An analysis of the relationship between international bond markets

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Abstract

It is frequently suggested that the globalisation of financial markets has been responsible for reducing the scope for independent monetary policy action by strengthening the relationship between national fixed income markets. An associated concern is that the linkages between these markets become stronger in times of financial market stress. In this paper we decompose the relationship between the government bond markets of Germany, the United Kingdom and the United States. We find that the yield curves for each of these markets are influenced by international factors. Furthermore the impact of these factors increases significantly during times of financial stress. We also find that while the total covariation between these markets is relatively stable, components of the covariance can vary substantially over time.

1. Introduction

The correlations between major asset classes are of concern to monetary authorities and financial regulators alike − the potential for a worldwide decline in consumption resulting from a dramatic fall in equity market wealth could have serious implications for the health of both financial institutions and 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 process by which information flows between markets. Perhaps the main catalyst for this interest 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.

International bond markets are also important. Typically, monetary authorities are able to influence directly only the very short end of the term structure.[1] But in principle the long bond rate is determined by expectations about future short-term real interest rates and inflation. So monetary policy actions affect the whole of the term structure. If the covariation between government bond rates in different countries increases, the ability of monetary authorities to influence the term structure may decline.

Correlation between bond markets may arise through a number of channels, for example: if investors hold internationally diversified portfolios; 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 indicate 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, despite the fact that 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 on 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, an important and related issue is the extent to which co-movements in long

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[1] For a more comprehensive view of such issues see Woodford (1999).

bond rates, or indeed the components of these co-movements, 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 two components.[2] The first represents the no-arbitrage REHTS projection of the long rate, while the second represents an *ex post* measure of the risk premium. The decomposition is achieved by using the Campbell and Shiller (1987) VAR methodology. Each VAR that 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 that is influenced by domestic factors from that portion that is driven by international factors. By invoking the REHTS, we then turn our attention to calculating a conditional measure of international bond market covariation, decomposing this measure into its REHTS and risk premia components. 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 again become dominated by domestic factors. 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. The rest of the paper is organised as follows: in Section 2 we briefly outline the relevant academic literature on the topic of financial market linkages; in Section 3 we describe our methodology; in Section 4 we present the data and our results; and, finally, Section 5 concludes the paper.

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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.

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 themselves and simply respond by 'shooting first and asking questions later' (see Shiller, Konya and Tsutsui (1991)).

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)) whereas more recent studies have focused on the relationships between conditional first and second moments. Engle, Ito and Lin (1990) examine the phenomenon of volatility clustering in foreign exchange markets making the distinction between what they term '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 that is relevant to their market. For example, Lin, Engle and Ito (1994) decompose return surprises from one market into their 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 has been an increase in the correlation between both 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 stronger than 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 while most of the variability in excess returns is unexplained, that part of stock returns that can be explained is driven mainly by news about future stock returns, while the explainable portion of bond returns is driven predominantly by expected inflation. These results offer some explanation for the low correlation that is generally found 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, see Dahlquist, Hordahl and Sellin (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

The theory of uncovered interest parity (UIP) states that the difference between the one-period return on holding any two assets denominated in different currencies should be equal to the expected exchange rate movement between the two currencies over the period, plus any risk premium attached to the uncertainty about the exchange rate forecast. Furthermore, the purchasing power parity condition (PPP) associates expected exchange rate movements with the expected differential between future inflation rates. Using these theoretical considerations a number of studies have tried to model the co-movements of international interest rates by regressing domestic long-term bond yields, or the slope of the domestic

term structure, on their foreign currency counterparts (see Beenstock and Longbottom (1981), Booth *et al* (1985), Krol (1986), Murray and Khemani (1989) and Booth (1991)). These studies interpret the high explanatory power of these regressions as evidence of close links between international interest rates.

In this paper we employ the rational expectations hypothesis of the term structure to model long-term rates as averages of future short-term interest rates plus a risk premium. Using the REHTS allows us to study the co-movements of international long-term rates and also to differentiate between that proportion of the covariation that is due to the theoretical long rate and the proportion of the covariation that is due to the presence of risk premia. Unfortunately our methodology does not enable us to distinguish between the likely components of the risk premium, ie uncertainty about future inflation or future real rates.

