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THE INFORMATION IN THE TERM STRUCTURE OF
INTEREST RATES:
FURTHER RESULTS FOR GERMANY

Abstract

This paper tests the Expectations Hypothesis (EH) of the term structure of interest rates using new data for Germany. The German term structure appears to forecast future short-term interest rates surprisingly well, compared with previous studies with US data, while it has lower predictive power for long-term interest rates. However, the direction suggested by the coefficient estimates is consistent with that implied by the EH, that is when the term spread widens, long rates increase. The use of instrumental variables to deal with possible measurement errors in the data significantly improves regressions for the long rates. Moreover, reestimation with proxy variables to account for the possibility of time-varying term premia confirms that the evolution of both short and long rates corresponds to the predictions of the EH and that most of the information is in the term spread. These results are important as they suggest that monetary policy in Germany could be guided by the slope of the term structure.

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1. Introduction[*]

The information in the term structure of interest rates has been the subject of extensive research using data for the US. The aim of this literature is to examine whether the relationship between interest rates at different maturities, that is, the term structure, helps to predict future movements in interest rates. Many empirical studies have focused on tests of the Expectations Hypothesis (EH) relating long-term interest rates to expected future short-term rates. The validity of the EH is of interest since it has important implications for economic policy: if the EH is supported by the data, it suggests that monetary policy could be guided by the yield curve. However, the empirical evidence on the EH for the US is by no means conclusive. Typically, the hypothesis has been rejected with data related to the postwar period (see, inter alia, Campbell and Shiller, 1991, Hardouvelis, 1994, Evans and Lewis, 1994, and Rudebusch, 1995) and accepted with data for the period before the founding of the Federal Reserve System (see Mankiw and Miron, 1986). According to Mankiw and Miron, the lack of predictive power of the term spread after the founding of the Federal Reserve has to be attributed to its short rate stabilisation procedure, under which the short rate evolves as a random walk, and interest rate changes become unpredictable. Finally, a recent study by Hsu and Kugler (1997) suggests a revival of the EH with evidence for the period 1987-1995. Hsu and Kugler attributed this finding to changes in the conduct of monetary policy in the US during the most recent period, particularly the introduction in 1988 of the use of the term spread as a policy indicator by the Federal Reserve.

Studies of the EH also differ depending on the methodology

and the type of data used. With regard to the methodology, the most direct test of the EH uses standard regressions of changes in interest rates on different measures of the slope of the term structure. In this literature, one can distinguish between regressions which use the *term spread* as a regressor, that is the difference between a long rate and a short rate (see Campbell and Shiller, 1991), and regressions which adopt *the forward-spot spread* (see Fama, 1984, and Fama and Bliss, 1987). Moreover, within the term spread regressions, there are two different specifications: regressions which predict changes in the short rate, and regressions which predict changes in the long rate. Tests based on regressions for the short rate are usually in favour of the EH, while tests based on regressions for the long rate indicate that actual long rates move in the opposite direction from that predicted by the EH.

Another strand of the literature uses the Vector Autoregression (VAR) approach (Shiller, 1979, and Campbell and Shiller, 1987). In these studies, VAR models are specified for changes in the short rate and the term spread, and the estimated coefficients are used to assess the deviation in the behaviour of the actual term structure spread from the 'theoretical' spread under the EH. This approach is based on the result that the EH of the term structure can be expressed in the form of the present value model, and it is therefore strictly valid only when the long rate is a perpetuity or when bonds have very long life (for example, twenty years).

With regard to differences in the type of data used, some studies use *estimated term structures* based on interpolation methods such as McCulloch, 1971, and Chambers, Carleton and Waldman, 1984; other studies use interest rates on bonds of maturities that are actively traded, i.e. treasury bill yields, government bond rates, money market interest rates and Eurorates. Estimated term structures have some potential advantages over other types of data in that they enable one to examine a wider range of maturities and provide more comprehensive results than those obtained with other data. On the other hand, the use of estimated term structure data introduces measurement errors, but this problem can be

easily overcome with instrumental variable estimation. Studies which have used estimated term structures for the US are, amongst others, Fama (1984, 1990), Jorion and Mishkin (1991), and Evans and Lewis (1994).

In contrast to the large number of studies for the US, only limited evidence exists for other countries (see, inter alia, Mills, 1991, Hardouvelis, 1994, Engsted, 1996, and Gerlach and Smets, 1997). Although these studies are in general more favourable to the EH, there is a clear suggestion that the predictive power of the slope of the term structure is stronger under monetary targeting than under interest rate targeting, and results vary, to some extent, according to the regression specification adopted. Thus, it is important to ascertain whether assessments in favour or against the EH can be replicated over independent data sets and different economies.

In this paper, we present evidence for Germany based on new data derived from estimated term structures. The data cover the period 1983-1994, and have a monthly frequency. The procedure adopted to estimate the term structure is based on the interpolation method suggested by Chambers, Carleton and Waldman (1984). We have applied this approach to German Government bond data provided by the Karlsruher Kapitalmarkt Datenbank (KKMDB)[1]. During the whole period under investigation the Bundesbank has pursued a monetary targeting policy. Hence, according to the Mankiw and Miron (1986) argument, we would expect to find support for the EH in the German data.

The EH is tested in this paper by employing standard regressions. We use both the term spread and forward-spot spread approaches, and estimate specifications for both the long and short-term interest rates. The VAR methodology is not appropriate in our context because the data span a relatively short time period, and the long rates are not of infinite life.

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[1] For further details on the data see Boero, Madjlessi and Torricelli (1995). The data are available from the authors on request.

Our results strongly support the information content of the term structure in regressions which 'predict' shorter-term interest rates, and the results are broadly consistent with the EH in terms of the coefficient value of the spread. On the other hand, the term spread does not have much predictive power for long-term interest rate movements, although the sign of the coefficient estimates on the term spread is in most cases consistent with the EH; that is, when the term spread increases, long rates increase. This latter result contrasts with previous evidence for the US suggesting that the spread does not even predict the right direction for the long rate movements (see, for example, Evans and Lewis, 1994, and Hardouvelis, 1994).

Results for the long rate regressions improve when we use instrumental variables to correct for possible measurement errors in the data. We also attempt to evaluate the effects of a time varying term premium in tests of the EH. This analysis is conducted by estimating extended regressions which include alternative proxies based on different measures of interest rate volatility. We find that, in general, the volatility terms do not have predictive power, confirming that most of the information in the term structure for movements in interest rates is contained in the term spread, and that both long rates and short rates move in the direction consistent with the predictions of the EH.

