Interest rate risk of German financial institutions: the impact of level, slope, and curvature of the term structure

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Abstract We investigate here the sensitivity of the equity values of a large sample of German financial institutions to movements in the term structure of interest rates. While similar approaches rely on a single interest rate factor only, we quantify the exposure to changes in level, slope, and curvature, which are the driving factors of term structure changes. Our main findings are: (i) banks and insurances are exposed to level and curvature changes but only marginally to slope movements; (ii) the interest rate risk exposure depends on the banking sector investigated; (iii) level and curvature changes are priced in the cross-section of stock returns.

Keywords German financial institutions · Interest rate sensitivity · Term structure · Nelson–Siegel approach

JEL Classification G12 · G21 · G22

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1 Introduction

Traditionally, banks and insurance companies have served as intermediaries in transforming financial resources from savings to investments. As noted by Bhattacharya and Thakor (1993), in this process, financial institutions often act as "qualitative asset transformers" by changing the attributes of financial claims with respect to risk, size, maturity, and so forth. Especially banks invest in longer-term risky assets but accept rather low-risk and short-term deposits, which insure savers against unexpected liquidity needs. As a consequence, banks and insurance companies hold predominantly nominal and often fixed-interest rate assets and liabilities with, especially in the case of banks, diverging maturities. Following the reasoning of Samuelson (1945) and, in more detail, French et al. (1983), this has been widely claimed to be the specific reason for the interest rate sensitivity of financial institutions.

Despite a global trend towards an increasing relevance of capital markets in the allocation of capital, Schmidt et al. (1999) and Allen and Santomero (2001) find that, for the traditionally bank-based financial system of Germany, the role of financial institutions as qualitative asset transformers in the process of allocating financial resources between savers and borrowers has remained unchanged. Hence, the interest rate risk of financial institutions, i.e., the variation in the market values of their equity positions induced by changes in the term structure and the mismatch of their assets and liabilities, has been, and still is, of viable interest to both investors (e.g., for purposes of hedging and performance attribution) and regulators (e.g., for an assessment of systemic interest rate risk).[1]

Since financial intermediaries hold essentially nominal assets and liabilities, these firms resemble a levered mutual fund investing mainly in fixed income securities. Not surprisingly, the standard approach to quantify the interest rate risk exposure of the equity value of financial institutions suggested by Stone (1974) parallels the duration approach, one of the most basic tools in fixed income portfolio management. In both cases, interest rate risk is measured as an asset's sensitivity to a single interest rate factor. Most recent contributions using variants of this approach include Madura and Zarruk (1995), Oertmann et al. (2000), and Elyasiani and Mansur (2003) who compare the interest rate sensitivity of financial institutions in an international context; Faff and Howard (1999) for Australia; Dinenis and Staikouras (1998, 2000) for the UK; Elyasiani and Mansur (1998, 2004), Tai (2000), Fraser et al. (2002), and Brewer et al. (2007) for the US, and, most relevant in the context of this study, Bartram (2002), Bessler and Opfer (2005), and Scholz et al. (2008) who provide an investigation of German financial and non-financial corporations.

The assumptions necessary to derive the duration measure, particularly those relating to the shape and movements of the term structure, have led researchers to criticize this approach as being too restrictive in the context of bond risk management. For this reason, more complex models accounting for non-linearity in the shape of the term structure and for non-parallel shifts driven by multiple factors have been proposed to overcome this restriction.[2] Because of its conceptual similarity, the critique of the classical duration approach applies to the Stone (1974) model as well. However, attempts to quantify the exposure of equity securities to more complex movements in the term structure by

[1] Staikouras (2003) provides an in-depth discussion of the reasons to investigate the interest rate sensitivity of financial institutions.

[2] See, e.g., Ho (1992), Willner (1996), and Diebold et al. (2006).

modelling more than a single interest rate factor have been rare.[3] Notable exceptions are studies by Lynge and Zumwalt (1980) and Fogler et al. (1981) for the US market, where two interest rate factors of different maturities are simultaneously employed. Applications to German data include Elgeti and Maurer (2000), Bessler and Opfer (2003), and Behr and Sebastian (2006) who employ two heuristic level and slope factors.

In the wake of discussions questioning the application of classic approaches to measuring the interest rate sensitivity of equity investments, we contribute to the literature by suggesting the use of an extended factor model based on the Nelson and Siegel (1987) approach to fit the term structure. The parameters of this model can be interpreted as level, slope, and curvature and have been shown to be the underlying factors driving term structure changes. Thus the advantage of the extended factor model is that it captures the exposure of a firm's equity value to changes in the entire shape of the term structure. We examine the extended factor model empirically and find it to be superior to existing approaches with regard to gauging the exposure to interest rate risk of equity investments.

In essence, this paper addresses the following questions:

1. How should we measure the interest rate risk of the equity value of (financial) corporations, i.e., the sensitivity of stock returns to changes in the term structure?
2. What is the impact of term structure changes on the equity value of German firms?
3. Should we consider the factors driving changes in the term structure to represent systematic risk factors in the German equity market such that an exposure to these factors should be rewarded by risk premia?

Our key findings related to these questions are: (1) Our extended factor model outperforms the standard model suggested by Stone (1974) in the measuring of interest rate risk of bond returns. Since stock returns of financial institutions are partly determined by the factors driving bond returns, we recommend using this extended model to measure the interest rate risk of (financial) corporations. (2) By investigating a broad sample of German financial institutions, we show that not only level but also curvature changes have a significant impact on equity returns. In contrast, changes in the slope factor are mostly insignificant. Moreover, the exposures to these factors are both time-varying and related to the principal business activity of financial institutions. (3) We find that the exposure to level and curvature changes are rewarded in the German equity market. Thus both factors affect the cost of capital of financial institutions. Like the results for interest rate exposure, we find evidence that risk-premia vary over time.

The remainder of the paper is organized as follows. In Section 2 we discuss methodological aspects. We briefly present the Nelson–Siegel model to fit the term structure of interest rates and discuss its application in a multi-factor model explaining stock returns. The data is presented in Section 3. Section 4 analyzes the sensitivity of bond and stock returns to changes in the term structure. Section 5 investigates whether the Nelson–Siegel factors have a systematic influence on the German stock market and if those factors are priced in an Arbitrage Pricing Theory context. Section 6 concludes.

[3] There are several studies which model interest rate volatility in addition to an interest rate factor; see, e.g., Dinenis and Staikouras (1998), Elyasiani and Mansur (1998, 2003), and Tai (2000). However, since the additional factor does not model the shape of the term structure, we do not consider these studies here.

2 Methodology

2.1 The Nelson–Siegel framework to model the term structure of interest rates

Using factor analysis, Litterman and Scheinkman (1991) and more recently Bliss (1997) identify three common factors driving changes in the term structure of interest rates. They show that these factors are closely related to changes in level, slope, and curvature of the term structure. Hence, any attempt to describe the shape of the term structure for a given point in time should at least be able to model these components.

Nelson and Siegel (1987) proposed a parsimonious model of the (zero) yield curve which describes the yield of a zero bond with time-to-maturity T at time t, $s_t(T)$, as a function of three factors L_t, S_t, and C_t and an additional parameter τ_t.[4]

$$s_t(T) = L_t + S_t \frac{1 - \exp(-T/\tau_t)}{T/\tau_t} + C_t \left(\frac{1 - \exp(-T/\tau_t)}{T/\tau_t} - \exp(-T/\tau_t) \right) \qquad (1)$$

Diebold and Li (2006) demonstrate that Eq. 1 is consistent with the reported factor analytical investigations of changes in the term structure of interest rates since the factors L_t, S_t, and C_t can be interpreted as level, slope, and curvature of the term structure: The (implicit) loading of the spot rates $s_t(T)$ on the first factor in (1), L_t, is one and thus independent of time-to-maturity. Any change in this factor affects all interest rates equally, thereby causing a parallel or a level shift of the term structure.

Taking limits of (1), we have $s_t(\infty) = L_t$ and $s_t(0) = L_t + S_t$. Since the slope of the term structure of interest rates might be defined as the difference between the long rate $s_t(\infty)$ and the short rate $s_t(0)$, it follows that S_t models the slope of the term structure times -1. Note that the loading of $s_t(T)$ on S_t in (1) is governed by an exponential function which decreases asymptotically to zero with increases in T. Therefore, the resulting zero yield curve will already display a concave shape in the case of a positive slope ($S_t < 0$) or a convex shape in the case of a negative slope ($S_t > 0$).

C_t is of particular relevance for medium-term rates since loadings of spot rates on this factor decay to zero for both short-term and long-term maturities and take on positive values in between. Hence, any positive (negative) value of C_t will lead to an increase (decrease) in interest rates, assuming all else is equal. As a consequence, if S_t and C_t have different signs, the curvature of the term structure of interest rates is accentuated, whereas in the case where both have the same sign, the curvature is reduced. In the latter case, especially when the term structure is rising ($S_t < 0$), a negative C_t might even induce an inflection point. Hence, C_t is termed (excess) curvature factor. Finally, the parameter τ_t has a pure statistical meaning by influencing the decay of the exponential functions in Eq. 1.