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 rational expectations hypothesis of the term structure. 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:

$$R_{k,t} = R_{k,t}^e + RP_{k,t} \qquad (1)$$

where $R_{k,t}$ is the yield on a k-maturity pure discount bond; and $R_{k,t}^e$ is the sum of expected one-period interest rates:

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

where E_t denotes the market's expectations conditional on information available at time t and $r_{1,t+i}$ is the one-period rate at time $t+i$. $RP_{k,t}$ is the risk premium at time t associated with buying a long bond relative to rolling over one-period bonds for the maturity of the k-period bond. In the absence

of a bond market risk premium, the fully anticipated rational expectation of the long rate would, on average, equal the actual long rate (subject to random, unsystematic errors); it is in this sense that we interpret the risk premium required for holding government bonds as being the difference between R_k and R_k^e. It can be shown that the risk premium, as written in expression (1) above, is related to the variance–covariance matrix of the relevant subjective one-period discount factors and inflation outcomes over the life of the k-period bond (see Kozicki *et al* (1996)), ie uncertainty about future inflation and real rates.

Similarly we can define foreign bond rates as:

$$R_{k,t}^* = R_{k,t}^{e*} + RP_{k,t}^* \qquad \qquad (3)$$

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

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

How can we interpret these components ?[3] The first component in expression (4) measures that part of the covariation between two bond markets that can be attributed to the covariation in investors' expectations about future short-term interest rates in the two countries. These expectations will reflect considerations about the future path of inflation, real interest rates and the monetary policy stance in each country, thus this component will hopefully reflect the part of the total covariation due to these factors. The remaining components are straightforward. The second (third) component represents the covariation between domestic (foreign) long-horizon interest rate expectations and the foreign (domestic) interest rate risk premium (as defined above). Finally, the fourth component measures the covariation between domestic and foreign risk premia.

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[3] It is possible to achieve this decomposition without invoking the REHTS. However, as Shiller (1990) notes, while only the notion of risk neutrality need be invoked to justify this decomposition, this is not a 'terribly attractive' assumption. See Shiller (1990) for more details.

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 is directly observable. Since the components of expression **(4)** depend on 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 multi-period expectations of the long rate (see Campbell and Shiller (1987)).[4]

Having chosen this VAR methodology the next issue relates to the choice of conditioning variables. In undertaking this exercise using US data Campbell and Shiller (1987) use a two-dimensional vector of state variables that includes the changes in the short rate and the slope of the term structure. 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 rates expectations are jointly determined. This allows for possible interactions between domestic and international components of long rates. In order to achieve this interaction we expand the information set to include information on three different term structures.[5] As a result, the vector of state variables is defined as:

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

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

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[4] For a more detailed discussion of alternative methodologies used to evaluate multi-period expectations of unobserved variables and their shortcomings relative to the VAR approach, see Campbell and Ammer (1993).

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

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:

$$s_{k,t}^e = R_{k,t}^e - r_{1,t} \tag{6}$$

Substituting (2) into (5) we get:

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

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

$$z_t = A z_{t-1} + w_t \tag{8}$$

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 de-mean the variables before including them in the VAR. Finally, we note that the assumption of the first-order VAR process is not restrictive.[6]

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:

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

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

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

and

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

where $h_1^T = [1,0,0,0,...]$, $h_2^T = [0,1,0,0,...]$ and $h_3^T = [0,0,1,0,...]$ 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 *ex post* estimate of the domestic and foreign bond market risk premium, $RP_{k,t}$. It should be noted that it is not possible to distinguish between the potential components of this risk premium measure such as uncertainty about future inflation rates, or future real rates of return. Estimates of $R_{k,t}^{e*}$, $RP_{k,t}^*$ and $R_{k,t}^{e**}$, $RP_{k,t}^{**}$ are produced by a similar procedure.[7] 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 using 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

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[7] These premia estimates 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 then the estimates may be biased.

where the VAR described above is estimated using one years' 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 that 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.

3.3. Extending the analysis to interest rate swaps

Interest rate swaps are contracts that 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, eg 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 that affected interest rate swap markets after the recent Russian debt crisis.[8] The main aim of this analysis is to identify periods in which 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[9] may be misleading.

Previous research (see for example Sun, Sundaresan and Wang (1993) or Minton (1997)) has shown that long-term swap spreads are affected by

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[8] Although we cannot meaningfully decompose the rates into their 'theoretical' and risk premium components as we did for the government bond yields.
[9] See for example 'Swap spreads show a new aversion to risk', *Financial Times*, 10 August 1999, page 24.

changes in the slope of the term structure. Hence we can define the following vector of state variables:

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

(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-year and ten-year US, UK and German interest rates. These are zero-coupon interest rates estimated from the prices of coupon-paying government bonds using the Svensson methodology (Svensson (1994, 1995)).[10] 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.[11] 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 A.

