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A MULTI-COUNTRY COMPARISON OF TERM STRUCTURE FORECASTS AT LONG HORIZONS

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ABSTRACT

This paper extends previous work on the information in the term structure at longer maturities to other countries besides the United States, using a newly constructed data set for 1 to 5 year interest rates from Britain, West Germany and Switzerland. Even with wide differences in inflation processes across these countries, there is we find strong evidence that the term structure does have significant forecasting ability for future changes in inflation, particularly so at long maturities. On the other hand, the ability of the term structure to forecast future changes in 1-year interest rates is somewhat weaker; only at the very longest horizon (5 years) is there significant forecasting ability for interest rate changes.

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1 Introduction

There is by now accumulating evidence that the term structure of interest rates in the United States contains substantial information on the future path of interest rates and of inflation rates. Work by Fama (1984), Fama and Bliss (1987) has shown that forward-spot spreads display significant forecasting power for future spot rate changes, especially at long horizons. Fama (1990) and Mishkin (1990a, 1990b) have also reported that the slope of the term structure is correlated with future changes in inflation rates.

In most cases, the information content of the U.S. term structure is found to increase with the forecast horizon, which has been studied up to a length of five years. One problem with these studies that they typically focus on monthly data observed over a sample period of 30 years or less. Given the overlapping nature of the sample, it is difficult to evaluate the stability of the results over shorter sample periods. An alternative procedure to assess the robustness of these findings is to analyze foreign term structure data.

Although the information content of foreign term structures at short maturities has been studied with Eurocurrency data,[1] the information in longer maturities has not been studied because of the lack of foreign data. In this paper, we have constructed a new and unique data set for the 1 to 5 year interest rates from Britain, West Germany and Switzerland. In addition, we do not rely on asymptotic distributions to conduct statistical inference; instead, we conduct inferences based on the small sample distributions derived from Monte-Carlo simulations. This allows us to analyze the information content of U.S., British, German and Swiss term structures

[1] Mishkin (1991) examines the information in the term structure about future inflation at short horizons (twelve months or less) for the U.S. and nine other OECD countries.

at longer horizons where the greatest information content is usually found.

Such comparisons are bound to be informative because of the wide differences in inflation processes across these countries. Britain has been characterized by a high inflation environment, while Germany and Switzerland have enjoyed relatively low inflation rates. Given these differences, an important issue is whether the results found for the U.S. term structure carry over to foreign markets, and in particular, whether the nominal term structure reveals similar information about the term structure of real interest rates and inflation rates.

This research also bears directly on whether central banks should use the term structure as a guide for monetary policy. If the prevalent view that an upward-sloping spot rate curve reflects expectations of higher future long-term inflation is supported, then monetary policy could conceivably be guided by the slope of the term structure. Of course, such an interpretation is subject to caution, because changes in the conduct of monetary policy could affect the long-run relationship between the term structure and changes in inflation rates.

The paper is structured as follows. Section 2 presents the tested models and summarizes the econometric issues. Section 3 details the data sources, and explains how foreign term structure data have been obtained for long horizons. Empirical tests are reported in section 4, and interpreted in section 5. The last section contains some concluding remarks.

2 Methodology

The information content of the term structure is examined in this paper by estimating several regression equations. As in Mishkin (1990a, 1990b and 1991), the information in the term structure about the future path of inflation is tested by estimating the following inflation-change regression equation:

$$\pi_t^m - \pi_t^1 = \alpha^m + \beta^m(i_t^m - i_t^1) + \epsilon_t^m, \tag{1}$$

where the future annualized m-year inflation rate (from year t to year $t+m$) minus the 1-year inflation rate is regressed on the slope of the term structure, defined as the spread between the annualized m-year interest rate and the 1-year interest rate, both measured at time t. Throughout the analysis, all inflation rates and interest rates are continuously compounded.

The slope coefficient β^m in this regression reveals information on the forecasting ability of the term structure with respect to future inflation changes. As described in Mishkin (1990a), a value of β^m significantly different from zero suggests that the term structure contains information about the path of future inflation, and that the slopes of the real and nominal term structures do not move one-for-one with each other. A value of β^m significantly different from one indicates that the term structure of real interest rates is not constant over time, and that the nominal term structure contains information about the future path of real interest rates.

Alternatively, as in Fama (1984) and Fama and Bliss (1987), the information content of the term structure can be analyzed in terms of future changes in the one-year spot rate:

$$i_{t+m-1}^1 - i_t^1 = \gamma^m + \delta^m(f_t^m - i_t^1) + \epsilon_t^m, \tag{2}$$

where f_t^m is the one-year forward rate derived from spot rates for maturities at $m-1$ and m into the future. A value of δ^m significantly different from zero indicates that the term structure contains information about future spot rate changes, while a value of δ^m significantly different from one indicates a rejection of the expectations hypothesis of the term structure.

The approach above can be related to the previous equation (1), by noting that the one-year spot rate i^1_{t+m-1}, observed at time $t+m-1$, can be decomposed into an "ex post" one-year inflation rate component π^1_{t+m} plus an "ex post" one-year real interest rate component rr^1_{t+m}, both observed at time $t+m$. Thus, as in Fama (1990), the equation above can be separated into:

$$\pi^1_{t+m} - \pi^1_t = \gamma'^m + \delta'^m(f^m_t - i^1_t) + \epsilon'^m_t \tag{3}$$

and

$$rr^1_{t+m} - rr^1_t = \gamma''^m + \delta''^m(f^m_t - i^1_t) + \epsilon''^m_t. \tag{4}$$

Since adding (3) and (4) together produces equation (2), the coefficients γ'^m and γ''^m must sum to γ^m, and δ'^m and δ''^m to δ^m.[2]

The specification in terms of multi-year inflation changes relative to one-year inflation changes in (1) is clearly linked to the model analyzing changes in the one-year inflation rates in (3). For example, with $m=2$, we have $\pi^m_t = (\pi^1_{t+1} + \pi^1_t)/2$, and $i^m_t = (i^1_t + f^2_t)/2$, so that β^2 must be identical to δ'^2. In general, for m greater than 2, the coefficient β^m will be a weighted average of the coefficients $\delta'^2, ..., \delta'^m$.

Before discussing the data and empirical results, we need to address several important econometric issues. An essential econometric consideration is that the regression error terms are likely to exhibit serial correlation which renders the usual OLS standard errors invalid. One source of the serial correlation arises from the use of overlapping forecasts with a monthly observation interval that is shorter than

[2]Note that in these regressions, the hypothesis that δ'^m and δ''^m equal one has no natural interpretation. Hence in the following empirical analysis, we only test for the statistical significance of δ'^m and δ''^m.

the forecast horizon. For instance, with $m=5$ years, the overlapping forecasts in (2) induce an $MA(12(m-1)-1) = MA(47)$ process in ϵ_t^m. Because the error terms in equations (1), (3), (4) are realized one year later, these error terms follow an $MA(12m-1)$ process, which is for instance an $MA(59)$ for $m=5$ years.

However, another possible source of serial correlation could arise from serial correlation in such variables as term premiums. There is thus a possibility that there would be serial correlation beyond the lag lengths arising from overlapping forecasts. We test for serial correlation beyond that arising from overlapping forecasts using a statistic developed by Cumby and Huizinga (1989) that extends the usual portmanteau statistic to properly account for the fact that lower order terms are not zero. To test whether 12 additional lags beyond those resulting from overlapping forecasts should be included for each regression, we computed the "L-statistic", distributed as $\chi^2(12)$, which is reported in Appendix A. None of the reported statistics indicates that additional lags are required. Therefore, the standard errors only need to be corrected for the moving average process induced by overlapping forecasts. The standard error corrections are computed using the method proposed by Hansen and Hodrick (1980) in which the autocovariances are estimated from the data, with a modification due to White (1980) that allows for conditional heteroskedasticity, and a modification suggested by Newey and West (1987) that ensures that the variance-covariance matrix is positive definite.

As has been pointed out in Mishkin (1990b), although the corrected standard errors are valid asymptotically, they can produce misleading inferences in small samples. This bias can be especially serious when examining five-year forecasts measured over a fifteen year period. Monte Carlo simulations described in detail in

Appendix B,[3] demonstrate that the small sample bias is indeed very severe. Using a standard 5% critical value from the asymptotic distribution, the test statistics reject far too often under the null, typically around 20% of the time for $m=2$ years, and often as high as 50% of the time when $m=5$ years. We found that the 5% critical values from the simulation were of the order of 3.5 for $m=2$ years, and 5.0 for $m=5$ years. As a result, all the critical values and p-values for every single test statistic reported in the following empirical analysis have been obtained from the finite sampling distributions generated by Monte Carlo simulations.

3 Data

The empirical analysis is based on monthly observations from August 1973 to June 1989 for the United States, Britain, Germany and Switzerland. The August 1973 starting point for the sample was chosen because it begins after exchange rates began to float and also because it is the first date for which data are available for all four countries. All interest rate and inflation rate data are continuously compounded and expressed in percent per annum.

The spot rates for the U.S. government bond market are taken from Shiller and McCulloch (1987) until February 1987. These data are updated to June 1989 using the same method, which involves fitting splines to the discount function for each month of the sample. The same methodology was applied to the "gilt" (British government bond) market and is explained in more detail in Appendix C. The procedure involves fitting discount functions to bond price data as reported by the

[3] These simulations were carried out as follows. First, ARMA models are fitted for all time-series, under each null hypothesis examined. Next, errors terms are drawn from a multivariate normal distribution and transformed so as to follow ARCH processes. Finally, empirical p-values are calculated from the number of times that the test statistics were exceeded in one thousand trials.

Financial Times. For the "bund" (German government bond) market, spot rates were inferred from constant maturity yield data provided by the Bundesbank. In the case of Switzerland, government bond rates were not available,[4] so the interest rates used are euro swiss franc rates obtained from *Data Resources Incorporated*. Euromarket interest rates were also available for the U.S. dollar and the German mark, and we verified that the conclusions from the empirical analysis were not affected as a result of using government bond data rather than euromarket data.

Finally, consumer price levels are taken from the *International Monetary Fund*'s International Financial Statistics. For the United States, the series prior to December 1983 is that used by Huizinga and Mishkin (1984), which appropriately treats housing costs on a rental-equivalent basis.