2.2 The common two-factor approach to quantify interest rate risk

Stone (1974) suggested extending the basic market model to a two-factor model by including a debt or interest rate factor. The advantage of this additional factor is at least twofold. First, there might be influences of interest rates on individual companies that are not captured by the market factor, and second, even if interest rate risk is already included in the market factor (which, due to its often-postulated systematic nature, is expected to be

[4] We present the Nelson-Siegel model in a slightly modified version as described in Diebold and Li (2006) since this factorization allows for a more intuitive interpretation. As shown by Diebold and Li (2006, p. 341) this version might be easily reconciled with the one originally proposed by Nelson and Siegel (1987).

largely the case) it should provide valuable insight into which movements in the equity market can be explained via changes in interest rates. Stone's basic two-factor model can be described as follows.

$$r_{i,t} = \delta_{i,0} + \delta_{i,M} r_{M,t} + \delta_{i,D} r_{D,t} + \varepsilon_{i,t} \tag{2}$$

$r_{i,t}$ is the (excess) stock return of an asset i in period t adjusted for the one-period risk-free rate, $\delta_{i,0}$ is a constant and $\varepsilon_{i,t}$ is a mean-zero residual. $r_{M,t}$ is the excess return on the market factor and $r_{D,t}$ is the excess return of a bond index. The respective sensitivities of the stock returns to changes in these indices are $\delta_{i,M}$ and $\delta_{i,D}$. The debt market or interest rate factor $r_{D,t}$ does not necessarily have to be traded. Alternatively, one might as well use changes in interest rates as in, e.g., Madura and Zarruk (1995), Hirtle (1997), Dinenis and Staikouras (1998), Oertmann et al. (2000), and Bessler and Opfer (2003, 2005).[5] The advantage of using this specification of $r_{D,t}$ relates to the interpretation of the interest rate risk coefficient $\delta_{i,D}$ which, following Reilly et al. (2005), can be interpreted as the ith asset's implied or empirical duration.

For the very reason that equities and interest rates should not be independent, one would expect the market factor, $r_{M,t}$, and the interest rate factor, $r_{D,t}$, in (2) to be correlated. In this case, Hirtle (1997) argues that the interest rate coefficient $\delta_{i,D}$ only partially measures the interest rate risk exposure of asset i since changes in interest rates affect the market factor as well. Hence, interest rate risk is partly captured by the market risk coefficient $\delta_{i,M}$. In order to obtain a measure of the total interest rate risk exposure of asset i, Hirtle (1997) suggests running an auxiliary regression of the market factor on the interest rate factor to decompose the market return into a component which is uncorrelated with interest rate changes (i.e., the residuals) and a second component capturing the sensitivity of the market to changes in the term structure. Replacing $r_{M,t}$ by the residuals of this regression, $r^*_{M,t}$, yields an interest rate risk coefficient which captures both direct and indirect (i.e., via the market factor) influences of term structure changes on equity values.[6] Thus, in order to estimate the total interest rate risk exposure, Eq. 2 is modified as follows:

$$r_{i,t} = \beta_{i,0} + \beta_{i,M} r^*_{M,t} + \beta_{i,D} r_{D,t} + \varepsilon_{i,t} \tag{3}$$

In (3), $\beta_{i,D}$ is a measure of the total interest rate risk exposure of asset i which is also identical to the respective regression coefficient from a (hypothetical) univariate regression of $r_{i,t}$ on $r_{D,t}$ and a constant.[7] $\beta_{i,M}$ can be interpreted as the sensitivity to general market risk excluding influences of term structure changes and $\beta_{i,0}$ is a constant. Since the auxiliary

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[5] Scholz et al. (2008) compare the results of a two-factor model with the interest rate factor specified as either bond holding period returns of a given maturity or, more directly, as changes in the interest rate of the corresponding maturity. In terms of variance explained and also with respect to the significance of the estimated coefficients, their results are very similar for both alternatives.

[6] In the present context, similar specifications of the market factor have also been used by, e.g., Akella and Greenbaum (1992) and Fraser et al. (2002). Moreover, the use of a residual market factor is also common in APT studies employing observable macroeconomic factors in an attempt to capture only those systematic influences which are not already accounted for by the macroeconomic variables, see, e.g., McElroy and Burmeister (1988) and Chang (1991).

[7] Nevertheless, Giliberto (1985) criticizes the use of a residual market factor in the two-factor model proposed by Stone (1974) since this would lead to both biased point estimates and standard errors of the interest rate coefficient. Hirtle (1997) rejects Giliberto's critique since it implicitly assumes that only the direct effect of interest rate changes on equity values, beyond the effect of the market factor, would be of interest. Analog to Hirtle (1997), we here aim at quantifying the total interest rate risk exposure.

regression (which is also often termed as "orthogonalization") does not change the explanatory power of the model, the residuals $\varepsilon_{i,t}$ in (3) are identical to those in (2).

2.3 Interest rate risk in respect to changes in level, slope, and curvature of the term structure

Litterman and Scheinkman (1991) and Bliss (1997) demonstrate that parallel shifts or, equivalently, variations in the level of interest rates constitute the single most important but not the only relevant determinant of term structure changes. Additional changes can be (largely) attributed to movements in its slope and curvature. However, the (classical) duration concept ignores changes of the term structure other than parallel ones, which means that a part of an asset's interest rate risk is not accounted for by this concept. In an attempt to overcome this restriction, Ho (1992) suggests the use of a key rate duration vector, i.e., a vector of sensitivities of an asset's market value to changes in a range of different interest rates for purposes of bond risk management. Since changes in different interest rates can be (largely) boiled down to changes in level, slope, and curvature of the term structure, Willner (1996) suggests directly determining the sensitivities to changes in these factors as an extension of the key rate approach.

As noted by Reilly et al. (2005), while pricing models allow one to obtain level, slope, and curvature durations for fixed income securities, we lack such a possibility in the context of equity securities. For this reason, we suggest integrating Willner's approach into the Stone (1974) model by using changes in the Nelson–Siegel factors as interest rate factors in order to capture not only the sensitivity to changes in the level ($\Delta L_t = L_t - L_{t-1}$), but variations in the slope ($\Delta S_t = S_t - S_{t-1}$) and curvature ($\Delta C_t = C_t - C_{t-1}$) as well. Analogously to the two-factor case in Eq. 2, this allows us to determine empirical level, slope, and curvature durations.[8]

If, however, the Nelson–Siegel factors are not statistically independent, we cannot extract the exclusive impact of changes in a single factor on stock returns. Therefore, we apply an orthogonalization procedure to the time series of these factors as well: Following the results of studies by Litterman and Scheinkman (1991) and Bliss (1997), we consider the level factor to be the primary determinant while the slope factor is ranked second and the curvature factor third in terms of their relevance in driving term structure changes. Hence, the second interest rate factor, ΔS_t^*, constitutes the residuals of an auxiliary regression of the slope factor on the level factor. Likewise, any correlation with the level and the slope factor is removed from the curvature factor which is then denoted ΔC_t^*. Finally, consistent with the "total interest rate risk" approach, we construct a residual market factor, $r_{M,t}^*$, from the residuals of a multivariate regression of the market factor on the Nelson–Siegel factors. Thus, our extended version of the common two-factor approach (2) can be described as follows.

$$r_{i,t} = \beta_{i,0} + \beta_{i,L}\Delta L_t + \beta_{i,S}\Delta S_t^* + \beta_{i,C}\Delta C_t^* + \beta_{i,M} r_{M,t}^* + \varepsilon_{i,t} \quad (4)$$

The regression coefficients in (4) can be interpreted as follows: $\beta_{i,0}$ is a constant while $\beta_{i,L}$, $\beta_{i,S}$, and $\beta_{i,C}$ denote the sensitivities to changes in the level, to slope changes beyond those already expected because of the level change, and to curvature changes beyond those already accounted for because of level and slope changes, respectively. As before, $\beta_{i,M}$ can

[8] To facilitate readability, we henceforth use the expression "level factor" ("slope factor" or "curvature factor") when we address the time series of changes in the respective factor. However, if we should refer to the level of (and not changes in) these factors, we will explicitly mention it.

be interpreted as a sensitivity measure to general market risk excluding the exposure to movements in the term structure.

Since we use linearly independent factors, we are able to compare the relative importance of any of the explanatory factors in (4) by expressing the total asset return variance, $\mathrm{Var}(r_{i,t})$, as the sum of individual contributions of risk factor variances and the error variance.[9] Denoting the kth risk factor as $F_{k,t}$, the individual contribution of this factor to total asset return variance is measured by the product of the squared sensitivity of the asset return to this factor, $\hat{\beta}_{i,k}^2$, and this factor's variance, $\mathrm{Var}(F_{k,t})$.

$$\mathrm{Var}(r_{i,t}) = \hat{\beta}_{i,L}^2 \mathrm{Var}(\Delta L_t) + \hat{\beta}_{i,S}^2 \mathrm{Var}(\Delta S_t^*) + \hat{\beta}_{i,C}^2 \mathrm{Var}(\Delta C_t^*) + \hat{\beta}_{i,M}^2 \mathrm{Var}(r_{M,t}^*) + \mathrm{Var}(\varepsilon_{i,t}) \quad (5)$$

In order to compare the relative impact of factors on different assets, we divide Eq. 5 by $\mathrm{Var}(r_{i,t})$. The resulting expression for the kth risk factor, $\hat{\beta}_{i,k}^2\,\mathrm{Var}(F_{k,t})/\mathrm{Var}(r_{i,t})$, represents the percentage contribution of this risk factor to the total asset return variance, and will be referred to as "factor R^2" from now on. Note that, by construction, the sum over all factor R^2s must equal the R^2 of the multivariate regression in Eq. 4.