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[12] 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.

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

[11] From January 1999 the German rates are replaced by euro interest rates.

[12] Appendix B gives more details about the estimation of zero-coupon interest rates estimated from swap rates.

4.2 Results

We now present the results relating to various versions of the VAR outlined in Section 3 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.

4.2.1 Variance decomposition results

In Chart 1 we present the variance decomposition for the slope of the US yield curve, based on a VAR that includes German, UK and US variables. The chart 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. The variance decomposition results presented here could be based on coefficients that 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, ie 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.[13]

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'etre* 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.[14]

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[13] 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.

[14] Experimentation with alternative orderings did not change our general results.

Chart 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, 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 Chart 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 variation in the German rates accounts for almost 100% of the variation of 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, on 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.

Chart 3 reports analogous results for the factors influencing the slope of the United Kingdom's 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 markets 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, Chart 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 that can be explained by US bond market variables.

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; the variance of the slope of the US yield curve has tended to have been influenced by domestic factors, though 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.[15]

Finally, we consider the variance decomposition of the relationship between the US dollar and sterling swap markets in Charts 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. When we consider Chart 4, we can see 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, Chart 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.

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

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

being more heavily influenced by developments in the US bond and US dollar swap markets than by UK factors.

4.2.2   *Covariance decomposition results*

We now turn to the results of decomposing the covariances between the major government bond markets. In Chart 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. Chart 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. First, 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 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.

In Chart 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 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.[16]

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

One caveat that we should add to our conclusions is that there have been instances in the past where G7 countries have tried to coordinate monetary policy, most notably during times of financial stress (for example during the Russian debt/LTCM crisis). It is therefore possible that some of our results will be influenced by such coordination. In other words, where our statistical results indicate 'foreign influence' and therefore 'loss of control' on the part of domestic monetary authorities, this loss may be the result of

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[16] Although we are not suggesting that risk premia are not part of what is fundamental to our economic understanding of such phenomena.

welcome international coordination. Although the fact that international efforts are required in the first place must indicate some loss of domestic control.

5. 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. 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 them to be if international bond rates were determined solely by the REHTS arbitrage.

Table A
Descriptive statistics

Rates	From	To	No. obs	Mean	St. Dev.	Min.	Max.
US interest rates							
1 year	15-Aug-90	08-Aug-99	456	5.23	1.07	3.13	7.99
10 years	15-Aug-90	08-Aug-99	456	6.64	0.94	4.55	8.90
Slope	15-Aug-90	08-Aug-99	456	1.42	1.01	0.04	3.63
UK interest rates							
1 year	15-Aug-90	08-Aug-99	456	7.06	1.93	4.71	13.37
10 years	15-Aug-90	08-Aug-99	456	7.71	1.62	4.16	11.62
Slope	15-Aug-90	08-Aug-99	456	0.66	1.30	-1.87	3.10
DM interest rates							
1 year	09-Oct-91	08-Aug-99	408	5.01	1.91	2.55	10.68
10 years	09-Oct-91	08-Aug-99	408	6.33	1.15	3.77	8.53
Slope	09-Oct-91	08-Aug-99	408	1.33	1.36	-1.87	3.54
UK swap spreads							
10 year	15-Aug-90	08-Aug-99	456	0.38	0.20	0.00	1.05
US swap spreads							
10 year	15-Aug-90	08-Aug-99	456	0.36	0.16	0.10	0.89