Table I provides summary statistics for the inflation rates and inflation changes for the four countries under consideration, sampled on a monthly basis. Over the period 1973 to 1989, the U.S. inflation rate has averaged 6%, while Germany and Switzerland have had a lower inflation rate, of about 3.5%; the British inflation rate, on the other hand, has been much higher, around 10%, and has displayed very high volatility.[5] Thus the sample of inflation environment selected for this study

[4]The Swiss government bond market is very small since Switzerland has recently been running a moderate budget surplus. At year-end 1989, outstanding issues amounted to about $7 billion in the Swiss government bond market, versus approximately $1530 billion for the U.S. Treasury market, $200 billion for the gilt market and $220 billion for the bund market.

[5]Part of the volatility can be attributed to distortions in the UK index due to various factors. For instance, the gradual imposition of the Value Added Tax in 1973 is reflected in the UK Retail Price Index. In addition, the official index in Britain includes mortgage interest payments as the main element of owner-occupied housing cost, and local taxation, as measured by real estate taxes ("rates") or the recently imposed poll tax. Other countries in this sample measure housing costs on a more appropriate rental-equivalent basis, and thus have CPI's that are more comparable to the series used in the US. The British CPI, therefore, may have distortions not found in the CPI of other countries. The Institute for Fiscal Studies, for instance, has recently compiled a different measure of the British CPI that attempts to correct the treatment of housing costs, and reports that, for the year ending April 1990, the UK inflation rate was 3% below the official measure of 9.4%. Further

Table I

Summary Statistics for Inflation Rates and Changes: August 73-June 89

Means, standard deviations, autocorrelations (for the number of lags between parentheses), contemporaneous correlations with US data. The inflation rates and inflation changes series, annualized and continuously compounded, are: (1) one-month rate (multiplied by 12 for comparison with annual data), (2) one-year rate, (3) two-year minus one-year rate, (4) three-year minus one-year rate, (5) four-year minus one-year rate, (6) five-year minus one-year rate. Series (2) to (6) are measured with overlapping data.

Period	Series	Mean	S.Dev.	Autocorrelations (1)[a]	(12)	(60)	Correlation with US
	US						
7308-8905	1Month	6.01	3.55	.696	.465	-.016	1.000
7308-8806	1Year	5.97	2.57	.993	.738	-.081	1.000
7308-8706	2-1 Year	-.17	.93	.969	.253	-.298	1.000
7308-8606	3-1 Year	-.32	1.53	.984	.483	-.366	1.000
7308-8506	4-1 Year	-.57	1.88	.988	.565	-.331	1.000
7308-8406	5-1 Year	-.79	2.12	.992	.614	-.271	1.000
	Britain						
7308-8905	1Month	9.97	9.36	.453	.525	.489	.335
7308-8806	1Year	9.82	5.69	.991	.659	.680	.734
7308-8706	2-1 Year	-.43	2.31	.959	-.364	.443	.444
7308-8606	3-1 Year	-1.09	2.91	.971	-.013	.433	.542
7308-8506	4-1 Year	-1.78	3.36	.974	.029	.464	.543
7308-8406	5-1 Year	-2.36	3.41	.973	.032	.499	.513
	Germany						
7308-8905	1Month	3.49	3.68	.481	.483	.162	.490
7308-8806	1Year	3.35	2.01	.988	.729	-.162	.824
7308-8706	2-1 Year	-.15	.73	.940	.012	-.476	.636
7308-8606	3-1 Year	-.35	1.09	.972	.377	-.569	.656
7308-8506	4-1 Year	-.63	1.30	.976	.512	-.526	.624
7308-8406	5-1 Year	-.80	1.47	.982	.615	-.522	.627
	Switzerl.						
7308-8905	1Month	3.49	5.29	.295	.330	-.128	.286
7308-8806	1Year	3.23	2.22	.977	.383	-.337	.609
7308-8706	2-1 Year	-.22	1.14	.947	-.012	-.388	.610
7308-8606	3-1 Year	-.36	1.69	.972	.323	-.557	.613
7308-8506	4-1 Year	-.52	2.04	.977	.437	-.571	.592
7308-8406	5-1 Year	-.55	2.32	.981	.452	-.496	.566

[a] Number of lags.

ranges from low-inflation countries (Germany and Switzerland) to a high-inflation country (Britain), with the United States as an intermediate case.

Term structure statistics for the four countries are presented in Table II. As expected, the ranking of average one-year spot rates corresponds to the ranking of average inflation rates: Switzerland and Germany display the lowest average nominal interest rates, while the United States and Britain have higher interest rates. For all countries, the term structure has been on average positively sloped, and the standard deviation of the slope is similar across countries.

4 Empirical Results

Table III displays estimates of the inflation-change regression (1) for the U.S., British, German government bond markets and the Swiss euromarket at maturities $m = 2, 3, 4, 5$. Underneath each t-statistic is the p-value, reported in brackets, calculated from the small sample distribution obtained from the Monte Carlo simulations described in Appendix B. The results for the U.S. indicate that the slope of the U.S. term structure for long maturities has substantial forecasting power for future U.S. inflation changes. Two of the four β^m slope coefficients are statistically significant at the five percent level and the third, for m=4 is nearly so (with a p-value of 0.08). In addition, the explanatory power of the regression substantially increases with the maturity: the R^2's rise from 26% up to 53%. Furthermore, none of the β^m coefficients is significantly different from one, indicating that the we cannot reject the hypothesis that the slope of the real term structure is constant over time for maturities greater than one year, which implies that the nominal term

information on the construction of the UK and German price indices can be found for instance in Teekens (1989).

Table II

Summary Statistics for the Term Structure: July 73-June 89

Means, standard deviations, autocorrelations (lags between parentheses), contemporaneous correlations with US data. Term structure data for the the United States, Britain, Germany measured from government bond data; for Switzerland, the series are based on Eurocurrency data. The data, sampled monthly and continuously compounded, are: (1) the one-year spot rate, (2) the two-year minus the one-year spot rate (which is also the 1- to 2-year forward rate) (3) the three-year minus the one-year rate, (4) the four-year minus the one-year rate, (5) the five-year minus the one-year spot rate.

Period	Series	Mean	S.Dev.	Autocorrelations (1)[a]	(12)	(60)	Correlation with US
	US						
7308-8806	1Year	8.85	2.68	.956	.643	-.733	1.000
7308-8706	2-1 Year	.21	.50	.909	.514	-.232	1.000
7308-8606	3-1 Year	.29	.79	.916	.513	-.318	1.000
7308-8506	4-1 Year	.30	.95	.911	.496	-.368	1.000
7308-8406	5-1 Year	.25	1.04	.900	.420	-.186	1.000
	Britain						
7308-8806	1Year	10.58	1.81	.911	.248	-.016	.598
7308-8706	2-1 Year	.44	.57	.823	.187	-.068	.140
7308-8606	3-1 Year	.74	.82	.859	.137	-.005	.168
7308-8506	4-1 Year	.96	.85	.872	.108	-.115	.273
7308-8406	5-1 Year	1.15	.90	.875	.172	-.245	.372
	Germany						
7308-8806	1Year	6.38	2.22	.985	.612	-.527	.710
7308-8706	2-1 Year	.43	.44	.958	.427	-.619	.573
7308-8606	3-1 Year	.63	.69	.962	.436	-.610	.579
7308-8506	4-1 Year	.75	.88	.965	.446	-.586	.569
7308-8406	5-1 Year	.82	1.05	.969	.462	-.598	.591
	Switzerl.						
7308-8806	1Year	4.64	2.16	.966	.402	-.441	.517
7308-8706	2-1 Year	.32	.61	.676	.184	-.326	.320
7308-8606	3-1 Year	.60	.86	.836	.264	-.498	.350
7308-8506	4-1 Year	.82	1.11	.893	.333	-.598	.403
7308-8406	5-1 Year	.97	1.27	.911	.377	-.713	.469

[a] Number of lags.

Table III

Estimates of Inflation Change Regressions: $\pi_t^m - \pi_t^1 = \alpha^m + \beta^m(i_t^m - i_t^1) + \epsilon_t^m$

where the annualized m-year inflation rate minus the 1-year inflation rate is regressed against the slope of the term structure $i_t^m - i_t^1$, defined as the spread between the annualized m-year interest rate and the 1-year interest rate.

Period	Series	α^m (s.e.)[a]	β^m (s.e.)	R^2	t-test[b] of $\beta^m = 0$ [Simulation p-values][c]	t-test of $1 - \beta^m = 0$
	US					
7308-8706	2-1 Year	-.385	0.948	0.260	3.85*	0.21
		(.203)	(.246)		[0.03]	[0.88]
7308-8606	3-1 Year	-.702	1.220	0.392	4.75*	-0.86
		(.307)	(.257)		[0.03]	[0.61]
7308-8506	4-1 Year	-1.034	1.372	0.483	3.91	-1.06
		(.363)	(.351)		[0.08]	[0.61]
7308-8406	5-1 Year	-1.210	1.491	0.535	3.96	-1.30
		(.446)	(.377)		[0.12]	[0.55]
	Britain					
7308-8706	2-1 Year	-.812	0.913	0.050	1.08	0.10
		(.517)	(.845)		[0.43]	[0.94]
7308-8606	3-1 Year	-1.772	0.931	0.069	0.99	0.07
		(.893)	(.940)		[0.51]	[0.96]
7308-8506	4-1 Year	-3.194	1.464	0.138	1.81	-0.57
		(.879)	(.811)		[0.29]	[0.72]
7308-8406	5-1 Year	-4.168	1.585	0.175	2.83	-1.04
		(.597)	(.560)		[0.17]	[0.60]
	Germany					
7308-8706	2-1 Year	-.273	0.276	0.027	0.99	2.59
		(.205)	(.279)		[0.54]	[0.16]
7308-8606	3-1 Year	-.664	0.473	0.091	2.35	2.62
		(.282)	(.201)		[0.25]	[0.21]
7308-8506	4-1 Year	-1.120	0.636	0.189	5.01	2.87
		(.298)	(.127)		[0.09]	[0.19]
7308-8406	5-1 Year	-1.522	0.876	0.385	8.82*	1.25
		(.273)	(.099)		[0.03]	[0.61]
	Switzerl.					
7308-8706	2-1 Year	-.454	0.689	0.133	2.58	1.16
		(.289)	(.267)		[0.07]	[0.35]
7308-8606	3-1 Year	-.996	1.019	0.263	4.17*	-0.08
		(.460)	(.244)		[0.03]	[0.96]
7308-8506	4-1 Year	-1.555	1.223	0.432	6.00*	-1.09
		(.510)	(.204)		[0.03]	[0.56]
7308-8406	5-1 Year	-1.900	1.362	0.539	7.41*	-1.97
		(.473)	(.184)		[0.03]	[0.37]

[a] Asymptotic standard errors between parentheses.
[b] Significance at 5% level denoted by *, using critical values from simulations.
[c] Simulation p-values between brackets.

