Decomposing the relationship between international bond markets

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1. Introduction

The correlations between major asset classes are of concern and interest to monetary authorities and financial regulators alike – the potential for a worldwide decline in consumption which might result from a dramatic fall in equity market wealth could have serious implications for both the health of financial institutions and that of the real economy. This concern is reflected in the academic literature, where an increasing number of researchers have tried to understand the characteristics of these linkages and the nature of the processes by which information flows between markets. Perhaps the main catalyst for this concern in recent years was the equity market crash of October 1987. This event more than any other highlighted the high levels of correlation between national equity markets at times of extreme market stress.

However, of equal importance is the relationship between international bond markets. Typically, monetary authorities are able to influence directly only the very short end of the term structure. Nevertheless, given that the long bond rate is determined by expectations about future short-term real interest rates and inflation, a credible monetary policy should trigger a transmission mechanism through which monetary policy actions are passed through to the whole of the term structure. As the covariation between government bond rates in different countries increases, the ability of monetary authorities to influence the term structure may decline, and hence their ability to control domestic inflation may also decline.

Correlation between bond markets may arise through a number of channels, for example: if there is a world price of risk; if real rates are determined by global factors; or if there is a “flight to quality” in times of financial stress. Unconditional measures of the correlations between major international bond markets showed that the linkages between these markets increased from the 1960s until the early 1980s, but, according to Solnik et al. (1996) and Christiansen and Pigott (1997), these correlations have not exhibited a clear trend since this time. However, while simple unconditional, rolling measures of international bond market correlations may not have been trending up in recent times, the question of how much control monetary authorities can bring to bear upon the shape of the yield curve through changes in short rates still remains. Another issue relates to the extent (in terms of duration and magnitude) to which the slope of the yield curve is influenced by international factors during periods of financial crisis. Finally, another important and related issue is the extent to which comovements in long bond rates, or indeed the components of these comovements, change during periods of financial market stress. This paper addresses all of these issues.

Using the intuition from the rational expectations hypothesis of the term structure (REHTS), we decompose the long bond rates of Germany, the United Kingdom and the United States into their respective “fundamental” and risk premium components.[2] The decomposition is achieved by using the

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[2] Our technique does not allow us to distinguish between more permanent risk premium components and temporary contagion effects. However, for expositional simplicity we use the term risk premium in this paper to mean some combination of the two.

Campbell and Shiller (1987) VAR methodology. Each VAR which we estimate contains both domestic and foreign conditioning variables, which means that we can separate that portion of the variance of the slope of the yield curve which is influenced by domestic factors from that portion which is driven by international factors. We then turn our attention to calculating a conditional measure of international bond market covariation, decomposing this measure into its fundamental and risk premia components, by invoking the REHTS. We extend our analysis to consider the relationships between sterling and US dollar swap markets, a relationship which to our knowledge has not been considered in this context by previous researchers. Finally, because we estimate each of the VARs on a rolling basis, we can monitor the time variation in both the variance and the covariance decompositions.

Our results suggest that there have been periods associated with financial market crises when the slopes of the government yield curves studied here are determined more by international than by domestic factors, for example during the sterling exchange rate crisis of 1992. However, our evidence suggests in general that once the crisis has passed, the yield curves become dominated by domestic factors once again. With respect to the covariance between bond yields, we find that while the total covariance between the markets is fairly stable over time, the components of this covariance can vary considerably over time. The rest of the paper is organised as follows: in Section 2 we briefly outline relevant academic literature on the topic of financial market linkages; in Section 3 we describe our methodology; in Section 4 we present the data used here; in Section 5 we present our results; and finally, Section 6 concludes the paper.

2. Brief literature review

One of the main spurs to research into financial market linkages was the October 1987 stock market crash. Koutmos and Booth (1995) (amongst others) find evidence to suggest that interdependencies between the world's three major stock markets – London, New York and Tokyo – increased after the 1987 crash. This apparent increase in the linkages between national equity markets could be due to the globalisation of finance, and hence to an increase in the presence of "international investors". Alternatively, volatility transmission could be the result of contagion, as proposed by King and Wadhwani (1990), where, for example, agents do not assess the economic implications of news from an overseas market for their own and simply respond by "shooting first and asking questions later" (see Shiller et al. (1991)).

While some early studies of the informational linkages between markets investigated the interdependencies between conditional first moments (see, for example, Eun and Shim (1989), King and Wadhwani (1990) or Koch and Koch (1991)), more recent studies have focused upon the relationships between conditional first and second moments. Engle et al. (1990) examine the phenomenon of volatility clustering in foreign exchange markets, making the distinction between what they term to be "heat wave" and "meteor shower" effects: the former referring to volatility which is not transmitted to other markets, the latter referring to volatility which is transferred between markets. The Engle et al. study finds more evidence for meteor shower than for heat wave behaviour in the foreign exchange data in their study. Using daily data on London, New York and Tokyo stock indices, Koutmos and Booth (1995) estimate a multivariate E-GARCH model to test for spillover effects between the conditional first and second moments of returns in these markets. While they find clear evidence of such spillovers, they also find that the volatility transmission is asymmetric, with negative shocks from one market having a larger impact upon the volatility of another market than equivalent positive shocks. Following King and Wadhwani (1990), other studies have couched the volatility transmission issue as a signal extraction problem, where agents in the local market have to extract from any news event that portion of the news which is relevant to their market. For example, Lin et al. (1994) decompose return surprises from one market into its global and local components using Kalman filtering techniques.

An alternative approach to the analysis of the relationship between national equity markets can be found in Ammer and Mei (1996), who use a variant of the Campbell and Shiller (1987) variance decomposition for equities to analyse the relationship between US and UK stock returns. From 1957 to 1989 they find that there was an increase in the correlation both between expected dividends and between risk premiums in these two countries, but that these correlations have changed little since 1989.

Finally, some researchers have also considered the relationship between bond and stock markets. Shiller and Beltratti (1992) and Campbell and Ammer (1993) investigate the relationship between bond and stock markets using the VAR approach of Campbell and Shiller (1987) to decompose asset returns. Shiller and Beltratti find that the negative relationship observed between real stock prices and long-term interest rates is much bigger in magnitude compared to the relationship implied by the simple rational expectations present value model. Using a similar VAR decomposition for US data, Campbell and Ammer (1993) find that stock returns are driven mainly by news about future stock returns, while bond returns are predominantly driven by inflation, thus explaining the low correlation between the returns on these two long-term assets.

