Common risk factors in the US and UK interest rate swap markets: Evidence from a non-linear vector autoregression approach

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Abstract

This paper produces evidence in support of the existence of common risk factors in the US and UK interest rate swap markets. Using a multivariate smooth transition autoregression (STVAR) framework, we show that the dynamics of the US and UK swap spreads are best described by a regime-switching model. We identify the existence of two distinct regimes in US and UK swap spreads; one characterized by a "flat" term structure of US interest rates and the other characterized by an "upward" slopping US term structure. In addition, we show that there exist significant asymmetries on the impact of the common risk factors on the US and UK swap spreads. Shocks to UK oriented risk factors have a strong effect on the US swap markets during the "flat" slope regime but a very limited effect otherwise. On the other hand, US risk factors have a significant impact on the UK swap markets in both regimes. Despite their added flexibility, the STVAR models do not consistently produce superior forecasts compared to less sophisticated autoregressive (AR) and vector autoregressive (VAR) models.

Keywords: Interest rate swaps, swap spreads, term structure of interest rates, regime switching, smooth transition models.

JEL classification: C51, C52, C53, E43.

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1. Introduction

The identification of the risk factors that determine the dynamics of the spread between fixed-for-floating interest rate swaps and the underlying government bond yields is important for both market participants and policy makers. Better understanding of the nature and dynamics of the risk factors in swap markets will allow market participants to construct more accurate swap pricing models and policy makers to extract more accurate information on credit and liquidity conditions in the economy. Many other theoretical and empirical studies, discussed below, have already examined whether different proxies for liquidity and credit risk as well as proxies for market structure can account for the variability of interest rate swap spreads. The contribution of this paper is that it focuses on the interlinkages between the international interest rate swap markets, instead of looking at them in isolation, and asks whether the existing risk factors are priced internationally. More specifically we examine the existence of common factors in the US and UK interest rate swap markets. The questions we address include: i) whether shocks to the common risk factors have a positive or negative impact on US and UK swap spreads, ii) what is the magnitude of the impact of the shocks to swap spreads, iii) how these shocks propagate across time for each swap spread maturity and iv) whether the significance of the risk factors varies across swap spread maturity. All these issues are addressed within a multivariate non-linear framework that allows for asymmetric effects of the shocks on swap spreads conditional upon the shape of the term structure of the US interest rates, the size of the shocks and the direction (i.e. positive or negative) of the shocks. The out-of-sample performance of our model (based on weekly data) is compared to more basic autoregressive (AR) and vector autoregressive models (VARs) for various forecast horizons over a period of two years.

Earlier research by Smith, Smithson and Wakeman (1988) showed that under the assumption of no default and liquidity risk, the fixed rate of an interest rate swap can be considered as the yield of an identical maturity that trades at par. Subsequent contributions have shown that swap spreads represent a reward for the investors above government bond yields for bearing either liquidity risk in the interbank market, e.g. Grinblatt (1995), or both liquidity and default risk in swap markets, e.g. Duffie and Singleton (1997). Brown, Harlow and Smith (1994) have argued that swap spreads can also be used to cover hedging costs for swap market deals. In addition, Sorensen and Bollier (1994) argue that the swap spreads reflect the price of a series of European options to default implicitly held by the counterparty that is in-the-money during the initial stages of the swap contract.[1] This research is complemented by the work of Lang, Litzenberger and Liu (1998) and Fehle (2000) who examine how the swap market structure can affect spreads through the supply and demand for swaps.

The empirical implications of these swap-pricing models have been examined in a series of papers in the literature. One of the first studies to empirically test the implications of swap pricing models was by Sun, Sundaresan and Wang (1993). They examine the relationship between swap rates and Treasury yields as well as yields on interbank par bonds. The find that although swap rates are highly correlated with treasury yields, the swap rates are significantly higher than treasury yields, irrespective of the shape of the treasury yield curve. This positive relationship is less pronounced when the term structure is inverted. They also report that swap

[1] A similar approach is adopted by Duffie and Hung (1996) who examine the case of asymmetric default risk between counterparties.

rates are less correlated with par interbank bond rates and that interbank rates were significantly higher than swap rates. In a similar fashion, Minton (1997) examines the relationship between swap rates and Eurodollar futures rates as well as yields on portfolios of non-callable corporate bonds. Her results indicate that although swap rates are highly correlated with both instruments the relationship is less than perfect. Other factors that swap rates are sensitive to, include the shape of the term structure of default-free interest rates, the level of interest rates and the volatility of short-term interest rates. According to Minton (1997), these results provide evidence that the counterparty option to default is priced in swap rates. Brown, Harlow and Smith (1994) look at swap spreads as a function of the difference between Eurodollar LIBOR rates and the corresponding maturity treasury Bill rates (TED) and various measures for credit risk and hedging costs for swap market dealers. They found that while all of these factors are significant their explanatory power is low. Eom, Subrahmanyam and Uno (2000) report that the slope and curvature of the default-free interest rates and the corporate bond yields are significant factors in the determination of the Japanese swap spreads, while factors like the TED spreads and short-term interest rates play only a minor role.

These studies employed a linear regression methodology, which allows the estimation of the direct (contemporaneous) effect of the explanatory factors on swap spreads, to assess the significance of the risk factors. Duffie and Singleton (1997) and Lekkos and Milas (2001) have extended this research to a multivariate vector autoregression (VAR) framework. Duffie and Singleton (1997) find that the biggest part of swap spreads variation is due to their own shocks. Liquidity shocks are more important in short horizons[2] while default risk is clearly priced in swap spreads. Default risk is more significant over long horizons and for longer maturity swap spreads. Lekkos and Milas (2001) assess the ability of factors such as the level, volatility and slope of the zero-coupon government bond yield curve, the TED spread and the corporate bond spread to describe the term structure of the US and UK swap spreads. They find that the slope of the term structure has a significant countercyclical effect across maturities while the TED and corporate spreads play a smaller role and their significance varies across maturities.

Despite this extensive research effort, the issue of international linkages between interest rate swap markets has not been properly addressed[3]. Advances in financial engineering have made it possible for fixed corporate debt in one country to be transformed into fixed borrowing in another by combining two interest rate swap deals - one in each currency - and an foreign exchange (FX) swap to eliminate the presence of FX risk. Provided that the interest rate differential between the two countries is substantial, then this form of financial engineering will allow firms to lower their cost of borrowing. In addition, financial engineering can assist market participants to circumvent market or regulatory restrictions. Eom, Subrahmanyam and Uno (2000) report that attempts of market participants to construct a spread position between Japanese government bonds (JGBs) and US treasury bonds combined with difficulties in shorting JGBs, creates an increased demand for Japanese interest rate swaps. This results to an increase in the correlation between Japanese swap rates and the interest rate differential between US treasury bonds and JGBs. Such activities can create direct links between the movements of swap spreads in the two markets. These links can be strengthened even further through common variations in the business cycles of the two economies. Lumsdaine and Prasad (1997) show that business cycles in each economy are not independent; instead they are affected, in

[2] Duffie and Singleton (1997) define liquidity risk as the spread between generic and on-the-run repo rates for the 10-year government bonds, while Lekkos and Milas (2001) define liquidity risk as the difference between the 3-month LIBOR and 3-month T-Bill rates (TED spread).

[3] Lekkos and Milas (2001) have provided some preliminary evidence on the impact of US factors on UK swap markets and Eom, Subrahmanyam and Uno (2000) on the links between US and Japanese swap markets.

different degrees, by a "world business cycle". Due to the dominant size of the US economy, the world business cycle is highly correlated with the US business cycle.[4] Hence, changes in the fundamentals of the US economy, such as the level of interest rates or credit spreads, should affect the UK interest rate swap markets through this business cycle channel.

The current paper complements the existing literature by focussing on the identification of common risk factors priced in the US and UK interest rate swap markets. The risk factors we employ are: the slopes of the term structures of zero-coupon government bonds of the two countries, estimates of the corporate bond spreads of the two countries and the interest rate differentials between the US and UK government bonds. The slopes are included to provide evidence of any default option prices in swap spreads, and the interest rate differentials are used to provide evidence of arbitrage trades between the two markets. The corporate bond spreads are used as proxies for credit risk. Corporate bond spreads are not perfect proxies for credit risk in swap markets. Duffie and Huang (1996) have pointed out that spreads in swap markets should be much lower than the corresponding spreads in corporate debt. This is either due to the fact that a swap can be either an asset or a liability depending on the movements of short-term interest rates or to the existence of credit enhancements such as margins or marking to market in swap markets. Despite these shortcomings, corporate bond spreads are always a major factor in accounting for the dynamics of swap spreads in all previous empirical studies.

We examine the ability of these risk factors to account for the dynamics of the term structure of swap spreads within a non-linear multivariate smooth transition autoregression (STAR) model. A STAR model can be considered as a regime switching model where the transition from one regime to the other occurs in a smooth way. Non-linear models have been used in previous research to either estimate the dynamics of the short-term interest rates or the relationship between the short-term and long-term interest rates implied by the expectations hypothesis (see Ang and Bekaert (2001), Bekaert, Hodrick and Marshall (2001), Hamilton (1988) and Gray (1996)). These studies have employed the Markov regime switching (MRS) methodology pioneered by Hamilton (1989). The main difference between MRS and STAR regime switching methodologies is that MRS assumes that the switching between the two regimes is driven by a Markov state variable, which is unobserved to the econometrician. STAR models on the other hand assume that the switching is controlled by an observed state variable. This feature of the STAR models, that the transition from one regime to the other is not probabilistic but is a function of the underlying variables, allows us to test the ability of the different economic variables to best describe the non-linear dynamics of the term structure swap spreads. More specifically, we find that amongst the different candidates, the slope of the US term structure of interest rates suitably describes the transition between the two regimes in both the US and UK swap spreads across maturities.

The paper is organised as follows. The next section presents the multivariate STAR methodology used for the estimation of our model. Section 3 describes the data and sections 4 and 5 present the estimation and main findings of the paper. The design and results of our forecasting exercise are presented in section 6. Finally, section 7 concludes.

2. Specification of the Smooth Transition Vector Autoregressive (STVAR) model

2.1 *The theoretical STVAR model*

[4] Harvey (1991) found that the correlation between the world and US business cycles is 87%.

Let $\mathbf{y_t} = (y_{1,t}, y_{2,t}, ..., y_{k,t})'$ be a k-dimensional vector of time series. The corresponding STVAR model can be specified as:

$$\mathbf{y}_t = \left(\boldsymbol{\mu}_1 + \sum_{j=1}^{p} \boldsymbol{\Phi}_{1,j} \mathbf{y}_{t-j}\right)(1 - \mathbf{G}(s_t)) + \left(\boldsymbol{\mu}_2 + \sum_{j=1}^{p} \boldsymbol{\Phi}_{2,j} \mathbf{y}_{t-j}\right)\mathbf{G}(s_t) + \boldsymbol{\varepsilon}_t, \qquad (1)$$

where $\boldsymbol{y}_t$ is a (k x 1) time series vector, $\boldsymbol{\Phi}_{1,j}$ and $\boldsymbol{\Phi}_{2,j}$, j = 1,…, p, are (k x k) matrices, $\boldsymbol{\mu}_1$ and $\boldsymbol{\mu}_2$ are $(k \times 1)$ vectors, and $\boldsymbol{\varepsilon}_t \sim iid\,(0, \boldsymbol{\Sigma})$. $\boldsymbol{G}(s_t)$ is a $(k \times 1)$ vector of transition functions that control the regime switching dynamics of $\boldsymbol{y}_t$. The STVAR model is a regime switching model where the transition between the two alternative regimes is controlled by a transition function $g(.)$ which is continuous and bounded between 0 and 1. Values of zero by the transition function identify the one regime and values of 1 identify the alternative and the transition between the two regimes occurs in a smooth way, i.e. the model does not allow jumps from one regime to the other. The regime that occurs at any time t is not probabilistic. Instead it is determined but the transition variable s_t and the functional form of the transition function $g(s_t)$. In this paper we focus our attention on the 'logistic' function:

$$g(s_t;\gamma,c) = \{1 + \exp[-\gamma(s_t - c)/\sigma(s_t)]\}^{-1}, \gamma > 0, \qquad (2)$$

where $\sigma(s_t)$ is the sample standard deviation of s_t. Model (2) allows for asymmetric adjustment to positive and negative deviations of s_t relative to c. The parameter c is the threshold between the two regimes, in the sense that $g(s_t)$ changes monotonically from 0 to 1 as s_t increases, and takes the value of $g(s_t) = 0.5$ at $s_t = c$. The parameter γ determines the smoothness of the change in the value of the logistic function and thus the speed of the transition from one regime to the other. When $\gamma \rightarrow 0$, the 'logistic' function equals a constant (i.e. 0.5), and when $\gamma \rightarrow +\infty$, the transition from $g(s_t) = 0$ to $g(s_t) = 1$ is almost instantaneous at $s_t = c$.