The paper is organised as follows. In Section 2, we explain the theory of the EH of the term structure and describe different types of models used in tests of the EH. In Section 3, we perform tests of these models and consider the possible effects of measurement errors, ignoring the term premium. In Section 4, we describe the characteristics of time-varying term premia within stochastic models of the term structure and re-estimate the standard regressions by including different proxies for the riskless rate volatility (the term premium) in the information set. Section 5 closes the paper with conclusions and further remarks.

2. The theoretical framework

A great deal of empirical research on the term structure of interest rates has focused upon the EH, relating long-term interest rates to actual and expected future short rates. According to the most common version of the EH, a longer-term interest rate is a simple average of the current and expected future short-term interest rate plus a constant term premium. In the case of an *n*-period rate, R^n, and a sequence of one-period short rates, r, in linearised form the EH can be stated as follows:

$$R_t^n = (1/n)\left[r_t + \sum_{i=1}^{n-1} E_t r_{t+i} \right] + \boldsymbol{p}(n) \tag{1}$$

where $\boldsymbol{p}$(n) is a constant term premium on the longer rate, and E_t is the rational expectations operator conditional on information at time t.

The EH can also be expressed in terms of the relationship between R^n and any m-period rate R^m, for which k=n/m is an integer:

$$R_t^n = (1/k) \sum_{i=0}^{k-1} E_t R_{t+im}^m + \boldsymbol{p}(n,m) \tag{1a}$$

where $?$(n,m) is the term premium between the n and m period rates.

This relationship implies that an upward-sloping term structure curve predicts an increase in short rates and subsequently in long rates, and viceversa. The literature has investigated the *information* in the term structure of interest rates using different spreads as measures of the term structure and using substantially different data.

In the present paper, we use two approaches: the spread between a long rate and a short rate as a predictor of future changes in the short rate and in the long interest rate, and the forward-spot differential to predict future changes in the short rate.

2.1 The long-short yield spread approach

After some rearrangements, equation (1a) can be shown to have testable implications regarding the predictive power of the spread (R^n_t-R^m_t) for future interest rates: the spread should predict (a weighted average of) changes in the *short* rate over the n-m-period horizon, and the change in the n-period rate over the m-period horizon. These implications can be tested by using the following regressions :

$$\sum_{i=1}^{(n/m)-1}(1-(im/n))\Delta^m R^m_{t+im} = a + b(R^n_t - R^m_t) + e_{t+n-m} \qquad (2)$$

with n/m an integer, and $\Delta^m R^m_{t+im} = R^m_{t+im} - R^m_{t+im-m}$, and

$$R^{(n-m)}_{t+m} - R^n_t = a + b\left(\frac{m}{(n-m)}\right)(R^n_t - R^m_t) + e_{t+m} \qquad (3)$$

In these equations ε_{t+n-m} and ε_{t+m} are forecast errors which under Rational Expectations are orthogonal to information at time t, and therefore uncorrelated with the spread. Hence, assuming no measurement errors, OLS will give consistent estimates. The errors in (2) will follow a moving average process of order n-m-1 if the difference between n and m is larger than the data frequency (monthly in our case). The errors in (3) will follow a moving average process of order m-1 if m is larger than the data frequency. So, standard errors are usually calculated with the Newey-West (1987) or Hansen and Hodrick (1980) corrections. Tests of the predictive content of the spread imply testing for the significance of β (that is β=0) while tests of the EH with Rational Expectations and constant term premium imply testing for β=1.

2.2 The forward-spot yield spread approach

Similar tests can be conducted using the forward-spot yield spread approach which is based on the version of the EH stating that forward rates are (unbiased) predictors of future short rates. The corresponding regression model for these tests takes the following form:

$$r_{t+n-1} - r_t = \boldsymbol{a} + \boldsymbol{b}\big(F_t(n-1,n) - r_t\big) + \boldsymbol{e}_{t+n-1} \qquad (4)$$

where r_t is the *one*-period rate and $F_t(n-1,n)$ denotes the *one*-period forward rate, i.e. the rate at trade date t for a loan between periods t+n-1 and t+n. ε_{t+n-1} is the expectational error orthogonal to the information available at time t. Equation (4) states that the forward-spot yield spread $F_t(n-1,n)-r_t$ is an unbiased predictor of the expected change in interest rates over the n-1 horizon. Hence, assuming a time-invariant term premium, the EH implies $\beta=1$.

2.3 Previous evidence

Most previous evidence relates to US data. Evidence based on equation (2) is well summarised in Dotsey and Otrok (1995) and Rudebusch (1995): while short or medium term spreads have very little or no predictive information for future changes in the short or medium rates, long term spreads show some predictive content for movements in future short interest rates. Evans and Lewis (1994) comment on evidence for the US based on equation (3) and conclude that the spread does not even predict the right direction of the long rates movements, obtaining negative β coefficients. Finally, evidence on tests using forward rates, based on equation (4), is consistent with the results for the US summarised above for equation (2), namely that the EH performs poorly at the short end of the maturity spectrum, but improves at longer maturities (see, *inter alia*, Fama and Bliss, 1987, and Mishkin, 1988).

Only few studies have analysed the EH using data for

Germany, and none has used data obtained from estimated term structures. Gerlach and Smets (1997) present some results in favour of the EH for Germany, using 1, 3, 6 and 12-month Euro-rates, for the period 1972-1993, focusing only on regressions based on equation (2). Hardouvelis (1994) presents evidence based on equations (2) and (3) for the countries which belong to the Group of Seven (G7), using data on a 3-month and a 10-year government yield. In the study by Hardouvelis estimates of equation (2) for Germany, for the period 1968-1992, show that the evolution of future short rates corresponds closely to the predictions of the EH. By contrast, OLS estimation of equation (3) shows movements of the long rate in the opposite direction to that implied by the EH, however, the negative regression sign is reversed with the use of instrumental variables. The discrepancy between the behaviour of long and short rates is manifested primarily in the US (Hardouvelis, p. 258).

In the next section, we start the empirical analysis with the implementation of standard tests of the EH. As the data are derived from the estimation of the term structure, approximation errors can have an effect on the OLS estimates. We explore this possibility by using an instrumental variables approach in the estimation of the regressions used for the tests and compare the results with the OLS estimates.

Next we extend the standard framework of equations (2)-(4) by including different proxies for time varying term premia in the information set.

3. Empirical regularities and econometric results

3.1 Empirical regularities in the data

The empirical results of this study are based on time series drawn from estimated term structure curves using the Chambers, Carleton and Waldman (1984) approach, as explained in Boero, Madjlessi and Torricelli (1995). The data are monthly annualised rates, refer to the 15th of each month, and cover the period from

December 1983 to December 1994. Figure 1 reports the interest rates both against time and against time to maturity. Panel (a) shows the time period from November 1983 to June 1989, and Panel (b) covers the time period from July 1989 to December 1994. From the Figure, it is evident that there have been parallel shifts over time in the term structure of interest rates, but we can also see that the term structure has been at times upward sloping, and at times downward sloping.