Chart 1: Variance decomposition of US slope


25
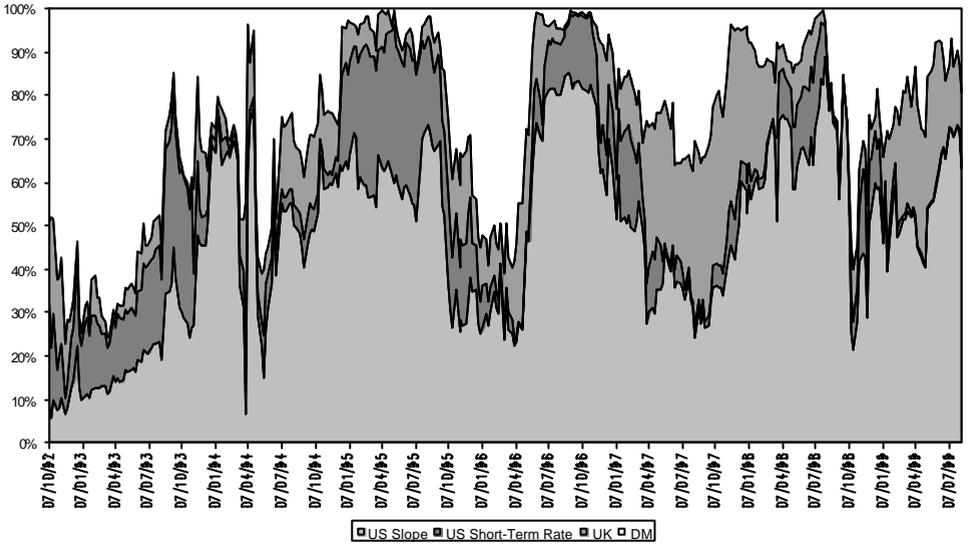
Chart 2: Variance decomposition of DM slope
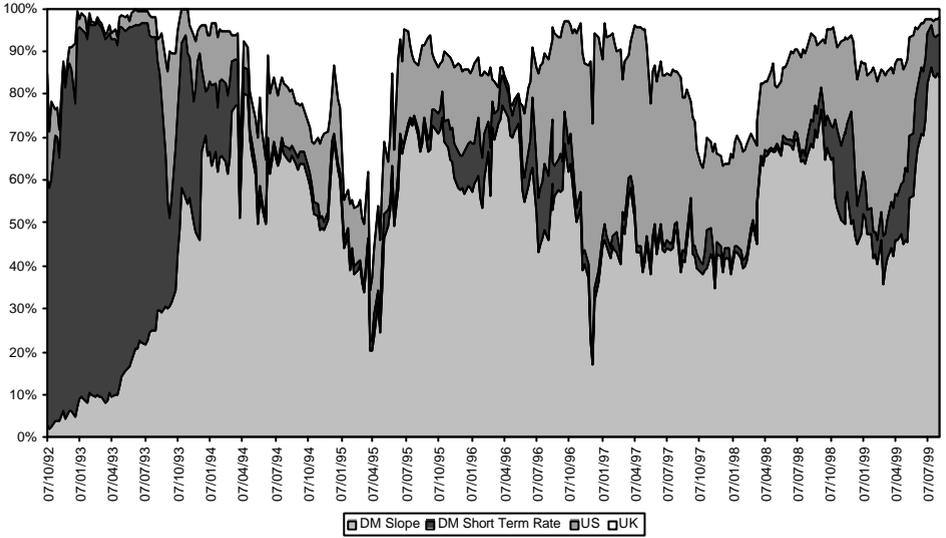
Chart 3: Variance decomposition of UK slope

27
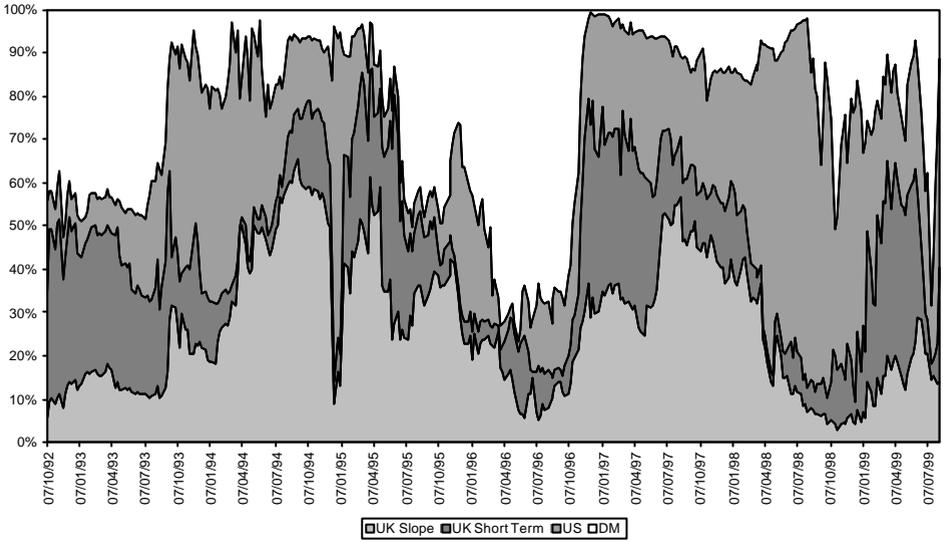
**Chart 4: Variance decomposition of the 10-year US swap spread**