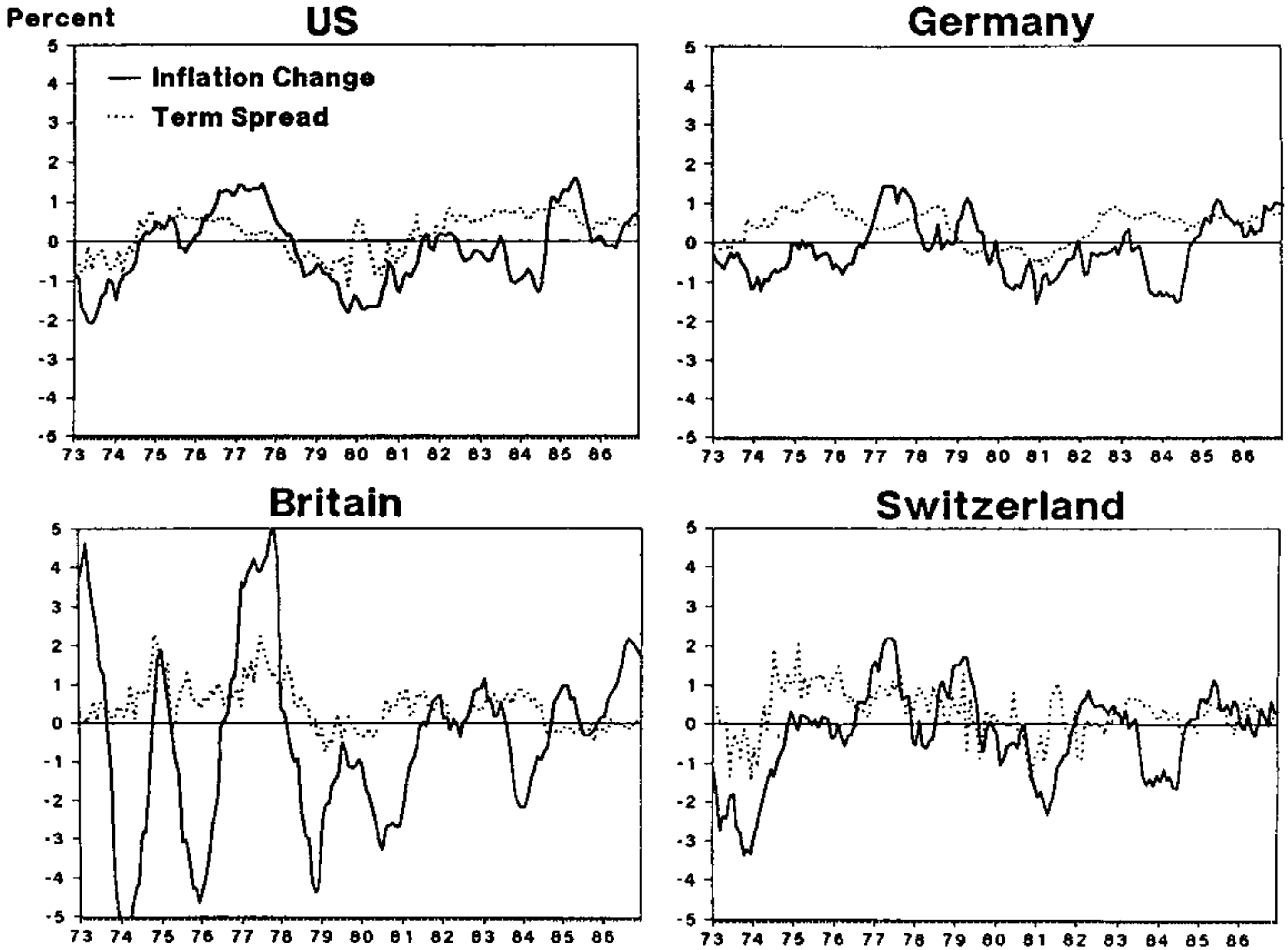
structure contains no information about the slope of the real term structure.

The U.S. results presented here are very similar to those found in Mishkin (1990b), which are estimated for a sample period (data from 1953 to 1987) which is less current but is substantially longer than that here. The estimated β^m coefficients have a similar rising pattern as m increases, and are of a similar magnitude. Furthermore, the percentage of variation explained by the U.S. regressions in Table III are also similar in magnitude to those in Mishkin (1990b), but the R^2s are actually slightly higher here. One difference with previous results is that the β^m coefficients are not quite as statistically significant. This is readily explained by the fact that the sample here is half the size of the Mishkin (1990b) sample period.

The results for Germany and Switzerland also show significant ability of the term structure to forecast the future path of inflation. The Swiss β^m coefficients for m=3,4,5 are significant at the 5% level, and the remaining β^m coefficient for m=2 is significant at 10%. The German β^m coefficient for m=5 is significant at the 5% level, and for m=4 it is significant at 10%. However, for shorter horizons the German β^m coefficients are small and are not statistically significant. The British data indicate that, although most of the slope coefficients are close to one, the standard deviations of the estimates are much higher than for other countries. The null hypothesis of $\beta^m = 1$ cannot be rejected in any country, so we cannot reject the hypothesis that for these maturities the slope of the real term structure is constant over time.

Some of these results can be interpreted in terms of Figure 1, which displays the relationship between the 2-to-1-year slope of the term structure and 2-to-1-year inflation change for the four countries under study. For comparability, the vertical scale has been kept the same for all countries. The figures dramatically illustrate

Fig. 1. 2-1 Year Inflation Change and Term Spread



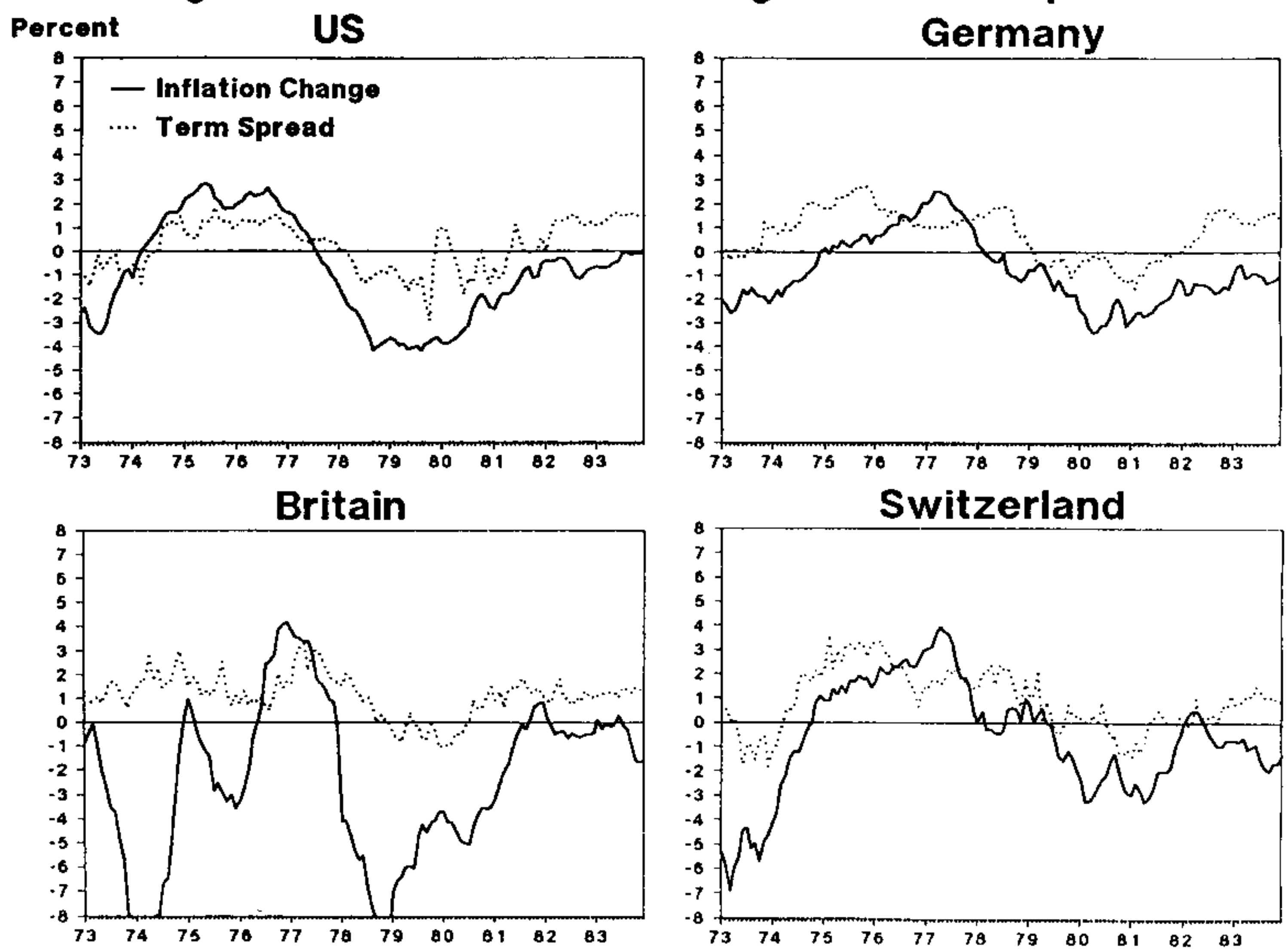
the volatility of the British inflation rate and the stability of the German inflation rate compared to other countries. The fit of the U.S. term structure seems quite good, while the results for the pound are erratic. Changes in the German inflation rate, however, are not adequately captured by the 2-to-1 year slope of the term structure.