In Figure 2 we show the evolution of the annualised rates with maturity 1, 3, 9 and 18-months, for the period 83.12 to 94.12; in Table 1 we report their summary statistics. The interest rates move mostly in the same direction, as do those at intermediate maturities, not shown in the figure. All interest rates have approximately the same minimum, around 1988, ranging from 3.37% for the 1-month rate to 3.67% for the 18-months rate, while the maximum, exhibited in connection with the ERM crises in 1992, decreases with maturity (9.98% for the 1-month rate, 8.83% for the 18-months rate). The term structure is upward sloping for most of the period up to 1990, and is inverted for most of the period from 1990 onwards.

An important issue to be addressed is that of the time series properties of the variables which appear in equations (2)-(4). Estimation of these equations requires that the variables are stationary. Unit root tests to determine the order of integration of the variables were performed. The test statistics, not reported for reasons of space, suggest that all interest rate changes and all spreads used in the regressions below are stationary, which implies that the inference presented below, using the t- and F-distributions, is valid. Furthermore, it is important to note that during the whole period under investigation, the monetary policy followed by the Bundesbank has been officially monetary targeting, so our regression estimates are free from structural breaks caused by regime shifts.

Before turning to the regressions results, it is useful to inspect Figure 3, where we report a selection of scatter plots of the dependent variables in equations (2)-(4) against the relevant

spreads. Panel (a) shows the cases of n,m=6,1 and n,m=9,3 for regressions based on equation (2); Panel (b) considers the cases of n,m=3,1 and n,m=6,3 for regressions based on equation (3); finally, Panel (c) plots the change in the *one*-month interest rate against the forward-spot spread for the cases of n=3 and n=6, as formulated in equation (4).

The EH with a constant term premium implies that the observations should scatter around a line with unit slope. Inspection of Figure 3 suggests that while it is realistic to expect a slope close to unity for most regressions relating the change in the short-term interest rate to the term spread (equation 2) and to the forward-spot spread (equation 4), there is less visual evidence a fitted line would have a unit slope for regressions relating the change in the long-term rate to the term spread (equation 3). For these regressions, in fact, the scatter plots suggest a very low R^2. However, R^2s from these regressions are typically low, so most work on the EH concentrates on statistical testing rather than informal evaluation of the 'fit' of the models.

3.2 Standard regression tests: OLS results

The results from OLS estimation are reported in Panels A of Tables 2, 3 and 4. The sample period used for each regression is the longest possible using data from 1983:12 through 1994:12.

Regressions based on equation (2) are shown in Table 2 for different pairs of maturities n and m. Due to overlapping data, the equations are estimated with OLS with corrections based on Newey-West (1987) for a moving average of order n-m-1, and for conditional heteroscedasticity. The corrected standard errors are reported in parentheses below the coefficient estimates of β, in square brackets are the Wald tests for the expectations hypothesis $\beta=1$.

Our results complements previous findings for Germany, and give further evidence of the ability of the German term structure to predict future short rates. Unlike similar regressions for the US, the results given in Table 2 indicate that the coefficient of the

spread is significantly different from zero at the 1% level in all cases[2]. Moreover, the R^2 values are much higher than those reported in earlier studies for the US, indicating that the slope of the term structure has higher information content for predicting future short rates in Germany than in the US. Furthermore, the estimates of β are close to the theoretical value of 1 for almost any two pairs of maturities n and m, according to the predictions of the EH, although there are cases where the EH is rejected in a strict statistical sense. For example, in regressions with spread 6-1 and 6-3 the hypothesis is rejected at the 1% level, and in the regression with spread 9-1 at the 10% level. Finally, the regressions show higher information content (higher R^2) and increasing support for the EH when longer horizons are considered. This result is in line with the evidence for the US in Fama (1984, 1990) and Fama and Bliss (1987) and suggests that it is easier to predict changes in short rates over longer horizons.

Regressions for the long rate have been the focus of attention of many studies attempting to explain failures of the EH. In fact, while the EH implies that the slope coefficient should be equal to one, most of the empirical literature, using data for the US, has reported very low values for the R^2, and estimated coefficients below unity, becoming negative as yields of longer-term bonds are used to form the dependent variable and the term spread. Negative values indicate that long rates move in the opposite direction to that implied by the theory. There is only limited evidence for Germany regarding the relation between the spread and the future evolution of long rates. For example, Hardouvelis (1994), in his study for the G7 countries, focusing on the behaviour of a 10-year government yield and a 3-month yield during the period 1968-1992, finds that the long rate move in the opposite direction to that implied by the EH. However, this movement is apparently due to a white noise error that does not

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[2] All regressions presented in this section include a constant term which is never significantly different from zero at the 1% level, and is therefore not tabulated.

affect the information in the term structure and the use of instrumental variables reverses the negative regression sign (Hardouvelis, p. 258).

Table 3 reports our estimates of the slope coefficients based on equation (3). The results show that for nearly all pairs of maturities the coefficient estimates of the spread are consistently positive, although not always significantly so. Thus, to the extent that the term spread predicts changes in the long rates, it does so in the direction implied by the EH. Moreover, we find that while for large n and small m the estimated coefficient is significantly smaller than one, its value approaches one as m increases. However, the R^2 values for these regressions are all very low, as already suggested by visual inspection of the scatter plots in Figure 3, and Wald tests for the EH that the spread coefficient is equal to one show rejections in a strict statistical sense. These results are quite similar to previous evidence in the term structure literature, indicating that the spread between the long and short term interest rates has poor predictive content for changes in the longer rate. On the other hand, an interesting result is the positive sign for the coefficient of the spread obtained in most regressions, suggesting that long-term rates move in the direction predicted by the EH.

Finally, in Table 4 we report estimates of equation (4) in which we use the spread between the one-month forward rate and the one-month spot rate to predict changes in the spot rate over n-1 periods, with n = 3, 6, 9, 12 and 15 months. Results from specification (4) show close similarities to those based on equation (2). In fact, also for these regressions the slope coefficient is always significantly different from zero at the 1% level, so there is significant predictive power of the forward-spot spread. The high information content of the forward-spot spread also emerges from the relatively high values of the R^2. Moreover, tests on the restriction $\beta=1$ are in general in favour of the EH, with only few exceptions: the hypothesis is rejected at the 5% level for the regression with spread *f(2,3)-r*, and at the 10% level for the regression with spread *f(14,15)-r*.