Legend: US Spread, US Term Structure, UK Spread, UK Term Structure
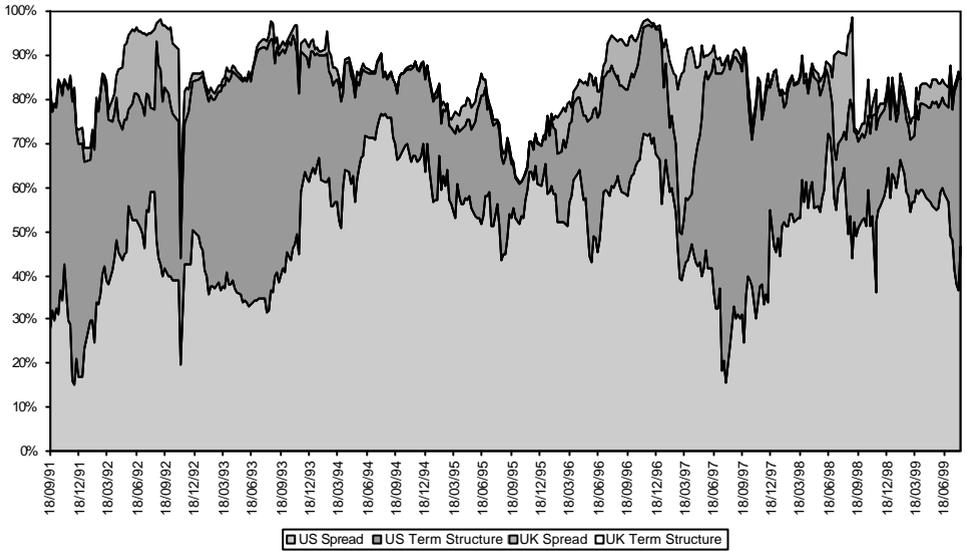
Chart 5: Variance decomposition of the 10-year UK swap spread

Legend: UK Spread, UK Term Structure, US Term Structure, US Spread
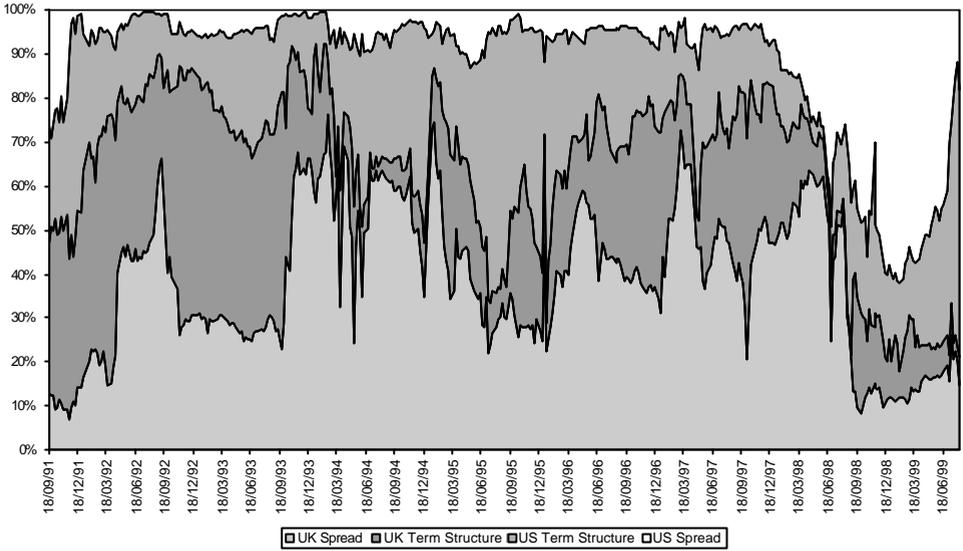
Chart 6: Decomposition of covariance between 10 year US-UK interest rates