2.2 *Linearity testing in a STVAR model*

Testing for linearity in the STVAR model (1) using the 'logistic' transition model (2) is equivalent to testing the null hypothesis H_0: $\gamma = 0$ against the alternative H_1: $\gamma > 0$. To do this, define $w_t = (y_{1t-1},\ldots, y_{1t-p}, y_{2t-1},\ldots, y_{2t-p},\ldots, y_{kt-1},\ldots, y_{kt-p})$ and assume that the transition variable (denoted by s_t) is known. Following Luukkonen, Saikkonen and Teräsvirta (1988), linearity testing equation by equation is based on a first-order Taylor approximation of the transition function around $\gamma = 0$. We first estimate $y_{it} = \beta_{i0} + \sum_{j=1}^{pk} \beta_{ij} w_{jt} + \varepsilon_{it}$ and then use the estimated residuals e_{it} to run the following regression: $e_{it} = \alpha_{i0} + \sum_{j=1}^{pk} \alpha_{ij} w_{jt} + \sum_{j=1}^{pk} \delta_i s_t w_{jt} + \eta_{it}$.

A Lagrange Multiplier (LM) test can be constructed as: $LM = T\,(SSR_0 - SSR_1) / SSR_0$, where $SSR_0 = \sum e_{it}^2$ and $SSR_1 = \sum v_{it}^2$. Under the null hypothesis of linearity the LM statistic is distributed as a $\chi^2(pk)$. In small samples, the χ^2 test may be heavily oversized. Therefore, it is preferable to use the equivalent F version of the LM test statistic, which is given by

$F = [(SSR_0 - SSR_1) / pk] / [SSR_1 / (T - (2pk + 1))]$. Both the χ^2 and F versions of the LM statistic are equation specific tests for linearity. To test the null hypothesis H_0: $\gamma = 0$ in all equations simultaneously, we need a system-wide test. Following Weise (1999), define $\Omega_0 = \sum e_t e_t' / T$ and $\Omega_1 = \sum v_t v_t' / T$ as the estimated variance-covariance residual matrices from the restricted and the unrestricted estimated equations, respectively. The appropriate log-likelihood system-wide test statistic is given by $LR = T\{ \log|\Omega_0| - \log|\Omega_1| \}$, which, under the null hypothesis of linearity is asymptotically distributed as $\chi^2(pk^2)$.

3. The data

Our data sample consists of weekly observations from June 1991 to June 2001. We estimate our models up to December 1998, retaining the last two and a half years for forecasting analysis. We proxy the slope of the term structure of interest rates (denoted by *USslope* and *UKslope*, respectively) with the difference between the yields of the 10-year default-free zero-coupon bonds and the 3-month T-Bill rates. The US and UK zero-coupon yields are provided by the Bank of England. They are estimated by fitting a set of cubic splines to the prices of observed coupon-paying government bonds. The quality of the fit is controlled by a penalty function that restricts the curvature of the implied forward rates (see Anderson and Sleath (1999)). Zero-coupon yields are also used to estimate the difference between the 3-year, 7-year and 10-year US and UK interest rates, denoted by *dif*_3, *dif*_7 and *dif*_10, respectively. The US corporate spreads (denoted by *UScorp*) are estimated as the difference between Moody's AAA corporate bond yield index and the yields of the 10-year Treasury bonds. The UK corporate spread (denoted by *UKcorp*) is estimated as the difference between the corporate bond yield index provided by Datastream and the 10-year UK government bond yield. Finally, the US and UK swap spreads (denoted by *USsp_i* and *UKsp_i*, respectively, with i = 3, 7 and 10 years) are estimated as the difference between the bootstrapped zero-coupon swap rates and the corresponding maturity default-free zero-coupon rates.

Table 1 reports the descriptive statistics for both the US and UK swap spreads and the relevant risk factors. Based on table 1 we see that on average swap spreads increase with maturity in both markets. In addition, same maturity US and UK swap spreads are roughly equal, although UK swap spreads have higher volatility. The UK slope has also been more volatile compared to the US slope. A big part though of this variation might be related to the period around September 1992 when sterling exited the ERM. The average difference between US and UK interest rates is negative, implying that US interest rates were lower than the UK rates over the sample period. Finally, the mean spread between US corporate and US treasury yields was 119 basis points and the corresponding UK corporate spread was 92 basis points.

4. Estimation of STVAR models

The estimation process begins by defining a vector of state variables; one for each maturity we examine. For each maturity, this vector contains the relevant swap spreads as well as the US and UK term structure slopes, the difference between US and UK interest rates and the US and UK corporate spreads. We focus on the 3-year, 7-year and 10-year maturity swap spreads. For each of these maturities the vector of state variables is given by:

$$\mathbf{y_t} = [USslope, UKslope, dif\_i, UScorp, UKcorp, USsp\_i, UKsp\_i]' \qquad (3)$$

where i = 3, 7 and 10 years.

4.1 *Linearity testing and selection of transition variable*

The first step involves the estimation of a benchmark linear VAR (one for each maturity) and then testing for the existence of non-linearities and selecting the best candidate for the transition variable s_t. Taking into account that a high-order VAR may cause over-fitting and add considerably to the difficulties associated with getting converging estimates for the non-linear models, we restrict our analysis to second order VAR models (i.e. we set p = 2 lags in the linear VAR models (3) above). We have also tried third order VAR models but all third lags turned out to be insignificant. Due to the presence of autocorrelation and heteroskedasticity in our models of weekly swap spreads, all models have been estimated using the Generalised Method of Moments (GMM; see Hansen, 1982), which is robust to heteroskedasticity and autocorrelation of unknown form. All insignificant regressors are dropped based on the χ^2-version of the Wald test.[5]

Having estimated the base linear models, we test for linearity, equation by equation and then test for linearity in the system as a whole. Given the lack of previous work that could guide our selection of transition variables suitable for controlling the non-linear dynamics, we test the performance of all lagged variables in (3), as possible transition candidates s_t. Tables 2 to 4 report equation specific *LM* tests and system-wide *LR* linearity tests for the different transition variable candidates. The common approach is to select the appropriate transition variable associated with the smallest p-value. The results in tables 2 to 4 indicate that all VAR equations react in a non-linear way to all lagged variables in the system. This is particularly true with reference to the *LR* system test of linearity as the corresponding p-values are almost always equal to zero. Therefore, the empirical results make it difficult for us to choose the most appropriate transition variable based on the criterion of the smallest p-value. Given the inability of the non-linearity tests to identify a single variable that can capture the non-linear dynamics of our model, we proceed by using the slope of the US term structure of interest rates as the transition variable. There are several intuitive reasons for this choice. A number of studies have shown that the slope of the term structure of interest rates is closely linked to changes in real economic activity and a reliable predictor of periods of economic expansion and recession (for such evidence in a linear context, see e.g. Estrella and Hardouvelis (1991), Estrella and Mishkin (1995), Dueker (1997) and Stock and Watson (2001), whereas Galbraith and Tkacz (2000) and Venetis, Paya and Peel (2001) report such evidence using non-linear models). Slopes higher than average, tend to precede periods of economic expansion, whereas flat or negative slopes tend to indicate recessions. In addition, the US slope has been found to have significant links to the UK fundamentals. Harvey (1991) reported that the US term structure is significant in forecasting changes in real economic activity in the UK and Ang and Bekaert (2001) provided evidence that the US slope Granger-causes the UK term structure.

4.2 *Estimation of STVAR models*

Next, we proceed by estimating non-linear models for the US and UK spreads. Before doing that, it is worth mentioning that Granger and Teräsvirta (1993) and Teräsvirta (1994) stress particular problems like slow convergence or overestimation associated with estimates of the γ parameter. For this reason, we follow their suggestion in scaling the 'logistic' function (2) by

[5] The estimated linear VARs are not reported here but are available on request.

dividing it by the standard deviation of the transition variable $\sigma(s_t)$, so that γ becomes a scale-free parameter. Based on this scaling, we use $\gamma = 1$ as a starting value and the sample mean of s_t as a starting value for the parameter *c*. The estimates of the second order parsimonious linear VAR equations for the *USsp_i* and *UKsp_i*, (*i* = 3, 7, and 10) are used as starting values for the parameters in the STVAR model (1). In order to conserve space we do not report the estimated coefficients of the three STVAR models we estimate. Instead, we focus on the properties of the transition functions for the six swap spreads[6] and the seven non-linear responses for the six swap spreads.

4.3 *Non-linear impulse responses*

Based on the estimated non-linear STVAR models, impulse response functions (IRFs) are calculated for the US and UK swap spreads. These functions trace out the dynamic response of one variable to a shock in another variable in the system. Within the non-linear framework, we can assess the impact of shocks depending upon regime as well as positive versus negative shocks and large versus small shocks. Therefore, in contrast with linear models, shocks occurring in non-linear models depend on the history of the variables, the sign and the size of the shocks (see e.g. the discussion in Koop, Pesaran and Potter, 1996, and Franses and van Dijk, 2000).

To account for the possibility of correlation of the errors across different equations, the IRFs are orthogonalized. More specifically, the equation errors of the non-linear STVAR models are orthogonalized by a Choleski decomposition so that the covariance matrix of the resulting errors is diagonal (see e.g. Lutkepohl, 1993). One disadvantage of the impulse response analysis is that it is sensitive to the ordering of the variables in the system, meaning that different ordering of the variables may lead to different results. To reduce this problem, the ordering needs to be chosen such that the first variable is the only one with a potential contemporaneous impact on the other variables in the system. Then, the second variable has to be chosen such that it may have a direct impact on all other variables but not on the first one, and so on. The vector of the endogenous variables (y_t) as defined in (3) above, represents the way in which we choose to order the variables in each STVAR. In particular, the US slope is the first variable in the STVAR models. We see this as the most fundamental variable, in the sense that shocks to the US slope may have a contemporaneous effect on all remaining variables, whereas shocks to all other variables may only have lagged effects on the US slope. The UK spread enters last in each STVAR, therefore allowing for potential contemporaneous and lagged effects from all other variables on the swap spread. The decision for the US variables to precede the corresponding UK ones is justified based on the relative size and liquidity of the two markets.

To calculate the non-linear IRFs, we use bootstrapping techniques following Koop, Pesaran and Potter (1996), and Weise (1999). Shocks for periods 0 to *j* are drawn with replacement from the residuals of the non-linear models. For given initial values of the variables, the shocks are fed through the estimated models to compute baseline forecast values of the variables. Next, we repeat the previous procedure using the same initial values and residual draw with one exception: the US slope shock in period 0 (or the 0 period shock to any other variable we wish to assess) is fixed at the standard error of the corresponding non-linear model. As the shocks feed through the estimated models, a new forecast value is computed. The IRF is calculated as the difference between this forecast value and the baseline forecast value for given initial values

[6] We discuss only two transition functions (i.e. the ones related to the US and UK swap spread equations) out of the seven transition functions that each STVAR employs.

and a given shock sequence. Using the procedure discussed above, IRFs are computed for one hundred draws and then averaged so that they become conditional only on initial values. These IRFs are averaged over initial values from subsamples of the data. In particular, IRFs for regime 1 (when the US slope is flat) are averaged over initial values corresponding to all dates where the transition variable is lower than the threshold parameter. To compute IRFs for regime 2 (when the US slope is upward sloping) we use initial values from all dates where the transition variable is higher than the threshold parameter.[7] To account for the possibility that outliers may have affected the average values of the IRFs, we have also computed the medians of the IRFs. This made no qualitative difference to the results reported below.

5. Discussion of the results

5.1 *Regime identification*

The relationship between the values of the transition functions and the US slope is reported in Figure 1. The figure also reports the speed of transition between regimes and the threshold parameter that marks the half-way point between the two regimes. The reported transition functions indicate that a roughly flat US slope (i.e. values of the US slope below the threshold parameter of 1.25% for the 7-year swap spread and approximately 3% for all other swap spreads) corresponds to the first regime, while an upward slopping US term structure corresponds to the alternative regime. The regime identification of our models is reported in Figure 2 which plots the value of the transition function estimated for the 3-year US swap spread over calendar time.[8]

The periods from June 1991 to December 1991 and from January 1995 to December 1998 are classified into the first regime, while the periods from June 1992 to June 1993 and from March 1994 to August 1994 are classified into the second regime. While the regime identification of our models is, for most periods, quite accurate (i.e. values of the transition function are either close to zero or close to one), the economic interpretation of the regime identification is not straightforward. The use of the US slope as an indicator for the transition between the two regimes was motivated by the evidence of previous studies according to which the slope of the term structure of interest rates is a significant indicator of changes in future economic activity and a reliable predictor of economic recessions. According to this rationale, the first regime that corresponds to a flat term structure should correspond to periods of economic recession, while the alternative regime should coincide with periods of economic expansion.

Our regime identification scheme seems to be working well during the beginning of our sample since it captures the recession that ended in December 1991 and the subsequent recovery of the US economy. Nevertheless, the years from 1995 to 1998, which are classified into the first regime, were periods of significant economic expansion and rapid growth of both productivity and GDP. The reason why this period is identified with the first regime is because the US slope (also reported in figure 2) started disinverting by the end of 1994 and continued to trend downwards for the whole of the 1995 to 1998 period despite the fact that these were periods of robust economic growth.[9] As a result of this apparent break in the relationship between the US

7 For a more rigorous analysis on how the IRFs are calculated in a non-linear multivariate framework, see Koop, Pesaran and Potter (1996) and Weise (1999).