Overall, the empirical analysis presented in this section suggests that both the long-short rate and the forward-spot rate spreads are very powerful predictors of future short interest rate changes, in accordance with the EH. On the other hand, the spread between the long and short-term interest rates has poor predictive content for changes in the longer rate, although our estimates suggest that long rates move in the direction consistent with the EH[3]. However, because our data are derived from estimates of the term structure, they may introduce an approximation error in our regressions, in which case the slope of the coefficient estimates obtained with OLS may be biased. To explore the possible effect of measurement errors in tests of the EH, in the next section we use an instrumental variable (IV) approach.

3.3 Standard regression tests: IV results

In the presence of measurement error, the OLS estimators of the slope coefficients in equations (2)-(4) will not converge to unity (see Mankiw, 1986, and Hardouvelis, 1994). To avoid the possible bias that a measurement error on short rates and long rates would generate, we reestimate the equations using instrumental variables. The instruments are lags of the spread and lags of interest rates changes, and were selected on the basis of their ability to predict the term spread [4]. The IV coefficients should equal one, as implied by the EH. The results are displayed in Panel B of Tables 2, 3 and 4.

Tables 2 and 4 show only minor evidence of a white noise error in the short rates. The IV estimates are in fact very similar to the OLS estimates in Panel A, although they are now closer to the value of one, supporting the EH in all cases.

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[3] These results are robust to different sample periods. Specifically, estimation over different sub-samples yielded a predominance of coefficient estimates close to one in regressions for the short rates, and a predominance of positive signs in regressions for the long rates in every period. Results for sub-samples are not reported here, but are available from the authors on request.

[4] For errors which follow an MA(q) process, we use as instruments variables lagged t-q-1 periods or earlier.

On the other hand, the use of instrumental variables significantly improves the regressions for the long rates. As shown in Table 3 the coefficient estimates are much closer to the value of one, according to the EH, for all pairs of maturities; we also notice that the negative signs in Panel A for maturities n=12,18 and m=1 are now reversed. This result is robust with previous findings by Hardouvelis (1994) using different data for Germany, and contrasts with previous results for the US.

Overall, the results presented in this section suggest that the slope of the term structure between almost any two pairs of maturities n and m predicts changes in the short and long rates according to the EH. This result has important policy implications for the conduct of monetary policy in Germany. For example, a currently high spread reflects expectations in the market of higher future short rates. Therefore, the interest rate spread provides monetary policy makers with useful information on how the market expects future monetary policy to be conducted.

4. Time varying term premia and extended regression

4.1 Proxies for time-varying term premia

Several studies have investigated the effect of time-varying term premia in tests of the EH. The basic assumption is that the spread combines information about the variation of expected future rates and term premia. Therefore, if term premia are time-varying and correlated with the term spread, then estimates of the spread coefficient β in equations (2)-(4) will be biased, due to omitted variables problems.

Time-varying term premia cannot be easily reconciled with the EH, and the need for a theory able to endogenise them has been underlined by many authors (see for example Mankiw and Summers, 1984, and Mankiw, 1986). General equilibrium models, such as Cox, Ingersoll and Ross (1985) and Longstaff and

Schwartz (1992) offer some answers to this problem[5].

The functional form of the term premium resulting from the Longstaff and Schwartz model is particularly interesting for our empirical analysis. In fact, the term premium is, for any fixed maturity, a linear function of both the interest rate level and its volatility, where the sign of the relationship with the latter is indeterminate. This suggests that the short rate level and/or its volatility can be added as further regressors in equations (2)-(4). Previous studies (e.g. Fama, 1990) have shown that the level of the short rate does not add much information to that already contained in the spread. Therefore, in this paper we use volatility as a further source of information and include it as a second regressor in the extended regressions:

$$\sum_{i=1}^{(n/m)-1} (1-(im/n))\Delta^m R_{t+im}^m = \boldsymbol{a} + \boldsymbol{b}(R_t^n - R_t^m) + \boldsymbol{g}TP_t + \boldsymbol{e}_{t+n-m} \quad (2a)$$

$$R_{t+m}^{(n-m)} - R_t^n = \boldsymbol{a} + \boldsymbol{b}\left(\frac{m}{(n-m)}\right)(R_t^n - R_t^m) + \boldsymbol{g}TP_t + \boldsymbol{e}_{t+m} \quad (3a)$$

$$r_{t+n-1} - r_t = \boldsymbol{a} + \boldsymbol{b}\left(F_t(n-1,n) - r_t\right) + \boldsymbol{g}TP_t + \boldsymbol{e}_{t+n-1} \quad (4a)$$

TP_t is the proxy for the term premium, and γ is its coefficient, whose sign, according to the Longstaff and Schwartz model, is indeterminate and depends essentially on the maturity length[6].

Theoretically, in Longstaff and Schwartz (1992) the volatility is defined as the instantaneous variance of changes in the riskless rate and for its estimation the GARCH framework is suggested. However, as the choice of the volatility proxy is mainly an empirical matter, to see if results are sensitive to the particular proxy chosen, we use three alternative measures and estimate the

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[5] See Boero and Torricelli (1996) for a comparative discussion of these and other stochastic models of the term structure.
[6] See Longstaff and Schwartz (1992), page 1268.

extended regressions (2a)-(4a) for each of them.
The proxies used are:

(i) a moving average of absolute changes in the short rate, computed over the previous 6 periods:

$$TP_{MA,t} = \sum_{i=0}^{5} \left| R_{t-i}^{m} - R_{t-i-1}^{m} \right| / 6$$

(ii) the expected square of excess holding period returns:

$$TP_{(ex\text{-}returns)^2, t} = E_t \left[H_{t+m}^{n} - R_{t}^{m} \right]^2,$$

where
$$H_{t+m}^{n} = \left(\frac{n}{m} \right) R_{t}^{n} - \left(\frac{n-m}{n} \right) R_{t+m}^{n-m}$$

is the the m-period holding period return on an n-period zero coupon bond between t and t+m;

(iii) estimates of conditional variances from GARCH models:

$$TP_{GARCH,t} = h_{t,}$$

where we have chosen the lag structure of GARCH(1,1) :

$$h_t = \alpha_0 + \alpha_1 \, \alpha_{t-1}^2 + \alpha_1 \, h_{t-1}$$

although various extended lag specifications were attempted.

The first measure has been used in previous work by Fama (1976), Jones and Roley (1983), and Simon (1989), the second has been used by Simon (1989) and more recently by Harris (1998). The third measure was initially proposed by Engle, Lilien and Robins (1987), and extensively used in subsequent studies.