To our knowledge, far fewer researchers have investigated the relationships between international bond markets (for an exception to this general rule, see Dahlquist et al. (1999)). The purpose of this paper, then, is to add to the literature on financial market linkages by considering the links between fixed income markets.

3. Methodology

3.1 Structural decomposition of bond market covariation

We begin by outlining a decomposition of the covariation between long-term bond rates. To achieve this more structural approach to the linkages between international bond markets, we make use of the REHTS. In its original form the REHTS defines current long-term interest rates as an average of expected future short-term rates plus a constant risk premium. Given the overwhelming empirical evidence against the pure expectations hypothesis, we adopt a more general version of the REHTS that allows for a time-varying, risk premium (see Evans and Lewis (1994)). For pure discount bonds we can write:

(1) $$R_{k,t} = R^{e}_{k,t} + RP_{k,t}$$

where $R_{k,t}$ is the yield on a k-maturity pure discount bond and $RP_{k,t}$ is the risk premium at time t associated with buying a long bond relative to rolling over one-period bonds. $R^{e}_{k,t}$ is the theoretical k-maturity rate according to the expectations hypothesis given by:

(2) $$R^{e}_{k,t} = \frac{1}{k}\sum_{i=0}^{k-1} E_t r_{1,t+i}$$

where E_t denotes the market's expectations conditional upon information available at time t and $r_{1,t+i}$ is the one-period rate at time $t+i$.

Similarly we can define foreign bond rates as:

(3) $$R^{*}_{k,t} = R^{e*}_{k,t} + RP^{*}_{k,t}$$

Given equations (1) and (3), the covariance between domestic and foreign interest rates can be written as:

(4) $$\begin{aligned} Cov(R,R^{*}) &= Cov(R^{e} + RP, R^{e*} + RP^{*}) \\ &= Cov(R^{e},R^{e*}) + Cov(R^{e},RP^{*}) + Cov(RP,R^{e*}) + Cov(RP,RP^{*}) \end{aligned}$$

How can we interpret these components? The first component in expression (4) measures that part of the covariation between two bond markets which can be attributed to the covariation in investors' expectations about future short-term interest rates in the two countries. Given that these expectations will reflect considerations about the future path of inflation, real interest rates and the monetary policy stance in each country, we assume that this component reflects the part of the total covariation due to "economic fundamentals" between the two economies. If the two economies track each other through the business cycle, we might expect the links between the two bond markets to be quite strong. The remaining components are a direct result of our use of the REHTS. In the absence of a bond market risk premium the fully anticipated rational expectation of the long rate will equal the actual long rate. We can therefore interpret the difference between R_k and R_k^e as the risk premium required for holding government bonds, *RP*. The second (third) component then represents the covariation between domestic (foreign) fundamentals and the foreign (domestic) interest rate risk premium. Finally, the fourth component measures the covariation between domestic and foreign risk premia.

3.2 Generating expectations of future long rates

One difficulty in calculating the covariance decomposition given by expression (4) is that none of the long-term interest rate components are directly observable. Since the components of expression (4) depend upon long-horizon expectations of short-term interest rates, we need some way to condition these expectations. To this end we use the vector autoregression (VAR) methodology to calculate multiperiod expectations of the long rate (see Campbell and Shiller (1987)).[3]

Having chosen this VAR methodology, the next issue relates to the choice of conditioning variables. Campbell and Shiller (1987) use a two-dimensional vector of state variables, which includes the changes in the short rate and the slope of the term structure, in undertaking this exercise using US data. An assumption inherent in such a formulation is that investors' expectations about future short-term rates are affected only by information concerning domestic fundamentals as reflected in the short rate and the slope of the term structure. However, since the aim of this paper is to investigate the linkages between national bond markets, we condition expectations about future long rates on both domestic and international measures of the short rate and the slope of the term structure. Our intention then is to formulate a VAR using information from the bond markets of Germany, the United Kingdom and the United States in such a way that interest rate expectations are jointly determined, thus allowing for possible interactions between domestic and international fundamentals. In order to achieve this interaction, we expand the information set to include information on three different term structures.[4] As a result the vector of state variables is defined as:

(5) $$z_t = [\Delta r_{1year,t}, \Delta r^{*}{}_{1year,t}, \Delta r^{**}_{1year,t}, Slope_t, Slope_t^{*}, Slope_t^{**}]'$$

where the superscripts * and ** relate to the first and second "foreign" markets respectively.

Having chosen the information set, we can follow Campbell and Shiller (1987) and define the theoretical slope of the term structure under the expectations hypothesis, $s_{k,t}^e$, as:

(6) $$s_{k,t}^e = R_{k,t}^e - r_{1,t}$$

Substituting (2) into (5), we get:

(7) $$s_{k,t}^e = \frac{1}{k}\sum_{i=1}^{k-1}(k-i)E_t(\Delta r_{1,t+i+1})$$

where Δ denotes the one-period backward difference operator defined as $\Delta r_{1,t+i+1} = r_{1,t+i+1} - r_{1,t+i}$.

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3 For a more detailed discussion on alternative methodologies used to evaluate multiperiod expectations of unobserved variables and their shortcomings relative to the VAR approach, see Campbell and Ammer (1993).

4 The number of countries included in the vector of state variables is limited only by data availability.

Similar expressions to (6) and (7) hold for $s_{k,t}^{e*}$ and $s_{k,t}^{e**}$.

To estimate the expectations of future short-rate changes, we assume that the vector of state variables defined by (5) follows a first-order VAR process:

(8) $$z_t = \mathbf{A} z_{t-1} + w_t$$

where z_t is the vector of state variables given by (5), **A** is the matrix of the VAR coefficients and w_t is the vector of residuals. By including the interest rate changes rather than the levels, we ensure stationarity in the VAR. Furthermore, for reasons of notational simplicity and computational convenience, we demean the variables before including them in the VAR. Finally, we note that the assumption of the first-order VAR process is not restrictive.[5]

Based on this formulation, the long-horizon expectations of changes in one-period interest rates *j*-periods in the future, *j*=1,...,*k*-1, can be estimated by:

(9) $$E_t(\Delta r_{1,t+j}) = \mathbf{h_1^T} \mathbf{A}^j \mathbf{z_t}$$

(10) $$E_t(\Delta r_{1,t+j}^{*}) = \mathbf{h_2^T} \mathbf{A}^j \mathbf{z_t}$$ and

(11) $$E_t(\Delta r_{1,t+j}^{**}) = \mathbf{h_3^T} \mathbf{A}^j \mathbf{z_t}$$

where $\mathbf{h_1^T} = [1,0,0,0,...]$, $\mathbf{h_2^T} = [0,1,0,0,...]$ and $\mathbf{h_3^T} = [0,0,1,0,...]$ are used to pick out the first, second and third element of the state vector.