8 The remaining transition functions give very similar classification of regimes, and for that reason are not reported.

9 One reason suggested to us for the loss of the predictive power of the term structure is a change in the behaviour of the monetary policy in the US from reactive to proactive, changing interest rates in order to avoid economic

slope and economic activity, the regimes we identify based on the dynamics of the US slope do not correspond to periods of economic expansion or recession.[10]

5.2 *The effect of common risk factors on US and UK swap spreads*

The significance of each risk factor and its ability to explain the dynamics of US and UK swap spreads can be gauged by examining the impulse responses of swap spreads generated by the STVAR models. Each impulse response traces out the impact that a shock to a risk factor has on the swap spreads. The impulse responses presented here allow for three sets of comparisons to be made. First we compare the impact of a given risk factor, i.e. the US slope, across swap spread maturities. We also assess the differential impact that risk factors have across the US and UK interest rate swap markets. An advantage of the non-linear specification of the models is that it allows us to examine the asymmetric effect of shocks to the risk factors occurring during the "flat" slope regime as opposed to shocks occurring during the "upward" slopping regime. Finally, we test for the existence of asymmetric effects of large vs. small and negative vs. positive shocks on swap spreads, in any of the two regimes.

Figures 3 to 5 report the impulse responses for the US swap spreads up to 52 weeks into the future. The impact of shocks to the US slope on the US spreads varies across spread maturities. Shocks to the US slope will increase the short-term (3-year) and lower the long-end (7-year and 10-year) swap spreads in both regimes. The magnitude and the propagation of the shocks are considerably more pronounced in the "flat" slope regime. Increases in the UK slope have a negative impact on US spreads across maturities in the "flat" slope regime and a negligible effect otherwise. The effect of the US and UK interest rate differential also varies according to the regime. A widening of the interest rate differential has a positive short-term impact for US swap spreads in the "upward" slopping regime. Its effect is also positive in the short run during the "flat" slope regime but turns into negative in the medium run. A case where the asymmetry between regimes is most pronounced is the effect of US corporate spreads on US swaps. Corporate spreads are used as proxies for the credit conditions in the economy. Most research has documented a positive relationship between credit risk in corporate and swap markets. In contrast, the evidence we produce clearly indicates that this positive relationship holds only in periods characterised by a flat term structure. On an upward slopping regime positive shocks to US spreads do not signal a deterioration of credit conditions. Instead, these shocks can be a result of increased corporate bond issuance. This can result in lower swap spreads perhaps due to increased liquidity in swap markets, as fixed corporate debt is swapped into floating. A negative relationship is also estimated between the US swap and the UK corporate bond markets during the "flat" slope regime. A plausible mechanism that could create this negative correlation is through UK corporates swapping fixed sterling debt into fixed US debt in periods of low US interest rates. Finally, our empirical results indicate that there is no impact of the 3-year and 7-year UK swap spreads on to the corresponding US spreads.[11] At long end of the market there exists a significant positive impact of UK to US swap spreads, especially in the flat term structure regime.

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slowdowns rather than reacting to them after they occurred. This in particular might have been the case during the Asian crisis in 1997, the Russian crisis in 1998 and the subsequent collapse of the Long Term Capital Management (LTCM) fund.

[10] In contrast, the regime classification reported by Ang and Bekaert (2001) using the Markov regime switching methodology does correspond to the different stages of the business cycle. Nevertheless, their regime classification covers the period from 1972 to 1996 based on monthly observations.

[11] For this reason, impulse responses of 3-year and 7-year US swap spreads to shocks on UK spreads are not reported.

Figures 6 to 8 report the impulse responses for the UK swap spreads under an "upward" slopping and a "flat" US term structure regime. Given that the classification of the regimes is based on the US fundamentals we would expect the impact of only the US variables such as the US slope and the US corporate spread, to vary across regimes. The impulse responses reveal that the impact of both US and UK shocks varies across regimes. Shocks to US slope vary significantly across regimes and across maturities. For the 3-year UK swap spread, shocks to the US slope have a significant positive effect in the long-run in the flat regime and a negative effect in the upward slopping regime. For the 7-year and the 10-year UK swap spreads, shocks to the US slope in the "flat" slope regime have a significant negative effect. In the upward slopping regime the US slope has no impact on the 7-year UK spread but has a significant positive effect on the 10-year UK swap spread. Shocks to the UK slope have always a negative effect on UK swap spreads across regimes and maturities. The effect of the shocks to UK swap spreads is more pronounced and long-lived in the flat US slope regime. Shocks to the differential between the US and UK interest rates have a significant negative effect on the 3-year UK swap spread in both regimes and a negative effect on the 7-year UK spread only in the flat US slope regime. Conversely, shocks to the interest rate differential have a considerable positive effect on the 10-year UK swap spread in the upward slopping regime. Shocks to US corporate spread have a positive effect on UK swap spreads in the short-run and a negative effect in the long-run across both regimes. The impact of the shocks to the UK corporate spread mirrors the effect of the US corporate spreads. The difference is that the shocks are more pronounced in the "flat" slope regime. The dominant role of the US swap market is revealed by comparing the effect of US swap shocks on the UK swap spreads to the effect of UK swap shocks on US spreads. Shocks to the US swap spreads have a significant positive effect on UK swap spreads across maturities especially during the flat US slope regime. On the contrary only shocks to the 10-year UK spreads have an effect on the US swap market. Finally, own shocks to the UK swap spreads have a significant positive effect. For the 3-year and 10-year UK spreads, this effect is more pronounced in the flat term structure regime.

The non-linear framework also allows us to assess the impact of shocks depending on their sign (i.e. positive versus negative shocks) and size (i.e. large versus small shocks). Overall, we find very little evidence in favour of asymmetries across these dimensions. Figure 9 reports the effect of positive versus negative US slope shocks on the 3-year US swap spread in the upward slopping regime. For ease of comparison, the negative shock is multiplied by –1. The impulse responses to positive and negative shocks are very similar. Figure 10 reports the effects of large versus small positive US slope shocks on the 3-year, 7-year and 10-year US swap spreads across regimes. The shocks to the US slope are equal to 1, 2 and 3 standard deviations of its orthogonalized innovation. For ease of comparison, 2 s.e. and 3 s.e. shocks are scaled down by a factor of 2 and 3, respectively. Compared to large (i.e. 2 and 3 s.e.) shocks, small US slope shocks (i.e. 1 s.e. shocks) have a stronger impact on the 3-year and 7-year US swap spreads in the medium run but only in the flat term structure regime.[12]

6. Forecasting analysis

In order to assess the usefulness of our non-linear STVAR models, dynamic out-of-sample forecasts for the US and UK swap spreads are computed over the period from January 1999 to

[12] Detailed impulse responses for the US and UK swap spreads to positive versus negative and large versus small shocks to all variables in the system are available by the authors on request.

June 2001 with forecasting horizons of h = 1, 4, 8, 26, 52, 78, and 104 weeks ahead. Generating dynamic out-of-sample forecasts from non-linear models is more complicated compared with generating forecasts from linear models as the expected value of a non-linear function is different from the function evaluated at the expected value of its argument (see e.g. Brown and Mariano (1989), Granger and Terasvirta (1993), and Franses and Van Dijk (2000), among others). We tackle the issue by adopting in each step of our forecasting exercise a bootstrap method where errors used at step h (h >1) are the average errors obtained from simulating the STVAR model at step h, one thousand times.

The h –step ahead forecasts (h = 1, 4, 8, 26, 52, 78, and 104 weeks ahead) from the STVAR models are compared with the forecasts from the corresponding linear VAR models in (3) as well as those from autoregressive (AR) swap spread models.[13] Forecasting performance is evaluated using the Mean Absolute Error (MAE) and the Mean Squared Error (MSE) criteria. Further, in order to compare the forecasting accuracy of the STVAR relative to the linear VAR and AR models, we employ the Diebold and Mariano (1995) test. Following Diebold and Mariano (1995), the time t loss associated with a forecast of model i (where i = STVAR, Linear VAR, AR) is an arbitrary function of the realisation and prediction, $g(y_t, \hat{y}_{it})$. The loss function is a direct function of the forecast error, that is, $g(y_t, \hat{y}_{it}) = g(e_{it})$. The null hypothesis of equal accuracy of the forecasts of two competing models can be expressed in terms of their corresponding loss functions, $E[g(e_{it})] = E[g(e_{jt})]$, or equivalently in terms of their loss differential, $E[d_t] = 0$, where $d_t \equiv [g(e_{it}) - g(e_{jt})]$. Thus, the "equal accuracy" null hypothesis is equivalent to the null hypothesis that the population mean of the loss-differential series is 0.

Let $\bar{d} = \frac{1}{T}\sum_{t=1}^{T}[g(e_{it}) - g(e_{jt})]$ denote the sample mean loss differential (over T forecasts), and let $g(e_{it})$ be is a general function of forecast errors (e.g. MAE or MSE). Then, $\sqrt{T}(\bar{d} - \mu) \xrightarrow{d} N(0, 2\pi f_d(0))$, where $N(.)$ refers to the normal distribution. The Diebold and Mariano (1995) test is given by:

$$DM = \frac{\bar{d}}{\sqrt{\frac{2\pi \hat{f}_d(0)}{T}}} \xrightarrow{d} N(0,1) \tag{4}$$

where $\hat{f}_d(0)$ is a consistent estimate of the spectral density of the loss differential at frequency 0. To counteract the tendency of the DM test statistic to reject the null too often when it is true in cases where the forecast errors are not bivariate normal, Harvey, Leybourne and Newbold (1997) propose a modified Diebold-Mariano test statistic:

$$DM^* = \left[\frac{T + 1 - 2h + T^{-1}h(h-1)}{T}\right]^{1/2} DM \xrightarrow{d} t_{(T-1)} \tag{5}$$

[13] We use two lags for all AR swap spread equations except for the *USsp*_7 and *USsp*_10 equations where three lags are used; lags are selected based on the Akaike Information Criterion. In all models, the estimated parameters are not updated as new observations become available.

where *DM* is the original Diebold and Mariano (1995) test statistic for *h*-steps ahead forecasts and $t_{(T-1)}$ refers to Student's *t* distribution with $(T - 1)$ degrees of freedom.

The results of our forecasting exercise are reported in tables 5 to 8. The comparison of the forecasting accuracy across models has two dimensions. We test the performance of each model across the term structure of the US and the UK swap spreads and for each spread maturity, we test for forecasting performance across forecasting horizons. In tables 5 to 8 we report the MAE and MSE criteria for the different versions of the US and UK swap spread models. The statistical significance of the forecasting performance of the non-linear STVAR models relative to the linear VAR and AR models is examined using both the *DM* and *DM** tests. We report *p*-values for the *DM* and *DM** statistics against the one-sided alternative that the MAE and MSE of the STVAR models are less than the MAE and MSE of the VAR and AR models, respectively.

Our results in tables 5 and 6 for the US swap spreads suggest forecasting superiority of the STVAR models over both the VAR and AR models for the shorter maturity spreads (i.e. the *USsp*_3 swap spread). In particular, the non-linear *USsp*_3 model outperforms the AR model at all forecast horizons. It also outperforms the VAR model at horizons up to 26 weeks ahead. At longer maturities, the linear VAR models produce the lower MAE and MSE statistics while the non-linear swap models (i.e. the *USsp*_7 and *USsp*_10 equations) offer improved forecasting accuracy only against the AR models and at longer forecast horizons.

For the UK swap spread models, the results in Tables 7 and 8 provide some rather mixed evidence in terms of the forecasting accuracy of the STVAR swap models against the VAR and AR models. Non-linear UK swap spread models outperform the VAR models for shorter maturity UK swaps (i.e. the *UKsp*_3 swap spread) almost at all forecast horizons. On the other hand, longer maturity non-linear UK swap spread models (i.e. the *UKsp*_7 and *UKsp*_10 swap spreads) beat the VAR models at short forecast horizons (up to 8 weeks ahead) and at very long forecast horizons (104 weeks ahead). Longer maturity non-linear UK swap spread models beat the AR models as we move at longer forecast horizons (between 52 and 104 weeks ahead).

Overall, our forecasting exercise shows some evidence of forecasting superiority of the STVAR models against linear models. However, this evidence is not overwhelming, as it appears sensitive to swap spread maturity and different forecast horizons. Other studies assessing the forecasting performance of macroeconomic time series using STAR models also obtain inconclusive results (for more details see the survey of recent developments in STAR models by van Dijk, Teräsvirta and Franses, 2000).

7. Conclusions

This paper discusses the effects of common risk factors in the US and UK interest rate swap markets. Starting from a linear VAR model, we reject linearity in favour of a regime-switching STVAR model for the dynamics of the US and UK swap spreads. Using the slope of the US term structure of interest rates to control the regime-switching dynamics, we are able to identify two distinct regimes in the US and UK interest rate swap markets. The first is characterised by a "flat" term structure of US interest rates, while the alternative is characterised by an "upward" slopping US term structure. The regimes that we identify do not coincide with periods of economic recession and expansion. Our results indicate - although we do not explicitly test this finding - that there has been a structural break in the relationship between the term structure of interest rates and real economic activity in the US. A possible explanation for the breakdown of this "stylised" relationship might be a change in the stance of monetary policy in the US from reactive to proactive, especially in view of the significant external shocks that affected the US economy, such as the Asian and Russian financial crises and the LTCM collapse.

Despite this fact, our model is successful in capturing the non-linear relationship between the risk factors and the US and UK swap spreads. According to our results, the US and UK slopes, the interest rate differentials and the US and UK corporate spreads affect the dynamics of swap spreads. In addition, we report significant asymmetries on the way these risk factors affect the US and UK swap spreads across the two regimes. The option to default is clearly priced in swap spreads since both US and UK slopes have a negative effect on the corresponding spreads across regimes and across maturities (the only exception being the 3-year US swap spread). Nevertheless, we find that the effect of both slopes on the swap spreads is more pronounced during the "flat" slope regime. Another case where significant asymmetries are found is the impact of US corporate spreads on the US swap spreads. Increases in the spreads of US corporate bonds lead to a widening of the US swap spreads only during the "flat" slope regime. On the contrary, positive shocks to the US corporate market have negative effects on the US swap spreads in the "upward" slopping regime. Moreover, we estimate significant asymmetries on the links between the US and US swap markets. UK oriented risk factors have a significant impact on the US swap market only during the "flat" slope regime. During the "upward" slopping regime, the US swap market is dominated by domestic factors. On the contrary, US oriented risk factors affect the UK swap market in both regimes.

