized to consider rates of return on n- and m-period investments, n being a multiple of m:

$$r_t^n = \frac{n}{m}\sum_{j=0}^{\frac{n}{m}-1} E_t r_{t+jm}^m + \pi^{n,m} \tag{2}$$

An interesting special case occurs when $n = 2m$, as in the comparison between returns on 3- and 6-month investments, or between returns on 6- and 12-month investments. Then:

$$r_t^n = \frac{1}{2}(r_t^m + E_t r_{t+m}^m) + \pi^{n,m} \tag{3}$$

so that in the case of a 3-month reference period, the rate of return on a 6-month investment should be equal to the average of the rate of return on a 3-month investment and the rate of return on a 3-month deposit expected to prevail 3 months hence, plus a possible term premium.

Under rational expectations, the result is:

$$r_{t+m}^m = E_t r_{t+m}^m + \varepsilon_{t+m}^m \tag{4}$$

where ε_{t+m}^m, the rational expectations error in forecasting at time t, has a $MA(m\text{-}1)$ structure. Finally, substituting (4) into (3) and subtracting r_t^m from both sides, the result is:

$$r_t^n - r_t^m = \tfrac{1}{2}(r_{t+m}^m - r_t^m) - \tfrac{1}{2}\varepsilon_{t+m}^m + \pi^{n,m} \tag{5}$$

so that the current spread between long- and short-term interest rates (left hand side) should be a good predictor of future changes in the short-term rate (right hand side).

With continuously compounded rates of return, *implicit forward rates* are defined by $(n-m)f_{t,t+m}^{n-m} = nr_t^n - mr_t^m$. Hence, with $n = 2m$, the result is: $f_{t,t+m}^m = 2r_t^{2m} - r_t^m$ so that using Equations 3 and 4,

$$r_{t+m}^m = f_{t,t+m}^m - 2\pi^{2m,m} + \varepsilon_{t+m}^m \tag{6}$$

The rational expectations version of the EH of the term structure of interest rates has often been discussed by analysing whether its implication (Equation 6) holds in a particular market. To that end,

$$r_{t+m}^{m} = \alpha + \beta f_{t,t+m}^{m} + u_{t+m} \qquad (7)$$

is usually estimated, testing the hypothesis $H_0 : \alpha = 0, \beta = 1$, which is referred to as the forward rate being an *unbiased predictor* of the future spot rate. Under the stronger version of the EH (incorporating neutrality) there is no risk or term premia, so H_0 should hold. In that case Equations 4 and 6 imply that forward rates, which are known at time t, are just expectations of future short term rates: $f_{t,t+m}^{m} = E_t r_{t+m}^{m}$. A weaker version of the EH allows for a constant risk/term premium and suggests testing: $H_0' : \beta = 1$ in Equation 7. When significant, α will be a negative multiple of the possible risk/term premium $\pi^{2m,m}$. This analysis is specially interesting in the comparisons of 3- versus 6-month rates, and 6- versus 12-month rates, since the 3- and 6-month are some of the more actively traded maturities in most financial markets. The one-month interest rate is also of great interest, but it needs an assumption of the form: $E_t r_{t+1}^{1} = E_t r_{t+2}^{1}$ to relate expectations one and two periods ahead, since this comparison does not exactly fit our framework. With that, and the definition of the 2-month forward rate: $2f_{t,t+1}^{2} = 3r_t^3 - r_t^1$, a regression similar to Equation 7 can be run to test unbiasedness of the 2-month forward rate, relative to the future one-month spot rate. In this case, the intercept will be equal to $-(3/2)\pi^{3,1}$.

III. LONG-RUN RELATIONSHIPS BETWEEN CURRENT FORWARD AND FUTURE INTEREST RATES

Hence, as shown in Equation 7, if the EH holds true, implicit forward rates should summarize all information contained in the term structure, relevant to forecast future spot rates, and the slope in a projection like 7 should be equal to one. Besides, under the stronger version of the hypothesis, the intercept α should be zero.

As with many other term structure characteristics, empirical evidence on this area is somewhat contradictory. Even though initial work with US Treasury bill data (Shiller *et al.*, 1983; Fama, 1984; Fama and Bliss, 1987 and Shiller, 1990) consistently rejected the restrictions implied by the EH, it provided evidence on the existence of explanatory power in the short/long-term interest rate spread on future short-term rates. Fama (1990) and Mishkin (1988) both found that the spread contained information on short-term rates several periods into the future. Fama and Bliss (1983) concluded that, over 1964–1985, one year forward rates on Treasury bills contained information on expected returns on bills one year in advance. Mankiw and Summers (1984) and Mankiw and Miron (1986) analysed 3- and 6-month US rates, concluding that the term structure had important explanatory power for future interest rates, although it seems to have faltered after the founding of the Federal Reserve System. Campbell and Shiller (1987, 1991) found again that the restrictions of the EH do not hold, but that the US spread explains the direction of changes in short-term rates. However, the predicted changes are small, suggesting a possible time varying risk or term premium. Similar results were obtained by Jorion and Mishkin (1991). Working with 1973–1988 data, Jorion (1992) also found that in the market for US dollar and Deutsche mark eurodeposits the forward/spot spread contains information on future spot rate changes. On the other hand, Hamburger and Platt (1975) and Shiller *et al.,* (1983) working with data on different markets, both concluded that the *predictive* power of forward rates, in the sense of providing a good explanatory power of future interest rates, is scarce.

In recent work with Eurorates, Gerlach and Smelts (1997) have estimated regressions of cumulative changes in short-term rates on current spreads, finding general evidence in favour of a unit slope, in consistency with the EH, although results differ widely over countries. Those regressions include, in special cases, model 7. These authors have estimated the relationships of 3-, 6- and 12-month to the 1-month Euro-rates, for 17 countries, finding strong support for the hypothesis that the term spread does predict future short rate movements. Dominguez and Novales (1999) implement a battery of tests of EH on Eurorates on a variety of currencies and a wider array of maturity comparisons, finding general support for the hypothesis in a long sample, 1978–1997.