The results are more clear-cut in Figure 2, which reports 5-to-1-year changes in inflation rates, which have longer swings than shorter-term changes. As a result, the fit of the U.S. term structure is quite good, and the fit of the German term structure improves considerably.

A comparison of these results with those for shorter maturities in Mishkin (1991) provides an additional perspective on the results. At maturities of twelve months or less in the U.S., Germany and Switzerland, the ability of the term structure to forecast the future path of inflation is quite low: the β^m coefficients are small, are typically not statistically significant, and the R^2's of the inflation change regressions are well below 0.10. In addition, the β^m coefficients are typically significantly less than 1.0, so that there does appear to be information in the nominal term structure about the real term structure. The results at the shorter maturities are thus quite different from those in Table III which indicate that at longer maturities there is significant information in the nominal term structure about the future inflation but not about the real term structure. This is given further confirmation by the pattern of increasing R^2's as m increases in Table III.

In contrast to the other countries, the results on the British inflation change regressions are similar for both shorter and longer maturities: the β^m coefficients for maturities of twelve months or less are much closer to 1.0 than to zero, and have similar magnitudes to those in Table III. However, the β^m coefficients are typically

Fig.2. 5-1 Year Inflation Change and Term Spread



statistically significant at the shorter maturities, while this is not the case here. The findings for the shorter maturities suggest that a likely explanation for the lack of statistical significance for the longer-term British results is the low power of the tests because there is a higher degree of data overlap with forecast horizons much greater than the observation interval. Indeed, the longer maturity regressions for Britain do display higher R^2's than are found in the shorter maturity results in Mishkin (1991). The R^2 are also increasing with maturity.

In view of these results, a natural question to ask is whether the results differ across countries. In Table III, the slope coefficients are not all that different in magnitude and therefore it is entirely possible that differences are just due to sampling variation. To explore this possibility, we tested for the equality of the β^m coefficients across countries, using a chi-square test statistic for which the p-value was calculated from the small sample distribution obtained from the Monte Carlo simulations. Table D-I in Appendix D contains bilateral tests as well as tests that the β^m coefficients are equal for all the countries. Underneath each chi-square test statistic is the marginal significance level calculated from the small sample distribution obtained from the Monte Carlo simulations. Not one of the statistics in Table D-I is statistically significant. Thus we cannot reject the null hypothesis that the information in the term structure is similar for these four countries. A reasonable conclusion is then that in all four countries, the term structure has some ability to forecast future long-term changes in inflation rates.

The information content of the term structure about future interest rate changes is analyzed in Table IV, which displays estimates of equation (2). These regressions of the changes in the one-year spot rates on the forward-spot spread are comparable to Fama and Bliss's (1987) results. A surprising finding is that, in contrast

Table IV

Estimates of Spot Change Regressions: $i^1_{t+m-1} - i^1_t = \gamma^m + \delta^m(f^m_t - i^1_t) + \epsilon^m_t$

where the change in the 1-year spot rate from t to $t+m-1$ is regressed on the forward-spot spread, defined as the spread between the annualized 1-year forward rate derived from the $(m-1)$-year and m-year spot rates, and the 1-year interest rate.

Period	Series	γ^m (s.e.)[a]	δ^m (s.e.)	R^2	t-test[b] of $\delta^m = 0$ [Simulation p-values][c]	t-test of $1-\delta^m = 0$
	US					
7308-8706	2-1 Year	0.008	-.156	0.005	-.48	3.59
		(.486)	(.322)		[0.76]	[0.06]
7308-8606	3-1 Year	-.136	-.036	0.000	-.06	1.77
		(1.107)	(.586)		[0.97]	[0.29]
7308-8506	4-1 Year	-.334	0.469	0.029	0.72	0.81
		(.651)	(.652)		[0.69]	[0.66]
7308-8406	5-1 Year	-.303	1.395	0.192	2.03	-0.57
		(1.716)	(.688)		[0.31]	[0.78]
	Britain					
7308-8706	2-1 Year	-.716	0.667	0.115	2.34	1.17
		(.357)	(.284)		[0.09]	[0.39]
7308-8606	3-1 Year	-1.485	1.056	0.270	2.40	-0.13
		(.458)	(.439)		[0.14]	[0.91]
7308-8506	4-1 Year	-1.595	1.068	0.202	2.40	-0.15
		(.567)	(.445)		[0.15]	[0.92]
7308-8406	5-1 Year	-2.121	1.195	0.256	3.19	-0.52
		(.527)	(.375)		[0.11]	[0.75]
	Germany					
7308-8706	2-1 Year	-.764	0.408	0.035	0.78	1.14
		(.720)	(.521)		[0.64]	[0.53]
7308-8606	3-1 Year	-1.520	0.737	0.094	1.67	0.60
		(.993)	(.440)		[0.38]	[0.76]
7308-8506	4-1 Year	-2.329	1.271	0.246	3.41	-.73
		(.837)	(.372)		[0.15]	[0.71]
7308-8406	5-1 Year	-2.924	1.705	0.447	6.88*	-2.84
		(.910)	(.248)		[0.03]	[0.31]
	Switzerl.					
7308-8706	2-1 Year	-.539	0.322	0.029	1.08	2.28
		(.509)	(.297)		[0.43]	[0.11]
7308-8606	3-1 Year	-1.590	0.836	0.151	1.56	0.31
		(.844)	(.535)		[0.39]	[0.87]
7308-8506	4-1 Year	-2.193	1.062	0.305	2.43	-0.14
		(.714)	(.437)		[0.27]	[0.94]
7308-8406	5-1 Year	-2.500	1.366	0.443	7.11*	-1.95
		(.951)	(.194)		[0.01]	[0.36]

[a] Asymptotic standard errors between parentheses.

[b] Significance at 5% level denoted by *, using critical values from simulations.

[c] Simulation p-values between brackets.

to Fama and Bliss's (1987) results, the forward-spot spread has no significant forecasting power for future changes in U.S. interest rates: none of the δ^m coefficients is statistically significant, and only one of the t-statistics is above 2.0. One possible explanation for the difference between these results and those in Fama and Bliss (1987) is the shorter sample period used here.[6] Rather, the explanation seems to be the additional two and a half years of data at the end of our sample. When estimating these regressions over the period August 1973 to December 1986, the results are very similar to those in Fama and Bliss (1987). The t-statistic on δ^m is below 2.0 for m=2 and 3, but rises to above 4.0 for m=4 and is above 10.0 for m=5. Figures 3 and 4 present plots of 2-1 year and 5-1 year changes in the 1-year spot rate, along with the forward-spot spreads, for the four countries. In Figure 4, it is particularly clear that the relationship between spot rate changes and the forward spread broke down, and was even reversed in the last three years of the sample for the United States. The conclusion in Fama and Bliss (1987) that there is substantial information in the term structure about future changes in interest rates at longer horizons, particularly when m=4 and 5,[7] is greatly weakened by the addition of another two and a half years of data.

The results for the other countries also do not reveal a great deal of information in the term structure about future spot interest rate changes. Only in Germany and Switzerland are there significant δ^m coefficients, and these occur only at the longest horizon of m=5. Note, however, that these tests are likely to have low power because as the last column in Table IV reveals, we are also unable to reject that δ^m

[6] For example when m=5, Fama and Bliss had 216 observations versus 131 in our sample.

[7] Note that although Fama and Bliss (1987) find a t-statistic of 2.65 for m=3, the Monte Carlo results here indicate that this statistic is unlikely to be statistically significant. Only in the m=4 and 5 regressions when the t-statistics are above 5.0 is it likely that the estimates of the δ^m coefficients are statistically significant.