We also test for asymmetric responses of the US and UK swap spreads to large and small shocks and negative and positive shocks, but we are not able to detect significant differences in any of the two regimes. Finally, our forecasting exercise shows some evidence of forecasting superiority of the STVAR models against linear univariate and multivariate models. However, this evidence is not overwhelming, as it appears sensitive to swap spread maturity and forecast horizons.

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Table 1

Descriptive statistics

	Mean	Maximum	Minimum	Std. Dev	Skewness	Kurtosis
*USsp*_3	0.353	0.958	0.014	0.193	0.779	2.872
*USsp*_7	0.433	1.141	0.088	0.237	1.167	3.313
*USsp*_10	0.440	1.227	0.093	0.249	1.255	3.792
*UKsp*_3	0.333	1.010	0.002	0.217	0.634	2.358
*UKsp*_7	0.413	1.198	0.002	0.277	0.775	2.306
*UKsp*_10	0.466	1.280	0.003	0.302	0.910	2.635
USslope	1.581	4.141	0.690	1.182	0.382	2.139
UKslope	0.463	3.976	-2.669	1.619	0.196	1.704
*Dif*_3	-1.100	0.699	-5.294	1.097	-0.996	3.986
*Dif*_7	-0.813	1.087	-3.064	0.965	0.106	1.916
*Dif*_10	-0.591	1.323	-2.157	0.991	0.338	1.781
UScorp	1.196	2.150	0.630	0.346	0.759	2.804
UKcorp	0.920	2.068	0.015	0.418	0.257	2.422

Notes: The Table reports descriptive statistics for the swap spreads and the risk factors defined in section 3.

Table 2

Linearity tests for: $\mathbf{y_t}$ = [*USslope, UKslope, dif_3, UScorp, UKcorp, USsp_3, UKsp_3*]′

Transition	*USslope*	*UKslope*	*Dif_3*	*UScorp*	*UKcorp*	*USsp_3*	*UKsp_3*	System *LR*
$USslope_{t-1}$	1.257 [0.505]	2.216 [0.073]	2.006 [0.127]	3.429 [0.004]	1.333 [0.505]	2.533 [0.042]	4.602 [0.001]	196.124 [0.000]
$USslope_{t-2}$	1.409 [0.384]	2.285 [0.060]	1.973 [0.135]	3.250 [0.010]	1.294 [0.520]	2.565 [0.019]	4.351 [0.000]	192.635 [0.000]
$UKslope_{t-1}$	1.035 [0.687]	1.374 [0.405]	2.731 [0.020]	1.874 [0.175]	3.366 [0.004]	2.176 [0.089]	2.468 [0.045]	185.626 [0.000]
$UKslope_{t-2}$	0.983 [0.730]	1.380 [0.423]	2.586 [0.028]	1.587 [0.311]	3.190 [0.005]	1.839 [0.177]	2.104 [0.103]	165.390 [0.002]
Dif_3_{t-1}	1.898 [0.138]	2.338 [0.057]	4.873 [0.000]	3.645 [0.004]	1.996 [0.126]	2.817 [0.015]	3.331 [0.005]	237.312 [0.000]
Dif_3_{t-2}	1.610 [0.258]	2.332 [0.050]	5.235 [0.000]	3.685 [0.001]	1.774 [0.201]	3.213 [0.002]	3.409 [0.001]	238.533 [0.000]
$UScorp_{t-1}$	1.494 [0.315]	3.249 [0.003]	2.769 [0.029]	2.266 [0.054]	2.292 [0.050]	1.360 [0.414]	3.118 [0.012]	192.307 [0.000]
$UScorp_{t-2}$	1.446 [0.350]	3.182 [0.002]	3.071 [0.008]	1.787 [0.189]	2.173 [0.085]	1.431 [0.373]	3.067 [0.008]	186.454 [0.001]
$UKcorp_{t-1}$	1.657 [0.227]	2.221 [0.048]	3.528 [0.006]	3.052 [0.005]	0.253 [0.999]	2.283 [0.053]	3.102 [0.008]	173.278 [0.001]
$UKcorp_{t-2}$	1.290 [0.430]	1.900 [0.136]	4.273 [0.001]	2.315 [0.046]	0.672 [0.912]	2.587 [0.021]	2.439 [0.040]	169.359 [0.000]
$USsp\_3_{t-1}$	1.538 [0.259]	2.035 [0.071]	1.366 [0.374]	2.908 [0.010]	2.346 [0.037]	3.304 [0.004]	3.286 [0.002]	195.074 [0.000]
$USsp\_3_{t-2}$	2.036 [0.070]	1.844 [0.114]	0.404 [0.989]	4.093 [0.000]	2.740 [0.012]	3.839 [0.001]	2.869 [0.011]	196.582 [0.000]
$UKsp\_3_{t-1}$	2.033 [0.103]	2.823 [0.014]	2.224 [0.077]	2.857 [0.015]	1.529 [0.321]	1.024 [0.682]	3.915 [0.000]	196.307 [0.000]
$UKsp\_3_{t-2}$	2.276 [0.047]	3.399 [0.002]	2.400 [0.055]	3.031 [0.015]	1.498 [0.357]	1.056 [0.689]	4.321 [0.000]	212.350 [0.000]

Notes: The Table reports equation specific Lagrange Multiplier *F* statistics and system wide *LR* test statistics together with corresponding bootstrapped *p*-values in square brackets. The *p*-values are derived from bootstrapping with one thousand replications. The null hypothesis is linearity. The alternative hypothesis is the STVAR representation.

Table 3

Linearity tests for: $\mathbf{y_t}$ = [*USslope, UKslope, dif_7, UScorp, UKcorp, USsp_7, UKsp_7*]′

Transition	*USslope*	*UKslope*	*Dif_7*	*UScorp*	*UKcorp*	*USsp_7*	*UKsp_7*	System *LR*
$USslope_{t-1}$	0.912 [0.810]	2.660 [0.025]	1.220 [0.600]	4.675 [0.000]	2.021 [0.132]	2.712 [0.023]	5.222 [0.000]	202.945 [0.000]
$USslope_{t-2}$	0.908 [0.803]	2.504 [0.029]	1.187 [0.637]	5.095 [0.000]	2.357 [0.057]	2.486 [0.046]	4.762 [0.000]	199.752 [0.000]
$UKslope_{t-1}$	2.871 [0.005]	1.387 [0.368]	2.986 [0.012]	2.077 [0.124]	2.761 [0.016]	4.128 [0.000]	3.841 [0.000]	217.641 [0.000]
$UKslope_{t-2}$	2.521 [0.026]	1.507 [0.309]	3.351 [0.005]	1.961 [0.145]	2.486 [0.040]	3.732 [0.001]	4.034 [0.001]	209.398 [0.000]
Dif_7_{t-1}	2.399 [0.034]	2.265 [0.075]	1.129 [0.584]	3.972 [0.002]	1.318 [0.485]	3.635 [0.006]	2.588 [0.030]	181.657 [0.001]
Dif_7_{t-2}	1.837 [0.156]	2.078 [0.111]	1.393 [0.389]	4.271 [0.001]	1.066 [0.679]	2.778 [0.008]	2.910 [0.013]	181.282 [0.000]
$UScorp_{t-1}$	2.363 [0.033]	2.686 [0.010]	1.280 [0.505]	2.111 [0.100]	2.032 [0.096]	1.950 [0.132]	1.064 [0.617]	153.401 [0.003]
$UScorp_{t-2}$	2.085 [0.095]	2.750 [0.014]	1.415 [0.408]	1.771 [0.173]	1.928 [0.134]	1.858 [0.182]	0.991 [0.696]	147.660 [0.013]
$UKcorp_{t-1}$	1.231 [0.527]	2.646 [0.016]	1.963 [0.122]	3.439 [0.004]	0.739 [0.867]	1.737 [0.209]	4.212 [0.002]	175.839 [0.000]
$UKcorp_{t-2}$	1.117 [0.579]	1.779 [0.198]	1.515 [0.341]	2.631 [0.027]	1.150 [0.573]	2.440 [0.042]	3.652 [0.003]	164.223 [0.001]
$USsp\_7_{t-1}$	2.043 [0.088]	1.792 [0.170]	0.799 [0.839]	5.214 [0.000]	2.746 [0.017]	4.401 [0.000]	3.592 [0.000]	217.719 [0.000]
$USsp\_7_{t-2}$	2.224 [0.055]	2.005 [0.094]	0.674 [0.918]	4.271 [0.000]	4.242 [0.000]	4.033 [0.000]	4.606 [0.000]	233.607 [0.000]
$UKsp\_7_{t-1}$	2.499 [0.029]	1.499 [0.315]	1.224 [0.576]	1.854 [0.175]	1.679 [0.247]	4.061 [0.002]	2.178 [0.083]	169.441 [0.000]
$UKsp\_7_{t-2}$	2.769 [0.012]	2.374 [0.045]	0.937 [0.766]	1.561 [0.298]	1.358 [0.459]	2.766 [0.020]	2.590 [0.019]	169.627 [0.000]

Notes: The Table reports equation specific Lagrange Multiplier *F* statistics and system wide *LR* test statistics together with corresponding bootstrapped *p*-values in square brackets. The *p*-values are derived from bootstrapping with one thousand replications. The null hypothesis is linearity. The alternative hypothesis is the STVAR representation.

Table 4

Linearity tests for: $\mathbf{y_t}$ = [*USslope, UKslope, dif_10, UScorp, UKcorp, USsp_10, UKsp_10*]′

Transition	*USslope*	*UKslope*	*Dif*_10	*UScorp*	*UKcorp*	*USsp*_10	*UKsp*_10	System *LR*
USslope$_{t-1}$	1.620 [0.256]	2.401 [0.041]	1.687 [0.288]	3.357 [0.011]	3.000 [0.012]	3.135 [0.008]	7.356 [0.000]	238.697 [0.000]
USslope$_{t-2}$	1.488 [0.327]	2.287 [0.047]	1.491 [0.415]	3.661 [0.000]	3.477 [0.001]	2.601 [0.027]	7.363 [0.000]	235.272 [0.000]
UKslope$_{t-1}$	2.237 [0.076]	1.826 [0.151]	1.298 [0.542]	2.579 [0.041]	2.498 [0.036]	2.298 [0.075]	4.720 [0.000]	198.273 [0.000]
UKslope$_{t-2}$	2.034 [0.110]	1.907 [0.113]	1.940 [0.146]	2.219 [0.086]	2.501 [0.041]	2.257 [0.058]	5.376 [0.000]	203.034 [0.000]
*Dif*_10$_{t-1}$	2.457 [0.026]	2.709 [0.018]	1.190 [0.577]	3.347 [0.008]	2.318 [0.039]	2.285 [0.054]	3.935 [0.000]	191.676 [0.000]
*Dif*_10$_{t-2}$	2.095 [0.082]	2.678 [0.021]	1.480 [0.347]	3.564 [0.002]	2.607 [0.029]	2.022 [0.094]	4.595 [0.000]	205.890 [0.000]
UScorp$_{t-1}$	1.857 [0.135]	3.117 [0.004]	1.553 [0.324]	1.684 [0.216]	3.143 [0.006]	1.802 [0.148]	2.186 [0.065]	170.599 [0.001]
UScorp$_{t-2}$	1.763 [0.181]	2.991 [0.005]	1.864 [0.153]	1.641 [0.211]	2.917 [0.007]	1.242 [0.477]	1.569 [0.258]	159.198 [0.002]
UKcorp$_{t-1}$	1.462 [0.327]	2.080 [0.083]	2.232 [0.075]	2.955 [0.013]	1.211 [0.530]	1.663 [0.232]	4.490 [0.000]	177.863 [0.000]
UKcorp$_{t-2}$	1.385 [0.398]	1.711 [0.198]	1.858 [0.155]	2.535 [0.037]	1.541 [0.300]	2.391 [0.052]	4.615 [0.000]	182.120 [0.000]
*USsp*_10$_{t-1}$	3.340 [0.002]	1.978 [0.075]	1.090 [0.614]	4.452 [0.000]	2.891 [0.009]	4.330 [0.001]	4.072 [0.001]	259.323 [0.000]
*USsp*_10$_{t-2}$	3.603 [0.000]	2.565 [0.025]	1.938 [0.140]	4.451 [0.000]	4.184 [0.000]	3.865 [0.000]	4.903 [0.000]	288.208 [0.000]
*UKsp*_10$_{t-1}$	3.100 [0.001]	2.924 [0.003]	2.325 [0.047]	3.956 [0.000]	2.902 [0.006]	1.527 [0.305]	4.078 [0.000]	227.762 [0.000]
*UKsp*_10$_{t-2}$	3.648 [0.000]	2.810 [0.011]	3.054 [0.011]	4.068 [0.001]	3.295 [0.008]	1.227 [0.497]	5.616 [0.000]	254.790 [0.000]

Notes: The Table reports equation specific Lagrange Multiplier *F* statistics and system wide *LR* test statistics together with corresponding bootstrapped *p*-values in square brackets. The *p*-values are derived from bootstrapping with one thousand replications. The null hypothesis is linearity. The alternative hypothesis is the STVAR representation.