Once the matrix **A** of VAR coefficients is estimated then for each *t*, *t*=1,...,*T*, the expectations of future changes in interest rates can be generated using expressions (9), (10) and (11), and the theoretical term structure slopes by using expression (7). We can calculate the theoretical long-term interest rate by solving (6) with respect to $R_{k,t}^{e}$. The differences between the theoretical and actual long-term rates provide an estimate of the domestic and foreign bond market risk premium, $RP_{k,t}$. Estimates of $R_{k,t}^{e*}$, $RP_{k,t}^{*}$ and $R_{k,t}^{e**}$, $RP_{k,t}^{**}$ are produced by a similar procedure.[6] Given the estimated theoretical long rates and the risk premia, then, for each pair of countries, components of the covariance between actual interest rates can be calculated according to expression (4).

Our intention is not only to identify the covariance components and the importance of domestic and international factors in determining interest rates, but also to examine how these derived variables vary over our sample period. To capture this effect, we adopt a rolling estimation procedure where the VAR described above is estimated using one year's worth of data. We then roll forward the estimation window by one week and repeat the procedure outlined above until the end of the sample period. By doing this, we can generate a time series of the components of expression (4).

Finally, the estimation of a VAR allows us to decompose the variance of the slopes of both the domestic and foreign term spreads, a procedure which is now common practice in papers using unrestricted VARs of the kind used here (see Sims (1980) for a description of the technique). The variance decomposition provides us with an estimate of the proportion of the movement in one variable which can be attributed to shocks in other variables in the VAR. Since we estimate the VARs on a rolling basis, we also create a time series of this variance decomposition allowing us, for example, to gauge the time-varying impact of shocks to overseas interest rates on the slope of the UK yield curve.

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[5] Campbell and Shiller (1988) demonstrate that it is straightforward to modify the model to allow for a higher VAR order.

[6] These estimates of the risk premia will be accurate provided that we include in our model all the relevant information that investors use to form their expectations about future interest rates and that the dynamics of the VAR are correctly specified. If these conditions are not met, estimates of risk premia will be biased upwards.

3.3 Extending the analysis to interest rate swaps

Interest rate swaps are contracts which allow two counterparties to exchange fixed for floating interest rate payments. The fixed rate of the swap is usually defined as the rate of the underlying government bond plus a mark-up, known as the spread. This spread is often used to make inferences about default risk in an economy, e.g. the sterling (US dollar) swap spread is often used in the financial press as a measure of default risk in the United Kingdom (United States). It is possible to extend the VAR methodology to investigate the importance of domestic versus foreign factors in determining the size of the swap spread, enabling us, for example, to trace the time path of the apparent credit crunch which affected interest rate swap markets after the recent Russian debt crisis. The main aim of this analysis is to identify periods where conditions in international swap markets override domestic factors as the driving force of swap spreads. During these periods the interpretation of the spread as an indicator of aggregate domestic default risk[7] may be misleading.

Previous research (see, for example, Sun et al. (1993) or Minton (1997)) has shown that long-term swap spreads are affected by changes in the slope of the term structure. Hence, we can define the following vector of state variables:

$$z_t = [\Delta r_{1year,t}, \Delta r^*_{1year,t}, Slope_t, Slope^*_t, swap\ spread_t, swap\ spread^*_t]' \qquad (12)$$

The analysis of swap spreads has been limited to only two countries purely due to data availability, as discussed in the following section. Using the vector of state variables given in expression (12), we can again calculate the rolling variance decomposition, as outlined in Section 3.2.

4. Data

4.1 Data description

We estimate the VARs using weekly one- and 10-year US, UK and German interest rates. These are zero coupon interest rates estimated from the prices of coupon-paying government bonds using the

Table 1
Descriptive statistics

Rates	From	To	No. obs.	Mean	St. dev.	Min.	Max.
US interest rates							
1-year	15 August 1990	8 August 1999	456	5.23	1.07	3.13	7.99
10-year	15 August 1990	8 August 1999	456	6.64	0.94	4.55	8.90
Slope	15 August 1990	8 August 1999	456	1.42	1.01	0.04	3.63
UK interest rates							
1-year	15 August 1990	8 August 1999	456	7.06	1.93	4.71	13.37
10-year	15 August 1990	8 August 1999	456	7.71	1.62	4.16	11.62
Slope	15 August 1990	8 August 1999	456	0.66	1.30	–1.87	3.10
German interest rates							
1-year	9 October 1991	8 August 1999	408	5.01	1.91	2.55	10.68
10-year	9 October 1991	8 August 1999	408	6.33	1.15	3.77	8.53
Slope	9 October 1991	8 August 1999	408	1.33	1.36	–1.87	3.54
UK swap spreads							
10-year	15 August 1990	8 August 1999	456	0.38	0.20	0.00	1.05
US swap spreads							
10-year	15 August 1990	8 August 1999	456	0.36	0.16	0.10	0.89

[7] See, for example, "Swap spreads show a new aversion to risk", *Financial Times*, 10 August 1999, p. 24.

Svensson methodology (Svensson (1994, 1995)).[8] The zero coupon data available for the three countries begin on different dates: from January 1979 for the United Kingdom, from August 1990 for the United States and from October 1991 for Germany.[9] Given that the VARs are jointly estimated for three countries at a time, the estimation period for each VAR is set equal to the period over which overlapping data between the three countries are available. Descriptive statistics for the data used are given in Table 1.

In addition, we extend our analysis to interest rate swap spreads. Only sterling and US dollar swap rates were available to us for a sufficient span of time. The swap data span the period from August 1990 to August 1999. From zero coupon swap rates[10] we subtract the equivalent maturity zero-coupon interest rate estimated from the appropriate Svensson yield curve to provide estimates of the sterling and dollar swap spreads.

5. Results

We now present the results relating to various versions of the VAR outlined in Section 4 above. This VAR is estimated using government bond market data for Germany, the United Kingdom and the United States. We also estimate the VAR given in expression (12) using swap market data. We begin by discussing the results of the variance decompositions of these VARs and then move on to discuss the decomposition of the covariance.