Fig.3. 2-1 Year Spot Change and Forward-Spot Spread

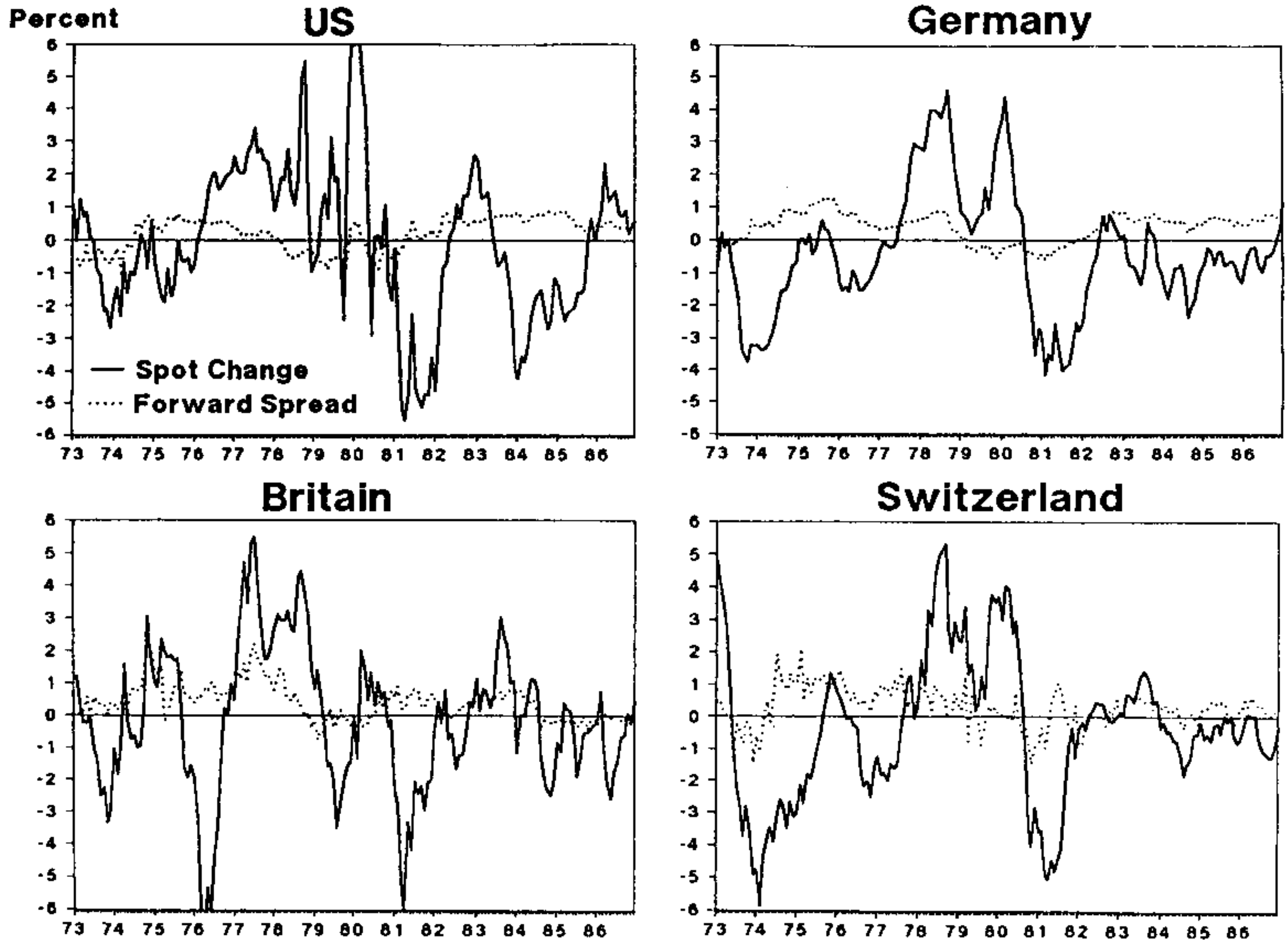
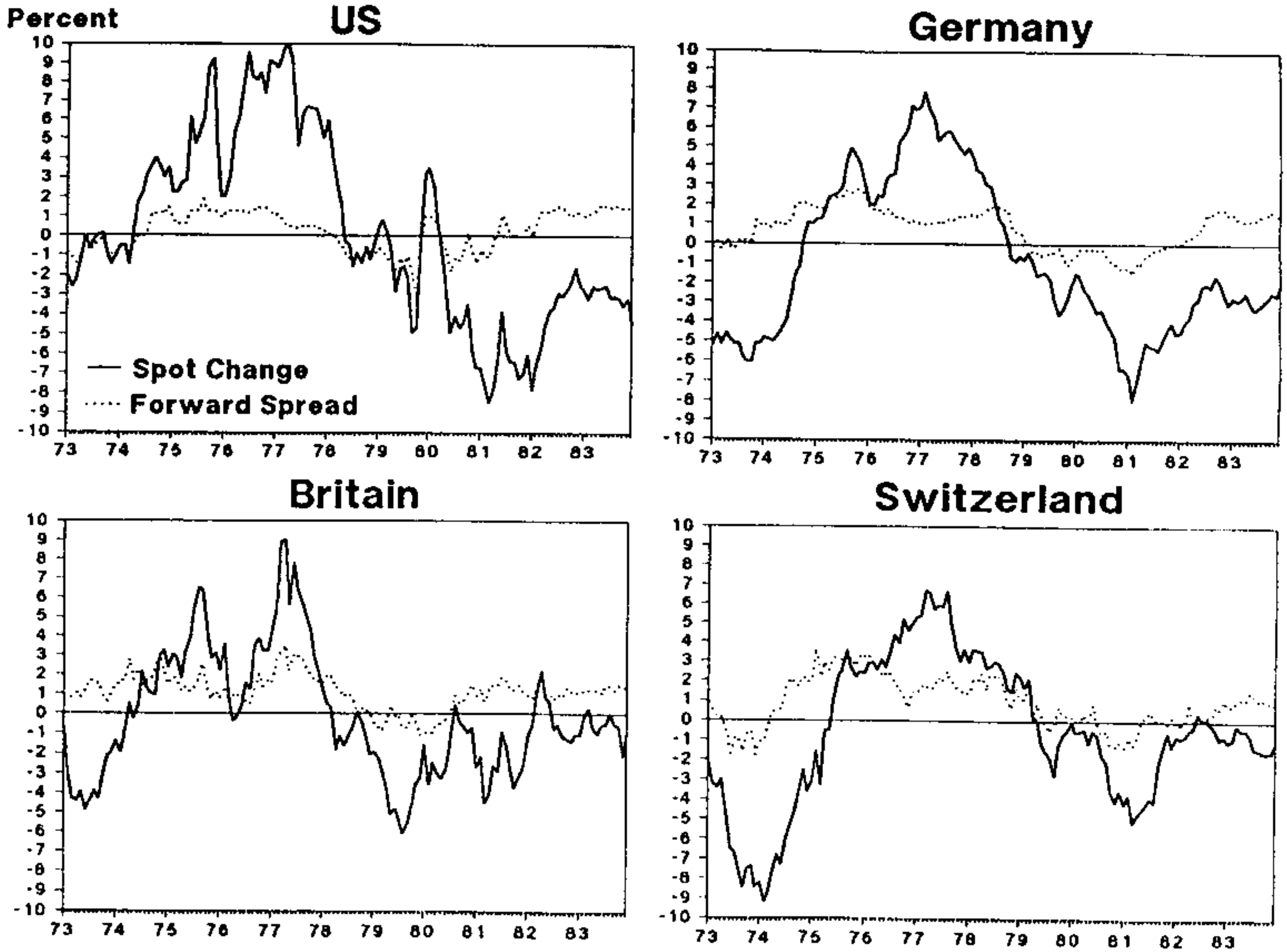


Fig.4. 5-1 Year Spot Change and Forward-Spot Spread



$= 1$ for any country or horizon. Table D-II which conducts tests of the equality of the δ^m coefficients across countries suggests that there are no major differences in the results among these countries: the null hypothesis that the δ^m are equal is never rejected. Given the low power of the tests and the fact that there are significant δ^m in two cases, the following conclusion seems to be warranted: there does seem to be evidence of some ability of the term structure to forecast future changes in spot interest rates, but only when the horizon is quite long.

The decomposition of the spot change regressions is found in Table V which displays estimates of equations (3) and (4). The ability of the term structure to forecast future inflation changes is again quite evident in this table. In all the countries except the U.K., most of the δ'^m coefficients are significant at the 5% level. In the case of the estimated δ''^m coefficients for the United States, which tell us about the ability of the term structure to forecast changes in one-year real rates, we find a result already reported by Fama (1990): the δ''^m coefficients are of opposite sign to the δ'^m coefficients, with the δ''^m coefficient for $m = 1$ statistically significant at the 5% level. Furthermore, at maturities less than five years the δ''^m coefficients almost exactly offset the δ'^m coefficients. This explains why the δ^m coefficients are so near zero for maturities less than five years, and hence why the term structure at these maturities has so little ability to forecast changes in spot rates. However, for the other countries, the δ''^m coefficients are not typically negative and none of the δ''^m coefficients are statistically significant. We thus see that for these countries, to the extent that forward-spot spreads can forecast future spot interest rate changes, this comes from the ability of the term structure to forecast future inflation changes. Not surprisingly considering the earlier results, the chi-square tests in Table D-III indicate that there is no evidence that the δ' and δ'' slope coefficients differ across

Table V

Decomposition of Spot Change Regressions

Inflation Rate Change: $\pi^1_{t+m} - \pi^1_t = \gamma'^m + \delta'^m(f^m_t - i^1_t) + \epsilon'^m_t$

Real Rate Change: $rr^1_{t+m} - rr^1_t = \gamma''^m + \delta''^m(f^m_t - i^1_t) + \epsilon''^m_t$

where the variables are regressed on the forward-spot spread, defined as the spread between the annualized 1-year forward rate derived from the $(m-1)$-year and m-year spot rates, and the 1-year interest rate.

Period	Series	γ'^m (s.e.)[a]	δ'^m (s.e.)	R^2	t-test[b] of $\delta'^m = 0$ [p-value][c]	γ''^m (s.e.)	δ''^m (s.e.)	R^2	t-test of $\delta''^m = 0$ [p-value]
	US								
7308-8706	2-1 Year	-.769	.948	0.260	3.85*	0.777	-1.104	0.152	-4.10*
		(.407)	(.246)		[0.03]	(.430)	(.269)		[0.02]
7308-8606	3-1 Year	-1.298	1.404	0.428	4.46*	1.163	-1.439	0.240	-2.56
		(.526)	(.315)		[0.04]	(.904)	(.562)		[0.16]
7308-8506	4-1 Year	-1.857	1.734	0.536	4.25	1.523	-1.265	0.167	-2.77
		(.629)	(.408)		[0.07]	(1.397)	(.456)		[0.17]
7308-8406	5-1 Year	-2.005	1.570	0.411	5.95*	1.702	-.175	0.003	-0.33
		(1.047)	(.264)		[0.04]	(1.684)	(.525)		[0.88]
	Britain								
7308-8706	2-1 Year	-1.624	0.913	0.050	1.08	0.908	-.245	0.004	-0.35
		(1.03)	(.845)		[0.43]	(1.135)	(.708)		[0.79]
7308-8606	3-1 Year	-2.955	0.624	0.028	0.58	1.471	0.431	0.013	0.48
		(1.874)	(1.073)		[0.73]	(1.968)	(.903)		[0.76]
7308-8506	4-1 Year	-4.187	0.649	0.020	0.56	2.592	0.419	0.010	0.50
		(2.060)	(1.169)		[0.77]	(2.010)	(.834)		[0.78]
7308-8406	5-1 Year	-5.519	0.826	0.056	1.76	3.398	0.369	0.012	1.12
		(1.165)	(.469)		[0.39]	(1.190)	(.330)		[0.60]
	Germany								
7308-8706	2-1 Year	-.546	0.276	0.027	0.99	-.218	0.132	0.003	0.31
		(.410)	(.279)		[0.56]	(.604)	(.424)		[0.81]
7308-8606	3-1 Year	-1.405	0.676	0.149	2.82	-.115	0.061	0.001	0.20
		(.449)	(.240)		[0.20]	(.765)	(.298)		[0.89]
7308-8506	4-1 Year	-2.272	1.018	0.329	6.57*	-.056	0.252	0.017	0.88
		(.355)	(.155)		[0.05]	(.592)	(.288)		[0.66]
7308-8406	5-1 Year	-3.015	1.370	0.657	12.34*	0.091	0.335	0.040	1.71
		(.211)	(.111)		[0.01]	(.753)	(.196)		[0.47]
	Switzerl.								
7308-8706	2-1 Year	-.908	0.689	0.133	2.58	0.369	-.367	0.027	-1.64
		(.578)	(.267)		[0.10]	(.464)	(.224)		[0.24]
7308-8606	3-1 Year	-2.048	1.228	0.336	4.78*	0.458	-.393	0.036	-1.36
		(.752)	(.257)		[0.03]	(.483)	(.290)		[0.45]
7308-8506	4-1 Year	-2.708	1.356	0.545	6.61*	0.516	-.294	0.025	-0.67
		(.612)	(.205)		[0.03]	(.299)	(.439)		[0.73]
7308-8406	5-1 Year	-2.934	1.549	0.589	9.50*	0.434	-.172	0.009	-0.94
		(.271)	(.163)		[0.01]	(.854)	(.183)		[0.67]

[a] Asymptotic standard errors between parentheses.