Previous studies that have allowed for the possibility of time varying term premia have provided contrasting results, depending on the choice of the proxy considered (see, for example, Simon, 1989, and Tzavalis and Wickens, 1997, for evidence with US data). By using different proxy variables we are able to check on the robustness of our results.

4.2 Extended results: the information content of volatility

Estimates of equations (2a) and (3a) are reported in Tables 5 and 6 for each of the three proxies. Panel A shows results for regressions with short rate maturity m=1, and Panel B for m=3. The maturity of the longer rate selected for this exercise is

n=3,6,9,12,18[7]. The Tables also report the OLS and IVE results from Tables 2 and 3 to facilitate the comparison. As the expected squared excess holding period return is replaced in the equations by its realisation, the actual squared excess holding period return contains an expectation error which is also present in the regression error, so the equations with this proxy are estimated with instrumental variables. Following Simon (1989), we use as instruments lagged values of the squared excess returns.

Tables 5 and 6 show that although the volatility term is not totally uninformative, these extended regressions represent only minor changes with respect to simple regressions which use only knowledge at time t of the slope of the term structure. These results indicate that most of the information in the term structure for movements in the interest rates is contained in the spread, and confirm that the evolution of both short rates and long rates is consistent with the predictions of the EH.

Previous studies that have allowed for the possibility of time varying term premia with US data have provided contradictory results, depending on the choice of the proxy considered. A possible interpretation of such a difference might be that German term premia are relatively small and constant, compared with US, so that most of the information about future rates is actually given by the term spread. This would explain why volatility does not add much information.

Finally, in Table 4, Panel C, we report the results for regressions with the forward-spot spread (equation 4a), but only for two of the term premium proxies: TP_{MA} and TP_{GARCH}. These results are qualitatively very similar to those for regressions in Table 5. Specifically, the volatility term is significant in only 2 cases out of 10, and there is only a marginal improvement in terms of R^2. The coefficient estimates of ? remain highly significant, confirming that the forward premium is a powerful predictor of expected changes in the short rate.

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[7] Results for other pairs of maturities were qualitatively similar, and are therefore not reported here.

5. Conclusion and further remarks

In this paper we have examined the information content of the term structure and tested the Expectations Hypothesis for the case of Germany, using a new data set constructed from the estimation of the term structure. The EH has been tested by employing two approaches: one has used the spread between the long rate and the short rate to predict future movements in both longer and shorter-term interest rates; the other the spread between the forward rate and the spot rate to predict changes in the spot rate. Standard regression tests of the EH have been conducted by using both OLS and IV estimation. The latter has been adopted to account for possible measurement errors introduced by the use of data derived from estimated term structures. Moreover, inspired by the most recent general equilibrium stochastic models of the term structure, we have extended the standard framework by including alternative measures of interest rate volatility as proxies for the term premium. The data used in this paper have enabled us to produce more comprehensive results than those obtained in previous studies for Germany, and several interesting findings have emerged from the empirical analysis.

First, our results suggest that both the term spread and the forward-spot spread are very powerful predictors of future short interest rate changes, in accordance with the EH. This is in strong contrast with previous evidence for the US, where, unlike in Germany, interest rate targeting has been the primary target of monetary policy. In this respect, our results support the argument put forward by Mankiw and Miron (1986), and later confirmed by empirical evidence for other countries (see among others, Kugler, 1988, and Engsted, 1996), that the predictive power of the spread is stronger under monetary targeting than under interest rate targeting. Second, although the slope of the term structure alone has less predictive power for longer term interest rates, an interesting result from our analysis is that both the sign and the value of the coefficient estimates are coherent with the predictions

of the EH. A high spread is followed by an increase in the long rate, and once measurement errors are taken into account with instrumental variables, the coefficient estimates are close to one.

So, the German yield curve conforms to the EH in its predictions of changes in the long rates as well as in the short rates. This results contrast with previous findings for the US, and suggest that in Germany the spread can be used as an important indicator for the conduct of monetary policy.

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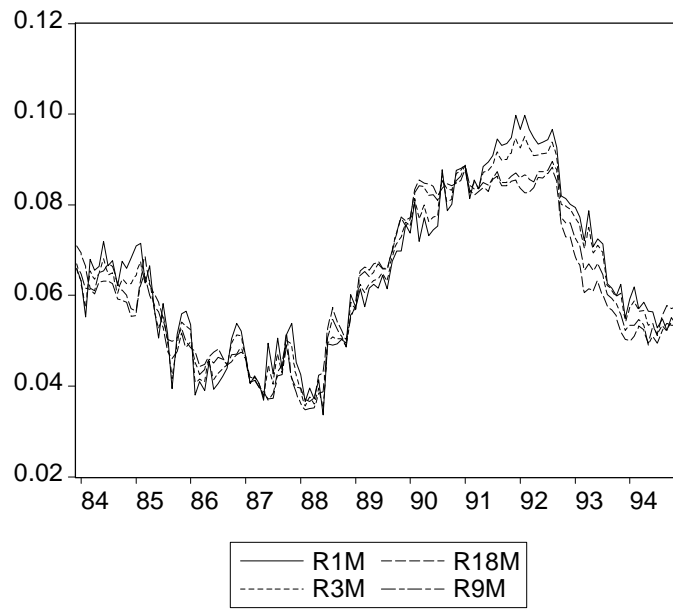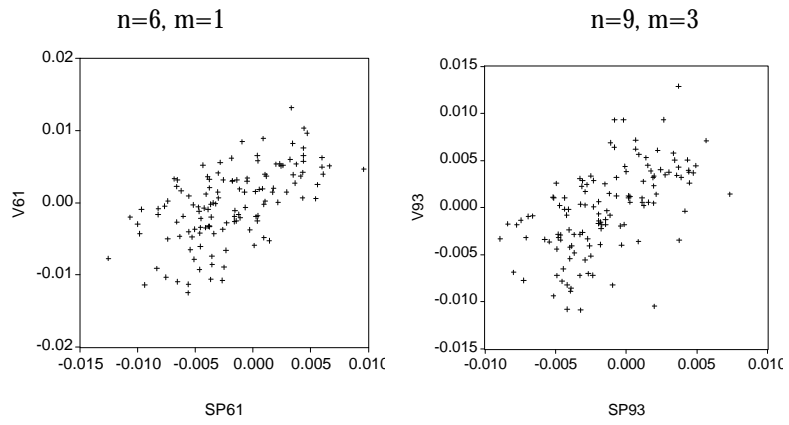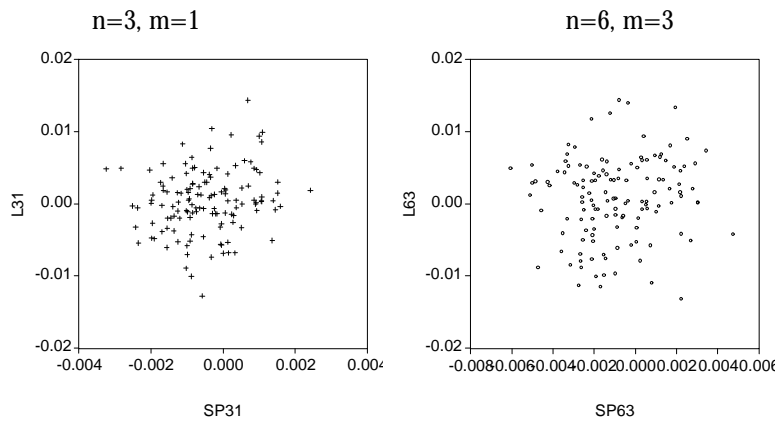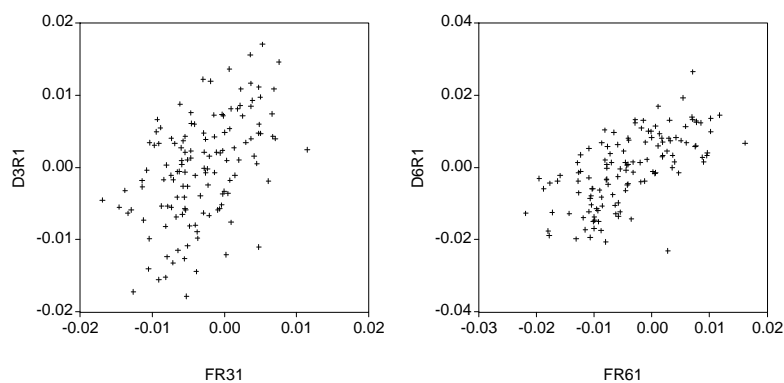
FIGURE 2