5.1 Variance decomposition results

5.1.1 Government bond market results

In Figure 1 we present the variance decomposition for the slope of the US yield curve, based upon a VAR which includes German, UK and US variables. The figure reports the proportion of the variance of the slope of the term structure that can be attributed to shocks in the variables of the VAR, 26 weeks into the future.[11] One known shortcoming of the VAR methodology is that the variance decomposition results may be influenced by the ordering of the variables in the VAR. In our VAR the first variable in the state vector is the change in short-term US interest rates, followed by the change in German and then UK short-term rates, which are followed in turn by the slopes of the US, German and UK yield curves. The raison d'être for this ordering is that shocks to short-term rates should affect the slopes of the yield curves. The ordering of the countries, with the United States first then Germany and then the United Kingdom, reflects our priors of the importance of these economies and their respective bond markets in a global sense.

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8 More details on the implementation of the Svensson methodology and the estimation of zero coupon term structures are provided in Appendix A.

9 From January 1999 the German rates are replaced by euro interest rates.

10 Appendix B gives more details about the estimation of zero coupon interest rates estimated from swap rates.

11 The variance decomposition results presented here could be based upon coefficients which are poorly determined. To test for this possibility, and to test for causation between foreign influences on the domestic term structure, we test a null hypothesis that the VAR coefficients relating to the foreign variables are jointly insignificant, i.e. that they do not help to predict the domestic slope and interest rate change. We undertake this test on a rolling basis. In the interests of brevity, we do not report the results in detail here; however, we find that for all of the VARs presented in this paper the null hypothesis of no foreign influence on domestic interest rates can be rejected for the majority of the sample period considered here, and in particular for the "crisis" periods. An alternative way of interpreting these results is that dual causality, in the Granger causality sense of the term, exists between these markets. These results are of course available on request from the authors.

Figure 1: Variance decomposition of US Slope

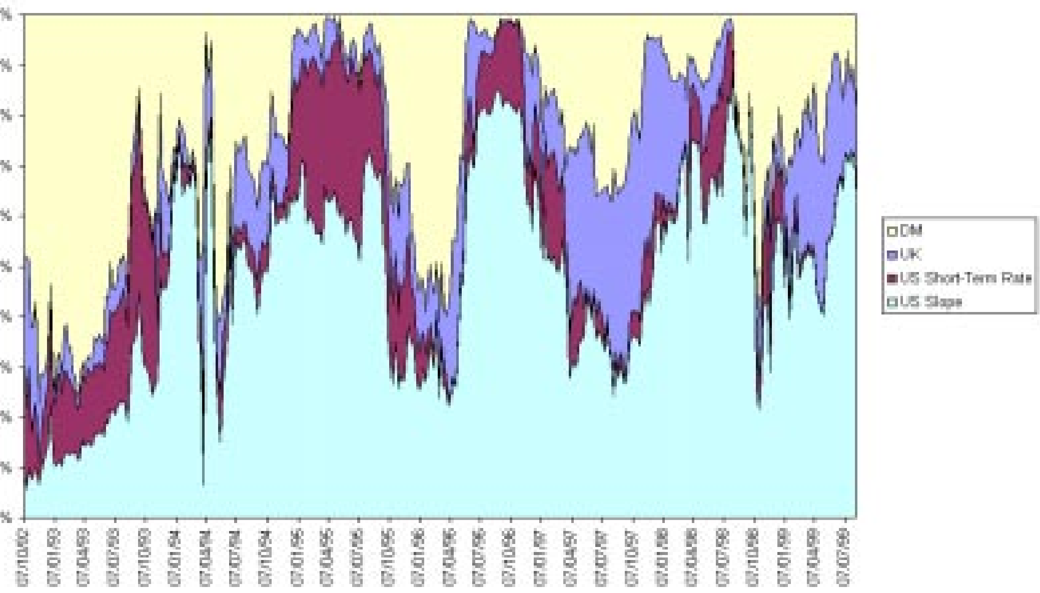


Figure 1 shows that on average 60% of the slope of the US yield curve is determined by US variables, and therefore that there is a significant international component in this slope on average, and during four periods in particular. The first period relates to the sterling exchange rate crisis when the United Kingdom was forced out of the ERM in 1992. During this period the German government bond market was exerting a considerable influence upon the US slope until “normal service” was resumed in early 1995. The second period of international influence relates to a period of monetary easing in Germany in preparation for the third stage of EMU in 1996. This easing was followed by a wave of associated monetary easings across other EU countries. This monetary easing was also associated with considerable EU convergence trades across international bond markets at this time. The third period appears to relate to the Asian crisis of 1997, while the fourth relates to the Russian debt crisis of 1998. These last two episodes were of course widely recognised as “international crises”, and therefore we believe that the UK and German markets are proxying here for wider international influences. Finally, and perhaps most importantly, we should note that after each of these four periods domestic factors gradually returned as the dominant influence over the slope of the US yield curve.

In Figure 2 we report the variance decomposition results for the slope of the German curve. On average, 70% of the slope of the German yield curve is determined by the German variables in the system. This is particularly true during the ERM crisis, where the variance in the German rates accounted for almost 100% of the variance in the yield curve. The results also indicate that the crisis in Asian financial markets in 1997 and the Russian debt crisis in 1998 both had a relatively large influence, via UK and US bond markets, upon the term structure of German government debt. Finally, we might also note that there has been an increase in the influence of US bond markets in the second half of our sample.

Figure 3 reports analogous results for the factors influencing the slope of the UK yield curve. The results show that the UK term structure is influenced the most by international factors, with just less than 40% of the slope on average being determined by the UK variables in the system. The German bond market exerts a large influence on the UK bond market in two periods. The first period coincides with the ERM crisis in 1992. The second, spanning 1995 and 1996, coincides with the loosening of German monetary policy during this period, as outlined above. Interestingly, there are also two periods where the US bond market influences the UK bond market. The first follows the ERM exchange rate crisis period in 1993 and 1994. The second period arguably begins before, but reaches a peak during the financial crisis in Asian markets and remains high until the impact of the Russian debt crisis declines towards the middle of 1999. Finally, Figure 3 also shows the brief but dramatic impact of the

Mexican crisis of 1994, revealing itself as a sharp increase in the proportion of the volatility of the UK yield slope which can be explained by US bond market variables.