This paper uses monthly averaged bid rates on 1-, 3-, 6-, and 12-month deposits from the London eurocurrency market for the US dollar, Japanese yen, German mark, British pound, Spanish peseta, French franc, Italian lira and Swiss franc, between January 1979 and December 1998, in their annualised, continuous equivalent form. Data for Spain started on June 1980. As an illustration, Figures 1 and 2 show the 1-month interest rates and 3-month forward rates (obtained from 3- and 6-month interest rates) to be apparently nonstationary. In fact, Augmented Dickey–Fuller (*ADF*) and Phillips–Perron tests for the presence of a unit root in forward rates $f_{t,t+1}^{2}, f_{t,t+3}^{3}$ and $f_{t,t+6}^{6}$ in the eight currencies we consider (not shown to save space) provided evidence in favour of that hypothesis, at the same time the null hypothesis of two unit roots was rejected in favour of the alternative of a single root.

Consequently, Equation 7 must be interpreted as a possible cointegrating relationship between current forward and future spot rates, on which to test the restrictions implied by the EH. Cointegration between interest rates over the term structure of a currency is consistent with the idea that market forces continuously adjust to correct any temporary disequilibrium, so that risk adjusted rates of return on different maturities do not drift apart perma-

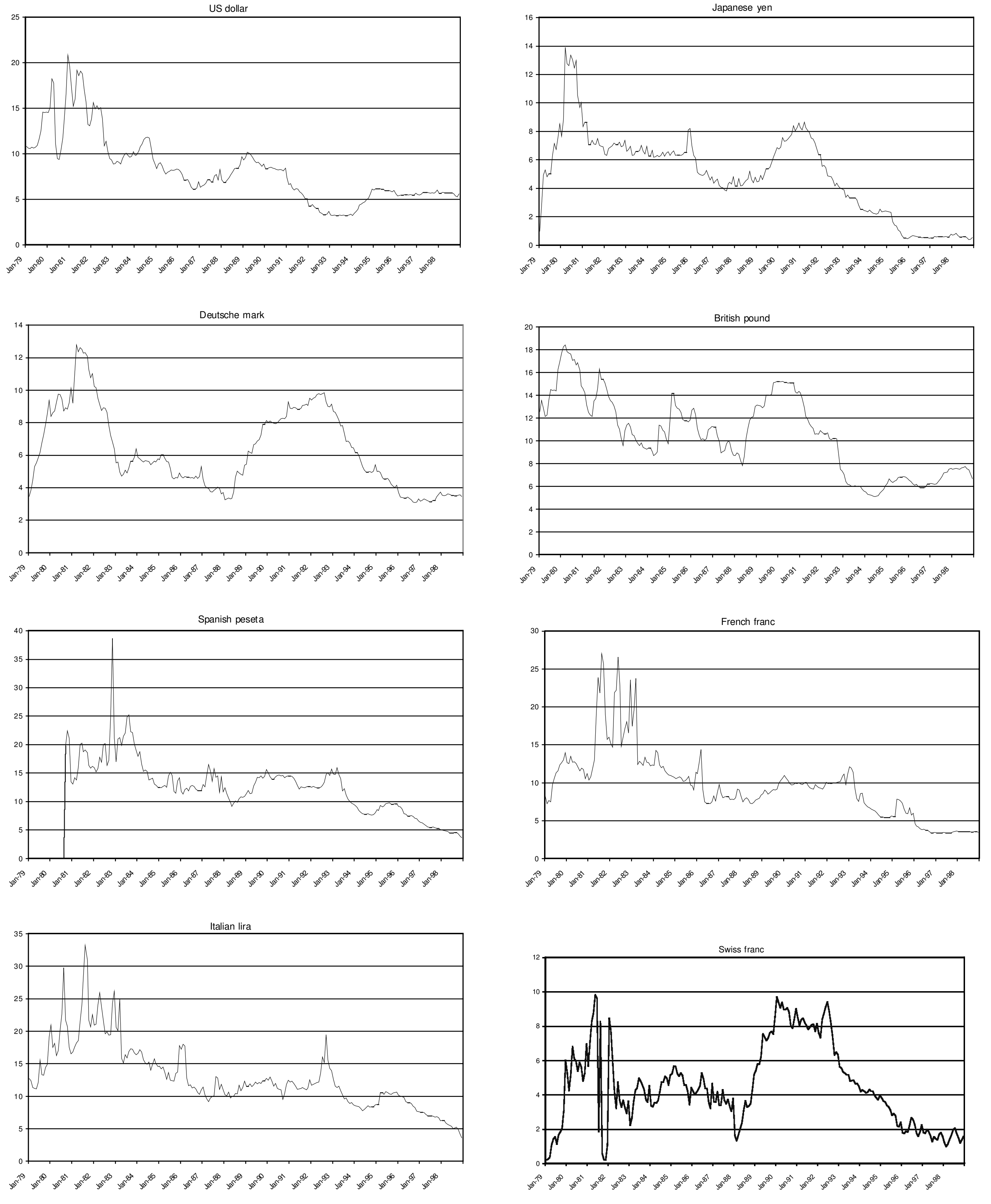

Fig. 1. *1-month interest rates 1979–1998*

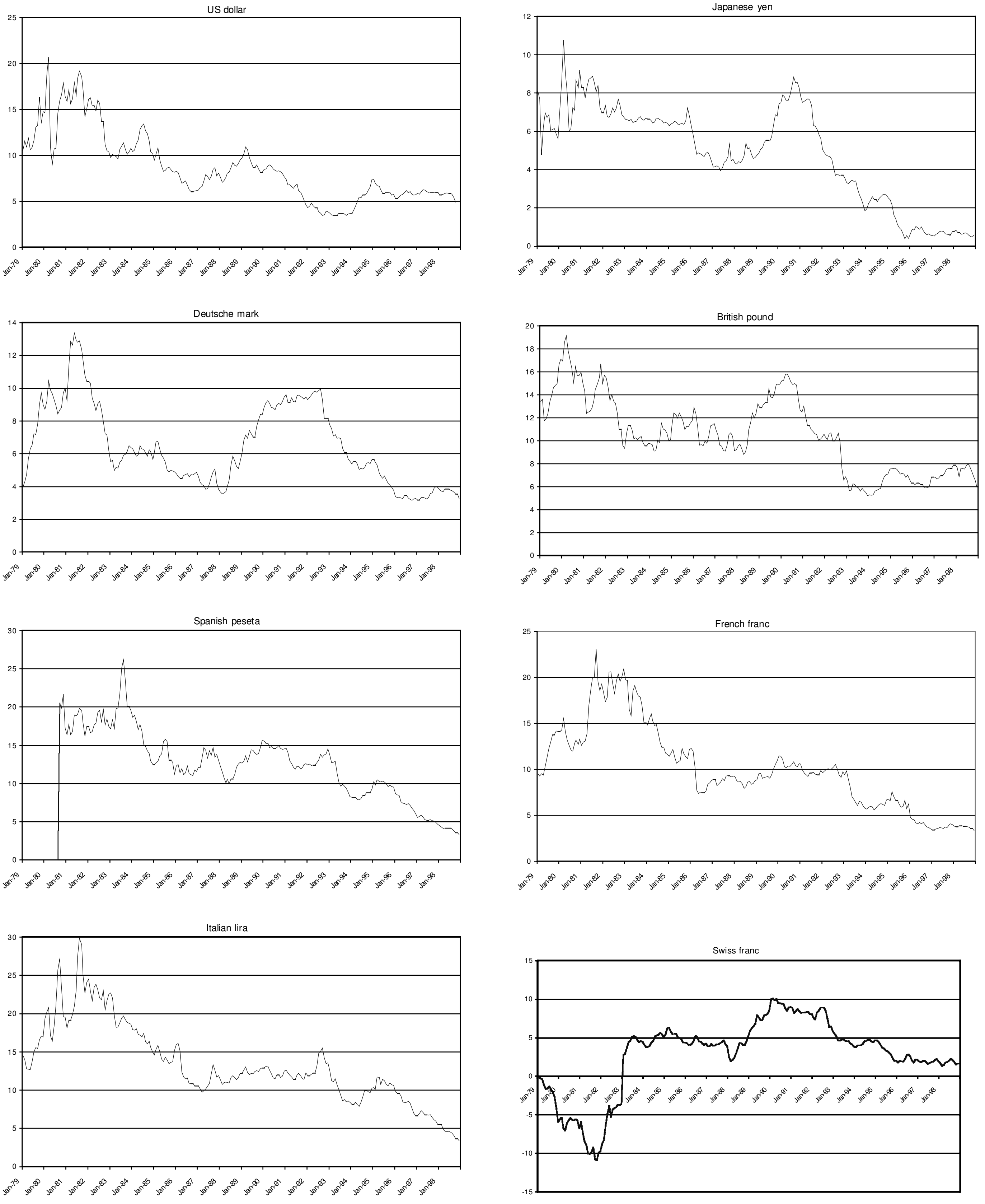

Fig. 2. *3-month forward rates 1979–1998*

Table 1. *Estimated cointegrating relationship:* $r_t^m = \alpha + \beta f_{t-m,t}^m + u_t, \quad m = 1, 3, 6$