Legend: Re-Re* —△— Historical
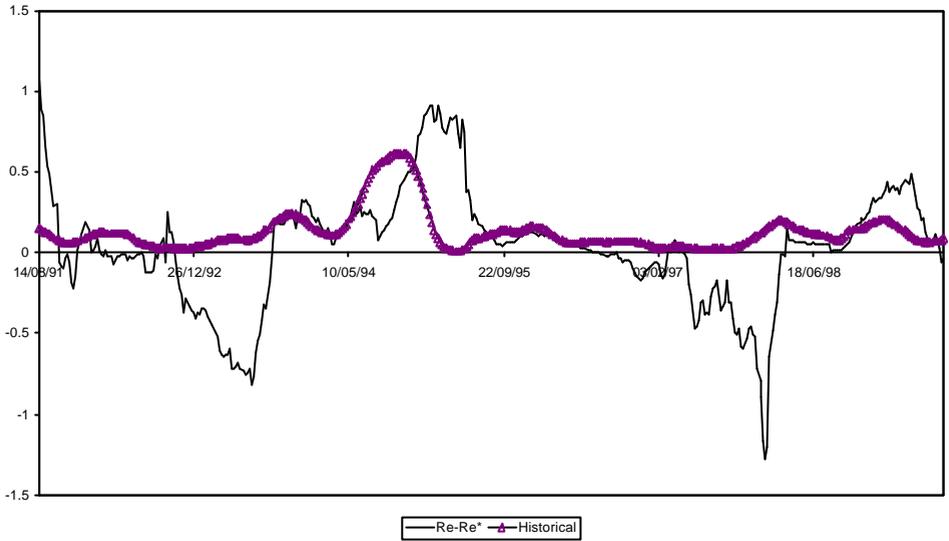
Chart 7: Decomposition of covariance between 10 year US-DM interest rates
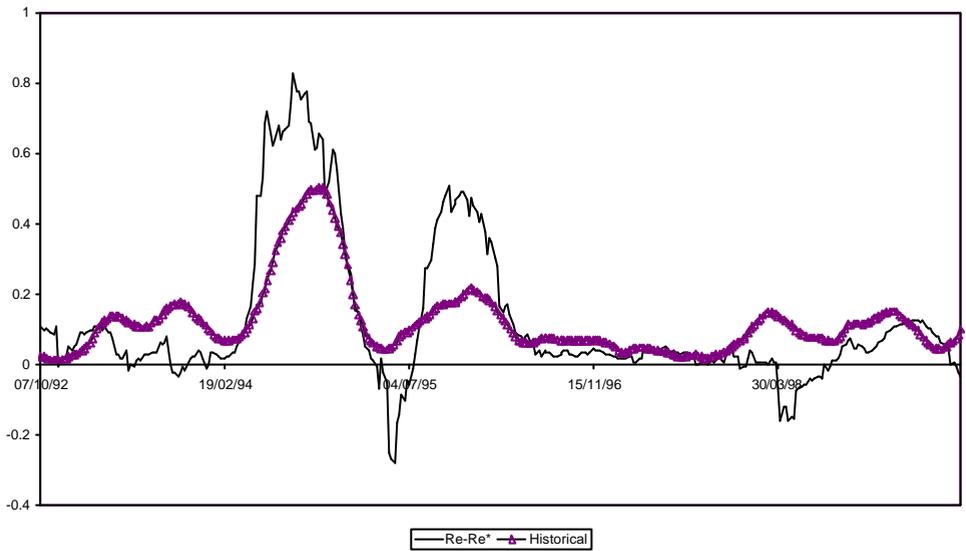
**Chart 8: Decomposition of covariance between 10 year DM-UK interest rates**