Figure 2: Variance Decomposition of DM Slope

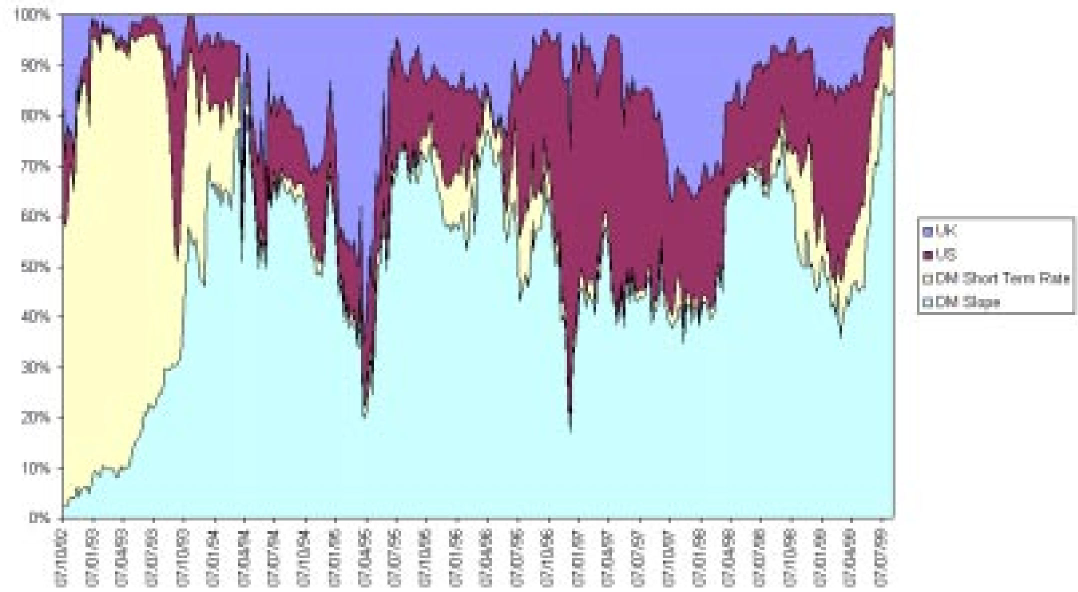
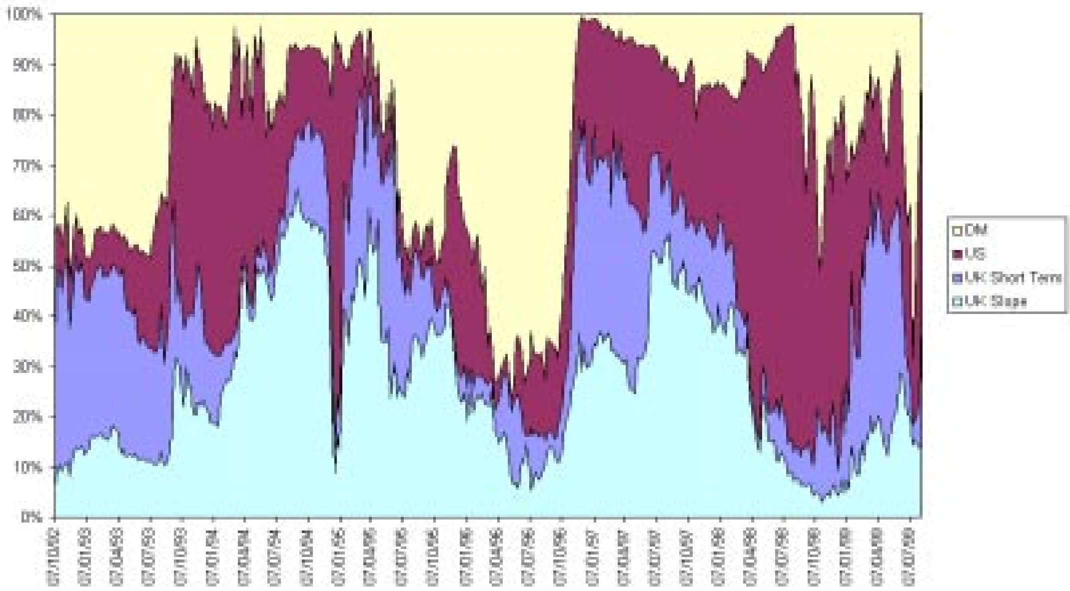


Figure 3 : Variance decomposition of UK Slope



We could summarise these results as follows: the variance of the slope of the UK yield curve appears to have been influenced most by international bond market factors, particularly the US market; while the variance of the slope of the US yield curve has tended to have been influenced by domestic factors, there have been significant periods of time when its variance has also been affected by international factors; finally, the variance of the slope of the German yield curve appears to have been the most domestically orientated of the three markets studied here, particularly during the early 1990s.[12]

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[12] This result is robust to alternative VAR orderings.

5.1.2 *Swap market results*

Finally, we consider the variance decomposition of the relationship between the US dollar and sterling swap markets in Figures 4 and 5. The first variables in the VAR are the changes in short-term rates, followed by the term structure slopes and finally by the swap spreads. The US dollar variable always precedes its sterling counterpart. Figure 4 shows that the variance of the US dollar swap spread is virtually unaffected by the sterling spread, while the slope of the UK yield curve on average determines 15% of the variance of the US dollar spread. The main factor affecting the US dollar swap spread, other than own variation, is movements in the slope of the US term structure. This reflects the way practitioners price interest rate swaps relative to government bond yields with similar maturities. In contrast to this result, Figure 5 shows that the variance of the sterling swap spread is influenced by the slope of the US yield curve. Perhaps more importantly, it is heavily influenced by the US dollar swap spread towards the end of our sample, a period beginning with the Asian financial crisis and extending into the period surrounding the Russian debt crisis.