[b] Significance at 5% level denoted by *, using critical values from simulations.

[c] Simulation p-values between brackets.

countries.

We can obtain an even better understanding of the information content in the term structure regarding both future inflation and interest rate changes by using the assumption of rational expectations, as was done in Fama (1984), Hardouvelis (1988) and Mishkin (1990a). Given rational expectations, the slope coefficients β^m or δ^m can be written as $(\sigma^2+\rho\sigma)/(1+\sigma^2+2\rho\sigma)$, where σ = the ratio of the standard deviation of the expected inflation change (or spot rate change) to the standard deviation of the slope of the real term structure (or the forward premium), and ρ = the correlation between the expected inflation (spot rate) change and the slope of the real term structure (forward premium). The dashed lines in Figures 5 and 6 show the theoretical relationship between σ and the slope coefficients for ρ = -0.5 or -0.9, which is the typical range of ρ values found in the data. The dashed lines indicate that high σ's result in slope coefficients that are substantially above zero, which means that the term structure has informational content. The σ's are best thought of as akin to signal-to-noise ratios where the noise is either variation in the real term structure slope or in forward premiums, which obscures the information in the term structure about expected changes in inflation or interest rates.

Estimated values of the σ's and ρ's can be computed using a procedure outlined in Mishkin (1990a); the resulting implied β^m and δ^m slope coefficients are plotted in Figures 5 and 6. The coefficient for m=2 is always the leftmost coefficient and a line is connected to the next higher m coefficient. The estimated implied coefficients in Figure 5 reveal why the β^m coefficients tend to be high for all countries, which means that the term structure does reveal information about future inflation changes. Except at the shorter horizons for Germany, the σ's are always above one, leading to β^m coefficients which exceed 0.5. Furthermore the pattern of β^m coefficients

Fig.5. Interpretation of Inflation Change Regressions

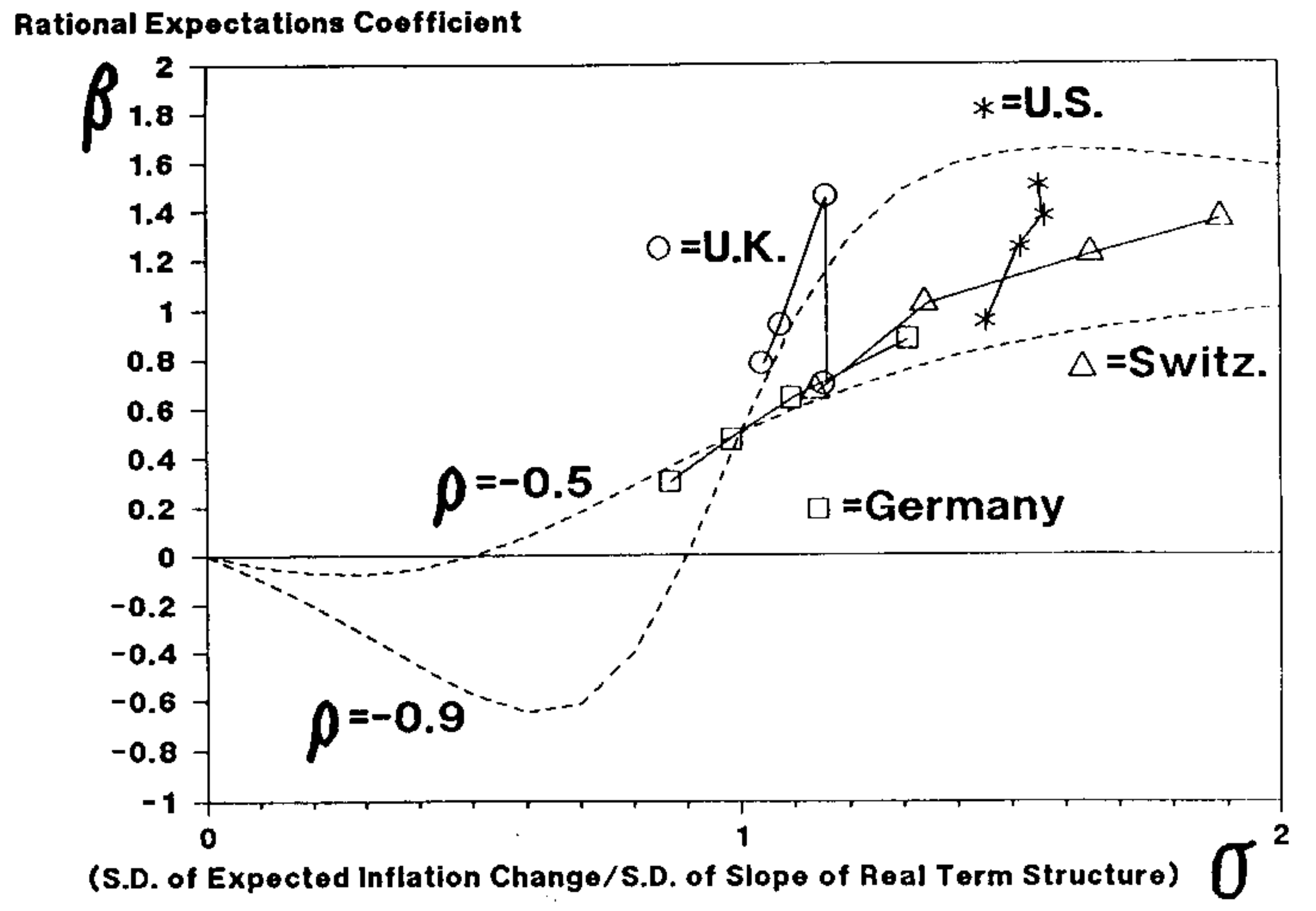
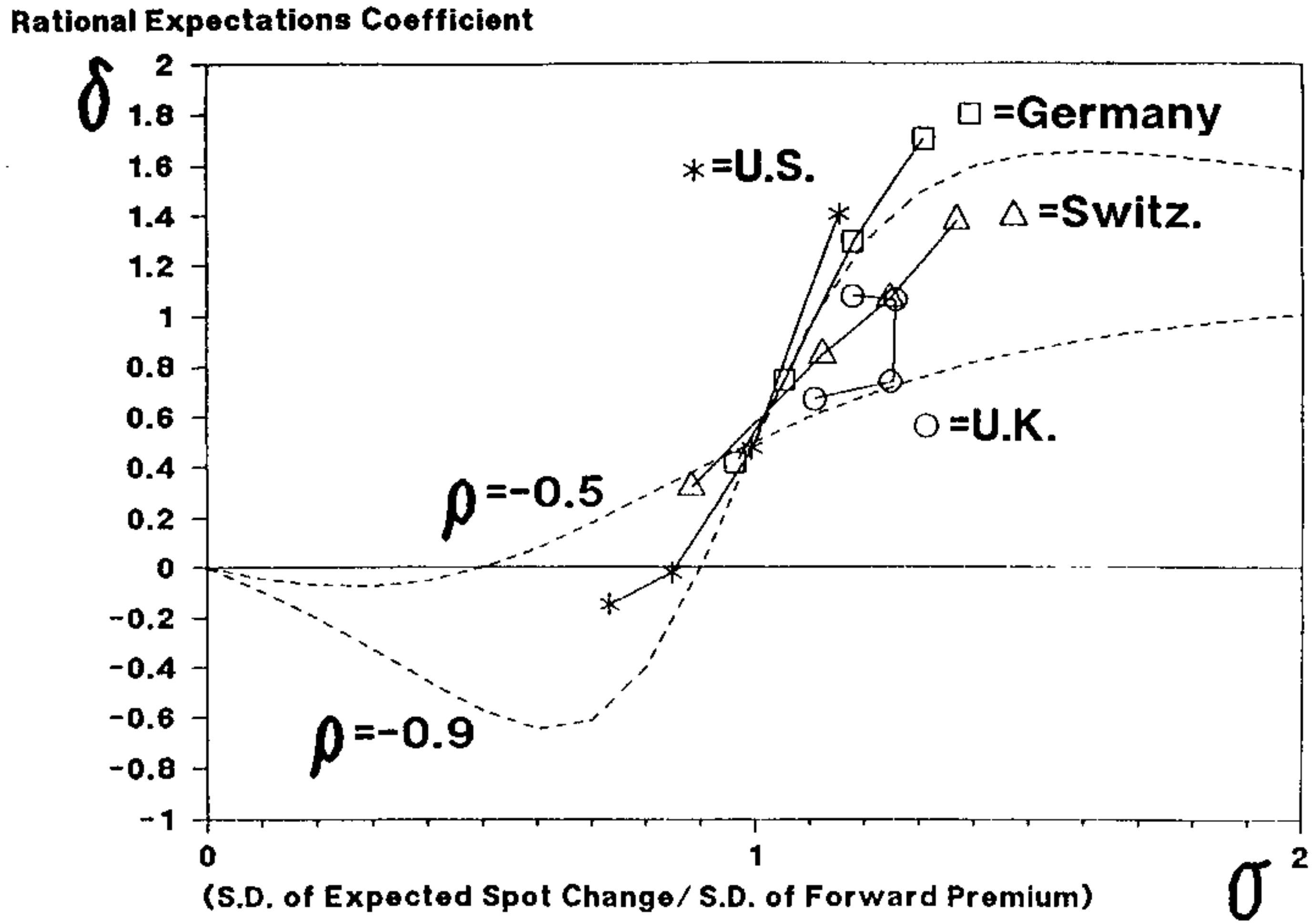


Fig.6. Interpretation of Spot Change Regressions



rising with m in Table III results from an increase in σ as the maturity lengthens. At longer horizons the variation of expected inflation changes rises relative to the variation in the real term structure slope, which produces greater information in the term structure about future inflation.