Finally, another important aspect relates to the question of whether only unexpected changes in risk factors should be employed since, in efficient capital markets, expected changes in risk factors should already be included in today's asset prices. However, this requires speculating about how investors form their expectations. Studies by Booth and Officer (1985), Bae (1990), and Dinenis and Staikouras (1998), among others, compare current and unexpected changes in interest rate factors using a variety of expectation generation processes. They were unable to show systematic differences in the estimated interest rate sensitivities of financial institutions using either current or unanticipated changes. Given the uncertainty related to the choice of the "correct" expectation formation process, we also use current changes in our factors.

2.4 An APT-based model to investigate the pricing of interest rate risk

We expect interest rate risk to influence the value of any asset providing future cash flows since discount factors (neglecting any credit and liquidity spreads) are directly determined by the term structure of interest rates. Hence, changes in the term structure, as described by changes in the Nelson–Siegel factors, should represent systematic risk factors in the capital market. Therefore, these factors potentially carry an ex-ante risk premium to persuade investors to risk exposure to them. We test whether these factors are priced in the context of the Arbitrage Pricing Theory (APT) by Ross (1976, 1977).

The APT assumes that returns are generated by the linear k-factor model in Eq. 6. This assumption is conceptually similar to the linear two-factor model by Stone (1974).

$$\mathbf{R}_t = \mathrm{E}(\mathbf{R}_t) + \mathbf{B}\mathbf{f}_t + \boldsymbol{\varepsilon}_t \quad (6)$$

$\mathbf{R}_t$ is an n-vector of returns in period t. $\mathbf{B}$ is the $(n \times k)$ matrix of sensitivities of the n assets to the assumed k systematic risk factors whose values in period t are contained in the k-vector $\mathbf{f}_t$. Note that $\mathbf{f}_t \equiv [\mathbf{F}_t - \mathrm{E}(\mathbf{F}_t)]$ where $\mathbf{F}_t$ is the k-vector containing the values of the k risk factors (i.e., changes in the Nelson–Siegel factors and the residual market factor) in period t. $\boldsymbol{\varepsilon}_t$ is an n-vector of residuals. In order for (6) to hold, we must have $\mathrm{E}(\mathbf{f}_t) = \mathrm{E}(\boldsymbol{\varepsilon}_t) = \mathrm{E}(\mathbf{f}_t\boldsymbol{\varepsilon}_t') = \mathbf{0}$.

[9] This follows simply from $\mathrm{Var}(r_{i,t}) = \mathrm{E}\{r_{i,t} - \mathrm{E}(r_{i,t})\}^2$, since any covariance terms are zero, see, e.g., Elton et al. (2003) for details.

The expected returns can be projected on an n-vector of ones, $\mathbf{\iota}_N$, and the sensitivity matrix $\mathbf{B}$ to get the projection coefficients λ_0 and $\boldsymbol{\lambda}$ where $\boldsymbol{\lambda}$ is a k-vector. Connor and Korajczyk (1995) demonstrate that, under some simplifying assumptions, (7) must hold exactly if there are no arbitrage opportunities.

$$\mathrm{E}(\mathbf{R}_t) = \lambda_0 \mathbf{\iota}_N + \mathbf{B}\boldsymbol{\lambda} \tag{7}$$

The coefficients λ_0 and $\boldsymbol{\lambda}$ represent the risk-free rate and the k factor risk premia, respectively. Substituting (7) in (6) yields the non-linear regression system (8), which includes both cross-section and time series restrictions, since the factor risk premia are forced to be identical across equations and over time series. Again, to simplify, we subtract $\lambda_0 \mathbf{\iota}_N$ from each side and use excess returns, denoted with $\mathbf{r}_t$.

$$\mathbf{r}_t = \mathbf{B}(\boldsymbol{\lambda} + \mathbf{f}_t) + \boldsymbol{\varepsilon}_t \tag{8}$$

3 Data

3.1 Fixed income

The sample period investigated in this study is 1974–2002 using monthly observations. We obtain end-of-month bond price quotes from the German capital market database of the University of Mannheim to estimate the German term structure of interest rates. For consistency reasons with benchmark data provided by the Deutsche Bundesbank, we only include bills, notes, and bonds issued by the Federal Republic of Germany. For the same reason, we exclude any securities with a time-to-maturity of less than three months.[10]

Equation 1 is estimated for each month t according to the three-step procedure suggested by Diebold and Li (2006). First, we use the well-known iterative procedure developed by Fama and Bliss (1987) to extract zero bond yields from the prices of coupon bonds as initial estimates of the left-hand side of (1). Note that the spot rates calculated in the course of this bootstrapping approach price the included bonds exactly. However, since bond prices are affected by individual influences, the resulting term structure will show an unsmooth pattern. Hence, the calculated zero bond yields are often called "unsmoothed Fama–Bliss zero yields".

In the second step, the values of the regressors of Eq. 1 (i.e., the loadings of spot rates on the slope and the curvature factor) are calculated for each of the estimated unsmoothed Fama–Bliss zero yields by prespecifying the decay parameter τ_t. Prior research by Nelson and Siegel (1987), Barrett et al. (1995), and Willner (1996) as well as our own calculations showed that the fit of (1) is relatively insensitive to the value of τ_t. Therefore, we follow standard practice tracing back to Nelson and Siegel (1987) and hold τ_t constant across the sample period at a value of 1.5627.[11]

[10] See Deutsche Bundesbank (1997).

[11] 1.5627 is the mean value of a time series of τ-values resulting from a tentatively investigated non-linear optimization approach of Eq. 1 where all four parameters have been optimized simultaneously. This value is reasonably close to both the values of 1.3683 used by Diebold and Li (2006) (note that the authors use a model specification with the reciprocal value of τ_t and a time-to-maturity on a monthly basis instead of our yearly basis) and the value of 3 which has been advocated by a number of other authors, including Barrett et al. (1995), Willner (1996), Dolan (1999), and Fabozzi et al. (2005) but leads to a marginally better fit for our data set.

Table 1 Descriptive Statistics, Nelson–Siegel factors
The table contains descriptive statistics of the time series of the parameters of the Nelson and Siegel (1987) approach as described in Eq. 1: $s_t(T) = L_t + S_t\,(1 - \exp(-T/\tau_t))/(T/\tau_t) + C_t\,((1 - \exp(-T/\tau_t))/(T/\tau_t) - \exp(-T/\tau_t))$. L_t is the level, S_t the slope and C_t the curvature factor of the German term structure of interest rates at time t with τ_t (the decay factor) prespecified to a value of 1.5627. The results have been estimated using end-of-month Fama–Bliss unsmoothed zero yields as initial estimates of the spot rates $s_t(T)$ which are calculated from securities issued by the German government for the period 1974:01–2002:12. The last three columns relate to the first differences of the given factors. Durbin–Watson tests for significant first-order autocorrelation in the changes of the given factor. The last two columns present results of an Augmented Dickey–Fuller test for the stationarity of the first differences and the corresponding MacKinnon (1996) one-sided p-values

Factor	Mean	Std. dev.	Min.	Max.	DW	ADF t-test	
						t-Stat.	(p-Value)
L_t (Level)	7.368	1.147	4.870	10.152	2.006	−18.841	(0.000)
S_t (Slope × (−1))	−1.866	2.016	−6.236	3.762	1.975	−17.539	(0.000)
C_t (Curvature)	−1.011	2.453	−6.002	7.425	2.002	−18.882	(0.000)

Third, since the regressors of the right-hand side of Eq. 1 are known, we can apply standard OLS to regress the unsmoothed Fama–Bliss zero yields (step 1) on a constant and the regressors calculated in step 2 to obtain estimates of the level, slope, and curvature factors of the term structure of interest rates at time t, L_t, S_t, and C_t.

In Table 1, we present descriptive statistics for the estimated Nelson–Siegel factors. We find the average spot rate curve to have a positive slope and a negative (excess-)curvature. Moreover, we find no significant first-order autocorrelation in the changes of the Nelson–Siegel factors, suggesting that these are indeed unexpected.[12]

For exploratory purposes, we further use the monthly total return time series of German government bond indices calculated by J.P. Morgan. These indices are subdivided in the maturity classes 1–3, 3–5, 5–7, 7–10, and over 10 years.

3.2 Equities

Our equity sample consists of 28 German banks included in the database of Thomson Financial Datastream. In order to assess possible differences between banks and other financial and non-financial corporations, we additionally selected 20 German insurance companies and 37 non-financials as control groups.[13] Along the lines followed by, e.g., Dinenis and Staikouras (1998), Elyasiani and Mansur (1998), Oertmann et al. (2000), Fraser et al. (2002), and Brewer et al. (2007), we form three equally weighted industry portfolios of individual firms (banks, insurances, non-financials) in order to smooth out the noisiness in single stock returns caused by idiosyncratic influences. The disadvantage of using portfolios is that potential dissimilarities between firms contained in a portfolio are averaged. Therefore, we further disaggregate the relevant banking portfolio by classifying

[12] Tests not shown here indicate that there is also no significant higher-order autocorrelation in the changes of the level and the slope factor. Weak evidence of autocorrelation of a higher order has been found for changes in the curvature factor.