			Parameter estimates: 1984–1998				ADF and Phillips-Perron statistics^e:
	Maturity	$\lambda_{\max}/Trace^a$	α^b	β^b	n^c	$H_0 : \beta = 1^d$	$r_t^m - f_{t-m,t}^m$
US	1 m.	15.0*/22.1**	−0.024 (0.251)	0.979 (0.010)	4	1.28 (0.26)	−5.6 (2)/−10.0
	3 m.	10.9/14.1	−0.138 (0.183)	0.983 (0.019)	12	0.04 (0.84)	−4.8 (9)/−5.7
	6 m.	14.8*/19.0*	−0.415 (0.296)	0.986 (0.037)	12	0.36 (0.55)	−3.7 (12)/−4.3
Yen	1 m.	29.6***/31.8***	−0.067 (0.039)	0.998 (0.008)	9	0.29 (0.59)	−7.2 (3)/−13.0
	3 m.	23.8***/26.5***	−0.137 (0.042)	1.029 (0.008)	6	13.56 (0.00)	−5.9 (3)/−6.9
	6 m.	17.5***/19.4*	−0.278 (0.135)	1.081 (0.027)	12	12.58 (0.00)	−4.8 (2)/−4.1
DM	1 m.	121.9***/25.0**	0.324 (0.182)	0.918 (0.030)	12	0.02 (0.90)	−3.8 (12)/−9.9
	3 m.	12.8/16.4	−0.151 (0.182)	0.996 (0.028)	4	2.20 (0.14)	−3.8 (6)/−5.6
	6 m.	11.0/13.8	−0.568 (0.286)	1.071 (0.044)	12	4.46 (0.03)	−4.2 (12)/−4.0
BP	1 m.	18.7**/20.8**	−0.335 (0.176)	1.025 (0.017)	4	4.38 (0.04)	−8.8 (1)/−9.4
	3 m.	22.1***/25.6***	−0.606 (0.293)	1.064 (0.029)	6	8.45 (0.00)	−4.2 (6)/−5.5
	6 m.	16.2**/18.6*	−1.500 (0.434)	1.138 (0.043)	7	7.55 (0.01)	−5.0 (1)/−4.1
SP	1 m.	14.1*/17.7	0.375 (0.454)	0.954 (0.038)	6	0.13 (0.72)	−4.8 (4) /−10.2
	3 m.	11.5/13.9	0.381 (0.505)	0.973 (0.042)	6	0.48 (0.49)	−4.4 (4)/−6.1
	6 m.	17.9**/21.1**	−0.702 (0.476)	1.043 (0.039)	10	1.29 (0.26)	−5.9 (4)/−4.0
FF	1 m.	19.4**/23.1**	−0.259 (0.404)	1.011 (0.049)	9	0.10 (0.75)	−3.7 (6)−12.1
	3 m.	16.2**/19.6*	−1.103 (1.018)	1.146 (0.133)	12	1.20 (0.27)	−9.4 (9)/−5.3
	6 m.	22.1***/26.2***	−0.750 (1,145)	1.081 (0.141)	12	1.44 (0.23)	−4.2 (7)/−5.7
LI	1 m.	17.0**/22.0*	0.417 (0.348)	0.951 (0.030)	12	2.02 (0.16)	−4.3 (10, c)/12.0
	3 m.	17.2**/21.0*	0.938 (0.440)	0.882 (0.037)	12	1.22 (0.27)	−3.1 (12)/−5.8
	6 m.	25.3***/29.9***	0.876 (0.314)	0.882 (0.025)		2.84 (0.09)	−4.2 (7, c)/−4.0
SF	1 m.	19.1**/20.5**	−0.230 (0.137)	1.103 (0.026)	12	1.41 (0.24)	−6.3 (3, c)/−8.8
	3 m.	13.2/15.3	−0.235 (0.121)	1.109 (0.022)	6	1.06 (0.30)	−4.7 (7, c)/−4.2
	6 m	14.0*/15.6	−0.455 (0.189)	1.105 (0.037)	7	8.29 (0.00)	−2.4 (12)/−3.2

Notes:

(a) *Maximum eigenvalue* and *Trace* statistics. Their critical values when testing the existence of *zero cointegrating relationships*, at the 10%, 5% and 1% significance levels, are 13.8, 15.7 and 20.2 for the *Maximum eigenvalue,* and 17.8, 20.0 and 24.7, for the *Trace* statistic (Osterwald–Lenum, 1992).

(b) Numbers in brackets are maximum-likelihood standard errors.

(c) Number of lags used in the *VAR* in first differences.

(d) *Likelihood ratio* statistic to test the null hypothesis that the cointegrating vector is (1,-1).

(e) *ADF* and *Phillips–Perron* statistics for presence of a unit root in the difference between future rates and current forward rates. Number of lags used in ADF test are shown in brackets. Critical values for both tests at the 10%, 5% and 1% significance levels are −1.62, −1.94 and −2.57 when no constant is included in the vector autoregression, and −2.57, −2.87 and −3.46 when a constant is included.

nently, which would otherwise give rise to arbitrage opportunities.

Column 2 in Table 1 contains the *Maximum eigenvalue* and *Trace* statistics to test for the number of cointegrating relationships between spot and lagged forward rates, which seems to be one in all cases, except at the 3-month horizon for the US dollar, Deutsche mark, Spanish peseta and Swiss franc, and the 6-month returns on deposits in Deutsche marks. There is some ambiguity for the 1-month interest rate for the peseta and the 6-month rates on the Swiss franc. There cannot be two cointegrating vectors, since both variables are $I(1)$. Maximum likelihood estimates (Johansen, 1988, 1991) of the single cointegrating vector are shown in the middle panel, even in the cases where the test failed, together with the number of lags used in the *VAR* specification. Slope estimates are again very close to one, being above that level in about half of the cases.

Looking at the estimated maximum-likelihood standard deviations, we would reject the null hypothesis that the slope is equal to one for the 3- and 6-month interest rate models for the yen, British pound and Italian lira, the 1-month interest rate on the Deutsche mark and the 6-month rate on the Swiss franc. A more formal, likelihood ratio test of the unit slope hypothesis (Johansen (1988, 1991) (column 4 in Table 1) leads to rejection again for the 3- and 6-month interest rate models for the yen, the 3-month rate on the British pound, and the 6-month rate on the Swiss franc, 4 of the 24 cases at the 1% significance level and in 6 cases at the 5% level, since this study has had to add the 6-month rate regression for the Deutsche mark and British pound. Four of the six rejections of this implication of the EH arise in the 6-month horizon, suggesting that the lower liquidity at the 12-month maturity may explain most of these observed deviations from the EH.

Rejection of the unit slope hypothesis at the 5% significance level comes together with a significant negative constant in most cases, since it always arises for slope estimates above one. Even when the hypothesis is not rejected, negative estimates for the intercept are obtained in all but five cases, which would be consistent with the existence of term/risk premia. Besides, the supposed premia seem to increase with maturity in most countries, as it should be expected. However, in most cases our intercept estimates are not significant, although specially for the peseta and French franc, lack of significance arises from estimates not being very precise. By and large, we cannot claim to have found consistent evidence of constant risk premia.

If we impose the restrictions of the EH in the form of a unit slope on forward rates and test for stationarity of the differences $r_t^m - f_{t-m,t}^m, m = 1, 3, 6$ (last column in Table 1), we reject the unit root hypothesis at the 95% confidence level for all currencies and maturities, although the evidence on the 6-month Swiss franc rate is not totally clear. With this qualification, these tests suggest that (1,–1) may be considered to be the approximate cointegrating vector between each of the 1-, 3- and 6-month returns and the corresponding forward rate, appropriately lagged, in support of the *EH*. It might well be that imposing the restrictions on the cointegrating vector increases the power of the test, allowing for more evidence of cointegration to emerge. However, preference for the likelihood-ratio test or the *ADF*/*PP* tests should rely on their finite sample properties, for which not much is known.