Figure 6 shows a similar pattern of σ's and implied δ^m coefficients increasing as m increases, except for the U.K. The rise in the σ's with increasing m in both figures is not coincidental, because variation in the real term structure slope can be in part attributed to variation in the forward premium. In addition, the presence of a Fisher effect –the positive correlation between nominal interest rates and expected inflation– might link expected inflation changes to expected interest rate changes. Thus when σ in Figure 6 rises, we might also expect the σ in Figure 5 to rise as well. The major difference between the two figures is that the σ's are more likely to be below 1.0 in Figure 6 when the m-horizon is short. This is what produces the low δ^m coefficients at the shorter horizons. This helps explain the empirical results that indicate that for shorter horizons, there is more information in the term structure about future inflation changes than there is about future interest rate changes.

5 Conclusions

This paper extends previous work on the information in the term structure at longer maturities to other countries besides the United States. The evidence indicates that results for these other countries are similar to those found for the U.S. There is strong evidence that the term structure does have significant forecasting ability for future changes in inflation, particularly so at long maturities. On the other hand, the ability of the term structure to forecast future changes in 1-year interest rates is somewhat weaker; only at the very longest horizon (5 years) is there significant forecasting ability for interest rate changes.

The evidence in this paper does suggest that for other countries besides the U.S., the term structure can be used to help assess future inflationary pressures in the longer run: a steepening of the slope of the longer maturity term structure indicates that the inflation rate will rise several years in the future and conversely, a negative slope indicates reduced inflationary pressures. However, we must be somewhat cautious about this interpretation because changes in the conduct of monetary policy could affect the variation of expected inflation changes relative to variation in the real term structure and hence alter the relationship between the term structure and changes in inflation rates.

References

Cumby, Robert E., and John Huizinga, 1989, Testing for Autocorrelation Structure of Disturbances in Ordinary Least Squares and Instrumental Variables Regressions, Mimeo, *New York University*, forthcoming *Econometrica*.

Engle, Robert, 1982, Autoregressive Conditional Heteroskedasticity with Estimates of the Variance of United Kingdom Inflation, *Econometrica*, 50, 987–1007.

Fama, Eugene F., 1984, The Information in the Term Structure, *Journal of Financial Economics* 13, 509-528.

Fama, Eugene F., 1990, Term Structure Forecasts of Interest Rates, Inflation and Real Returns, *Journal of Monetary Economics* 25, 59-76.

Fama, Eugene F. and Bliss, Robert R., 1987, The Information in Long-Maturity Forward Rates, *American Economic Review* 77, 680-92.

Hansen, Lars P., 1982, Large Sample Properties of Generalized Method of Moments Estimators, *Econometrica* 50, 1029-54.

Hansen, Lars P., and Hodrick, Robert, 1980, Forward Exchange Rates as Optimal Predictors of Future Spot Rates, *Journal of Political Economy* 88, 829-53.

Hardouvelis, Gikas A., 1988, The Predictive Power of the Term Structure During Recent Monetary Regimes, *Journal of Finance* 43, 339-56.

Huizinga, John and Mishkin, Frederic S., 1984, Inflation and Real Interest Rates on Assets with Different Risk Characteristics, *Journal of Finance* 39, 699-712.

Litzenberger, Robert and Rolfo, Jacques, 1984, An International Study of Tax Effect on Government Bonds, *Journal of Finance* 39, 1-22.

Mishkin, Frederic S., 1981, The Real Rate of Interest, An Empirical Investigation, The Cost and Consequences of Inflation, *Carnegie-Rochester Conference Series on Public Policy* 15, Amsterdam, North Holland, 151-200.

Mishkin, Frederic S., 1984, The Real Interest Rate, A Multi-Country Empirical Study, *Canadian Journal of Economics* 17, 283-311.

Mishkin, Frederic S., 1990a, What Does the Term Structure Tell Us About Future Inflation? *Journal of Monetary Economics* 25, 77-95.

Mishkin, Frederic S., 1990b, The Information in the Longer-Maturity Term Structure About Future Inflation, National Bureau of Economic Research Working Paper No.3126, *Quarterly Journal of Economics* 55, 815-28.

Mishkin, Frederic S., 1991, A Multi-Country Study of the Information in the Term Structure About Future Inflation, forthcoming, *Journal of International Money and Finance.*

Newey, W., and West Kenneth, 1987, A Simple, Positive Definite, Heteroskedasticity and Autocorrelation Consistent Covariance Matrix, *Econometrica* 55, 703-708.

Shiller, Robert J., McCulloch, J. Huston, 1987, The Term Structure of Interest Rates, *NBER Working Paper* 2341.

Teeken, Rudolf, 1989, Consumer Price Indices in the European Community, *Eurostat*, Luxembourg, Office for Official Publication of the European Communities.

White, Halbert, 1980, A Heteroskedasticity-Consistent Covariance Matrix Estimator and Direct Tests for Heteroskedasticity, *Econometrica* 48: 817-38.

Legend for Figures

Fig. 1. 2-1 Year Inflation Change and Term Spread

Time-series of the annualized 2-year inflation rate minus the 1-year inflation rate $\pi_t^2 - \pi_t^1$ ("inflation change"), and of the slope of the term structure $i_t^2 - i_t^1$ ("term spread"), defined as the spread between the annualized 2-year interest rate and the 1-year interest rate.

Fig. 2. 5-1 Year Inflation Change and Term Spread

Time-series of the annualized 5-year inflation rate minus the 1-year inflation rate $\pi_t^5 - \pi_t^1$ ("inflation change"), and of the slope of the term structure $i_t^5 - i_t^1$ ("term spread"), defined as the spread between the annualized 5-year interest rate and the 1-year interest rate.

Fig. 3. 2-1 Year Spot Change and Forward-Spot Spread

Time-series of the difference between the annualized 1-year spot rates $i_{t+1}^1 - i_t^1$ ("spot change"), and of $f_t^2 - i_t^1$ ("forward-spot spread"), defined as the spread between the annualized 1-year forward rate derived from the 1-year and 2-year spot rates, and the 1-year interest rate.

Fig. 4. 5-1 Year Spot Change and Forward-Spot Spread

Time-series of the difference between the annualized 1-year spot rates $i_{t+4}^1 - i_t^1$ ("spot change"), and of $f_t^5 - i_t^1$ ("forward-spot spread"), defined as the spread between the annualized 1-year forward rate derived from the 4-year and 5-year spot rates, and the 1-year interest rate.

Fig. 5. Interpretation of Inflation Change Regressions

The dashed lines represent the implied coefficients β of the regression of the inflation change on the slope of the term structure $\pi_t^m - \pi_t^1 = \alpha^m + \beta^m(i_t^m - i_t^1) + \epsilon_t^m$, for typical values of ρ ($\rho = -0.5$ and $\rho = -0.9$) under rational expectations; ρ is the correlation between the expected inflation change and the slope of the real term structure, while σ is the ratio of the standard deviation of the expected inflation change to the standard deviation of the slope of the real term structure. Each marker on the graph plots the implied regression coefficients β that correspond to the estimated values of ρ and σ for four maturities. The coefficient for m=2 is always represented by the leftmost marker, and a line is connected to the next higher m coefficient.

Fig. 6. Interpretation of Spot Change Regressions

The dashed lines represent the implied coefficients δ of the regression of the spot rate change change on the forward premium $i_{t+m-1}^1 - i_t^1 = \gamma^m + \delta^m(f_t^m - i_t^1) + \epsilon_t^m$, for typical values of ρ ($\rho = -0.5$ and $\rho = -0.9$) under rational expectations; ρ is the correlation between the expected spot change and the forward premium, while σ is the ratio of the standard deviation of the spot rate change to the standard deviation of the forward premium. Each marker on the graph plots the implied regression coefficients δ that correspond to the estimated values of ρ and σ for four maturities. The coefficient for m=2 is always represented by the leftmost marker, and a line is connected to the next higher m coefficient.

Appendix A: Tests of MA Process

Tests of Lag-Length for MA Process:

L-Statistic for 12 Additional Lags

Inflation Change: $\pi_t^m - \pi_t^1 = \alpha^m + \beta^m(i_t^m - i_t^1) + \epsilon_t^m$

1-Year Spot Change: $i_{t+m}^1 - i_t^1 = \gamma^m + \delta^m(f_t^m - i_t^1) + \epsilon_t^m$

1-Year Inflation Rate Change: $\pi_{t+m}^1 - \pi_t^1 = \gamma'^m + \delta'^m(f_t^m - i_t^1) + \epsilon_t'^m$

1-Year Real Rate Change: $rr_{t+m}^1 - rr_t^1 = \gamma''^m + \delta''^m(f_t^m - i_t^1) + \epsilon_t''^m$

Regressions	L-Statistic: Inflation Change	1-Yr Spot Change	1-Yr Infl Rate	1-Yr Real Rate
US				
2-1 Year	6.94	4.52	6.94	5.75
3-1 Year	4.55	4.61	4.15	6.24
4-1 Year	10.22	10.18	9.86	11.34
5-1 Year	10.43	11.48	13.24	14.08
Britain				
2-1 Year	6.80	10.69	6.80	7.81
3-1 Year	8.38	8.26	8.47	8.07
4-1 Year	8.87	6.63	8.90	8.94
5-1 Year	12.84	8.56	10.89	12.47
Germany				
2-1 Year	9.37	6.73	9.37	7.60
3-1 Year	8.33	6.90	8.42	5.78
4-1 Year	6.44	5.94	7.67	6.05
5-1 Year	11.61	9.13	11.67	20.60
Switz.				
2-1 Year	7.44	5.45	7.44	8.06
3-1 Year	8.34	5.20	8.21	6.49
4-1 Year	8.28	5.27	8.63	8.45
5-1 Year	19.31	8.32	12.71	10.36

Notes: Given that a number of MA terms are non-zero for the error process because of overlapping observations, the L-statistic tests whether additional 12 MA terms are significant. The statistic is distributed as χ_{12}^2, with a 5% critical value of 21.0.