Table 5

Forecast evaluation for the US swap spreads using
Mean Absolute Error (MAE)

h	STVAR model	VAR model	AR model	*DM* (VAR vs. STVAR)	*DM** (VAR vs. STVAR)	*DM* (AR vs. STVAR)	*DM** (AR vs. STVAR)
				*USsp*_3			
1	0.050	0.069	0.053	[0.000]	[0.000]	[0.084]	[0.085]
4	0.082	0.135	0.093	[0.000]	[0.000]	[0.089]	[0.095]
8	0.110	0.183	0.145	[0.003]	[0.004]	[0.019]	[0.026]
26	0.197	0.242	0.315	[0.001]	[0.009]	[0.000]	[0.003]
52	0.284	0.272	0.406	[0.500]	[0.501]	[0.000]	[0.001]
78	0.297	0.247	0.403	[0.900]	[0.901]	[0.000]	[0.000]
104	0.250	0.163	0.341	[0.999]	[0.999]	[0.000]	[0.000]
				*USsp*_7			
1	0.071	0.065	0.060	[0.992]	[0.991]	[0.999]	[0.999]
4	0.132	0.105	0.088	[0.994]	[0.993]	[0.999]	[0.999]
8	0.192	0.138	0.126	[0.999]	[0.999]	[0.999]	[0.999]
26	0.349	0.220	0.290	[1.000]	[1.000]	[0.907]	[0.842]
52	0.429	0.296	0.468	[1.000]	[1.000]	[0.000]	[0.000]
78	0.408	0.289	0.522	[1.000]	[1.000]	[0.000]	[0.011]
104	0.301	0.154	0.439	[1.000]	[1.000]	[0.000]	[0.000]
				*USsp*_10			
1	0.081	0.011	0.067	[1.000]	[1.000]	[0.999]	[0.999]
4	0.151	0.124	0.123	[0.999]	[0.998]	[0.973]	[0.969]
8	0.183	0.148	0.198	[0.997]	[0.996]	[0.201]	[0.216]
26	0.289	0.220	0.407	[1.000]	[1.000]	[0.000]	[0.000]
52	0.384	0.293	0.542	[1.000]	[1.000]	[0.000]	[0.000]
78	0.365	0.251	0.437	[1.000]	[1.000]	[0.000]	[0.000]
104	0.218	0.070	0.385	[1.000]	[1.000]	[0.000]	[0.000]

Notes: The forecasting period runs from 1999:1 to 2001:26. *h* = Forecast horizon: 1, 4, 8, 26, 52, 78 and 104 weeks ahead. Figures in [•] contain the *p*-values for the *DM* forecast comparison statistic of Diebold and Mariano (1995) and the modified *DM** statistic of Harvey, Leybourne and Newbold (1997) against the one-sided alternative that the MAE of the STVAR is less than the MAE of the VAR and AR models, respectively.

Table 6

Forecast evaluation for the US swap spreads using
Mean Squared Error (MSE)

h	STVAR model	VAR model	AR model	*DM* (VAR vs. STVAR)	*DM** (VAR vs. STVAR)	*DM* (AR vs. STVAR)	*DM** (AR vs. STVAR)
				*USsp*_3			
1	0.005	0.008	0.006	[0.000]	[0.000]	[0.108]	[0.108]
4	0.010	0.028	0.013	[0.000]	[0.000]	[0.044]	[0.048]
8	0.019	0.049	0.030	[0.003]	[0.004]	[0.023]	[0.030]
26	0.048	0.069	0.112	[0.006]	[0.028]	[0.003]	[0.017]
52	0.092	0.087	0.177	[0.511]	[0.531]	[0.000]	[0.000]
78	0.100	0.072	0.173	[0.900]	[0.900]	[0.000]	[0.000]
104	0.071	0.035	0.125	[0.999]	[0.999]	[0.000]	[0.000]
				*USsp*_7			
1	0.009	0.008	0.007	[0.935]	[0.934]	[0.998]	[0.998]
4	0.026	0.018	0.013	[0.993]	[0.991]	[0.999]	[0.999]
8	0.053	0.031	0.026	[0.997]	[0.995]	[0.999]	[0.999]
26	0.144	0.074	0.113	[0.997]	[0.984]	[0.851]	[0.785]
52	0.205	0.114	0.245	[1.000]	[1.000]	[0.000]	[0.000]
78	0.185	0.100	0.290	[1.000]	[1.000]	[0.000]	[0.000]
104	0.101	0.032	0.202	[1.000]	[1.000]	[0.000]	[0.000]
				*USsp*_10			
1	0.011	0.009	0.007	[1.000]	[1.000]	[0.999]	[0.994]
4	0.040	0.026	0.023	[0.999]	[0.998]	[0.995]	[0.994]
8	0.059	0.040	0.056	[0.990]	[0.985]	[0.634]	[0.626]
26	0.117	0.086	0.206	[1.000]	[1.000]	[0.001]	[0.007]
52	0.187	0.129	0.331	[1.000]	[1.000]	[0.000]	[0.000]
78	0.164	0.090	0.207	[1.000]	[1.000]	[0.000]	[0.000]
104	0.053	0.008	0.153	[0.995]	[1.000]	[0.000]	[0.000]

Notes: The forecasting period runs from 1999:1 to 2001:26. *h* = Forecast horizon: 1, 4, 8, 26, 52, 78 and 104 weeks ahead. Figures in [•] contain the *p*-values for the *DM* forecast comparison statistic of Diebold and Mariano (1995) and the modified *DM** statistic of Harvey, Leybourne and Newbold (1997) against the one-sided alternative that the MSE of the STVAR is less than the MSE of the VAR and AR models, respectively.

Table 7

Forecast evaluation for the UK swap spreads using
Mean Absolute Error (MAE)

h	STVAR model	VAR model	AR model	*DM* (VAR vs. STVAR)	*DM** (VAR vs. STVAR)	*DM* (AR vs. STVAR)	*DM** (AR vs. STVAR)
				*UKsp*_3			
1	0.042	0.056	0.037	[0.000]	[0.000]	[0.997]	[0.997]
4	0.078	0.108	0.054	[0.000]	[0.000]	[0.996]	[0.995]
8	0.109	0.144	0.071	[0.019]	[0.025]	[0.975]	[0.967]
26	0.109	0.160	0.116	[0.229]	[0.287]	[0.393]	[0.418]
52	0.108	0.214	0.122	[0.115]	[0.337]	[0.397]	[0.464]
78	0.105	0.315	0.124	[0.020]	[0.167]	[0.359]	[0.434]
104	0.122	0.463	0.065	[0.000]	[0.000]	[0.879]	[0.999]
				*UKsp*_7			
1	0.063	0.064	0.038	[0.197]	[0.197]	[0.999]	[0.999]
4	0.113	0.128	0.072	[0.060]	[0.065]	[0.990]	[0.988]
8	0.136	0.147	0.093	[0.277]	[0.289]	[0.888]	[0.874]
26	0.184	0.164	0.175	[0.612]	[0.585]	[0.786]	[0.726]
52	0.217	0.174	0.273	[0.678]	[0.564]	[0.001]	[0.143]
78	0.207	0.145	0.282	[0.888]	[0.898]	[0.000]	[0.000]
104	0.101	0.287	0.196	[0.019]	[0.000]	[0.000]	[0.000]
				*UKsp*_10			
1	0.044	0.057	0.042	[0.000]	[0.000]	[0.757]	[0.756]
4	0.072	0.109	0.083	[0.000]	[0.000]	[0.101]	[0.107]
8	0.093	0.136	0.110	[0.014]	[0.020]	[0.154]	[0.169]
26	0.170	0.209	0.244	[0.253]	[0.307]	[0.048]	[0.103]
52	0.249	0.213	0.402	[0.719]	[0.580]	[0.000]	[0.000]
78	0.259	0.162	0.434	[0.999]	[0.999]	[0.000]	[0.000]
104	0.110	0.227	0.327	[0.000]	[0.000]	[0.000]	[0.000]

Notes: The forecasting period runs from 1999:1 to 2001:26. *h* = Forecast horizon: 1, 4, 8, 26, 52, 78 and 104 weeks ahead. Figures in [•] contain the *p*-values for the *DM* forecast comparison statistic of Diebold and Mariano (1995) and the modified *DM** statistic of Harvey, Leybourne and Newbold (1997) against the one-sided alternative that the MAE of the STVAR is less than the MAE of the VAR and AR models, respectively.

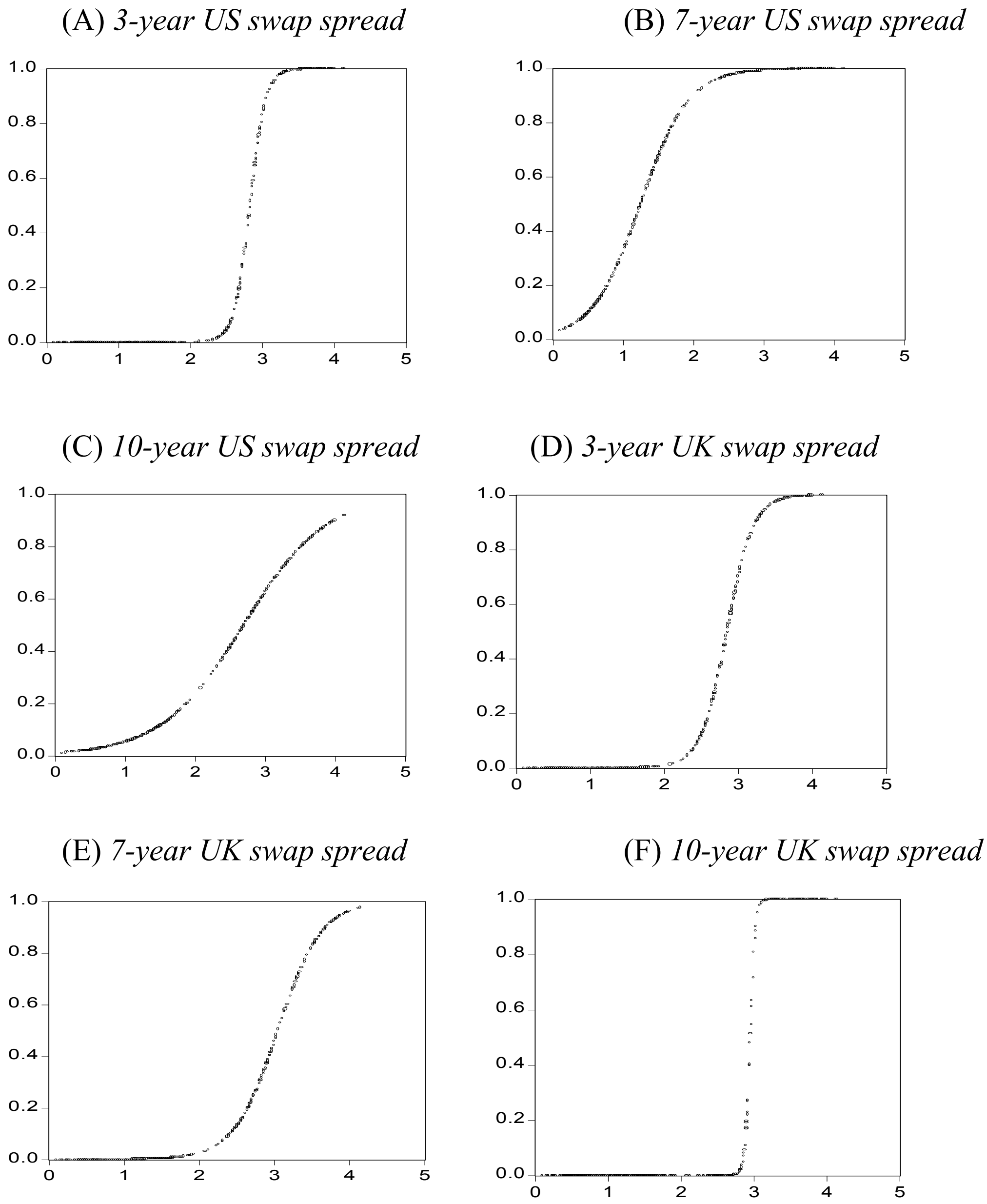
Table 8

Forecast evaluation for the UK swap spreads using
Mean Squared Error (MSE)

h	STVAR model	VAR model	AR model	*DM* (VAR vs. STVAR)	*DM** (VAR vs. STVAR)	*DM* (AR vs. STVAR)	*DM** (AR vs. STVAR)
			*UKsp*_3				
1	0.003	0.005	0.002	[0.000]	[0.000]	[0.998]	[0.998]
4	0.009	0.017	0.005	[0.000]	[0.000]	[0.994]	[0.993]
8	0.017	0.030	0.009	[0.018]	[0.024]	[0.954]	[0.944]
26	0.016	0.044	0.022	[0.163]	[0.229]	[0.236]	[0.293]
52	0.016	0.066	0.021	[0.122]	[0.342]	[0.394]	[0.463]
78	0.016	0.114	0.021	[0.062]	[0.237]	[0.398]	[0.453]
104	0.019	0.219	0.007	[0.000]	[0.000]	[0.887]	[0.999]
			*UKsp*_7				
1	0.006	0.007	0.003	[0.373]	[0.373]	[0.999]	[0.999]
4	0.019	0.024	0.008	[0.079]	[0.085]	[0.993]	[0.992]
8	0.029	0.035	0.013	[0.200]	[0.215]	[0.908]	[0.894]
26	0.041	0.038	0.044	[0.541]	[0.531]	[0.341]	[0.378]
52	0.072	0.044	0.096	[0.838]	[0.635]	[0.000]	[0.000]
78	0.055	0.036	0.110	[0.887]	[0.887]	[0.000]	[0.000]
104	0.013	0.091	0.049	[0.036]	[0.000]	[0.000]	[0.000]
			*UKsp*_10				
1	0.003	0.005	0.003	[0.000]	[0.000]	[0.535]	[0.534]
4	0.008	0.016	0.011	[0.000]	[0.000]	[0.069]	[0.075]
8	0.012	0.025	0.020	[0.016]	[0.021]	[0.067]	[0.079]
26	0.041	0.056	0.090	[0.240]	[0.297]	[0.023]	[0.066]
52	0.095	0.066	0.208	[0.930]	[0.697]	[0.000]	[0.000]
78	0.089	0.043	0.233	[0.999]	[0.999]	[0.000]	[0.000]
104	0.017	0.062	0.120	[0.000]	[0.000]	[0.000]	[0.000]

Notes: The forecasting period runs from 1999:1 to 2001:26. h = Forecast horizon: 1, 4, 8, 26, 52, 78 and 104 weeks ahead. Figures in [•] contain the p-values for the *DM* forecast comparison statistic of Diebold and Mariano (1995) and the modified *DM** statistic of Harvey, Leybourne and Newbold (1997) against the one-sided alternative that the MSE of the STVAR is less than the MSE of the VAR and AR models, respectively.