To summarize the results in this Section: a) there is overwhelming evidence in favour of forward rates having explanatory power for future short term spot rates, b) unbiasedness of the forward rate is an acceptable hypothesis, having found just some ambiguous evidence for some of the 6- versus 12-month comparisons, and c) we have not found consistent evidence of constant risk premia.

The next Section discusses whether this evidence can, in fact, be used to improve upon univariate interest rate forecasting.

IV. CAN THE TERM STRUCTURE BE USED TO FORECAST INTEREST RATES?

The results in the previous sections show that the term structure of Eurocurrencies contains significant information regarding future interest rate fluctuations, suggesting that it might be possible to exploit that information when forecasting interest rates. However, a good fit does not always come together with a good forecasting performance, and it is particularly interesting to check how the explanatory power this study has documented in the forward rate translates into good forecasting performance. Evaluating the performance of the forward rate model Equation 7 and comparing it with interest rate forecasts obtained from univariate autoregressive models in this international data set is the goal of this Section.

To check whether forward rates can be used to predict future interest rates, we estimated Equation 7 for 1-, 3- and 6-month, with data through December 1997 and obtained forecasts over 1998, computing forecast accuracy measures for the whole year. To make sure that these results were not spurious, this study also estimates with data up to December 1996, forecasting over 1997. No lagged interest rate was ever included in Equation 7, which had the appropriately lagged forward rate as its only explanatory variable. For each two maturities, the predictive power of the forecasting model was compared with that of an autoregression in first differences of the short-term rate.

For most interest rates considered in our sample, the restrictions imposed by a random walk model would not be rejected at standard significance levels but, trying to improve forecasts, this study forced some structure and fit an $AR(2)$ model to their first differences, from which this study obtained monthly univariate forecasts over 1998. In fact, the $AR(2)$ model turns out to predict significantly better than a random walk model in most cases. This study computed *static* and *dynamic* forecasts. *Static* forecasts are one-month ahead predictions, in which actual data was used for the lagged explanatory variable, as needed. *Dynamic* forecasts are once and-for-all predictions over all 1998, obtained with data up to December 1997. They are progressively based on previous forecasts, as this study runs out of actual data. To obtain dynamic forecasts from 7 for the three-month interest rate, this study used actual data on forward rates up to the April 1998 forecast. Starting in April, predictions of forward rates must be obtained in advance, to be used as the explanatory variable in the forecasting exercise. To that end, an $AR(2)$ model was again fitted to the first difference of the forward rate in all cases. Similar strategies apply to the computation of static and dynamic forecasts of the one- and six-month rates in each currency. It must be emphasized that the forward rate is the only explanatory power in this forecasting model.

Table 2 contains the Root Mean Square Error (RMSE), Mean Absolute Error (MAE), and Theil's inequality coefficient U as performance measures in the static and dynamic forecasting exercises:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(r_t - \hat{r}_t)^2}, \quad MAE = \frac{1}{n}\sum_{i=1}^{n}|r_t - \hat{r}_t|,$$

Table 2. *1-month interest rates*

		Static forecasts						Dynamic forecasts					
		1997			1998			1997			1998		
		RMSE	MAE	U	RMSE	MAE	U	RMSE	MAE	U	RMSE	MAE	U
US	Univariate	0.132	0.110	0.012	0.169	0.119	0.015	0.391	0.338	0.036	0.200	0.162	0.018
	Forward	**0.081**	**0.065**	**0.007**	**0.117**	**0.094**	**0.011**	0.536	0.465	0.049	**0.130**	**0.116**	**0.012**
		0.084	**0.068**	**0.007**	**0.138**	**0.112**	**0.012**	0.567	0.498	0.053	**0.145**	**0.126**	**0.013**
Yen	Univariate	0.118	0.101	0.115	0.094	0.081	0.085	0.407	0.368	0.509	0.120	0.100	0.113
	Forward*	**0.084**	**0.059**	**0.074**	**0.090**	**0.077**	**0.074**	**0.351**	**0.299**	**0.407**	**0.086**	**0.065**	**0.077**
		0.109	**0.077**	**0.103**	**0.071**	**0.055**	**0.061**	0.435	0.393	0.553	0.125	0.103	0.118
DM	Univariate	0.108	0.091	0.017	0.082	0.059	0.012	0.297	0.187	0.046	0.115	0.092	0.016
	Forward*	**0.079**	**0.062**	**0.012**	0.094	0.073	0.013	0.368	0.268	0.059	**0.091**	**0.068**	**0.013**
		0.117	0.101	0.018	0.164	0.142	0.023	**0.279**	**0.176**	**0.044**	0.161	0.141	0.023
BP	Univariate	0.159	0.126	0.012	0.146	0.107	0.010	1.149	0.919	0.091	0.270	0.223	0.018
	Forward	**0.123**	**0.105**	**0.009**	**0.129**	**0.101**	**0.009**	**0.894**	**0.712**	**0.069**	**0.254**	**0.195**	**0.017**
		0.112	**0.095**	**0.008**	**0.120**	**0.099**	**0.008**	**0.934**	**0.734**	**0.073**	**0.240**	**0.190**	**0.016**
SP	Univariate	0.243	0.217	0.022	0.237	0.191	0.026	1.413	1.324	0.114	0.912	0.794	0.095
	Forward*	**0.241**	**0.199**	**0.022**	**0.234**	**0.217**	**0.027**	**0.926**	**0.807**	**0.078**	**0.607**	**0.463**	**0.066**
		0.183	**0.152**	**0.016**	**0.211**	**0.155**	**0.024**	**1.190**	**1.088**	**0.098**	**0.852**	**0.729**	**0.090**
FF	Univariate	0.091	0.073	0.014	0.056	0.054	0.008	0.393	0.313	0.061	0.299	0.262	0.045
	Forward*	**0.087**	**0.074**	**0.013**	0.057	**0.051**	0.008	**0.230**	**0.188**	**0.034**	**0.245**	**0.207**	**0.036**
		0.141	0.126	0.021	0.096	0.082	0.013	0.512	0.449	0.081	0.304	0.263	0.055
LI	Univariate	0.155	0.114	0.011	0.312	0.238	0.029	0.366	0.303	0.026	0.898	0.710	0.081
	Forward*	0.295	0.251	0.021	0.347	0.304	0.034	**0.286**	**0.243**	**0.020**	**0.633**	**0.445**	**0.060**
		0.217	0.173	0.016	**0.295**	**0.243**	**0.028**	**0.229**	**0.166**	**0.016**	**0.797**	**0.609**	**0.073**
SF	Univariate	0.228	0.198	0.069	0.314	0.206	0.105	0.432	0.389	0.119	0.348	0.294	0.116
	Forward	0.264	0.222	0.085	**0.296**	**0.251**	**0.103**	**0.205**	**0.162**	**0.062**	0.378	0.317	0.133
		0.246	**0.088**	0.076	**0.284**	**0.261**	**0.247**	**0.292**	**0.232**	**0.084**	0.378	0.309	0.124