Legend: Re-Re*, Historical
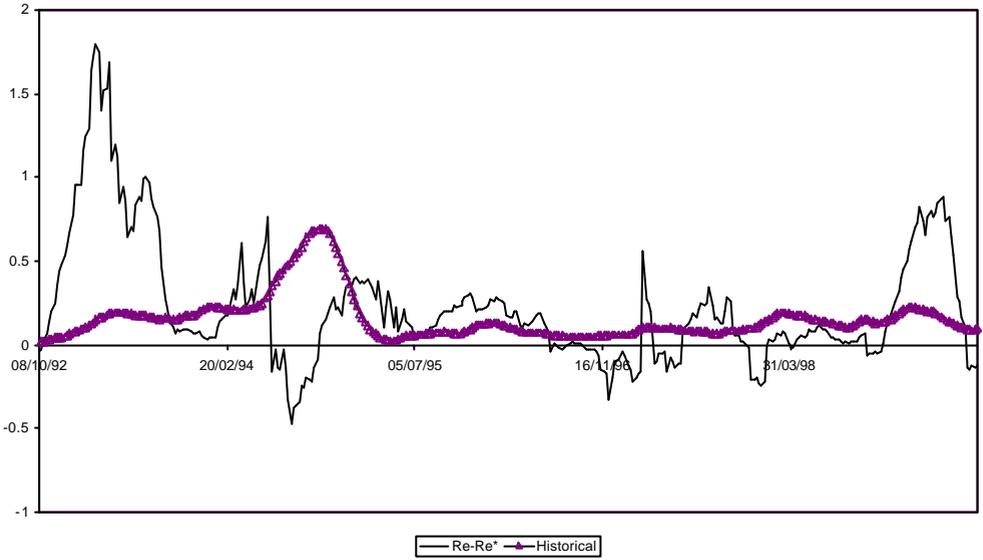
Appendices

A. *The estimation of the term structure of interest rates*[17]

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

$$P_{i,t}^G = \sum_j c_{ij} d(m_{ij}, \beta) + e_{ij}, \quad i = 1,..., n \qquad \textbf{(A1)}$$

where $d(m_{ij}, \beta)$ is a parametric discount function with parameter vector $\beta = (b_0, b_1, b_2, b_3, t_1, t_2)$.

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[17] 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.

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

$$y(m, \beta) = \boldsymbol{b}_0$$

$$+ \boldsymbol{b}_1 \frac{1 - e^{-\frac{m}{t_1}}}{m / t_1}$$

$$+ \boldsymbol{b}_2 \left[\frac{1 - e^{-\frac{m}{t_1}}}{m / t_1} - e^{-\frac{m}{t_1}} \right] \tag{A2}$$

$$+ \boldsymbol{b}_3 \left[\frac{1 - e^{-\frac{m}{t_2}}}{m / t_2} - e^{-\frac{m}{t_2}} \right]$$

and the discount function is

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

Equations **(A2)** and **(A3)** are substituted in equation **(A1)** and the parameter vector ß is estimated via a non-linear maximisation algorithm.

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, eg LIBOR rate. The payments of these cash flows usually occur either annually or semi-annually.

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 dollar swaps, where the swap cash flows occur annually, the prices of discount bonds implied by the swap market are given by:

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

where s_t is the swap rate, $i = 1,2,\ldots,t$ and the accrual factor is $a_{i-1,i}$.[18] The only problem is that swaps are available one for 2, 3, 4, 5, 7 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 sterling swaps, where the swap cash flows occur semi-annually the calculations are slightly more complicated.[19] If the swaps make semi-annual payments then we have to use swap rates every half a year in order to calculate the zero bond prices for the corresponding

---

[18] In the case of USD interest rate swaps the accrual factor is defined as $a_{i-1,i} = \dfrac{30}{360}$.

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

period. Again a linear interpolation has to be used to get an estimate of the missing swap rates. The only swap rate that we are not able to calculate using linear interpolation is the $s_{1.5}$ swap rate as 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

$$s_1 = \frac{1 - b_{0,1}}{a_{0.05}b_{0,0.5} + a_{0.5,1}b_{0,1}} \qquad \textbf{(B2)}$$

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 semi-annually such that $i = 1, 1.5, 2, 2.5, \ldots, t$.

Based on those zero-coupon bond prices we can estimate the implied annualised yields as[20]

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

One-year forward rates can be estimated by

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

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[20] The accrual factors now refer to bonds and are defined as $a_{i-1,i} = \dfrac{t_i - t_{i-1}}{365}$.

References

Ammer, J and Mei, J (1996), 'Measuring international economic linkages with stock market data', *Journal of Finance*, Vol 51(5), December, pages 1,743-63.

Anderson, N, Breedon, F, Deacon, A, Derry, M and Murphy, G (1996), *Estimating and interpreting the yield curve*, John Wiley & Sons, London.

Beenstock, M and Longbottom, J A (1981), 'The term structure of interest rates in a small open economy', *Journal of Money, Credit and Banking*, Vol 13, pages 14-59.

Bianchi, M (1997), 'Estimation of forward yield curves from conventional and index-linked bonds', *mimeo*, Bank of England.

Booth, P O (1991), 'Interest rate parity, cointegration and the term structure in Canada and the United States', *Canadian Journal of Economics,* Vol 24, pages 595-603.

Booth, P, Clinton, K, Cote, A and Longworth, D (1985), *International asset substitutability*, Bank of Canada, Ottawa.