[13] While we compiled a very broad sample of the financial institutions being listed at the Frankfurt stock exchange, we limited our sample of non-financial corporations according to the selection criterion “current or former membership in the German prime stock index DAX 30”, i.e., any non-financial corporation being included in the DAX at any point in time prior to the end of 2002 is comprised in our sample. Company names are listed in Appendix 1.

banks according to their principal business activities into international, regional, and mortgage banks. The international bank portfolio consists of the largest banking firms in our sample, which act on a global scale and combine both commercial and investment banking activities. In contrast, the regional bank portfolio consists of often much smaller banks which are also mostly more focussed both with respect to business activities and geographical extension. Finally, we separate the group of mortgage banks which constitute a speciality of the German banking law that, until recently, prohibited these firms from engaging in activities other than mortgage financing and public lending and restricted the refinancing to the issuance of a sort of mortgage-backed securities ("*Pfandbriefe*").

Because of its narrow focus on lending and borrowing, one might expect mortgage banks to be the most interest rate sensitive, the somewhat more diversified regional banks to have a lesser exposure to interest rate risk, and the international banks to have the least interest rate risk. However, there is an offsetting effect as well: Because of their exclusive reliance on traditional (interest rate-related) banking business with few opportunities to diversify, mortgage banks could be expected to control their interest rate risk the most. In contrast, larger banks might have a better access to the global capital markets because of their size and might thus be more active in the derivatives market. While in principle these activities would allow them to reduce their interest rate risk exposure, Hirtle (1997) finds evidence that US banks engaging in derivative markets use derivatives to effectively increase their interest rate risk exposure.

As banks, insurance companies hold predominantly nominal assets and liabilities. However, since maturity transformation has traditionally not been a task attributed to this industry, we expect insurance companies to have a lesser exposure to interest rate risks compared to banks. Finally, as far as non-financial corporations hold nominal contracts as well, there might also be an influence on their equity values. Nevertheless, this industry is expected to be the least interest rate sensitive.

Bartram (2002) argues that if interest rate risks are a major risk source for financial and possibly for non-financial corporations as well, firms with a particularly high exposure to interest rate risks might not have existed for the entire sample period. Limiting the sample to only those firms with complete data over the sample period might therefore introduce a survivorship bias. Hence, following, e.g., Elyasiani and Mansur (2004) and Brewer et al. (2007), our portfolios consist of any company with available data for the respective point in time. This means that the number of firms being included in a portfolio varies over time if firms are newly listed, fail, merge, or are acquired.[14] This approach thus reduces a possible survivorship bias and improves the efficiency of the estimators.[15]

Because of its broad market coverage, we employ the DAFOX as our stock market index which is a total return index provided by the University of Karlsruhe. All returns are adjusted for the German one-month interbank rate.[16] In Table 2, we analyze the correlation between changes in the Nelson–Siegel factors and the equity market index for the total sample period. Mostly, the explanatory variables are significantly correlated, although the

[14] Until recently, a squeeze-out of remaining shareholders was hardly possible after the acquisition of a company in Germany. Therefore, firms often remained listed after such a transaction but the very low free float prohibited liquid trading leading to distorted prices. If we observed signs of illiquidity (such as, e.g., extended periods without price changes) after a merger or an acquisition, we excluded the respective company for periods following the transaction.

[15] See Bartram (2002) and Brewer et al. (2007) for a discussion of the treatment of survivorship bias in sample selection.

[16] We use one-month FIBOR and one-month EURIBOR before and after the introduction of the Euro, respectively. Both time series are available from the time series database of the Deutsche Bundesbank.

Table 2 Correlation of explanatory variables
This table shows the correlation coefficients for the monthly first differences of the parameters of the Nelson–Siegel model (where L_t is the level, S_t the slope and C_t the curvature factor of the German term structure of interest rates at time t) and of the monthly excess return of the equity market index, $r_{M,t}$. The sample period is 1974:01–2002:12. Significant coefficients at the 10%/5%/1% level are marked */**/***. The last column presents the variance inflation factors (VIF) of the respective factors given in the first column. The VIF is calculated as $1/(1 - R^2)$, where the R^2 is the variance of a given factor explained by all of the other explanatory variables divided by the factor's total variance. The minimum value of 1 means that the respective factor is completely linearly independent of all of the other explanatory variables

	ΔL_t (Level)	ΔS_t (Slope)	ΔC_t (Curvature)	$r_{M,t}$ (DAFOX)	VIF
ΔL_t (Level)	1				1.420
ΔS_t (Slope)	−0.217***	1			1.252
ΔC_t (Curvature)	−0.386***	−0.278***	1		1.403
$r_{M,t}$ (DAFOX)	−0.234***	0.056	0.075	1	1.058

variance inflation factor (VIF) is always well below any critical value, indicating that multicollinearity should not be a serious problem. Nevertheless, in order to be able to isolate effects of individual factors, we use orthogonalized factors in our four-factor model as specified in (4).

4 Estimation of the interest rate risk of German financial institutions

4.1 The impact of changing term structures on government bond indices

Because of their economic role as qualitative asset transformers in the process of allocating capital between lenders and borrowers, financial institutions are expected to hold primarily nominal assets and liabilities. Since banks additionally accept short-term deposits to insure lenders against unexpected liquidity needs while financing rather long-term projects, they are expected to perform maturity transformation. Setting aside credit risk-related issues (which is consistent with the literature investigating the interest rate sensitivity of financial institutions) we can view banking and insurance corporations essentially as portfolios of long and short positions in fixed income securities. This is the motivation for our first taking a look at the sensitivities of bond indices of differing maturity classes to term structure changes in order to gain some insight into how changes in the value of nominal contracts of financial institutions (which are assumed to account for a large part of their total assets and liabilities) are expected to influence their stock returns.

Obviously, the degree to which the interest rate factor in traditional models such as (3) is capable of explaining the variance of the stock returns of financial institutions depends on the maturity composition of nominal assets and liabilities on the balance sheets of banks and insurance companies. If the time-to-maturity of the interest rate factor does not match the maturity composition of the balance sheet of an investigated company, the two-factor approach in (3) will attribute at least parts of the interest rate risk related stock return variance to either the residual market factor or to the error term.

In order to demonstrate the consequences of different specifications of interest rate factor(s) given different time-to-maturities of the assets investigated, we study the example of J.P. Morgan's German government bond indices (GBI). Monthly total return time series in excess of the German one-month interbank rate for maturity classes of 1–3, 3–5, 5–7, 7–10, and more than 10 years are used. We estimate several versions of a linear factor model similar to (3) and compare the (adjusted) R^2s to judge which model has the overall best fit. That is, we estimate the model

$$r_{i,t} = \beta_{i,0} + \sum_{k=1}^{K} \beta_{i,D,k} r_{D,k,t} + \varepsilon_{i,t} \tag{9}$$

for the example period of 1995–2002,[17] where $r_{i,t}$ is the tth observation of the time series of bond index excess returns with maturity class i. K is the number of interest rate factors employed, ranging from one to three. As before, $r_{D,k,t}$ is the interest rate factor, whereby the additional subscript k identifies the interest rate factor if more than one has been specified.

With a view to the specifications of the interest rate factor found in the literature, we specify four versions of (9). Most studies investigating the interest rate sensitivity of financial institutions use interest rate factors with maturities either at the long-end such as, e.g., Oertmann et al. (2000) and Bessler and Opfer (2005) or at the very short-end of the term structure as in Dinenis and Staikouras (1998, 2000) or they use both but in alternative models as in Madura and Zarruk (1995), Bartram (2002), and Fraser et al. (2002). Hence, we specify our model 1 with a single interest rate factor containing the monthly first differences in German government spot rates with a time-to-maturity of ten years. Similarly, model 2 is specified with the monthly first differences of the three-month spot rates. Alternatively, other authors including Bessler and Opfer (2003) and Behr and Sebastian (2006) specify models with a level and a heuristic slope factor where the latter is often defined as the difference between the level factor and another mostly shorter-term interest rate. Thus, our model 3 consists of model 1 extended by a second interest rate factor containing monthly changes of the difference between the ten-year and the three-month rate. Finally, model 4 is a three-factor version of Eq. 4 excluding the residual market factor. Table 3 reports R^2s for each of these models and for each maturity class of the government bond indices separately.[18]

As expected, for both model 1 and 2, the percentage of total variance explained attains a maximum for the maturity class which comes closest to the maturity of the interest rate factor but decreases in all other cases. Also, we note that model 3 offers an additional contribution to total variance explained as compared to model 1 and 2. Nevertheless, independent of the maturity class of the investigated bond index, model 4 has the highest R^2 values. Furthermore, this model's R^2s are comparatively constant and steadily above 90% for any of the investigated maturity classes. With respect to our first introductory question regarding the measurement of the interest rate risk of the equity value of (financial) corporations, we therefore conclude that applying the Nelson–Siegel factors as interest rate factors should be the most promising approach in view of our uncertainty about the maturity structure of the balance sheets of these firms.