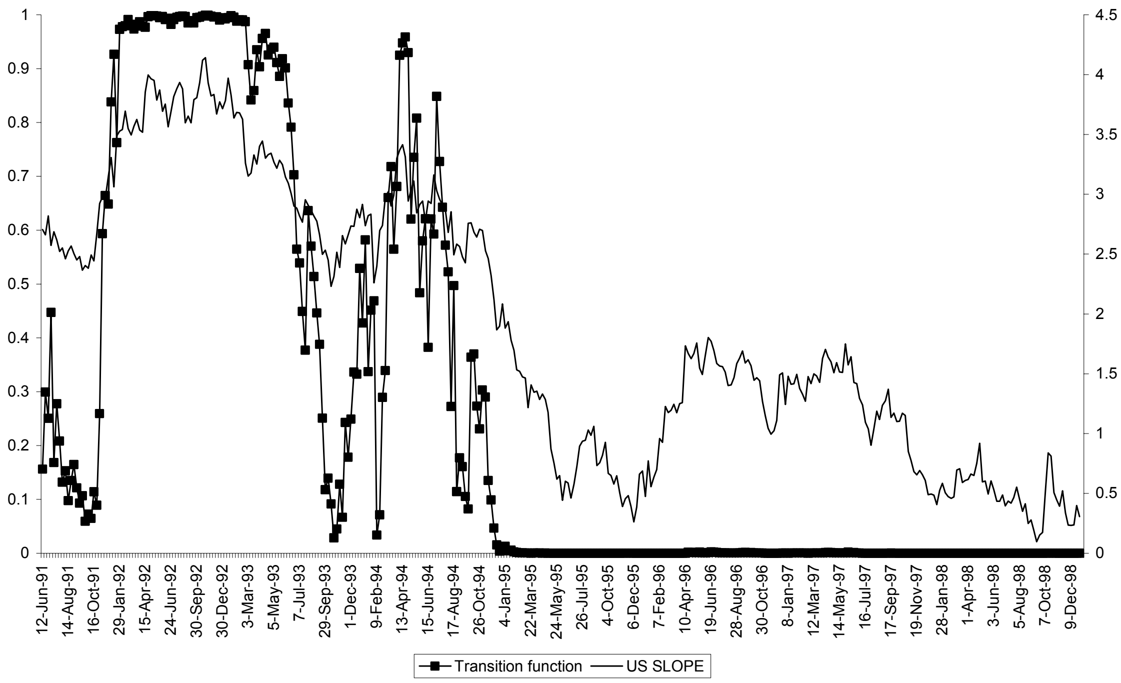
Figure 1: Estimated transition functions (vertical axis) against $s_{t\text{-}1}$ = $USslope_{t\text{-}1}$ (horizontal axis):



Notes:
Panels A, B, C, D, E and F plot the estimated transition functions for $USsp\_3_t$, $USsp\_7_t$, $USsp\_10_t$, $UKsp\_3_t$, $UKsp\_7_t$, and $UKsp\_10_t$ (vertical axis) against the transition variable $s_{t\text{-}1}$ = $USslope_{t\text{-}1}$ (horizontal axis in percent) from the corresponding STVAR models. The estimated transition functions are:

(A) $g(USslope_{t\text{-}1};\ \gamma, c) = \{1 + \exp[-10.528(USslope_{t\text{-}1} - 2.837) / \sigma(USslope_{t\text{-}1})]\}^{-1}$ for the $USsp\_3_t$ model
(B) $g(USslope_{t\text{-}1};\ \gamma, c) = \{1 + \exp[-3.342(USslope_{t\text{-}1} - 1.255) / \sigma(USslope_{t\text{-}1})]\}^{-1}$ for the $USsp\_7_t$ model
(C) $g(USslope_{t\text{-}1};\ \gamma, c) = \{1 + \exp[-1.928(USslope_{t\text{-}1} - 2.702) / \sigma(USslope_{t\text{-}1})]\}^{-1}$ for the $USsp\_10_t$ model
(D) $g(USslope_{t\text{-}1};\ \gamma, c) = \{1 + \exp[-6.420(USslope_{t\text{-}1} - 2.856) / \sigma(USslope_{t\text{-}1})]\}^{-1}$ for the $UKsp\_3_t$ model
(E) $g(USslope_{t\text{-}1};\ \gamma, c) = \{1 + \exp[-3.920(USslope_{t\text{-}1} - 3.056) / \sigma(USslope_{t\text{-}1})]\}^{-1}$ for the $UKsp\_7_t$ model
(F) $g(USslope_{t\text{-}1};\ \gamma, c) = \{1 + \exp[-32.272(USslope_{t\text{-}1} - 2.957) / \sigma(USslope_{t\text{-}1})]\}^{-1}$ for the $UKsp\_10_t$ model

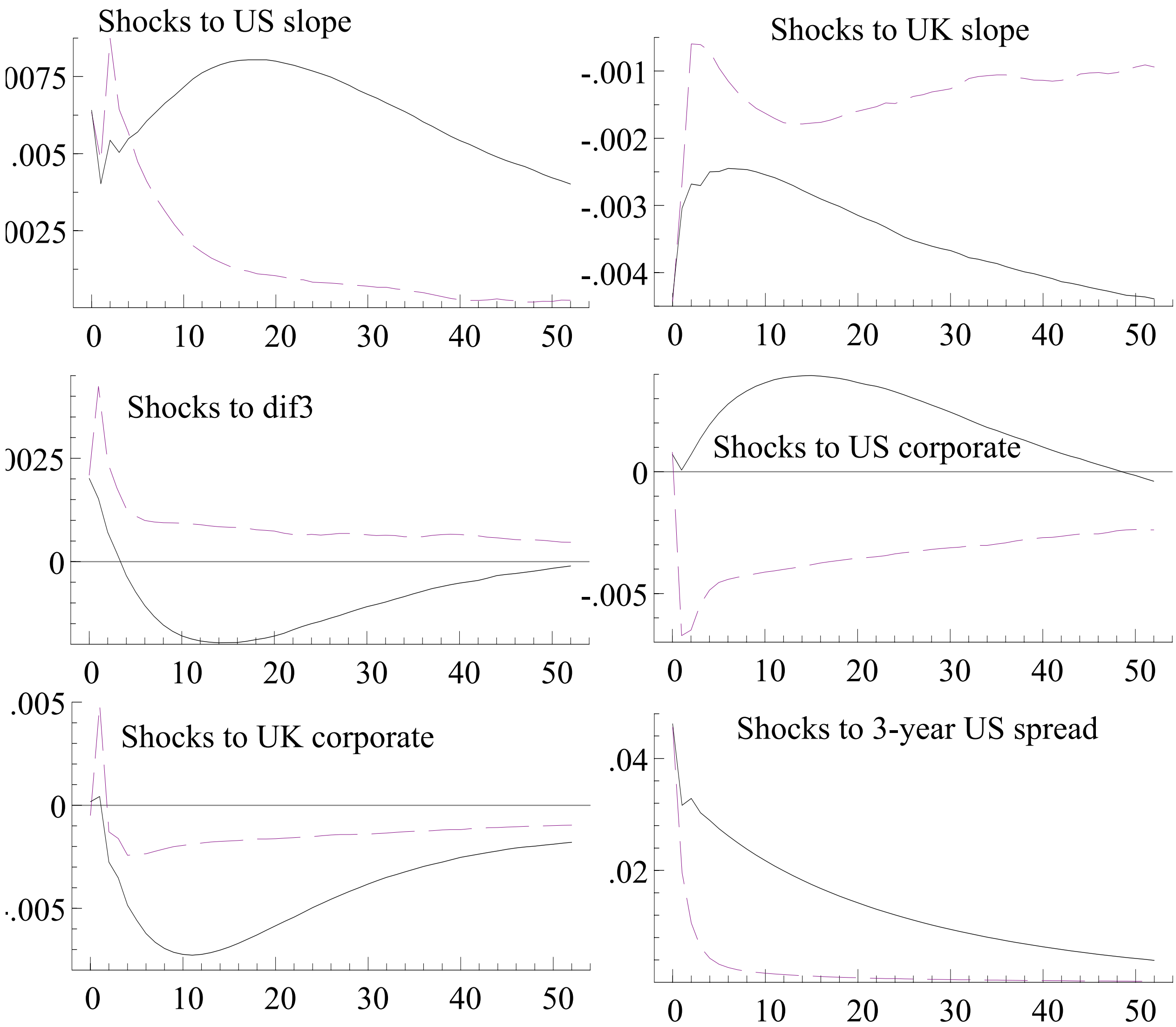
Figure 2: Regime classification and the slope of the US term structure of interest rates



Notes:

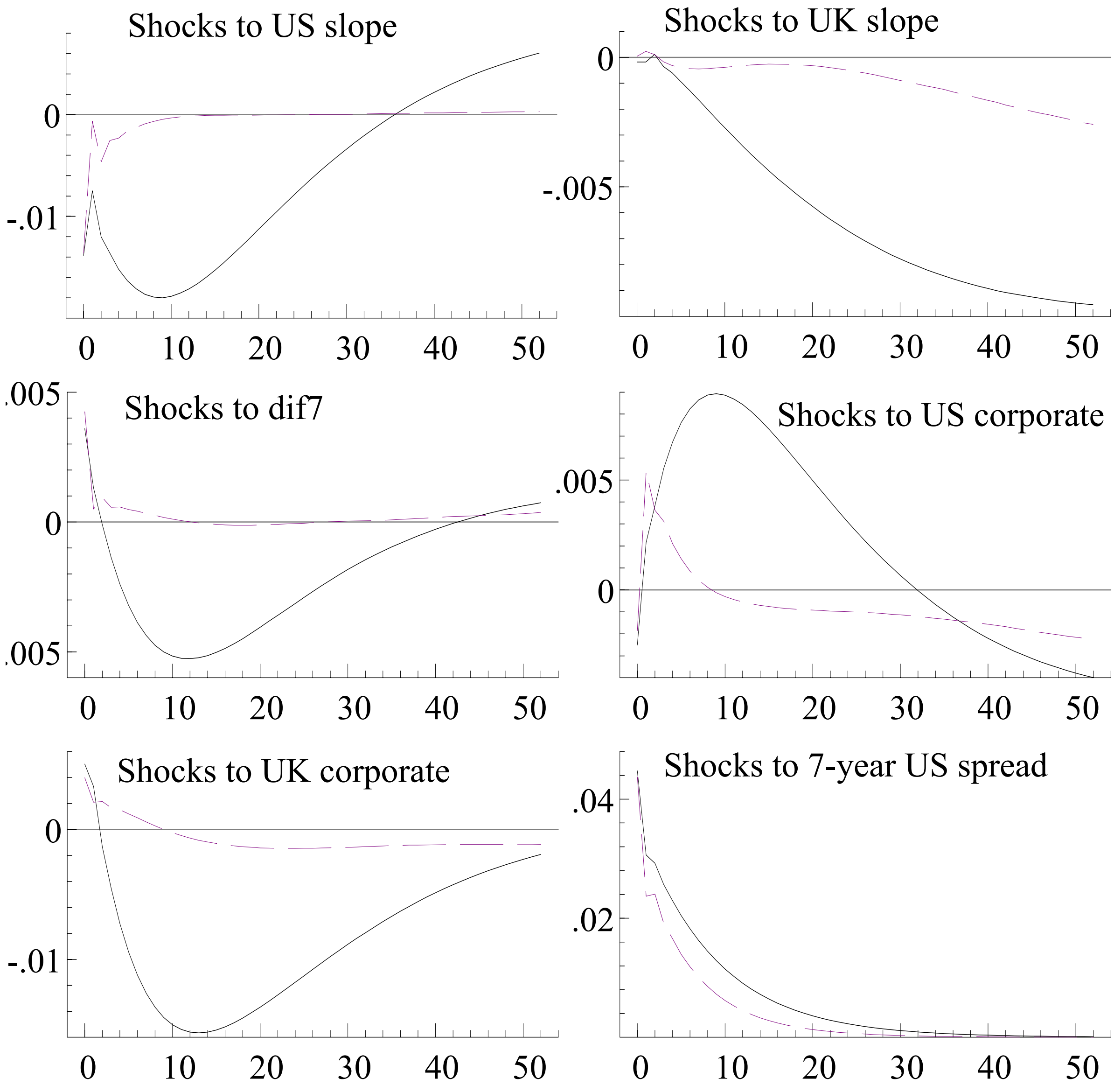
The figure plots the slope of the US term structure (solid line, right-hand axis, in percent) and the 3-year US swap spread transition function (line with blocks, left-hand axis) over time. Values of the transition function close to zero identify a period with the first regime while values of the transition function close to one identify a period with the second regime.