Note: Root Mean Square Error (RMSE), Mean Absolute Error (MAE) and Theil's U statistics for static and dynamic forecasts obtained from $AR(3)$ univariate autoregressions, as well as from a regression of the interest rate on the corresponding forward rate, appropriately lagged. Bold figures denote cases where the Forward model predicts better than the univariate model.

$$U = \frac{\sqrt{\frac{1}{n}\sum_{i=1}^{n}(r_t - \hat{r}_t)^2}}{\sqrt{\frac{1}{n}\sum_{i=1}^{n} r_t^2} + \sqrt{\frac{1}{n}\sum_{i=1}^{n} \hat{r}_t^2}}$$

Theil's U falls between 0 (in case of a perfect fit) and 1 (very bad forecasting performance). Percent Root Mean Square Errors are not advisable in this exercise, since interest rates are often small in absolute value over the forecasting horizon, to the point that even acceptable forecast errors might produce huge percent errors for a single period, dominating the value of any time aggregate forecasting performance indicator. Hence, this study uses their versions in absolute terms. There are two rows of forecast indicators for the *Forward model*. The upper row is obtained under least-squares estimation of the projection of interest rates on lagged forward rates, while the lower row is obtained under the maximum-likelihood estimates (Johansen, 1988, 1991), i.e., using the estimated cointegrating relationship between interest rates and lagged forward rates. As this study shows, there are some differences in forecasting performance between both methods, generally in favour of the least squares projection.

In one-step-ahead (*static*) forecasts of 1-month interest rates, the forward rate model produces better forecasts than those obtained from the own past of interest rates (left panel in Table 2) for the US dollar, yen, British pound, Spanish peseta and Swiss franc for 1998, and for the US dollar, yen, Deutsche mark, British pound, Spanish peseta and French franc for 1997. A similar average reduction is achieved in the RMSE, MAE and U statistics by the forward model, relative to univariate models, being of 27% and 13%, respectively, for 1997 and 1998. The estimated cointegrating relationship would have produced better 1998 *static* forecasts for the Italian lira, but the gain does not seem to be significant.

Results are even more evident when forecasting over a longer horizon (right panel in Table 2). At the end of 1997, the forward rate model would have predicted 1-month interest rates over a full year horizon better than the univariate model in all currencies except the Swiss franc. There is a broad gain in *dynamic* forecasting performance from using the forward model. For 1997 forecasts, forward models would have beaten univariate models for the yen, British pound, Spanish peseta, French franc, Italian lira and Swiss franc. However, the average reduction in each of the RMSE, MAE and U statistics is now 28% for 1997, and 21% for 1998.

The improvement produced by the forward model in *static* forecasting performance disappears for longer maturities (left panels in Tables 3 and 4). There is not even one currency for which the forward model beats the univariate model in *static* predictions of 3- and 6-month interest rates. It is clear that the gain from using forward rates is concentrated in *dynamic* forecasting, suggesting that forward rates anticipate possible changes in trend better than the own past of the interest rate being predicted. This is very much in consistency with the spirit of the EH. Searching for the causes of this regularity looks as an interesting issue for further research, for which decomposing spot and forward rates into transitory (short-term) and permanent (long-term) components might be an interesting approach.

On the other hand, the forward model still produces better *dynamic* forecasts than univariate models for a number of currencies every year. The forward rate model beats the univariate autoregression in once-and-for all forecasting of 3-month interest rates over all 1998 for the US dollar, French franc and Italian lira, and for the US dollar, yen, Deutsche mark, British pound, Spanish peseta and French franc over 1997 (right panel in Table 3). The average reduction in performance statistics is now of 28% both, for 1997 and 1998. For 6-month rates, the forward model produces better once-and-for-all forecasts than the univariate model for the British pound, French franc and Italian lira for 1998, and for the US dollar, Deutsche mark, British pound and French franc over 1997 [right panel in Table 4]. The maximum likelihood cointegrating relationship would have produced better 6-month interest rate forecasts than both, the univariate model and the least-squares forward