To better understand the influence of term structure changes on asset returns, we analyze the impact of changes in level, slope, and curvature on the bond indices examined. To this end, we report the sensitivities of the different maturity classes to changes in the Nelson–Siegel factors

[17] The time series of the longest maturity class (more than 10 years) does not start until the second half of 1994, although the other four classes were available from 1987 onwards. For these time series, the results of the extended period 1987–2002 were comparable to those reported below for the period 1995–2002.

[18] We also calculated R^2s adjusted for the different degrees of freedom ("adjusted R^2") resulting from the varying number of factors in the specified models. Qualitatively, the results of this analysis do not alter our conclusions presented below. However, for consistency reasons, we decided to present R^2s since these allow for a direct interpretation in terms of percentage of total variance explained by the model.

Table 3 R^2s of interest rate factor models explaining bond index returns

The table lists the R^2-values (%) of several specifications of the linear factor model $r_{i,t} = \beta_{i,0} + \sum_{k=1}^{K} \beta_{i,D,k} r_{D,k,t} + \varepsilon_{i,t}$ with $K = 1$ to 3 interest rate factors, $r_{D,k,t}$. Monthly excess returns of the total return bond indices given in the first column (denoted $r_{i,t}$) are used as dependent variables. Each model is estimated separately for each index for the period 1995:01–2002:12. Factors marked with an asterisk are orthogonal to the above-listed factors. Model 1 is specified with the monthly first differences of German spot rates with a time-to-maturity of 10 years, Δr_{10}. Model 2 is specified with the monthly first differences of German spot rates with a time-to-maturity of 3 months, $\Delta r_{0.25}$. Model 3 is specified as model 1 but is extended by a second interest rate factor which contains the monthly changes in the difference between the ten-year and the three month rate, $\Delta(r_{10} - r_{0.25})$. Model 4 is a three-factor version of Eq. 4, $r_{i,t} = \beta_{i,0} + \beta_{i,L}\Delta L_t + \beta_{i,S}\Delta S_t^* + \beta_{i,C}\Delta C_t^* + \varepsilon_{i,t}$ (The residual-market factor is excluded)

Interest rate factor(s), $r_{D,k,t}$	Model 1 Δr_{10}	Model 2 $\Delta r_{0.25}$	Model 3 Δr_{10} $\Delta(r_{10} - r_{0.25})$	Model 4 ΔL_t ΔS_t^* ΔC_t^*
JPM German GBI 1–3Y	45.46	32.75	64.19	93.50
JPM German GBI 3–5Y	68.10	19.79	75.26	94.47
JPM German GBI 5–7Y	83.24	13.59	86.11	94.39
JPM German GBI 7–10Y	90.35	6.62	90.57	93.10
JPM German GBI 10Y+	83.27	0.66	84.83	91.37

(model 4) in Table 4. Furthermore, the respective factor R^2s according to (5) are shown in order to assess the relative importance of these factors in explaining bond returns.

Any positive change in a factor of the Nelson–Siegel model will lead to an increase in the term structure which again leads to decreasing bond prices, assuming all else is equal. Therefore, it is plausible that all sensitivities of German government bond indices are negative and significantly different from zero. As expected, the relationship between the factor R^2 and the maturity class of an investigated bond index shows a pattern similar to the time-to-maturity-dependent loading of spot rates on the Nelson–Siegel factors in Eq. 1. The factor R^2 of the slope factor decays monotonically to zero with increasing time-to-maturity of the respective bond index considered. The percentage of total variance explained by the curvature factor achieves a maximum for the short-term maturity class of 1–3 years as well. Note, however, that for the medium-term maturity class of 3–5 years, the curvature factor R^2 is only slightly below its maximum.[19] Compared to the slope factor, the percentage of total variance explained by the curvature factor decays much more slowly to zero for longer maturities. In contrast to the decreasing factor R^2s of both the slope and the curvature factor, the level factor R^2 increases with a rising maturity class.

Based on our findings in this section, we can derive expectations for the following analysis of stock indices: Starting with the assumption of an all equity-financed firm that holds only financial assets, we would expect (i) this company to have a significant and negative exposure to changes in any of the factors of the Nelson–Siegel model, (ii) the level factor (slope and curvature factor) to have a stronger (weaker) influence on asset returns the longer the average maturity of the asset side is, and (iii) the slope factor to explain a significant part of total stock return variability for companies having a (very) short-term average maturity of their asset sides only.

[19] As a robustness check, we investigate synthetic bond indices with differing maturities. We found the curvature factor R^2 to attain a maximum for time-to-maturities between 2 and 3 years. For shorter maturities, the curvature factor R^2s decreased sharply. For longer maturities, the decay in the percentage of total variance explained by the curvature factor was found to correspond to the slower decay shown in Table 4.

Table 4 Sensitivities and variance explained of bond indices: the impact of changes in level, slope, and curvature of the term structure

The table shows the results from estimating a three-factor version of Eq. 4, $r_{i,t} = \beta_{i,0} + \beta_{i,L}\Delta L_t + \beta_{i,S}\Delta S_t^* + \beta_{i,C}\Delta C_t^* + \varepsilon_{i,t}$, (excluding the residual market factor) for the period 1995:01–2002:12. L_t is the level, S_t the slope and C_t the curvature factor of the German term structure of interest rates at time t which is estimated using the Nelson and Siegel (1987) approach. Factors marked with an asterisk are orthogonalized. 1-Month excess returns of the total return bond indices given in the first column are used as dependent variables. Sensitivities significant at the 10%/5%/1% levels are marked */**/***. Heteroskedasticity and autocorrelation-consistent (Newey and West 1987) t-ratios are presented in parentheses. The last four columns present the percentage contribution of individual factors to explaining total variance (factor R^2, %) as well as total variance explained by all factors collectively (R^2, %). For the kth risk factor, the factor R^2 is estimated as $\hat{\beta}_{i,k}^2\ \mathrm{Var}(F_{k,t})/\mathrm{Var}(r_{i,t})$ from Eq. 5, $\mathrm{Var}(r_{i,t}) = \hat{\beta}_{i,L}^2\ \mathrm{Var}(\Delta L_t) + \hat{\beta}_{i,S}^2 \mathrm{Var}(\Delta S_t^*) + \hat{\beta}_{i,C}^2\ \mathrm{Var}(\Delta C_t^*) + \mathrm{Var}(\varepsilon_{i,t})$ where the residual market factor is excluded

	$\hat{\beta}_{i,0}$	$\hat{\beta}_{i,L}$	$\hat{\beta}_{i,S}$	$\hat{\beta}_{i,C}$	Factor R^2 (%) of			R^2 (%)
					Level	Slope	Curv.	
JPM German GBI 1–3Y	0.001 (9.164)***	−0.245 (−4.413)***	−0.738 (−14.033)***	−0.513 (−18.733)***	1.72	11.43	80.35	93.50
JPM German GBI 3–5Y	0.002 (11.837)***	−1.232 (−11.557)***	−0.866 (−10.512)***	−0.950 (−36.913)***	12.28	4.43	77.77	94.47
JPM German GBI 5–7Y	0.003 (13.516)***	−2.510 (−20.726)***	−0.889 (−8.698)***	−1.171 (−27.301)***	27.68	2.54	64.17	94.39
JPM German GBI 7–10Y	0.003 (10.388)***	−4.027 (−20.870)***	−0.679 (−5.162)***	−1.288 (−24.658)***	44.12	0.92	48.06	93.10
JPM German GBI 10Y+	0.004 (7.366)***	−9.417 (−20.106)***	−0.786 (−2.272)**	−1.330 (−14.925)***	75.05	0.38	15.94	91.37

If we consider that firms are not all equity-financed but, in particular in the case of financial institutions, primarily debt-financed, we face two offsetting effects. First, if a firm attempts to match asset and liability durations, we expect this company's interest rate sensitivity to decrease. Second, a higher leverage of a firm causes a stronger impact of term structure changes on equity values for a given mismatch of asset and liability durations, i.e., for the hypothesized case of a positive maturity transformation performed by banks, the presence of shorter-term liabilities reduces (but does not eliminate) the impact of term structure movements on the market value of equity compared to the case of an all equity-financed firm while, in contrast, the typically high leverage of financial institutions reinforces the exposure to interest rates.

4.2 The impact of changing term structures on stock returns

Results for estimating Eq. 4 for the banking, insurance, and non-financial portfolios as well as for the three sub-samples of the banking sector are presented in Table 5 based on the entire sample period 1974–2002 (Panel A) and two sub-periods (Panels B and C). Additionally, we report the contribution of the individual factors to explaining total stock return variability according to Eq. 5.