Figure 4: Variance Decomposition of the 10 Year US Swap Spread

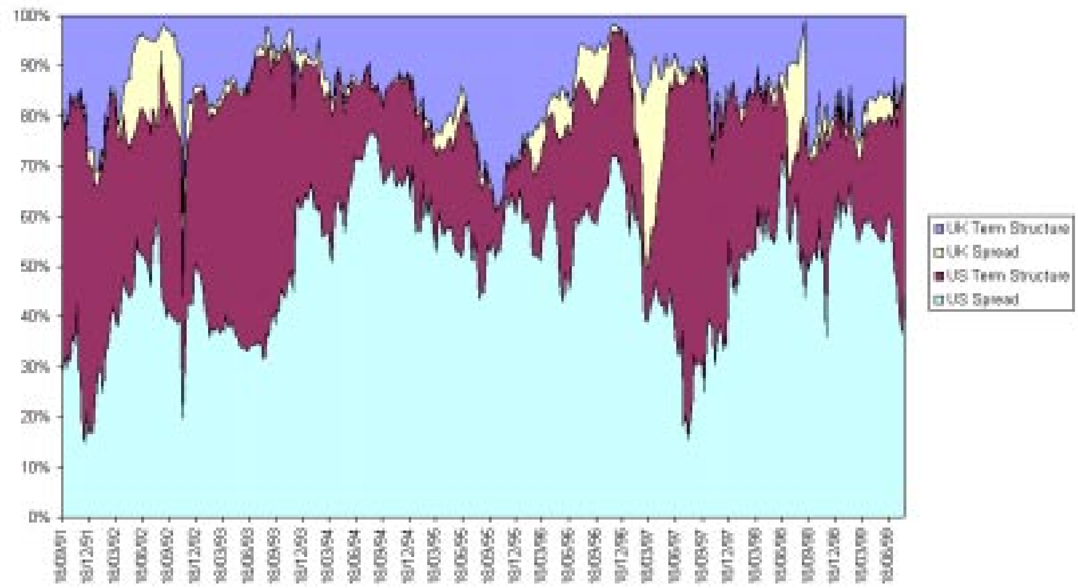
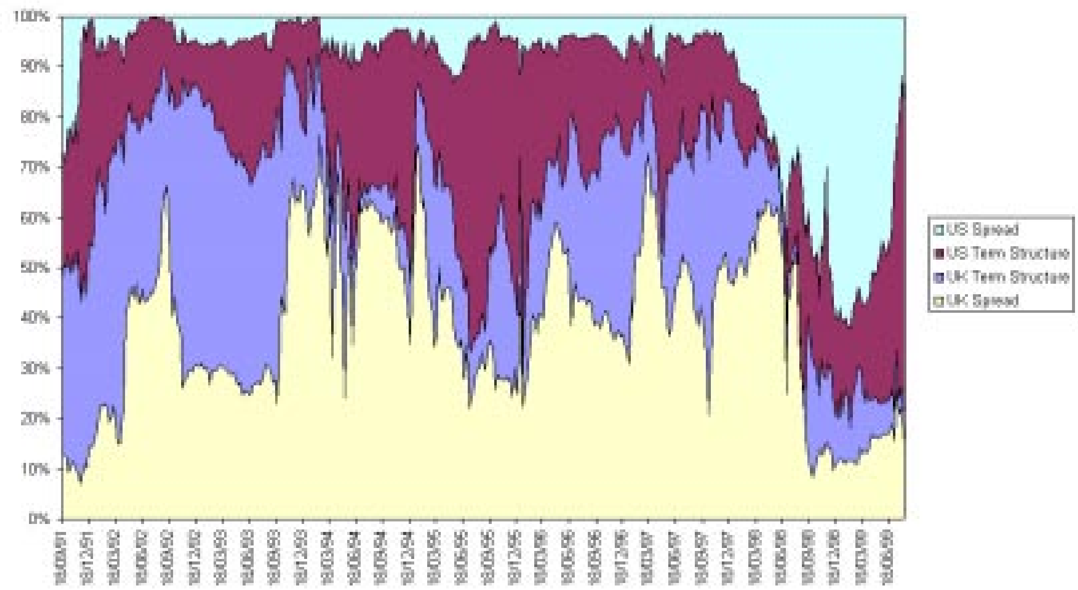


Figure 5: Variance Decomposition of the 10 Year UK Swap Spread

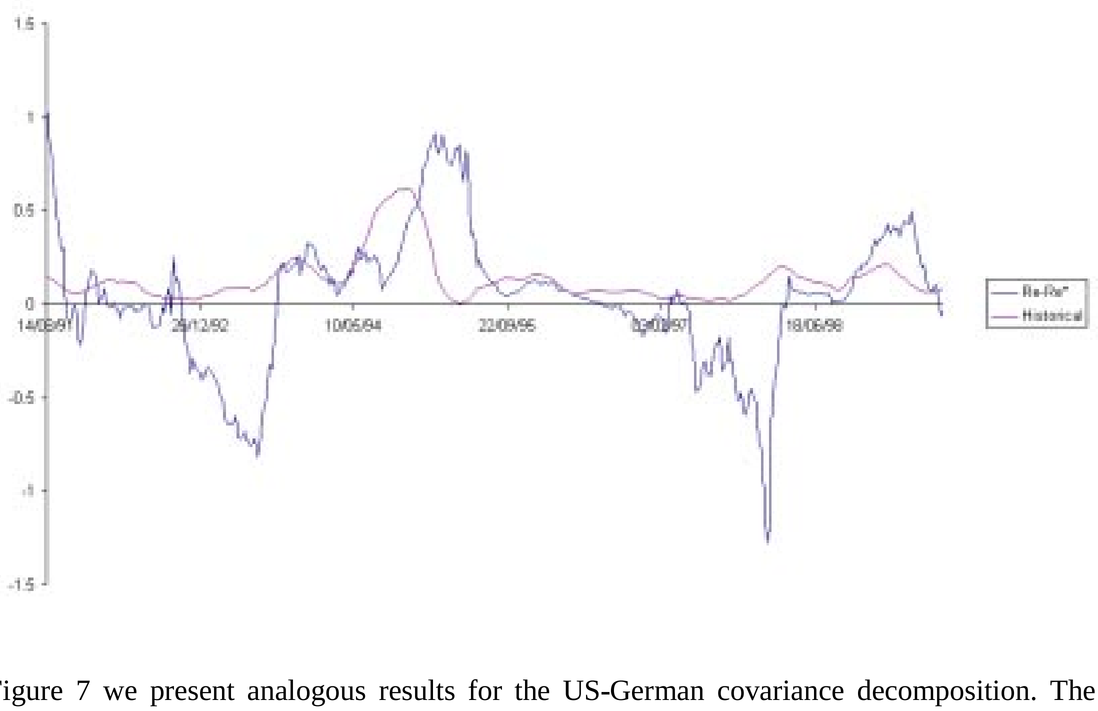


The results with respect to the sterling swap spread should act as a potential warning for those who believe that swap spreads are an indicator of domestic financial conditions. While this might be true for the US dollar swap market, clearly at the end of our sample the sterling swap spread was being more heavily influenced by developments in the US bond and US dollar swap markets than by UK factors.