Figure 3: Impulse responses for the 3-year US swap spread (1-s.e. positive shocks)



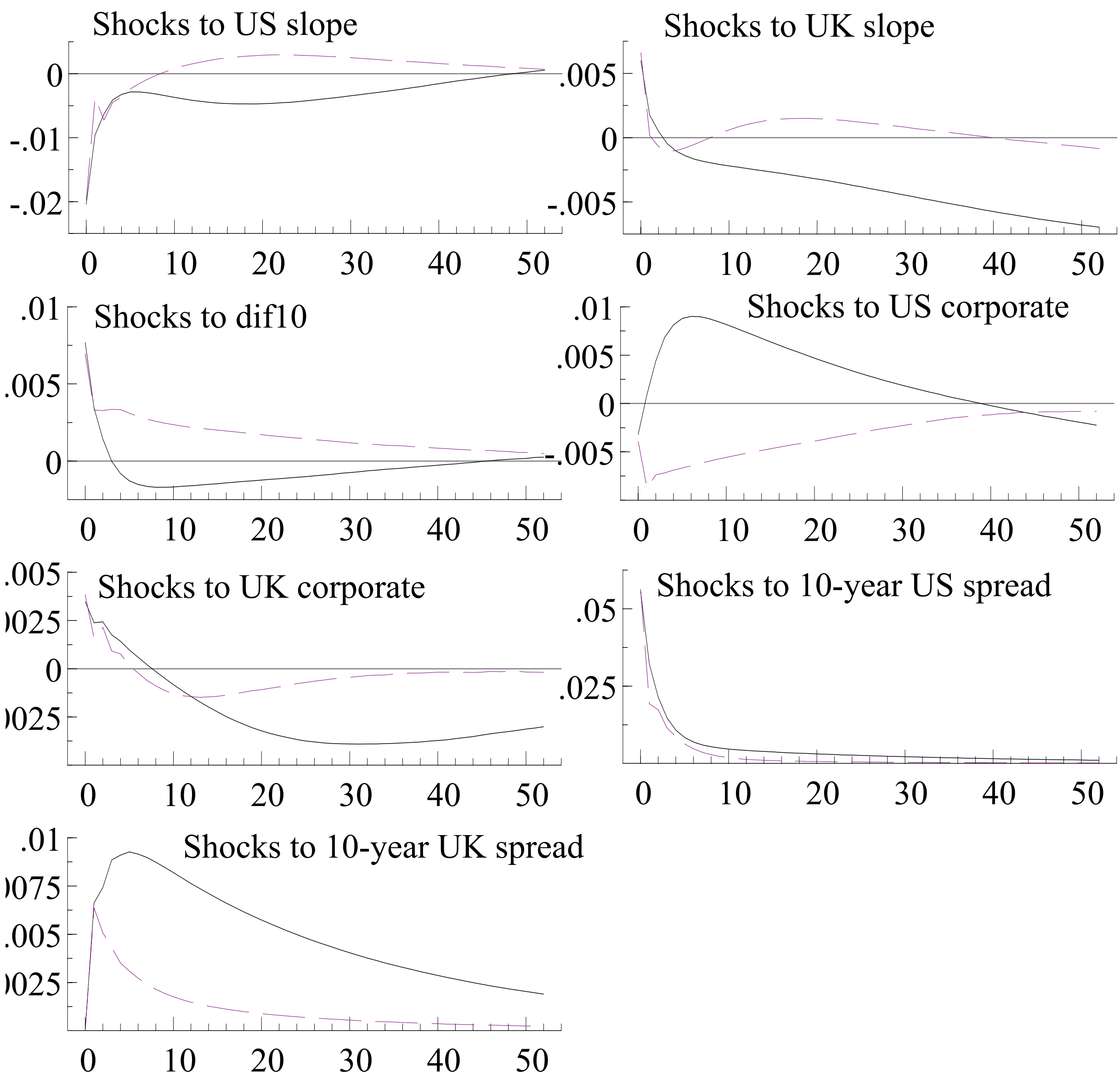
Notes:
The figure reports the impulse responses for the STVAR model described in equation (1) for the 3-year US swap spread. The impulse responses represent the effect on the 3-year US swap spread over a period of 52 weeks, of shocks to all the variables included in the system. The shock to each variable is equal to 1 standard deviation of its orthogonalized innovation. The solid line represents the impulse responses conditional on the system being at the flat term structure regime. The dashed line represents the impulse responses conditional on the system being at the upward slopping term structure regime.

Figure 4: Impulse responses for the 7-year US swap spread (1-s.e. positive shocks)



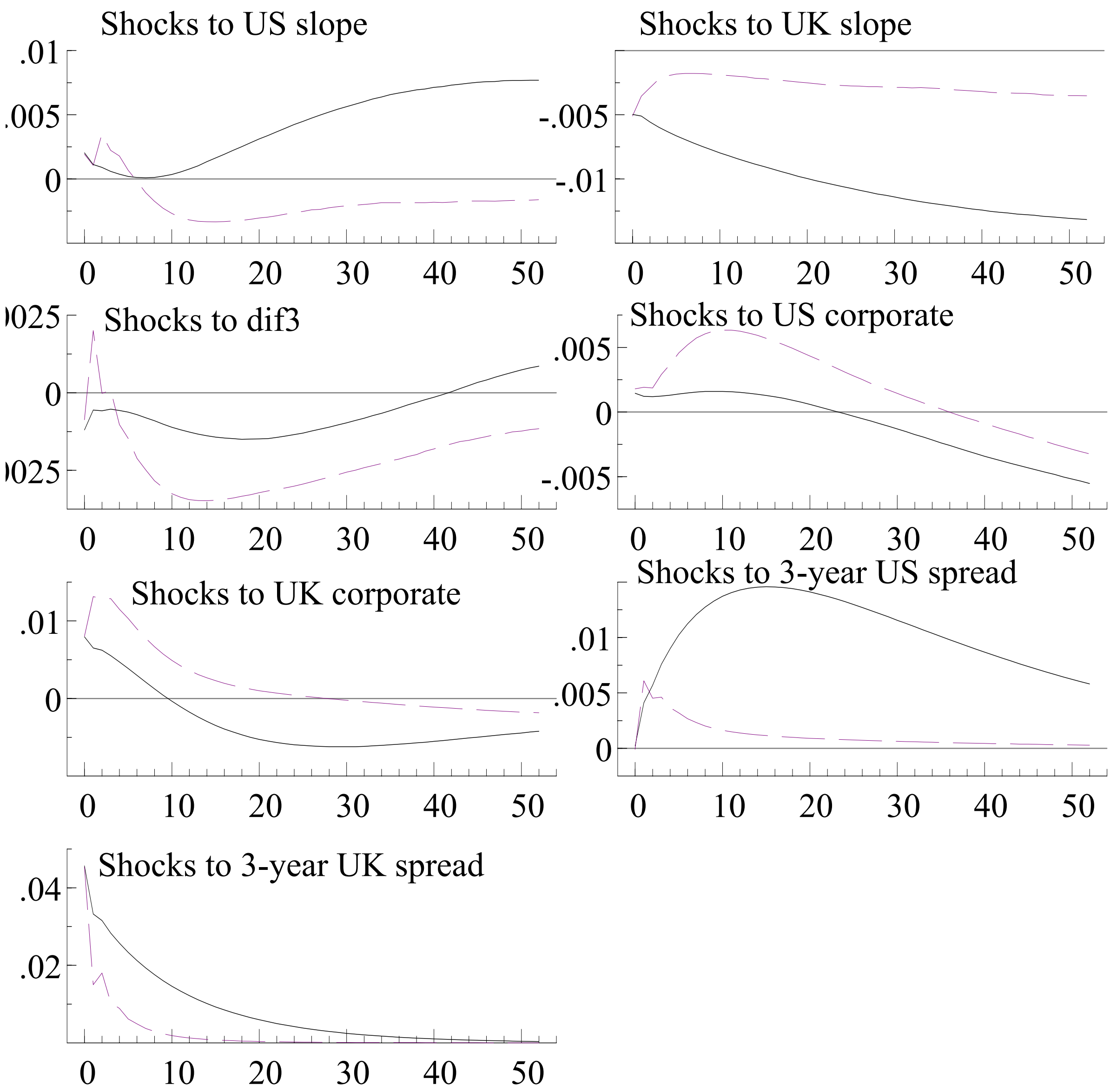
Notes:
The figure reports the impulse responses for the STVAR model described in equation (1) for the 7-year US swap spread. The impulse responses represent the effect on the 7-year US swap spread over a period of 52 weeks, of shocks to all the variables included in the system. The shock to each variable is equal to 1 standard deviation of its orthogonalized innovation. The solid line represents the impulse responses conditional on the system being at the flat term structure regime. The dashed line represents the impulse responses conditional on the system being at the upward slopping term structure regime.

Figure 5: Impulse responses for the 10-year US swap spread (1-s.e. positive shocks)



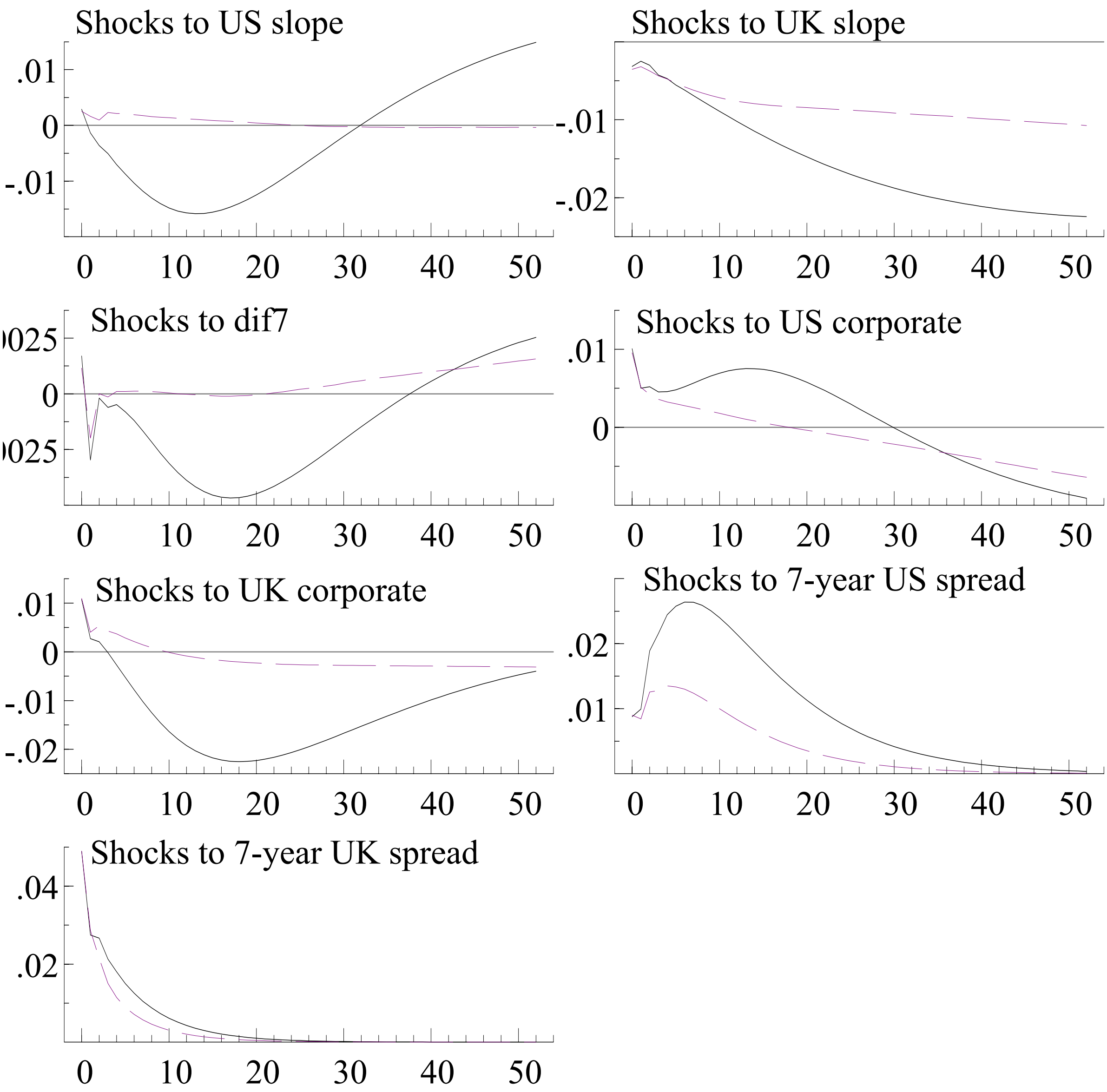
Notes:
The figure reports the impulse responses for the STVAR model described in equation (1) for the 10-year US swap spread. The impulse responses represent the effect on the 10-year US swap spread over a period of 52 weeks, of shocks to all the variables included in the system. The shock to each variable is equal to 1 standard deviation of its orthogonalized innovation. The solid line represents the impulse responses conditional on the system being at the flat term structure regime. The dashed line represents the impulse responses conditional on the system being at the upward slopping term structure regime.