First let us discuss the results related to the total sample period contained in Panel A. As expected, assuming a positive duration mismatch of assets and liabilities, the sensitivities of financial institutions to changes in level and curvature of the term structure are negative and, with one exception, significantly different from zero. In contrast, financial institutions generally do not show a significant exposure to changes in the slope factor. The single exception is the insurance portfolio which has a positive exposure to this factor, implying that this industry profits from rising short-term rates (for which the slope factor is the most relevant). A possible explanation is that the value of short-term liabilities exceeds the value of short-term assets meaning that, when short-term interest rates rise, losses of the value of the short-term assets are overcompensated by the decrease in value of the corresponding liabilities. We also observe positive sensitivities of regional and mortgage banks to changes in the slope factor. However, these are not significantly different from zero. Contrary to financial institutions, non-financial corporations are only exposed to changes in the level of the term structure and thus especially to changes in long-term rates.[20] While the coefficient to level changes is relatively high, by considering the sum of all three interest rate factor R^2s it becomes evident that interest rates are comparatively less important in explaining total stock return variability of non-financial institutions compared to banks.

Comparing the coefficients of the individual banking portfolios, we find international banks to have by far the highest exposure to changes in the level of the term structure and, hence, to changes in long-term rates. This finding corroborates earlier results by Elyasiani and Mansur (1998) who, based on a sample of US banks, showed that money center and large banks are more sensitive to changes in long-term rates than regional banks. In contrast, the mortgage bank portfolio has a stronger exposure to the curvature factor, which is particularly relevant for medium-term rates. Possibly, this could result from an average maturity of assets of international banks exceeding the one of mortgage banks. Nevertheless, by summing over the interest rate factor R^2s, we find interest rate risk to be almost equally important for international and mortgage banks while regional banks seemingly take on less interest rate risk. Consistent with our expectations, we further observe a much

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[20] Bartram (2002) also finds that German non-financial institutions are more often significantly exposed to changes in long-term rates compared to short-term rates.

Table 5 Sensitivities and variance explained of stock indices: the impact of changes in level, slope, and curvature of the term structure

The table contains the results of the estimation of Eq. 4, $r_{i,t} = \beta_{i,0} + \beta_{i,L}\Delta L_t + \beta_{i,S}\Delta S_t^* + \beta_{i,C}\Delta C_t^* + \beta_{i,M} r_{M,t}^* + \varepsilon_{i,t}$, which is estimated for the total sample period (1974:01–2002:12, panel A), for the sub-period prior to the start of the European Economic and Monetary Union (1974:01–1990:06, panel B) and for the sub-period following the introduction of the Economic and Monetary Union (1990:07–2002:12, panel C) for equally weighted industry portfolios whose returns are denoted by $r_{i,t}$. L_t is the level, S_t the slope and C_t the curvature factor of the German term structure of interest rates at time t which is estimated using the Nelson and Siegel (1987) approach. $r_{m,t}$ is the market factor. Factors marked with an asterisk are orthogonalized. Sensitivities significant at the 10%/5%/1% levels are marked */**/***. Heteroskedasticity and autocorrelation-consistent (Newey and West 1987) t-ratios are presented in parentheses. The last five columns present the percentage contribution of individual factors to explaining total variance (factor R^2, %) as well as total variance explained by all factors collectively (R^2, %). For the kth risk factor, the factor R^2 is estimated as $\hat{\beta}_{i,k}^2$ Var($F_{k,t}$)/Var($r_{i,t}$) as described in Eq. 5, $\text{Var}(r_{i,t}) = \hat{\beta}_{i,L}^2\text{Var}(\Delta L_t) + \hat{\beta}_{i,S}^2\text{Var}(\Delta S_t^*) + \hat{\beta}_{i,C}^2\text{Var}(\Delta C_t^*) + \hat{\beta}_{i,M}^2\text{Var}(r_{M,t}^*) + \text{Var}(\varepsilon_{i,t})$

	$\hat{\beta}_{i,0}$	$\hat{\beta}_{i,L}$	$\hat{\beta}_{i,S}$	$\hat{\beta}_{i,C}$	$\hat{\beta}_{i,M}$	Factor R^2 (%) of				R^2 (%)
						Level	Slope	Curv.	Mkt.	
Panel A: Total sample period (1974:01–2002:12)										
All banks	0.002 (1.509)	−4.449 (−7.727)***	0.081 (0.338)	−0.581 (−3.633)***	0.708 (20.770)***	7.32	0.01	1.19	65.14	73.66
Int'l banks	0.003 (1.596)	−7.344 (−9.735)***	−0.291 (−0.796)	−0.516 (−1.884)*	1.175 (20.735)***	7.08	0.03	0.33	63.86	71.31
Regional banks	0.001 (0.814)	−3.462 (−5.336)***	0.219 (0.741)	−0.254 (−1.358)	0.631 (13.835)***	4.29	0.05	0.22	50.26	54.82
Mortgage banks	0.002 (1.174)	−3.484 (−4.047)***	0.221 (0.658)	−0.833 (−3.720)***	0.496 (11.018)***	5.05	0.06	2.74	36.05	43.90
Insurances	0.006 (2.400)**	−3.274 (−4.651)***	0.876 (2.056)**	−0.553 (−2.735)***	0.897 (12.155)***	2.04	0.44	0.55	53.82	56.85
Non-financials	0.005 (4.324)***	−4.091 (−12.432)***	−0.260 (−1.338)	0.118 (0.981)	1.014 (32.369)***	3.94	0.05	0.03	85.13	89.15
Panel B: Sub-period 1 (1974:01–1990:06)										
All banks	0.004 (2.614)***	−4.155 (−6.477)***	−0.059 (−0.225)	−1.195 (−6.105)***	0.753 (23.194)***	8.30	0.01	5.96	63.08	77.34
Int'l banks	0.004 (2.531)**	−6.370 (−10.008)***	−0.560 (−1.607)	−1.685 (−7.842)***	1.143 (21.009)***	8.68	0.24	5.28	64.77	78.97
Regional banks	0.003 (2.161)**	−3.466 (−6.731)***	0.071 (0.244)	−0.721 (−3.861)***	0.611 (14.697)***	7.27	0.01	2.73	52.33	62.33
Mortgage banks	0.004 (1.896)*	−3.187 (−3.061)***	0.172 (0.431)	−1.220 (−4.142)***	0.613 (11.341)***	4.53	0.05	5.75	38.83	49.15
Insurances	0.011 (3.218)***	−1.720 (−1.996)**	0.643 (1.456)	−0.952 (−4.032)***	1.055 (12.726)***	0.66	0.33	1.76	57.77	60.53
Non-financials	0.007 (6.503)***	−3.084 (−10.188)***	−0.412 (−2.083)**	−0.587 (−4.973)***	0.993 (32.981)***	3.60	0.23	1.13	86.33	91.29

Table 5 continued

	$\hat{\beta}_{i,0}$	$\hat{\beta}_{i,L}$	$\hat{\beta}_{i,S}$	$\hat{\beta}_{i,C}$	$\hat{\beta}_{i,M}$	Factor R^2 (%) of				R^2 (%)
						Level	Slope	Curv.	Mkt.	
Panel C: Sub-period 2 (1990:07–2002:12)										
All banks	−0.001 (−0.471)	−5.256 (−4.359)***	0.561 (0.586)	0.502 (1.729)*	0.662 (12.123)***	6.56	0.09	0.68	63.33	70.67
Int'l banks	0.001 (0.179)	−9.779 (−4.437)***	0.045 (0.027)	1.595 (2.467)**	1.185 (14.118)***	6.47	0.00	1.96	57.87	66.30
Regional banks	−0.001 (−0.501)	−3.536 (−2.021)**	1.213 (0.980)	0.570 (1.463)	0.656 (9.036)***	2.25	0.33	0.67	47.27	50.52
Mortgage banks	−0.001 (−0.544)	−4.310 (−3.307)***	0.089 (0.096)	−0.176 (−0.575)	0.384 (6.173)***	6.72	0.00	0.13	32.44	39.29
Insurances	−0.001 (−0.233)	−7.266 (−5.151)***	0.317 (0.262)	0.058 (0.141)	0.749 (7.683)***	7.44	0.02	0.01	48.21	55.68
Non-financials	0.002 (1.125)	−6.528 (−7.696)***	−0.569 (−0.788)	1.466 (5.490)***	1.060 (19.116)***	4.98	0.05	2.87	80.03	87.92

lower market risk coefficient for mortgage banks suggesting that this group has indeed fewer risks besides interest rate risk to invest in.

Of course, the exposure of a firm to interest rate risk is not necessarily constant over time. For instance, by altering the maturity composition of assets and liabilities or by using interest rate derivatives, the management of a firm potentially influences the sensitivity of the equity value. In this context, we re-estimated the sensitivities to changes in the term structure for two sub-periods. We chose July 1990 to be the breakpoint between the first and the second sub-period, as this month marks the starting point of the European Economic and Monetary Union (EMU) which, due to the intensified cooperation between the member states in terms of freedom of capital transactions, cooperation between central banks, and the free use of the ECU, might have an influence on the volatility of the term structure and thus on interest rate risk.[21] The results are reported in Panel B and C of Table 5.

Our results for the first sub-period largely confirm the findings already discussed: Again, all financial institutions display a negative sensitivity to changes in the level and the curvature of the term structure. Now, all are significantly different from zero. Also the sensitivities to changes in the slope factor are similar. Some differences are observed with respect to the insurance and the non-financials portfolio. First, insurances appear to be quite well hedged to term structure changes. The sensitivity to level changes is much lower compared to the estimate for the total sample period and the sensitivity to slope changes, which was significantly different from zero in the case of the total sample period, is insignificant in this case. Second, the non-financials portfolio behaves as if it were an all equity-financed bond portfolio since it is significantly exposed to changes in any of the relevant factors. However, in terms of total variance explained by the interest rate factors, one finds again that interest rate risk is apparently less important for non-financials compared to banks.