Interest rates

FIGURE 3

n=6, m=1

n=9, m=3

(a) **:** **Short-rates regressions**

n=3, m=1

n=6, m=3

(b) : **Long-rates regressions**

(c) : **Forward-spot spread regressions**

The figure shows scatterplots of the dependent variables of equations (2)-(4) against the relevant spreads. In Panel (a), Vnm denotes the change in the short rate with maturity m, over the n-m period horizon; SPnm is the spread between the long rate R^n and the short rate R^m. In Panel (b), Lnm denotes the change in the long rate R^n over the m-period horizon; SPnm is the spread (R^n - R^m) multiplied by ($m/(n-m)$). In Panel (c), DnR1 denotes the change in the *one*-month rate over the n-1 horizon; FR$n1$ is the spread between the forward rate F(n-1, n) and the *one*-month spot rate.

TABLE 1

Summary statistics for the German interest rates

	R^1	R^3	R^9	R^{18}
Mean	0.0645	0.0635	0.0622	0.0625
Maximum	0.0998	0.0950	0.0896	0.0883
Minimum	0.0337	0.0351	0.0347	0.0367
Std. Dev	0.0173	0.0168	0.0162	0.0154

TABLE 2

Short rate regressions : OLS and IV estimates

$$\sum_{i=1}^{(n/m)-1}(1-(im\,/\,n))\Delta^m R_{t+im}^m = a + b(R_t^n - R_t^m) + e_{t+n-m} \qquad (2)$$

Panel A: OLS estimates				
n				
m=1	3	6	9	12	18
β_{OLS} (SE) [F] R^2	0.74 (0.15) [2.97][c] 0.21	0.71 (0.10) [7.19][a] 0.36	0.80 (0.10) [4.10][b] 0.47	0.88 (0.10) [1.44] 0.51	1.20 (0.15) [1.74] 0.45
m=3					
β_{OLS} (SE) [F] R^2		0.63 (0.1 3) [7.69][a] 0.18	0.77 (0.1 3) [3.20][c] 0.33	0.88 (0.14) [0.76] 0.40	1.14 (0.26) [0.27] 0.20
m=6					
β_{OLS} (SE) [F] R^2				0.93 (0.22) [0.10] 0.24	1.05 (0.28) [0.03] 0.24
m=9					
β_{OLS} (SE) [F] R^2					0.93 (0.36) [0.04] 0.16

---continued

Panel A reports OLS estimates of β in regressions for the short rates, Newey-West standard errors in parentheses below estimated coefficients, F-tests associated with the hypothesis that ?=1 in square brackets, and the R^2 value.
a, b, and c denote statistical significance at the 1%, 5% and 10% respectively. The estimation period used for each regression is the longest possible using data from 83:12 through 94:12

TABLE 2 (continued)

Panel B: IV estimates				
n				
m=1	3	6	9	12	18
β_{IVE} (SE) [F]	0.72 (0.21) [1.83]	0.93 (0.35) [0.04]	1.23 (0.39) [0.35]	0.99 (0.16) [0.003]	1.24 (0.16) [2.29]
m=3					
β_{IVE} (SE) [F]		1.01 (0.30) [0.002]	1.03 (0.39) [0.01]	0.91 (0.17) [0.28]	1.12 (0.26) [0.22]
m=6					
β_{IVE} (SE) [F]				1.29 (0.50) [0.34]	1.20 (0.67) [0.09]
m=9					
β_{IVE} (SE) [F]					1.07 (0.58) [0.02]

Panel B reports results obtained with IVE to account for small sample bias due to measurement errors. The instruments used are lags of the term spread and lags of interest rates changes, and were selected on the basis of their ability to predict the term spread. R^2 are not reported in the case of IV regressions as their use as measures of goodness of fit is not valid.

TABLE 3
Long rate regressions: OLS and IV estimates

$$R_{t+m}^{(n-m)} - R_t^n = a + b\left(\frac{m}{(n-m)}\right)(R_t^n - R_t^m) + e_{t+m} \qquad (3)$$

Panel A: OLS estimates					
n					
m=1	3	6	9	12	18
β_{OLS} (SE) [F] R^2	0.70 (0.36)[b] [0.73] 0.03	0.29 (0.33) [4.53][b] 0.01	0.09 (0.38) [5.72][b] 0.00	-0.006 (0.46) [5.28][b] 0.00	-0.13 (0.66) [2.89][c] 0.00
m=3					
β_{OLS} (SE) [F] R^2		0.26 (0.27) [7.70][a] 0.01	0.13 (0.16) [29.15][a] 0.01	0.09 (0.14) [44.5][a] 0.00	0.06 (0.13) [49.5][a] 0.00
m=6					
β_{OLS} (SE) [F] R^2			0.42 (0.44) [1.70] 0.01	0.86 (0.44)[b] [0.10] 0.06	0.97 (0.55)[c] [0.003] 0.07
m=9					
β_{OLS} (SE) [F] R^2				0.46 (0.71) [0.57] 0.01	0.86 (0.72) [0.04] 0.04