Appendix B: Monte Carlo Simulations

The Monte Carlo simulations are conducted as follows. The inflation rates, spot rate changes and spread variables for the four countries under consideration were constructed from ARMA models whose parameters were estimated from the relevant sample periods. Different ARMA models were fit under the null that the slopes are zero, under the null that the slopes are unity, and under the null that all slopes coefficients are equal. We assumed that the error terms from ARMA models for these variables are independent, because there was no evidence of significant cross-correlations.

For each experiment involving four countries, the error terms are initially jointly drawn from a multivariate normal distribution with a correlation matrix equal to the sample correlation matrix of the error terms from the ARMA models. Then, because Lagrange-multiplier tests described by Engle (1982) reveal the presence of ARCH (autoregressive conditional heteroscedasticity) in the error terms, the error terms are transformed to follow an ARCH processes whose parameters were also estimated from the relevant sample periods.

Start-up values for the time-series models are obtained from the actual realized data from five and six years before the sample period (or at the beginning of the sample period if earlier data were unavailable), followed by four years of draws from the random number generator which produces initial values. Then a sample size corresponding to the relevant regression is produced using errors drawn from the distribution described above followed by construction of the series based on the estimated ARMA model.

As an example, for the 2-to-1 year inflation regressions, univariate ARMA models were fit separately to the four 2-to-1 year inflation changes and to the four 2-to-1 year term spreads. Under the null that the slope coefficient is zero, simulated values of the inflation changes and of the term spread are generated, equation (1) is estimated, and the values of tests statistics recorded.

Each of the tables in the text reports the original t-statistics and chi-square statistics, as well as the proportion of times the value of the test statistic was exceeded under the null in one thousand Monte-Carlo trials.

Appendix C: Data Construction

The spot rates for the U.S. market are taken from Shiller and McCulloch (1987) until February 1987. These data are updated to December 1988 using the same method, which involves fitting splines to the discount function for each month of the sample. Since the same methodology was applied to the "gilt" (British government bond) market, it is worth explaining in some detail.

C.1 Spline Estimation

First, a functional form for the discount function is postulated. The discount function is formally defined as the present value of a dollar paid at time t, and will be used to price any bond. For computational ease, the discount function is assumed to take the shape of a cubic spline:

$$D(t) = a_{i0} + a_{i1}t + a_{i2}t^2 + a_{i3}t^3, t_i < t < t_{i+1},$$

where the values of the parameters a_{ij} are allowed to differ across knot points $t_i, i = 1, ..., N$. In order to ensure continuity and smoothness of the spline curve, the function value and its first and second derivatives are restricted to be the same at the knot points. In addition, the discount function is set equal to one at time zero. For N knot points, this yields $3 + N$ parameters to estimate.

Second, the theoretical prices of the sample of selected bonds are computed from this discount function. For instance, if a bond pays the cash flows $c_k, k = 1, .., K$ at respective times t_k, the model price is set at the present value of the future cash flows

$$\hat{P} = \sum_k c_k D(t_k),$$

which can be written as a linear function of the spline parameters

$$\hat{P} = a_0 f_0(c_k) + a_1 f_1(c_k) + a_2 f_2(c_k) + ...$$

The parameters $\{a\}$ are estimated by comparing the theoretical prices $\hat{P}$ with the market prices P for the selected bonds. Minimizing the square of the discrepancies amounts to running a simple linear regression of the market prices on the model prices expressed as a linear function of the parameters of interest.

Once the discount function is found from market data, annualized spot rates can be derived as $D(t) = exp(-i(t) * t)$, where t is expressed in years.

C.2 Data Sources

For the "gilt" (UK government bond) market, discount functions are estimated from bond price data as reported by the *Financial Times*. All bonds with maturities up to fifteen years were included in the sample. Given the presence of tax effects, reported for instance by Litzenberger and Rolfo (1984), low coupon bonds were discarded.

For the "bund" (German government bond) market, spot rates were inferred from data provided by the Bundesbank. The Bundesbank reports monthly bond yields for maturities from one to five years. These yields are then assumed to correspond to par instruments with annual coupons. The spot rates are recovered from the bond-equivalent yields by using the shorter spot rates to account for intermediate coupon payments. For instance, the two-year spot rate is found by subtracting from the value of the bond, which is assumed at par, the present value of the first interest payment, using the one-year spot rate.

Euromarket interest rates were obtained from DRI for the U.S. dollar, German mark (DM) and Swiss franc (SF) from June 1973 to December 1988. The end-of-month quotes consist of 1, 2, 3, 4 and 5-year rates on eurocurrency deposits, reported at the close of the London market. These deposits are essentially equivalent to par bonds paying an annual coupon equal to the eurocurrency rate. Spot rates were recovered from the eurocurrency rates by forward substitution, as performed above for DM government bonds.

Results with eurocurrency data are not reported for the U.S., Britain and Germany, but estimates are similar to those in the text. Tests for the equality of the slope coefficients across the eurocurrency and government data sets were conducted and in no case was the hypothesis of equal coefficient rejected.

Appendix D: Tests Across Countries

Table D-I

Inflation Change Regressions: Tests of Equal Slope Coefficients

$$\pi_t^m - \pi_t^1 = \alpha^m + \beta^m(i_t^m - i_t^1) + \epsilon_t^m$$

χ^2 statistics for $\beta_k^m = \beta_l^m$ across countries

[Simulation p-values]

Series	Country Pair US=BP	US=DM	US=SF	BP=DM	BP=SF	DM=SF	All Equal
2-1 Yr	0.002	4.831	0.786	0.491	0.079	1.237	5.354
	[0.96]	[0.23]	[0.55]	[0.66]	[0.84]	[0.52]	[0.61]
3-1 Yr	0.099	6.434	0.517	0.261	0.009	3.522	6.874
	[0.85]	[0.22]	[0.67]	[0.79]	[0.95]	[0.35]	[0.64]
4-1 Yr	0.014	6.348	0.267	1.347	0.078	6.843	17.912
	[0.94]	[0.28]	[0.77]	[0.53]	[0.85]	[0.26]	[0.44]
5-1 Yr	0.022	3.755	0.167	1.763	0.111	8.370	35.158
	[0.93]	[0.39]	[0.84]	[0.54]	[0.85]	[0.27]	[0.35]

Notes: Simulation marginal significance levels between brackets. For the bilateral tests, the test statistics are asymptotically distributed as χ_1^2; for the joint tests, the test statistics are asymptotically distributed as χ_4^2.

Table D-II

Spot Change Regressions: Tests of Equal Slope Coefficients

$$i^1_{t+m} - i^1_t = \gamma^m + \delta^m(f^m_t - i^1_t) + \epsilon^m_t$$

χ^2 statistics for $\delta^m_k = \delta^m_l$ across countries

[Simulation p-values]

Series	Country Pair US=BP	US=DM	US=SF	BP=DM	BP=SF	DM=SF	All Equal
2-1 Yr	3.349	0.806	1.423	0.225	0.667	0.031	3.504
	[0.17]	[0.49]	[0.42]	[0.69]	[0.54]	[0.89]	[0.60]
3-1 Yr	2.096	1.481	0.966	0.466	0.137	0.055	2.260
	[0.34]	[0.41]	[0.52]	[0.65]	[0.81]	[0.89]	[0.87]
4-1 Yr	0.484	1.122	0.407	0.433	0.001	0.499	4.402
	[0.69]	[0.55]	[0.68]	[0.75]	[0.99]	[0.72]	[0.78]
5-1 Yr	0.096	0.376	0.001	2.405	0.247	2.142	7.305
	[0.89]	[0.76]	[0.99]	[0.47]	[0.79]	[0.52]	[0.74]

Notes: Simulation marginal significance levels between brackets. For the bilateral tests, the test statistics are asymptotically distributed as χ^2_1; for the joint tests, the test statistics are asymptotically distributed as χ^2_4.

Table D-III

Spot Change Regressions: Tests of Equal Slope Coefficients

Inflation Rate Change: $\pi_{t+m}^1 - \pi_t^1 = \gamma'^m + \delta'^m(f_t^m - i_t^1) + \epsilon_t'^m$

Real Rate Change: $rr_{t+m}^1 - rr_t^1 = \gamma''^m + \delta''^m(f_t^m - i_t^1) + \epsilon_t''^m$

χ^2 statistics for $\delta_k'^m = \delta_l'^m$, $\delta_k''^m = \delta_l''^m$ across countries

[Simulation p-values]

	Country Pair						
Series	US=BP	US=DM	US=SF	BP=DM	BP=SF	DM=SF	All Equal
Infl.							
2-1 Yr	0.002	4.831	0.786	0.491	0.079	1.237	5.354
	[0.98]	[0.17]	[0.56]	[0.62]	[0.83]	[0.44]	[0.56]
3-1 Yr	0.554	5.116	0.228	0.003	0.334	4.751	8.292
	[0.63]	[0.23]	[0.78]	[0.98]	[0.72]	[0.23]	[0.57]
4-1 Yr	0.809	6.852	1.172	0.104	0.301	3.282	18.511
	[0.57]	[0.19]	[0.53]	[0.83]	[0.72]	[0.35]	[0.38]
5-1 Yr	2.498	0.551	0.006	0.971	1.494	7.114	7.617
	[0.38]	[0.67]	[0.97]	[0.57]	[0.51]	[0.20]	[0.70]
Real							
2-1 Yr	1.228	7.176	4.725	0.191	0.031	1.054	9.350
	[0.38]	[0.07]	[0.14]	[0.74]	[0.90]	[0.43]	[0.30]
3-1 Yr	3.195	11.423	2.601	0.151	0.631	1.603	17.243
	[0.26]	[0.07]	[0.30]	[0.81]	[0.61]	[0.44]	[0.28]
4-1 Yr	3.074	6.711	1.797	0.024	0.361	7.218	33.949
	[0.31]	[0.20]	[0.47]	[0.93]	[0.71]	[0.20]	[0.24]
5-1 Yr	2.709	1.516	0.000	0.014	1.720	5.464	15.786
	[0.43]	[0.58]	[1.00]	[0.95]	[0.49]	[0.34]	[0.62]

Notes: Simulation marginal significance levels between brackets. For the bilateral tests, the test statistics are asymptotically distributed as χ_1^2; for the joint tests, the test statistics are asymptotically distributed as χ_4^2.