Table 3. *3-month interest rates*

		Static forecasts						Dynamic forecasts					
		1997			1998			1997			1998		
		RMSE	MAE	U	RMSE	MAE	U	RMSE	MAE	U	RMSE	MAE	U
US	Univariate	0.085	0.066	0.008	0.108	0.088	0.010	0.522	0.458	0.047	0.132	0.109	0.012
	Forward	0.153	0.119	0.013	0.180	0.141	0.016	**0.400**	**0.342**	**0.036**	**0.122**	**0.103**	**0.011**
		0.188	0.165	0.016	0.170	0.134	0.015	0.531	0.477	0.048	**0.109**	**0.086**	**0.010**
Yen	Univariate	0.096	0.064	0.088	0.083	0.071	0.068	0.428	0.386	0.527	0.119	0.098	0.105
	Forward	0.129	0.105	0.105	0.178	0.152	0.138	**0.177**	**0.147**	**0.168**	0.173	0.133	0.150
		0.130	0.106	0.120	0.186	0.164	0.025	**0.283**	**0.247**	**0.308**	0.162	0.117	0.138
DM	Univariate	0.112	0.083	0.017	0.104	0.072	0.015	0.408	0.282	0.064	0.102	0.078	0.014
	Forward	0.168	0.139	0.026	0.178	0.143	0.025	**0.387**	**0.267**	**0.060**	0.144	0.123	0.022
		0.242	0.207	0.037	0.185	0.164	0.025	0.464	0.368	0.074	0.138	0.116	0.019
BP	Univariate	0.161	0.134	0.012	0.166	0.124	0.011	1.061	0.822	0.081	0.292	0.216	0.020
	Forward	0.282	0.226	0.021	0.434	0.366	0.029	**0.697**	**0.593**	**0.051**	0.329	0.247	0.022
		0.319	0.287	0.023	0.445	0.377	0.030	**0.843**	**0.687**	**0.063**	0.308	0.236	0.021
SP	Univariate	0.227	0.189	0.021	0.213	0.161	0.024	1.320	1.241	0.109	0.318	0.249	0.036
	Forward	0.324	0.251	0.029	**0.209**	0.189	0.025	**0.784**	**0.719**	**0.069**	0.559	0.431	0.062
		0.504	0.434	0.045	0.350	0.317	0.049	**1.003**	**0.953**	**0.085**	0.786	0.700	0.085
FF	Univariate	0.106	0.086	0.016	0.071	0.056	0.010	0.464	0.371	0.071	0.253	0.218	0.037
	Forward	0.155	0.132	0.023	0.109	0.086	0.015	**0.430**	**0.356**	**0.065**	**0.124**	**0.094**	**0.017**
		0.531	0.511	0.083	0.331	0.317	0.049	0.859	0.789	0.140	0.439	0.412	0.066
LI	Univariate	0.155	0.123	0.011	0.264	0.211	0.026	0.211	0.146	0.015	0.835	0.685	0.079
	Forward	0.514	0.461	0.037	0.385	0.348	0.039	0.376	0.306	0.027	**0.538**	**0.351**	**0.053**
		0.372	0.330	0.027	0.476	0.335	0.046	0.304	0.220	0.022	0.853	0.669	0.080
SF	Univariate	0.233	0.193	0.067	0.212	0.197	0.067	0.371	0.330	0.099	0.337	0.283	0.111
	Forward	0.880	0.865	0.348	0.804	0.710	0.331	0.729	0.691	0.267	9.703	0.633	0.281
		0.248	0.207	0.074	0.516	0.439	0.159	0.438	0.374	0.117	0.424	0.355	0.125

Note: Root Mean Square Error (RMSE), Mean Absolute Error (MAE) and Theil's U statistics for static and dynamic forecasts obtained from $AR(3)$ univariate autoregressions, as well as from a regression of the interest rate on the corresponding forward rate, appropriately lagged. Bold figures denote cases where the Forward model predicts better than the univariate model.

Table 4. *6-month interest rates*

		Static forecasts						Dynamic forecasts					
		1997			1998			1997			1998		
		RMSE	MAE	U	RMSE	MAE	U	RMSE	MAE	U	RMSE	MAE	U
US	Univariate	0.107	0.080	0.009	0.143	0.109	0.013	0.569	0.517	0.051	0.214	0.176	0.019
	Forward	0.521	0.417	0.132	0.299	0.232	0.027	**0.562**	**0.477**	**0.139**	0.342	0.177	0.027
		0.328	0.272	0.028	0.279	0.216	0.025	**0.456**	**0.423**	**0.040**	**0.178**	**0.148**	**0.016**
Yen	Univariate	0.081	0.052	0.070	0.075	0.061	0.060	0.377	0.339	0.420	0.083	0.070	0.064
	Forward	0.406	0.304	0.266	0.119	0.102	0.091	0.380	0.271	0.272	0.120	0.101	0.092
		0.335	0.244	0.246	0.166	0.135	0.151	0.403	0.335	0.325	0.166	0.135	0.151
DM	Univariate	0.117	0.086	0.017	0.105	0.065	0.014	0.535	0.393	0.083	0.095	0.088	0.013
	Forward	0.338	0.266	0.051	0.292	0.253	0.040	**0.463**	**0.349**	**0.071**	0.289	0.267	0.039
		0.408	0.346	0.063	0.301	0.252	0.041	0.552	0.441	0.086	0.297	0.268	0.040
BP	Univariate	0.164	0.131	0.012	0.274	0.229	0.019	1.064	0.854	0.081	0.421	0.309	0.027
	Forward	0.487	0.444	0.035	0.473	0.342	0.032	**0.598**	**0.515**	**0.044**	**0.401**	0.319	**0.026**
		0.690	0.634	0.051	0.484	0.361	0.033	**0.810**	**0.723**	**0.060**	**0.400**	0.335	0.027
SP	Univariate	0.168	0.134	0.016	0.129	0.099	0.015	0.528	0.504	0.047	0.286	0.231	0.033
	Forward	0.865	0.720	0.076	0.478	0.402	0.055	0.888	0.792	0.077	0.495	0.455	0.057
		0.625	0.504	0.057	0.278	0.223	0.033	0.608	0.436	0.055	**0.201**	**0.162**	**0.024**
FF	Univariate	0.151	0.127	0.022	0.090	0.076	0.013	0.769	0.638	0.119	0.410	0.363	0.060
	Forward	0.390	0.322	0.055	0.317	0.279	0.047	**0.624**	**0.533**	**0.091**	**0.241**	**0.210**	**0.033**
		0.486	0.457	0.071	0.236	0.194	0.033	0.807	0.699	0.122	**0.203**	**0.154**	**0.028**
LI	Univariate	0.180	0.148	0.013	0.215	0.161	0.022	0.408	0.368	0.031	0.564	0.481	0.057
	Forward	0.587	0.479	0.044	0.283	0.223	0.030	0.742	0.691	0.057	**0.265**	**0.212**	**0.028**
		0.646	0.558	0.047	0.694	0.635	0.069	0.551	0.433	0.041	0.698	0.646	0.069
SF	Univariate	0.210	0.169	0.058	0.204	0.189	0.061	0.461	0.426	0.116	0.271	0.266	0.082
	Forward	0.522	0.418	0.133	0.545	0.486	0.150	0.562	0.477	0.139	0.490	0.412	0.134
		0.650	0.350	0.121	0.465	0.416	0.135	**0.442**	**0.359**	**0.115**	0.372	0.299	0.108