---continued

See notes to Table 2

TABLE 3 (continued)

Panel B: IV estimates					
n					
m=1	3	6	9	12	18
β_{IVE} (SE) [F]	0.71 (0.36)[b] [0.64]	0.25 (0.37) [3.97][b]	0.29 (0.56) [1.63]	0.41 (0.69) [0.73]	0.50 (0.96) [0.27]
m=3					
β_{IVE} (SE) [F]		1.11 (0.63)[c] [0.03]	0.84 (0.41)[b] [0.15]	0.77 (0.33) [0.51]	0.60 (0.25)[b] [2.44]
m=6					
β_{IVE} (SE) [F]			0.86 (0.59) [0.06]	0.89 (0.46)[b] [0.06]	1.25 (0.36)[a] [0.50]
m=9					
β_{IVE} (SE) [F]				1.14 (0.82) [0.03]	1.09 (0.79) [0.01]

See notes to Table 2.

TABLE 4
Regressions with the forward-spot spread

$$r_{t+n-1} - r_t = \boldsymbol{a} + \boldsymbol{b}\left(F_t(n-1,n) - r_t\right) + \boldsymbol{e}_{t+n-1} \qquad (4)$$

$$r_{t+n-1} - r_t = \boldsymbol{a} + \boldsymbol{b}\left(F_t(n-1,n) - r_t\right) + \boldsymbol{g}TP_t + \boldsymbol{e}_{t+n-1} \qquad (4a)$$

	$f(2,3)$ - r	$f(5,6)$ - r	$f(8,9)$ - r	$f(11,12)$ - r	$f(14,15)$ - r
Panel A: OLS estimates of eq.(4)					
spread used in the equations					
β_{OLS}	0.72	0.83	0.97	1.11	1.35
(SE)	(0.14)	(0.11)	(0.12)	(0.15)	(0.20)
[F]	[3.82][b]	[2.09] 0.41	[0.18]	[0.60]	[3.23][c]
R^2	0.25		0.45	0.41	0.42
Panel B: IV estimates of eq.(4)					
β_{IVE}	0.98	0.96	1.12	1.32	1.62
(SE)	(0.30)	(0.18)	(0.14)	(0.19)	(0.20)
[F]	[0.01]	[0.06]	[0.69]	[2.73][c]	[9.13][a]
Panel C: extended regressions eq.(4a)					
β_{MA}	0.76	0.85	0.99	1.10	1.40
(SE)	(0.13)	(0.10)	(0.12)	(0.16)	(0.22)
γ_{MA}	-0.62	-0.72	-0.29	0.51	0.74
(SE)	(0.50)	(0.79)	(0.92)	(1.16)	(1.69)
[F]	[3.34][c]	[2.06]	[0.007]	[0.41]	[3.35][c]
R^2	0.26	0.41	0.46	0.40	0.45
β_{GARCH}	0.67	0.92	0.90	1.09	1.45
(SE)	(0.11)	(0.07)	(0.08)	(0.12)	(0.13)
γ_{GARCH}	-0.75	0.10	0.06	-1.19	-1.39
(SE)	(0.98)	(0.29)	(0.28)	(0.67)	(0.63)
[F]	[8.43][a]	[1.22]	[1.41]	[0.59]	[11.56][a]
R^2	0.26	0.38	0.45	0.48	0.56

Newey-West standard errors in parentheses below estimated coefficients; F-tests associated with the hypothesis that $\beta = 1$ are in square brackets. The IVE in Panel B account for small sample bias due to measurement errors. The instruments used are lags of the spread and lags of interest rates changes. R^2 are not reported in the case of IV regressions as their use as measures of goodness of fit is not valid. The first and third rows in Panel C report the estimates of β and γ in the extended regressions (4a). β_{MA} and γ_{MA} are obtained using as a proxy for the term premium TP_{MA}, that is a moving average of absolute changes in the short rate. β_{GARCH} and γ_{GARCH} are estimated from GARCH-M models. a, b, and c denote statistical significance at the 1%, 5% and 10% respectively. The estimation period used for each regression is the longest possible using data from 83:12 through 94:12.

TABLE 5
TABLE 5
Short rate regressions extended with proxies for the term premium

$$\sum_{i=1}^{(n/m)-1} (1-(im/n))\Delta^m R_{t+im}^m = \boldsymbol{a} + \boldsymbol{b}(R_t^n - R_t^m) + \boldsymbol{g}TP_t + \boldsymbol{e}_{t+n-m} \quad (2a)$$

Panel A					
			n		
m=1	3	6	9	12	18
β_{OLS}	0.74	0.71	0.80	0.88	1.20
(SE)	(0.15)	(0.10)	(0.10)	(0.10)	(0.15)
[F]	[2.97]c	[7.19]a	[4.10]b	[1.44]	[1.74]
R^2	0.21	0.36	0.47	0.51	0.45
β_{IVE}	0.72	0.93	1.23	0.99	1.24
(SE)	(0.21)	(0.35)	(0.39)	(0.16)	(0.16)
[F]	[1.83]	[0.04]b	[0.35]	[0.003]	[2.29]
β_{MA}	0.75	0.73	0.83	0.91	1.27
(SE)	(0.15)	(0.10)	(0.09)	(0.09)	(0.17)
γ_{MA}	-0.21	-0.40	-0.45	-0.37	-0.38
(SE)	(0.20)	(0.37)	(0.48)	(0.56)	(0.77)
[F]	[2.92]c	[6.74]a	[3.33]c	[0.96]	[2.46]
R^2	0.21	0.35	0.47	0.51	0.46
$\beta_{(ex\text{-}returns)2}$	0.73	0.72	0.80	0.88	1.12
(SE)	(0.14)	(0.11)	(0.10)	(0.10)	(0.15)
$\gamma_{(ex\text{-}returns)2}$	5.56	0.99	-0.05	-0.21	0.06
(SE)	(4.23)	(1.1)	(0.68)	(0.39)	(0.21)
[F]	[3.5]b	[7.2]a	[4.07]b	[1.47]	[1.74]
β_{GARCH}	0.76	0.64	0.91	0.96	1.12
(SE)	(0.13) 2.73	(0.07)	(0.06)	(0.05) 0.14	(0.06)
γ_{GARCH}	(18.0)	-3.32	0.17	(0.17)	0.40
(SE)	[3.58]c	(1.40)	(0.13)	[0.85]	(0.19)b
[F]	0.21	[26.9]a	[1.67]	0.51	[4.15]b
R^2		0.49	0.46		0.48