The most striking difference between the first and the second sub-period relates to the sensitivity to curvature changes. While all industries displayed a negative and significant exposure to this factor in the first sub-period, sensitivities were strongly reduced and, in all but one case, even shifted to a positive exposure during the second sub-period. This observation is coupled with a moderate (absolute) increase in the sensitivity to level changes in the case of banks and a strong increase in the case of the insurances. At the same time, one observes the average slope of the term structure of interest rates to decrease: While the mean of the slope factor (times -1) during the first sub-period is 197 bp, it is reduced to 172 bp during the second sub-period. Thus, if a bank performs maturity transformation and attempts to maintain the same spread between short-term (passive) and long-term (active) rates, it has to lengthen its asset duration in the second sub-period, which would help explain the observed shift from curvature to level exposure. Nevertheless, the overall importance of interest rate risk in explaining bank stock return variability decreased from the first to the second sub-period. This is possibly a consequence of an increasing availability of more elaborate interest rate risk management tools over time as suggested by Maher (1997) for the case of US banks. This observation, however, neither includes insurances nor non-financials, since the percentage of total variance explained by interest rates rose for both sectors.

[21] See Levitt and Lord (2000) for a detailed discussion of this issue. In effect, there were three stages (1990:07–1993:12, 1994:01–1998:12, and the final stage starting in 1999:01) to the Economic and Monetary Union. We repeated the analysis for each of these shorter sub-periods and found additional evidence of time-varying interest rate sensitivities. In particular, during two of these shorter sub-periods, the curvature is the most important interest rate factor in explaining the variance of the stock returns, while for the sub-period 1990–2002 the level factor ranks first.

With respect to our second introductory question, we can summarize the results of this Section as follows: We strongly confirm a sensitivity of German financial institutions to changes in level and curvature of the term structure. While this evidence is less clear-cut for the slope factor, we still document some occasions where sensitivities to this factor are significantly different from zero as well. Additionally, we document that the interest rate risk of German financial institutions relates to their principal business activity. Furthermore, there is evidence of time-varying interest rate sensitivity.

5 Estimation of interest rate risk premia in the German equity market

As stated by Chen et al. (1986), among others, only general economic state variables are expected to have an influence on expected asset prices since only these variables will potentially carry an ex-ante risk premium in order to persuade investors to risk exposure to them. Following this argument, variables will need to have a systematic (i.e., market-wide) influence on either future dividends or discount rates to qualify for being general economic state variables. In this respect, the authors further state that "(t)he discount rate (…) changes with both the level of rates and the term-structure spreads across different maturities. Unanticipated changes in the riskless interest rate will therefore influence pricing (…)".[22]

In view of this reasoning, we hypothesize level, slope, and curvature to have a systematic influence on equity prices. By analyzing the pricing of all three factors, we seek to elaborate on previous studies on the pricing of interest rate risk that have mostly focussed on changes of a single interest rate as interest rate risk factor.[23] The system of equations as described in (8) will be specified as follows:

$$\mathbf{r}_t = \mathbf{b}_L\left(\lambda_L + \Delta L_t^0\right) + \mathbf{b}_S\left(\lambda_S + \Delta S_t^{*,0}\right) + \mathbf{b}_C\left(\lambda_C + \Delta C_t^{*,0}\right) + \mathbf{b}_M\left(\lambda_M + r_{M,t}^{*,0}\right) + \boldsymbol{\varepsilon}_t \qquad (10)$$

$\mathbf{r}_t$ is an n-vector containing the cross-section of excess returns of n assets at time t. Each $\mathbf{b}_K$ is one column of the $(n \times k)$ matrix $\mathbf{B}$ from (8) containing the n sensitivities to the kth factor. λ_k is the risk premium of factor k. The time series of the explanatory factors (contained in the k-vector $\mathbf{f}_t$ in (8) above) are defined as before in Eq. 4. The only exception is that, following Ferson and Harvey (1994) and Oertmann et al. (2000), we use demeaned time series (marked with the superscript 0) in order to secure the zero-mean condition for the explanatory variables, $E(\mathbf{f}_t) = 0$, of Eq. 6 above. To this end, the sample mean of each explanatory time series is subtracted prior to the estimation. Since we use first differences of the Nelson–Siegel factors where the mean values are already very close to zero, this has practically no consequences for their time series. Nevertheless, we need to assume that the factor risk premia are not in any way related to the sample means.

Following Ferson and Harvey (1994), we estimate (10) as a seemingly unrelated regression model via Hansen's (1982) generalized method of moments. This approach has also been used by, e.g., Oertmann et al. (2000) and Tai (2000). There are several advantages in using this method. First, the covariance matrix of the residuals is allowed to be non-diagonal, thereby increasing the efficiency of the estimators. Second, by simultaneously estimating both factor sensitivities and risk premia, we avoid the errors-in-variables (EIV) problem that occurs if estimated betas are used in the second step of a

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[22] Chen et al. (1986, p. 385).

[23] See, e.g., Sweeney and Warga (1986), Yourougou (1990), Choi et al. (1992), Oertmann et al. (2000), and Staikouras (2005).

Fama and MacBeth (1973)-type regression to estimate the risk premia; and third, we do not assume that the error terms are homoskedastic or normally distributed. It is necessary to assume that the time series of both the dependent as well as the independent variables of our model are generated by strictly stationary and at least ergodic processes. An examination of the first differences of the Nelson–Siegel factors in Table 1 reveals that for all time series the null hypothesis of non-stationarity is strongly rejected. Autocorrelation is also not an issue, which means that single observations of the time series should be sufficiently independent as to not violate the ergodicity property.[24] Ferson and Foerster (1994) show that an iterative version of Hansen's (1982) generalized method of moments might lead to improved finite sample properties and is therefore employed to estimate the system (10).[25] We use the contemporaneous values of the explanatory variables and a T-vector of ones as instruments to generate the orthogonality conditions, where T is the length of the sample under investigation.

We follow Oertmann et al. (2000) in applying (10) to stock returns of individual companies instead of portfolio returns in order to maximize the information contained in the cross-section where all those corporations listed in Appendix 1 are included in our sample that have complete data over the sample period.[26]

Table 6 shows the estimation results of Eq. 10 for the periods already examined in the last section. The two right-hand columns contain the GMM J-statistic (times the sample length T), which is asymptotically distributed χ^2 with 28 degrees of freedom and the respective p-value. The reported values do not indicate any violations of the underlying assumptions. Therefore, we assume that our model specification can be validly applied.

The risk premium on the level factor, $\hat{\lambda}_L$, comes out as positive and significantly different from zero for the total sample period as well as for the first sub-period, while it is marginally negative and insignificant for the second sub-period. The significance of this risk premium in two out of three cases underlines our conjecture from Section 4 that this factor is indeed a systematic risk factor since (almost) all industries considered constantly displayed a significant sensitivity to level changes.

Similarly, we continually observe that the risk premium on the curvature factor, $\hat{\lambda}_C$, is significantly different from zero. The risk premium decreases in absolute terms and also changes its sign from the first to the second sub-period which is consistent with the change in sign of the curvature sensitivities described in the previous section. Possibly, the previously observed shift from a curvature exposure to a more pronounced level exposure from the first to the second sub-period might be related to the fact that curvature risk earned a lesser reward in the latter period.

In contrast, evidence for the existence of a risk premium on the slope factor, $\hat{\lambda}_S$, is more mixed as we document a risk premium significantly different from zero for the second sub-period only. Hence, the slope factor seemingly does not qualify, at least not constantly, as a general economic state variable. In order to interpret this result we need to consider that the slope factor is especially relevant for short-term rates. In view of the discounted dividend argument by Chen et al. (1986), it becomes evident that the slope factor will only influence

[24] Tests not shown here confirm these results for the time series of stock returns as well.

[25] We conduct a preliminary Fama and MacBeth (1973)-type regression to initialize the iteration process. Results are unaffected by a repeated iteration.

[26] Of course, this selection is subject to survivorship bias but, in this context, this bias is unavoidable since it is a necessary condition of the employed simultaneous estimation approach that all time series have the same number of observations. For further arguments in favor of applying a survivorship biased sample in this context see Prasad and Rajan (1995).