Note: Root Mean Square Error (RMSE), Mean Absolute Error (MAE) and Theil's U statistics for static and dynamic forecasts obtained from $AR(3)$ univariate autoregressions, as well as from a regression of the interest rate on the corresponding forward rate, appropriately lagged. Bold figures denote cases where the Forward model predicts better than the univariate model.

model for the US dollar and Spanish peseta over 1998, and the Swiss franc over 1997. Forecasting gains at these horizons are again important: a reduction of 28% is uniformly achieved in the *RMSE, MAE* and *U* statistics. Average reductions are now of 19% for 1997, and 34% for 1998.

As a final exercise, this study computed interest rate predictions under the *unbiasedness* property of forward rates, i.e., this study used the appropriate forward rate itself as a predictor of future interest rates. The results were not too bad for the shorter maturity: in 9 of the 16 *static* and *dynamic* forecast comparisons for 1-month interest rates for 1998, these *restricted* projection produced better forecasts than the *estimated* cointegrating relationship between interest rates and forward rates. In 4 of those 9 cases, they were, in fact, the best predictions. But, once again, the performance of the restricted projection deteriorated over longer maturities: in just 7 of the 16 forecast comparisons for 3-month interest rates, and in only 2 comparisons for 6-month rates, the restricted projection produced better forecast than the estimated projection, but they were never the best, being beaten by either those obtained from the least-squares projection or from the univariate model. Although there might be some gain to be exploited from fully imposing the restrictions of the EH when predicting 1-month rates, versus using the estimated interest rate/forward rate relationship, it seems hard to know *a priori* when that will be the case. In particular, we have not detected any connection with the results of testing for a unit slope in Table 1.

Focusing on *dynamic* forecasts, the forecasts obtained from the least-squares projection of interest rates on forward rates were better than those from univariate models in 29 out of the 48 forecasting exercises run for 1997 and 1998. Forecasts from the maximum-likelihood estimates of that projection as a cointegrating relationship were better than those from univariate models in 20 of the 48 comparisons, 16 of which in company of predictions obtained from the least-squares projection.

That the forecasting ability of forward rates is much better for shorter maturities should be expected. It has been shown in Table 1 that the restrictions of the EH sometimes fail to hold for the longer maturities, so it is not surprising that a model that incorporates such restrictions might not forecast too well. Nevertheless, the fact that forward rates can predict quite well 1-month interest rates one month in advance is quite remarkable, since it is in this case the 3-month/1-month spread which is being used, by itself, to forecast future 1-month rates one month in advance, without using lags of the interest rate being forecasted. That this spread can forecast even better than the own past of the 1-month interest rate should be seen as strong evidence in favour of the EH for short maturities from a practical point of view which is of fundamental relevance to the market participant, but not often documented.

V. CONCLUSIONS

The *Expectations Hypothesis* on the formation of the term structure of interest rates leads to regressions that purport to explain future short-term rates as functions of current forward rates. Usually, a good fit of these regressions has been interpreted as the forward rate having significant predictive power for future short-term interest rates, which is considered to be the essence of the Expectations Hypothesis. In fact, a zero intercept together with a unit slope in that projection of future interest rates on current forward rates is known as the forward rate being an *unbiased predictor* of future interest rates. However, a true forecasting exercise has rarely been conducted.

This study has examined the actual predictive power of those projections using 1-, 3- and 6-month interest rate monthly data for 1978–1998 on Eurodeposits on the US dollar, yen, Deutsche mark, British pound, Spanish peseta, French franc, Italian lira and Swiss franc, comparing such forecasts to those obtained from univariate autoregressions. Quite strikingly, our analysis shows that, by themselves, forward rates produce better one-step ahead forecasts, as well as better once-and-for all forecasts of 1-month interest rates over a full year horizon than those obtained form the own past of interest rates. That the information contained in forward rates can be put to that end is quite remarkable evidence in favour of the Expectations Hypothesis, at least over the shorter end of the maturity spectrum. However, the gain in one-step ahead forecasting disappears for longer maturities. Forward rates still produce better once-and-for all predictions of 3- and 6-month interest rates than univariate autoregressions for a number of currencies.

A strict interpretation of the EH would lead to using the appropriately lagged forward rate itself as a predictor of future interest rates. Again just for 1-month rates, such forecasts are in some cases still better than those obtained from the estimated projection of future interest rates on forward rates, although we have not found a way to detect *a priori* when such improvement will arise. Some more work is needed along this line.

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