----continued

Panel A shows results for regressions with short rate maturity *m*=1, and Panel B for *m*=3. See notes for Panel B.

m=3	3	6	9	12	18
β_{OLS} (SE) [F] R^2		0.63 (0.13) [7.69]a 0.18	0.77 (0.13) [3.20]c 0.33	0.88 (0.14) [0.76] 0.40	1.14 (0.26) [0.27] 0.20
β_{IVE} (SE) [F]		1.01 (0.30) [0.002]	1.03 (0.39) [0.007]	0.91 (0.17) [0.28]	1.12 (0.26) [0.22]
β_{MA} (SE) γ_{MA} (SE) [F] R^2		0.67 (0.12) -0.37 (0.25) [7.34]a 0.19	0.80 (0.13) -0.35 (0.60) [2.26] 0.32	0.91 (0.14) -0.04 (0.77) [0.42] 0.39	1.22 (0.30) 0.14 (1.58) [0.54] 0.20
$\beta_{\text{(ex- returns)2}}$ (SE) $\gamma_{\text{(ex- returns)2}}$ (SE) [F]		0.67 (0.15) 14.9 (11.7) [4.78]b	0.78 (0.13) 2.50 (3.73) [2.9]c	0.88 (0.13) 0.41 (2.19) [0.81]	1.13 (0.25) 0.10 (1.44) [0.29]
β_{GARCH} (SE) γ_{GARCH} (SE) [F] R^2		0.60 (0.11) -1.08 (0.61) [14.1]a 0.19	0.77 (0.04) 0.09 (0.14) [14.9]a 0.28	0.87 (0.06) 0.21 (0.20) [5.67]a 0.37	0.99 (0.10) -0.09 (0.15) [0.004] 0.19

The values in the first two rows of Panels A and B are taken from Table 2 and are reported here to facilitate the comparison with the figures in the remaining rows. These are obtained from the estimation of the extended regressions based on equation (2a). The first and third numbers in these rows are the estimates of β and γ respectively. Newey-West standard errors are in parentheses below estimated coefficients. F-tests associated with the hypothesis that $\beta=1$ are in square brackets. Estimation of regressions with the term premium proxied by the square excess returns is by IV, using as instruments lagged values of the squared excess returns. R^2 are not shown for these regressions, as their use as measures of goodness of fit is not valid in the case of IVE.

a, b, and c denote statistical significance at the 1%, 5% and 10% respectively.

TABLE 6
Long rate regressions extended with proxies for the term premium

$$R_{t+m}^{(n-m)} - R_t^n = a + b\left(\frac{m}{(n-m)}\right)(R_t^n - R_t^m) + g\mathrm{TP}_t + e_{t+m} \qquad (3a)$$

Panel A					
	n				
m=1	3	6	9	12	18
β_{OLS}	0.70	0.29	0.09	-0.006	-0.13
(SE)	(0.36)	(0.33)	(0.38)	(0.46)	(0.66)
[F]	[0.73]	[4.53][b]	[5.72][b]	[5.28][b]	[2.89][c]
R^2	0.03	0.01	0.00	0.00	0.00
β_{IVE}	0.71	0.25	0.29	0.41	0.50
(SE)	(0.36)	(0.37)	(0.56)	(0.69)	(0.96)
[F]	[0.64]	[3.97][b]	[1.63]	[0.73]	[0.27]
β_{MA}	0.73	0.38	0.27	0.23	0.50
(SE)	(0.36)	(0.34)	(0.39)	(0.49)	(0.71)
γ_{MA}	-0.29	-0.27	-0.24	-0.24	-0.27
(SE)	(0.25)	(0.19)	(0.18)	(0.18)	(0.18)
[F]	[0.55]	[3.21][c]	[3.38][c]	[2.46]	[0.48]
R^2	0.04	0.02	0.02	0.01	0.02
$\beta_{(ex-returns)2}$	0.68	0.31	0.09	-0.10	-0.11
(SE)	(0.35)	(0.32)	(0.37)	(0.46)	(0.67)
$\gamma_{(ex-returns)2}$	8.98	2.08	0.67	0.17	-0.02
(SE)	(3.12)	(0.55)	(0.23)	(0.13)	(0.06)
[F]	[0.86]	[4.73][b]	[6.16][b]	[5.62][b]	[2.72][c]
β_{GARCH}	0.77	0.30	0.09	-0.05	0.04
(SE)	(0.35)	(0.36)	(0.77)	(0.49)	(0.69)
γ_{GARCH}	0.45	0.28	0.04	-1.45	-0.90
(SE)	(0.51)	(1.46)	(0.14)	(1.00)	(1.02)
[F]	[0.42]	[26.9][a]	[1.40]	[4.56][b]	[1.91]
R^2	0.02	0.01	-0.03	0.02	0.01

---continued

See notes for Table 5.

TABLE 6 (continued)

Panel B					
			n		
m=3	3	6	9	12	18
β_{OLS} (SE) [F] R^2		0.26 (0.27) [7.70][a] 0.01	0.13 (0.16) [29.15][a] 0.01	0.09 (0.14) [44.5][a] 0.00	0.06 (0.13) [49.5][a] 0.00
β_{IVE} (SE) [F]		1.11 (0.63) [0.03]	0.84 (0.41) [0.15]	0.77 (0.33) [0.51]	0.60 (0.25)[b] [2.44]
β_{MA} (SE) γ_{MA} (SE) [F] R^2		0.34 (0.27) -0.74 (0.69) [5.91][b] 0.03	0.20 (0.17) -0.63 (0.67) [22.1][a] 0.02	0.17 (0.15) -0.62 (0.70) [32.0][a] 0.02	0.17 (0.14) -0.73 (0.75) [34.5][a] 0.03
$\beta_{(ex\text{-}returns)2}$ (SE) $\gamma_{(ex\text{-}returns)2}$ (SE) [F]		0.34 (0.30) 29.9 (23.32) [4.78][b]	0.15 (0.17) 7.28 (5.78) [25.8][a]	0.08 (0.14) 2.76 (2.61) [45.3][a]	0.05 (0.13) 0.32 (1.02) [51.4][c]
$?_{GARCH}$ (SE) γ_{GARCH} (SE) [F] R^2		0.20 (0.17) -1.16 (0.45) [23.14[a] 0.05	0.11 (0.09) -0.57 (0.29) [98.1][a] 0.00	0.08 (0.08) -0.34 (0.19) [79.4][a] -0.03	0.06 (0.08) -0.20 (0.16) [127.7][a] -0.05

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