5.2 Covariance decomposition results

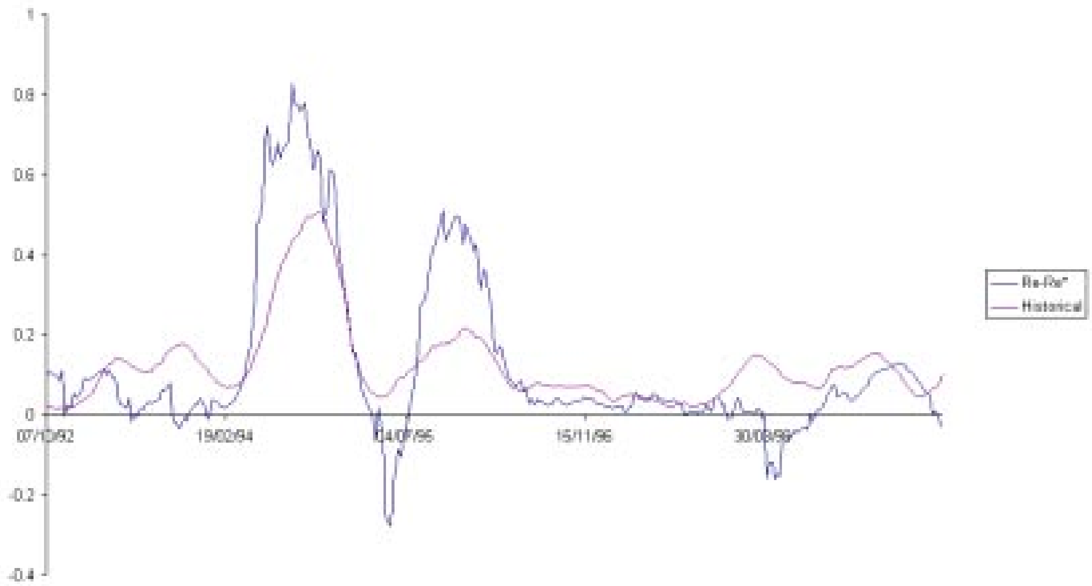
We now turn to the results of decomposing the covariances between the major government bond markets. In Figure 6 we present the unconditional covariance between UK and US long bond rates. In keeping with the results of Christiansen and Pigott (1997) and Solnik et al. (1996), we find no sign of an obvious increase in the total covariation between these two markets during the 1990s, which is always positive, although very close to zero for much of the period. Interestingly this covariance measure reaches a peak during 1994, not during the sterling, Asian or Russian crises. Figure 6 also shows the covariance over time between the REHTS-derived measures of expected long rates. The fact that this measure of covariance does not always track the total covariance closely indicates that at times the covariance between these markets is influenced very strongly by risk premium effects. This corroborates our previous findings that at times international factors exert considerable influence on the determination of the domestic interest rates, overriding in many cases considerations about domestic fundamentals. There are two such periods. Firstly, during the sterling exchange rate crisis in late 1992. The covariance between the REHTS-derived expectations of the two long rates indicates that the relationship should be strongly negative, reflecting the fact that the two economies were at different stages in the business cycle. However, since the total covariance is positive, this indicates that there were strong risk premium effects present at this time offsetting the influence of respective domestic economic conditions. The second notable deviation between the two series occurs during the Asian economic crisis, where domestic economic fundamentals were implying a negative covariance, but the impact of the crisis, which raised the total covariance between the two markets over this period, combined to produce a positive relationship. Finally, we might also note that there are also times when the REHTS-derived covariance term suggests a more positive relationship between the two markets than can be seen from the total covariance measure.

Figure 6 : Decomposition of Covariance between 10 year US-UK Interest Rates



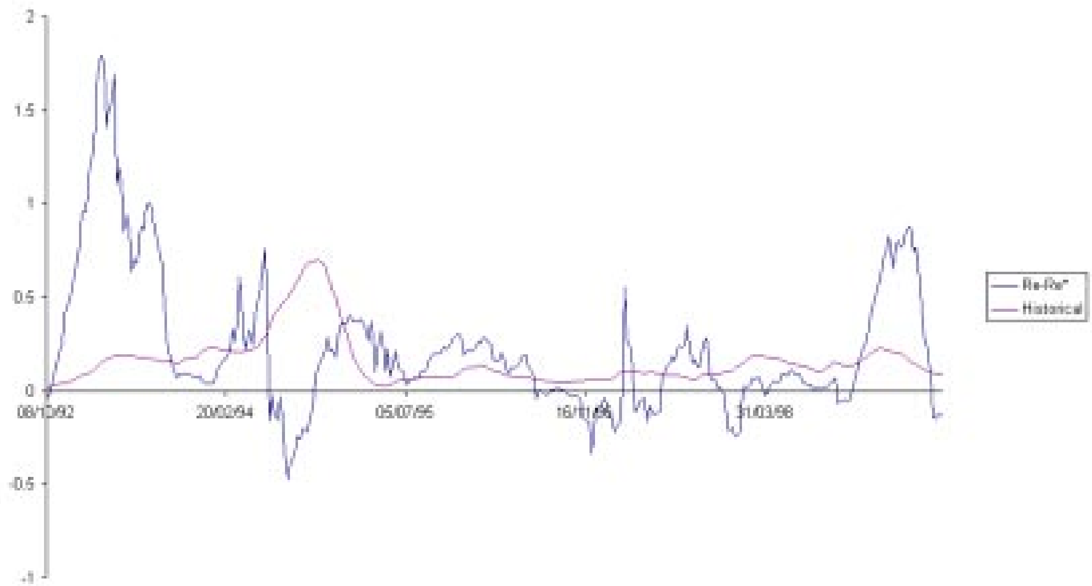
In Figure 7 we present analogous results for the US-German covariance decomposition. The total covariance between these two markets peaks in 1994. There is a noticeable, but small increase in this variable following the Asian crisis which persists until the end of our sample. Again this measure is always positive and close to zero for a significant portion of the sample. When we consider the difference between the total covariance and the REHTS-derived measure for the German-US pair, the results are in sharp contrast to those involving the United Kingdom and the United States. The REHTS-derived measure, with the exception of two minor, short-lived episodes in 1995 and in 1998, follows the total covariance measure fairly closely. Again this evidence is consistent with our previous findings. Variance decomposition results showed that, in contrast to the United Kingdom, the US and German yield slopes exhibit a smaller degree of variation due to international shocks. This result could be taken to indicate that the covariance between these two markets is driven more by macroeconomic fundamentals than by risk premia.

Figure 7 : Decomposition of Covariance between 10 year US-DM Interest Rates



The total covariance between the UK and German government bond markets, shown in Figure 8, reaches a peak in 1994 and remains, positive, but fairly low and stable during our sample period. The

Figure 8 : Decomposition of Covariance between 10 year DM-UK Interest Rates



sterling, Asian and Russian crises again seem to have had little impact upon total covariance over this period. There appear to be at least three periods where the REHTS-derived covariance component diverges substantially from the total measure. The first of these periods occurs after the United Kingdom's exit from the ERM in 1992, when the REHTS measure is strongly positive, while the total covariance measure remains positive, but small. This divergence suggests that the covariance between foreign risk premia and the REHTS measure of interest rate expectations is very negative over this period and analysis of this series confirms this to be true. During 1994, when the total covariance measure is at its maximum, the REHTS-derived measure is negative for a period, indicating strong positive correlations between risk premia. Finally, towards the end of our sample we see that the REHTS measure is indicating that the markets should be positively correlated while the total measure remains low, once again indicating that the risk-premia-related covariance components are negatively correlated with one another, and with the REHTS measure.