Figure 6: Impulse responses for the 3-year UK swap spread (1-s.e. positive shocks)



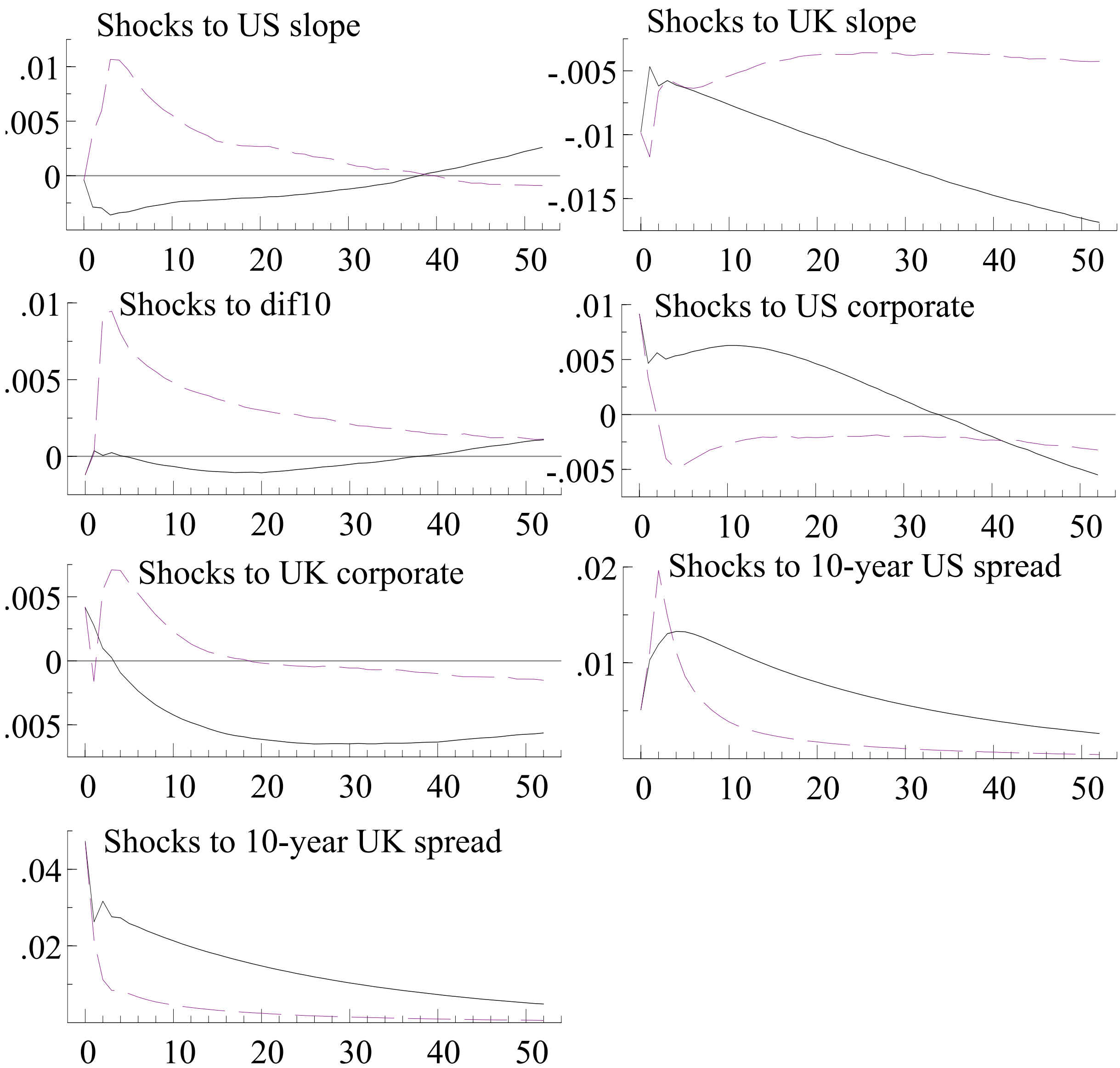
Notes:
The figure reports the impulse responses for the STVAR model described in equation (1) for the 3-year UK swap spread. The impulse responses represent the effect on the 3-year UK swap spread over a period of 52 weeks, of shocks to all the variables included in the system. The shock to each variable is equal to 1 standard deviation of its orthogonalized innovation. The solid line represents the impulse responses conditional on the system being at the flat term structure regime. The dashed line represents the impulse responses conditional on the system being at the upward slopping term structure regime.

Figure 7: Impulse responses for the 7-year UK swap spread (1-s.e. positive shocks)



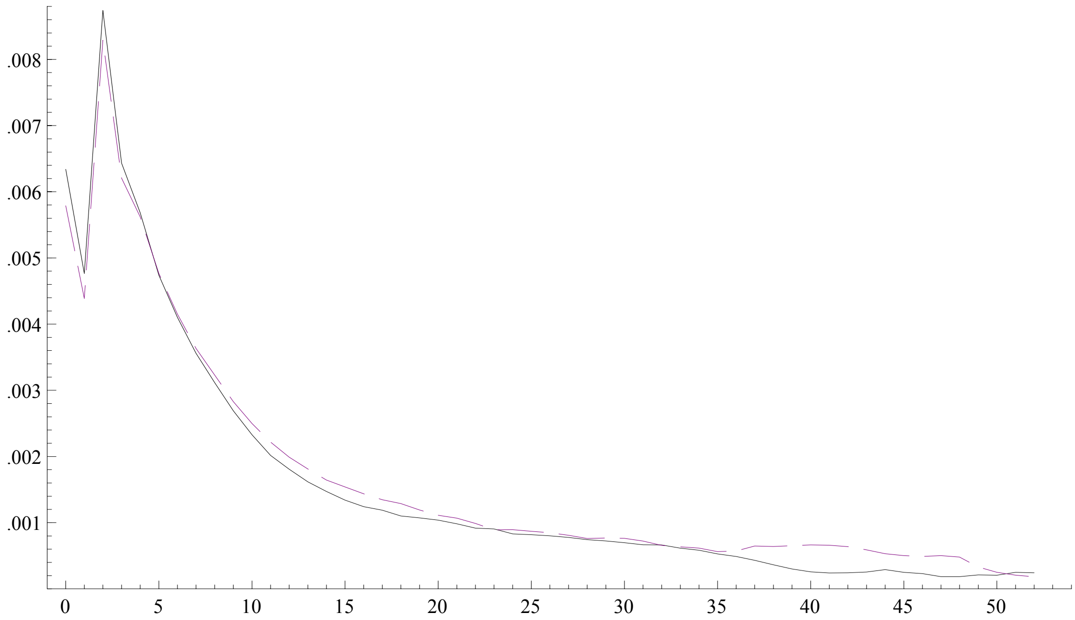
Notes:
The figure reports the impulse responses for the STVAR model described in equation (1) for the 7-year UK swap spread. The impulse responses represent the effect on the 7-year UK swap spread over a period of 52 weeks, of shocks to all the variables included in the system. The shock to each variable is equal to 1 standard deviation of its orthogonalized innovation. The solid line represents the impulse responses conditional on the system being at the flat term structure regime. The dashed line represents the impulse responses conditional on the system being at the upward slopping term structure regime.

Figure 8: Impulse responses for the 10-year UK swap spread (1-s.e. positive shocks)



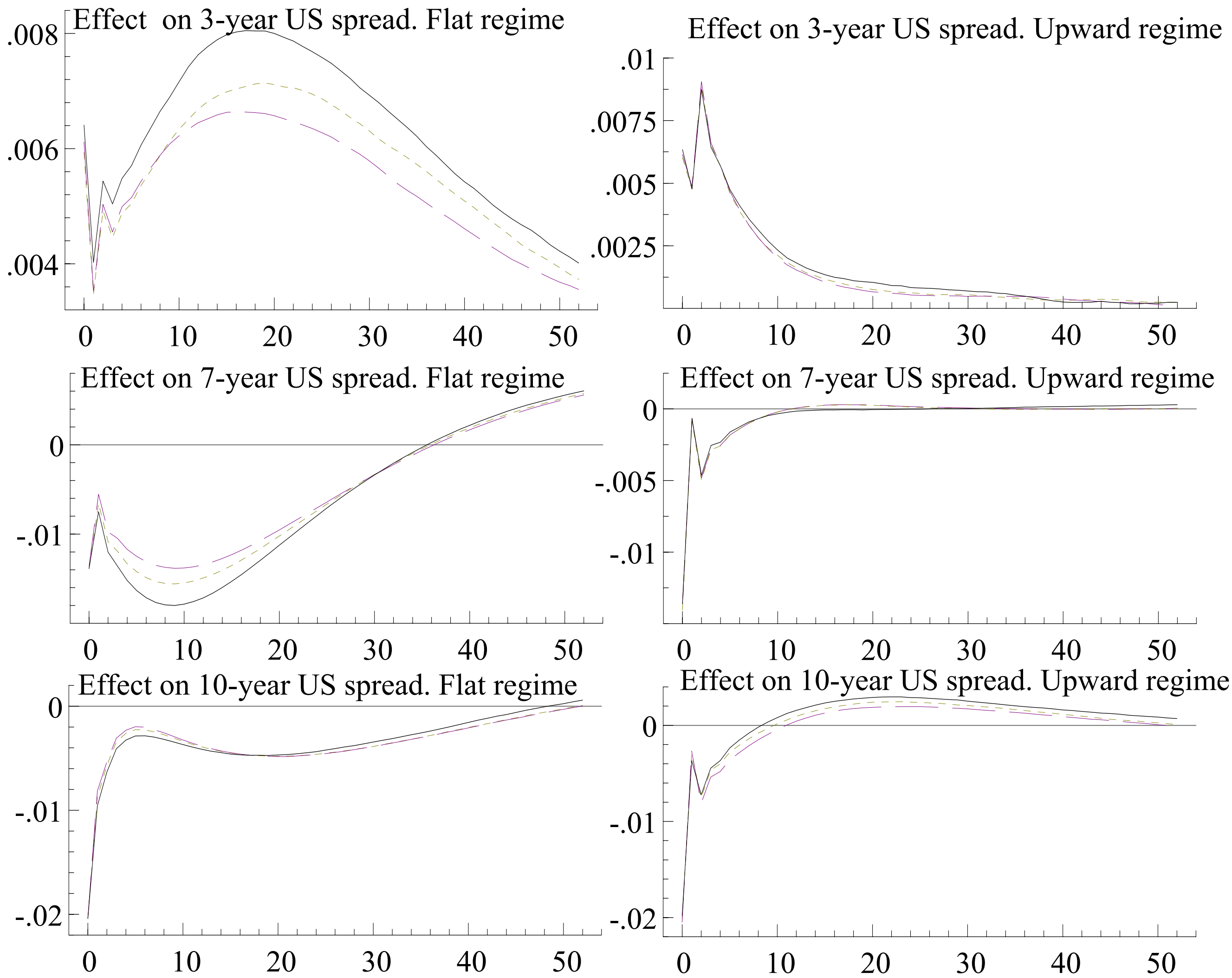
Notes:
The figure reports the impulse responses for the STVAR model described in equation (1) for the 10-year UK swap spread. The impulse responses represent the effect on the 10-year UK swap spread over a period of 52 weeks, of shocks to all the variables included in the system. The shock to each variable is equal to 1 standard deviation of its orthogonalized innovation. The solid line represents the impulse responses conditional on the system being at the flat term structure regime. The dashed line represents the impulse responses conditional on the system being at the upward slopping term structure regime.

Figure 9: Effect of positive versus negative (1-s.e.) US slope shocks on 3-year US spread.
Upward regime



Notes:
The figure reports the impulse responses for the STVAR model described in equation (1) for the 3-year US swap spread. The impulse responses represent the effect on the 3-year US swap spread over a period of 52 weeks, of a shock to the US slope conditional on the system being at the upward term structure regime. The shock to the US slope is equal to 1 standard deviation of its orthogonalized innovation. The solid line represents the impulse response to a positive shock. The dashed line represents the impulse response to a negative shock. For ease of camparison, the negative shock is multiplied by –1.

Figure 10: Effects of large versus small positive US slope shocks on US swap spreads



Notes:
The figure reports the impulse responses for the STVAR model described in equation (1) for the 3-year, 7-year and 10-year US swap spreads. The impulse responses represent the effect on the US swap spreads over a period of 52 weeks, of large and small shocks to the US slope conditional on the system being at the flat term structure regime and the upward slopping term structure regime, respectively. The shocks to the US slope are equal to 1, 2 and 3 standard deviations of its orthogonalized innovation. The solid line (—) represents the impulse response to 1 s.e. shock. The short dashed line represents the impulse response to 2 s.e. shock (this is divided by 2 for ease of comparison). The long dashed line represents the impulse response to 3 s.e. shock (this is divided by 3 for ease of comparison).