Table 6 Risk premium estimates

The table contains the estimated monthly risk premia (%) of a cross-section of German stocks which are estimated via the pooled cross-section/time series model (10), $\mathbf{r}_t = \mathbf{b}_L\left(\lambda_L + \Delta L_t^0\right) + \mathbf{b}_S\left(\lambda_S + \Delta S_t^{*,0}\right) + \mathbf{b}_C\left(\lambda_C + \Delta C_t^{*,0}\right) + \mathbf{b}_M\left(\lambda_M + r_{M,t}^{*,0}\right) + \boldsymbol{\varepsilon}_t$, employing iterated GMM. r_t denotes a vector containing the stock returns of the sample asset at time t. L_t is the level, S_t the slope and C_t the curvature factor of the German term structure of interest rates at time t which is estimated using the Nelson and Siegel (1987) approach. $r_{M,t}$ is the market factor. λ_L, λ_S, λ_C and λ_M denote the risk premia of the level, the slope, the curvature and the market factor, respectively. Factors marked with an asterisk are orthogonalized and the superscript 0 denotes a demeaned time-series. The investigated periods are the total sample period (1974:01–2002:12), the sub-period prior to the start of the European Economic and Monetary Union (1974:01–1990:06) and the sub-period following the introduction of the Economic and Monetary Union (1990:07–2002:12). The time series of the explanatory variables and a vector of ones are used as instruments. Heteroskedasticity and autocorrelation-consistent standard errors (Newey and West 1987) are presented in parentheses. */**/*** denotes significance at the 10%/5%/1% levels. The J-statistic is the target function of the GMM estimation. $TJ \sim \chi^2$ with 28 df where T is the number of observations in the sample

Period	Risk premium (%/month)				GMM statistics	
	$\hat{\lambda}_L$ (Level)	$\hat{\lambda}_S$ (Slope)	$\hat{\lambda}_C$ (Curvature)	$\hat{\lambda}_M$ (Res.-Mkt.)	TJ	(p-Value)
1974:01–2002:12	0.466 (3.291)***	0.029 (0.269)	−0.669 (−2.727)***	2.571 (4.144)***	15.801	(0.969)
1974:01–1990:06	0.871 (2.416)**	−0.173 (−0.923)	−1.210 (−3.040)***	2.478 (2.861)***	12.125	(0.996)
1990:07–2002:12	−0.027 (−1.114)	0.102 (3.287)***	0.245 (3.019)***	0.232 (1.007)	18.479	(0.913)

dividends paid in the near future, where the discount factor has a low influence on present values compared to longer-term maturities. The vast majority of an equities' market price is determined by dividends paid far in the future where the discount factor is mainly governed by the level and possibly by the curvature factor.

As expected, the risk premium on the residual market factor, $\hat{\lambda}_M$, turns out to be positive, but not significant during the second sub-period. However, one can not compare the estimate of this premium to "traditional" estimates of the equity risk premium since it presents an estimate of the compensation to investors for market risk, once all interest rate risk has already been accounted for.

The analysis of this section shows that, at least, the level and the curvature factor exert a systematic influence on the German equity market since they are generally priced in an APT context. With respect to the slope factor, we only find evidence of a significant risk premium during the second sub-period. Hence, for the level and the curvature factor, our third introductory question regarding the systematic influence of term structure changes on stock returns can be predominantly answered in the affirmative.

6 Summary and outlook

This study investigates the interest rate risk of German financial and non-financial corporations as measured by the sensitivities of their stock returns to changes in level, slope, and curvature of the German term structure of interest rates. We employ the Nelson and Siegel (1987) approach in order to model these movements in the term structure. The period under investigation is 1974–2002.

To demonstrate the potential error resulting from using the common two-factor approach by Stone (1974) to quantify the interest rate risk implicit in stock returns, we apply a multi-factor model to returns of German government bond indices with varying maturity classes using different specifications of a single or multiple interest rate factors. An investigation of the variance of these indices explained by the respective interest rate factors has shown that the common approach suggested by Stone (1974) might lead to an underestimation of the influence of term structure movements on stock returns, depending on the specification of the interest rate factor employed. In contrast, our extended version of Stone's model using the Nelson–Siegel factors as interest rate factors consistently explained more than 90% of the variance of the investigated bond index returns. Therefore, given the uncertainty related to the maturity structure of balance sheets of financial institutions and, thus, to the choice of a suitable interest rate factor, we suggest using the extended factor model to investigate the interest rate risk of financial institutions.

We then apply the extended factor model to indices covering the German banking industry, the insurance sector, and a selection of non-financial companies. The level factor is found to be the single most important interest rate factor explaining the variance of the stock returns of financial institutions. In this respect, the curvature factor ranks second. We document that, over time, financial institutions show an increased exposure to the level factor while their curvature exposure is reduced. Both changes coincide with a decrease in the average slope of the term structure. Hence, assuming banks to target a certain spread between short-term (passive) and long-term (active) rates, it is consistent to find a more pronounced level of sensitivity under these circumstances. In contrast to the level and the curvature factor, the slope factor seems to have only minor importance for German financial institutions.

Overall, in terms of stock return variability attributable to interest rate risks, we find that banks reduced their interest rate risk exposure over time which goes along with an increased availability of interest rate risk management tools. However, we find insurance companies to show an increased interest rate risk position over time. With respect to differences within the banking industry, we find international and mortgage banks to have higher interest rate risk compared to regional banks. In the case of mortgage banks, the German banking law did not allow these banks to diversify into activities other than lending and borrowing, which explains the relevance of interest rate risks for these banks. In contrast, due to their size, international banks might have a better access to global capital and particularly to derivatives markets. Possibly, as suggested by Hirtle (1997), these firms do not use derivatives to hedge their interest rate exposure but, much to the contrary, to even increase it.

Risk factors having a systematic influence on asset prices should be compensated by risk premia. Therefore, we investigate whether changes in level, slope, and curvature do indeed qualify for being general economic state variables. The level and the curvature factor mostly exhibit a significant risk premium while in the case of the slope factor this is only true for the second sub-period. Combined with our results concerning the sensitivity of financial institutions to changes in the term structure, our findings suggest that, generally, an exposure to (at least) level and curvature changes will directly affect the cost of capital of firms.

Finally, we want to highlight possible applications for this proposed extended version of the model by Stone (1974) and suggest directions for further research. In the context of asset allocation and portfolio management, Leibowitz (1986) emphasized the relevance of equity durations, especially when bonds and stocks are managed simultaneously. However, while the author ultimately relied on the sensitivity to changes in the ten-year rate only, our approach allows one to address explicitly the sensitivity of stock returns to changes in the entire shape of the term structure.

Second, with respect to risk management, this extended version of Stone's model can be applied to control the interest rate risk exposure of equity portfolios. For bond portfolios, Willner (1996) and Diebold et al. (2006) showed that hedging the exposure to changes in level, slope, and curvature of the term structure is superior to classical duration hedging. However, while the sensitivities of bonds to changes in the Nelson–Siegel factors can be calculated analytically, this is not the case for stock returns. In the latter case, the proposed four-factor model enables one to determine empirically the sensitivities of stock returns to changes in the shape of the term structure.

Finally, the recent studies by Dolan (1999), Fabozzi et al. (2005), and Diebold and Li (2006) have demonstrated the superior performance of interest rate forecasts based on the Nelson–Siegel model. Thus, given the more pronounced sensitivity of financial institutions to interest rates and assuming (at least for the near future) similar sensitivities, our approach might offer interesting applications in forecasting the reaction of financial institutions' stock returns to predicted changes in level, slope, and curvature of the term structure.

Altogether, our results suggest that changes in the shape of the entire term structure of interest rates should be considered in the context of asset allocation, hedging, and forecasting. While this finding has been recognized in fixed income management, we suggest its application for equities as well.

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Appendix 1: Sample companies

Corporation	Corporation
International Banks	*Insurances (cont'd)*
Bayerische Hypotheken- und Wechselbank	Münchener Rück
Commerzbank	Nordstern Allgemeine Versicherung
Dresdner Bank	Nürnberger Beteiligungs AG
Deutsche Bank	Thuringia Versicherung
HypoVereinsbank	Vereinte Versicherungen
	Volksfürsorge Holding
Regional Banks	Württembergische Lebensversicherungen
Baden-Württembergische Bank	
Berliner Bankgesellschaft	*Non-Financials*
Comdirect Bank	Adidas-Salomon
Direktanlagebank	Altana
DSL Bank	Babcock Borsig
DVB Bank	BASF
HSBC Trinkaus & Burkhardt	Bayer
IKB Deutsche Industriebank	BMW
ING BHF Bank	Continental
Merkur Bank	DaimlerChrysler
Oldenburgische Landesbank	Degussa
Vereins- und Westbank	Deutsche Börse
	Deutsche Lufthansa
Mortgage Banks	Deutsche Post
Aareal Bank	Deutsche Telekom
Allgemeine Hypothekenbank Rheinboden	E.ON
Berlin Hannoversche Hypothekenbank	Epcos
BHW	FPB Holding
Depfa	Fresenius Medical Care
Deutsche Hypothekenbank Hannover	Henkel
Eurohypo	Hoechst
Nürnberger Hypothekenbank	Infineon Technologies
Rheinhyp Rheinische Hypothekenbank	Karstadt Quelle
Württembergische Hypothekenbank	Kaufhof Holding
Wüstenrot & Württembergische	Linde
	MAN
Insurances	Mannesmann
Aachener und Münchener Lebensversicherung	MLP
AMB Generali Holding	Metallgesellschaft
Allianz Holding	Metro
Allianz Lebensversicherung	Nixdorf
AXA Konzern	RWE
AXA Leben	SAP
Berliner Lebensversicherung	Schering
DBV Winterthur	Siemens
Ergo Versicherungsgruppe	ThyssenKrupp
Gerling	TUI
Hannover Rück	Viag
Kölnische Rückversicherungsgesellschaft	Volkswagen
Mannheimer Holding	

Note: Companies with name changes during the sample period only appear under the most recent name

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