6. Conclusions

In this paper we examine the significance of domestic and international factors in determining the slopes of the US, German and UK yield curves, and how the magnitude of their impact fluctuates over the business cycle. Our main finding is that at times of global financial turmoil, like the sterling exchange rate crisis of 1992, the Asian financial crisis of 1997 and the Russian debt crisis of 1998, these slopes respond mainly to international factors, presumably as global investors reallocate their bond portfolio holdings and local investors readjust their expectations about domestic interest rates. We also examine the decomposition of the covariances between the US, German and UK long-term interest rates. Our decomposition of the covariance between these government bond markets indicates that risk premia and/or contagion effects have played an important role during these periods, moving the covariance between the markets away from where we might have expected it to be if international bond rates were determined solely by the REHTS arbitrage.

Appendix A

The estimation of the term structure of interest rates[13]

The term structures of US Treasury zero coupon bonds are provided by the Bank of England. Here we provide a brief discussion of the relevant issues. $P_{i,t}^{G}$, i=1,...,n, is the price (clean price plus accrued interest) of an ith maturity bond at time t. The bond $P_{i,t}^{G}$ pays a stream of cash flows, c_{ij}, (including redemption payments) at times m_{ij}. The vector of discount bonds corresponding to the coupon-paying bonds can be estimated from the following non-linear model:

(A1) $$P_{i,t}^{G} = \sum_{j} c_{ij}\delta(m_{ij},\boldsymbol{\beta}) + \varepsilon_{ij}, \quad i = 1,\ldots,n$$

where $\delta(m_{ij},\boldsymbol{\beta})$ is a parametric discount function with parameter vector $\boldsymbol{\beta} = (\beta_0,\beta_1,\beta_2,\beta_3,\tau_1,\tau_2)$.

The functional form selected by the Bank of England is based on the Svensson (1994, 1995) generalisation of the Nelson and Siegel (1987) model. According to Svensson the term structure of zero coupon yields is given by:

(A2) $$\begin{aligned} y(m,\boldsymbol{\beta}) &= \beta_0 \\ &+ \beta_1 \frac{1-e^{-\frac{m}{\tau_1}}}{m/\tau_1} \\ &+ \beta_2 \left[\frac{1-e^{-\frac{m}{\tau_1}}}{m/\tau_1} - e^{-\frac{m}{\tau_1}} \right] \\ &+ \beta_3 \left[\frac{1-e^{-\frac{m}{\tau_2}}}{m/\tau_2} - e^{-\frac{m}{\tau_2}} \right] \end{aligned}$$

and the discount function is:

(A3) $$\delta(m,\boldsymbol{\beta}) = \exp\left(-\frac{y(m,\boldsymbol{\beta})}{100} m \right)$$

Equations (A2) and (A3) are substituted in equation (A1) and the parameter vector $\boldsymbol{\beta}$ is estimated via a non-linear maximisation algorithm.

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[13] This appendix is largely based on the work undertaken by the Monetary Instruments and Markets division at the Bank of England. See Bianchi (1997) and Anderson et al. (1996) for more details.

Appendix B

Swap market data

The most common type of interest rate swap is the fixed-to-floating par swap. This is a contract between two counterparties to exchange future cash flows or equivalently to exchange interest rate risk positions. One party of the swap, namely the fixed payer, agrees to pay, on each payment day until the maturity of the swap, an amount equal to a fixed interest rate applied on a notional principal. In return, the fixed payer receives from the other counterparty, the floating payer, cash flows based on the same notional principal but calculated with respect to a floating interest rate, e.g. Libor. The payments of these cash flows usually occur either annually or semiannually.

The technique used to infer the prices of zero coupon bonds from swap rates is called bootstrapping and is based on the fact that interest rate swaps are par instruments with zero net present value. In the case of US dollars, where the swap cash flows occur annually, the prices of discount bonds implied by the swap market are given by:

(B1) $$b_{0,t} = \frac{1 - s_t\left(\sum_{i=1}^{t-1} \alpha_{i-1,i} b_{0,i}\right)}{1 + s_t \alpha_{t-1,t}}$$

where s_t is the swap rate, $i = 1,2,\ldots,t$ and the accrual factor is $\alpha_{i-1,i}$.[14] The only problem is that swaps are available only for one, two, three, four, five, seven and 10 years of maturity. Thus, a linear interpolation has to be used to get an estimate of the missing swap rates.

In the case of pound sterling swaps, where the swap cash flows occur semiannually, the calculations are slightly more complicated.[15] If the swaps make semiannual payments, then we have to use swap rates every half a year in order to calculate the zero bond prices for the corresponding period. Again a linear interpolation has to be used to get an estimate of the missing swap rates. The only swap rate we are not able to calculate using linear interpolation is the $s_{1.5}$ swap rate since the one-year swap rate is not available and the corresponding one-year rate available from the money market is quoted on a different basis. As a result an adjustment has to be made:

(B2) $$s_1 = \frac{1 - b_{0,1}}{\alpha_{0.0.5} b_{0,0.5} + \alpha_{0.5,1} b_{0,1}}$$

and $s_{1.5}$ can be calculated by interpolating between s_1 and s_2.

Finally, the zero bond prices can be calculated using the bootstrap method as in equation (B1) but now the index *i* in the summation is being done semiannually such that i = 1, 1.5, 2, 2.5, …, *t*.

Based on those zero coupon bond prices, we can estimate the implied annualised yields as:[16]

(B3) $$r_{0,t} = \left(\frac{1}{b_{0,t}}\right)^{-\alpha_{0,t}} - 1$$

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[14] In the case of US dollar interest rate swaps, the accrual factor is defined as $\alpha_{i-1,i} = \frac{30}{360}$.

[15] In the case of sterling swap markets, the swap day-count convention is 365 days per year. Thus, the accrual factor is defined as $\alpha_{i-1,i} = \frac{t_i - t_{i-1}}{365}$.

[16] The accrual factors now refer to bonds and are defined a $\alpha_{i-1,i} = \frac{t_i - t_{i-1}}{365}$.

One-year forward rates can be estimated by:

(B4) $$f_{0,t,t+12m} = \left(\frac{b_{0,t}}{b_{0,t+12m}} \right)^{-\alpha_{t,t+12m}} - 1$$

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