Campbell, J Y and Ammer, J (1993), 'What moves the stock and bond markets? A variance decomposition for long-term asset returns', *Journal of Finance,* Vol 48(1), March, pages 3-37.

Campbell, J Y and Shiller, R J (1987), 'Cointegration and tests of present value models', *Journal of Political Economy*, Vol 95, pages 1,062-88.

Campbell, J Y and Shiller, R J (1988), 'Stock prices, earnings, and expected dividends', *Journal of Finance*, Vol 43(3), July, pages 661-76.

Christiansen, H and Pigott, C (1997), 'Long-term interest rates in globalised markets', *OECD Working Paper Series*, Paris.

Dahlquist, M, Hordahl, P and Sellin, P (1999), 'Measuring international volatility spillovers', Sveriges Riksbank. Paper presented at the BIS Autumn 1999 Meeting of Central Bank Economists.

Engle, R F, Ito, T and Lin, W (1990), 'Meteor showers or heat waves? Heteroskedastic intra-daily volatility in the foreign exchange market', *Econometrica*, Vol 58, pages 525-42.

Eun, C S and Shim, S (1989), 'International transmission of stock market movements', *Journal of Financial and Quantitative Analysis*, Vol 24, pages 241-56.

Evans, M D D and Lewis, K K (1994), 'Do stationary premia explain it all? Evidence from the term structure', *Journal of Monetary Economics*, Vol 33, pages 285-318.

King, M A and Wadhwani, S (1990), 'Transmission of volatility between stock markets', *Review of Financial Studies*, Vol 3(1), pages 5-33.

Koch, P D and Koch, T W (1991), 'Evolution in dynamic linkages across daily national stock indexes', *Journal of International Money and Finance*, Vol 10(2), June, pages 231-51.

Koutmos, G and Booth, G G (1995), 'Asymmetric volatility transmission in international stock markets', *Journal of International Money and Finance*, Vol 14, pages 747-62.

Kozicki, S, Reifschneider, D and Tinsley, P (1996), 'The behaviour of long-term interest rates in the FRB/US model', *BIS Conference Papers*, Vol 2, pages 215-50.

Krol, R (1986), 'The interdependence of the term structure of eurocurrency interest rates', *Journal of International Money and Finance*, Vol 5, pages 245-53.

Lin, W, Engle, R F and Ito, T (1994), 'Do bulls and bears move across borders? International transmission of stock returns and volatility', *Review of Financial Studies*, Vol 7, pages 507-38.

Minton, B A (1997), 'An empirical examination of basic valuation models for plain vanilla US interest rate swaps', *Journal of Financial Economics*, Vol 44, pages 251-77.

Murray, J and Khemani, R (1989), *International interest rate linkages and monetary policy: a Canadian perspective*, Bank of Canada, Ottawa.

Nelson, C R, and Siegel, A F (1987), 'Parsimonious modelling of the yield curves', *Journal of Business*, Vol 60, pages 473-89.

Shiller, R J (1990), 'The term structure of interest rates', in Friedman, B M and Hahn, F H (eds), *Handbook of Monetary Economics*, Vol 1.

Shiller, R J and Beltratti, A E (1992), 'Stock prices and bond yields: can their co-movements be explained in terms of present value models?', *Journal of Monetary Economics*, Vol 30(1), October, pages 25-46.

Shiller, R J, Konya, F and Tsutsui, Y (1991), 'Investor behaviour in the October 1987 stock market crash: the case of Japan', *Journal of the Japanese and International Economy*, Vol 5(1), March, pages 1-13.

Sims, C A (1980), 'Macroeconomics and reality', *Econometrica*, Vol 48(1), January, pages 1-48.

Solnik, B, Boucrelle, C and Le Fur, Y (1996), 'International market correlation and volatility', *Financial Analysts' Journal*, September/October, pages 17-34.

Sun, T S, Sundaresan, S and Wang, C (1993), 'Interest rates swaps: an empirical investigation, *Journal of Financial Economics*, Vol 34, pages 77-99.

Svensson, L (1994), 'Estimating and interpreting forward rates: Sweden 1992-1994', *Working paper 114*, International Monetary Fund.

Svensson, L (1995), 'Estimating forward rates with the extended Nelson and Siegel method', *Quarterly Review*, Sveriges Riksbank.

Woodford, M (1999), 'Optimal policy inertia', *NBER Working Paper*, No 7261.