Spatial dependence in international bond markets

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Abstract

We extend Diebold et.al (2006)'s vector-autoregressive model for yield curves and study the interaction of yield curve across countries. We analyze to what extent shocks in yield curve and changes in macroeconomic variables in the US affect yield curves in European countries via channels such as cross-border asset holdings and cross-border bank lending. Bank lending dominates other channels in explaining the effect of US yield curve factors on corresponding factors of European countries. The degree to which the slopes of European countries depend on the US slope decreases in the recent US recession. A reverse pattern is observed for curvature.

Keywords: interest rate, yield curve factors, cross-border portfolio investment, macroeconomic variables, spatial dependence, spatial feedback

JEL codes: G1, E4, C3

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1. Introduction

The last decades have witnessed substantial increase of cross-border financial asset ownership. This increase in financial integration has great potential in smoothing consumption through cross border asset diversification but on the other hand poses challenges for market practitioners and policy makers because they are not only exposed to domestic macroeconomic and financial fluctuations but also to international shocks. Many studies have documented significant impact of financial integration on cross-border comovement in asset prices. However, albeit the close connection to the real economy, previous studies have paid little attention to dependence of international interest rate markets. The purpose of this paper is to analyze the importance of the cross-border financial asset ownership for the interaction of yield curve among European countries and the US. In addition, we examine the international transmission of macroeconomic shocks to interest rate markets.

Interest rates or yields form a transmission channel between the monetary policy, real activity, inflation and asset prices and can therefore tell us a lot about future economic activity. A simple monetary policy rule can explain most of the dynamics of the short end of the yield curve (e.g. Clarida et al., 1999). In combination with future expectations and risk premia, the connection to longer maturity yields is determined. This in turn, determines savings and investment decisions in the economy. For this reason, monetary policy makers follow the dynamics of the yield curve closely when determining whether to stimulate or restraining liquidity in the economy. Other asset prices are also affected by the cost of borrowing and change in wealth by interest rates with short maturities not only locally but also internationally through exchange rates via interest rate parity conditions.

Yield curve and its relation to the economic environment have been extensively investigated in previous literature. A main part of the previous studies build their models on latent factors to investigate the term structure of the interest rate (e.g., Knez et al., 1994; Duffie and Kan, 1996). The latent factor of the yield curve are usually indicated by “level”, “slope” and “curvature” (see e.g., Litterman and Scheinkman, 1991; Dai and Singleton, 2000), which describe the factors effect on the shape of yield curve. Even though there is a proven empirical relationship between the factors and the macro economy it is difficult to find a clear economic interpretation of the factors. In general, the factor level represents the overall level of the interest rates in the market, the slope of the yield curve reflects the market expectations of the future interest rates and the required bond risk premia, and the curvature is believed to be related to the interest rate volatility (see e.g., Lund and Christensen, 2005). Several studies have attempted to explicitly relate the unobserved factors to the macroeconomic variables and traditionally the level of the yield curve has been associated with inflation effects and the slope of the yield curve correlates well with business cycle components. Diebold et al. (2006) construct an autoregressive model with the three latent factors and observable macroeconomic variables, real activity, inflation, and the monetary policy instrument. They find evidence of both the effects of macro variables on future values of the yield curve factors and a reverse effect. Ang and Piazzesi (2003) analyze a latent factor model of the yield curve and show that forecasting ability of the vector autoregression significantly improves when macro variables are explicitly incorporated into the model. Evans and Marshall (2007) shows the macro economic factors such as technology have a strong impact on the level of the yield curve. Similarly Wu (2002) shows that the level of the yield curve is related to technology shocks and movements in the slope of the yield curve can be explained by monetary policy shocks. In a similar framework, Hördahl et al. (2006) find that inflation and output shocks affect the curvature of the yield curve. Estella and Hardouvelis (1991) also find a significant relationship between the spread between 10-year and 3-month rates and the growth in aggregate GDP. Lund and Christensen (2005) show that the volatility of the short term interest rate is significantly related to the slope and the curvature of the yield curve, while the relationship is stronger for the curvature than for the slope. Abbriti et al. (2013), finds empirical evidence that the curvature factor is closely related to future financial and economic instability. A theoretical link between the curvature and the level of the term premia was established by Campbell et al. (2013). They suggest, using an asset pricing model, that the curvature factor is the best proxy for bond risk premia.

The previous literature studies mainly the relationship between the domestic yield curve and domestic macro variables for a single country and the cross-border interactions among the variables have not been sufficiently investigated. An important exception is the study by Diebold et al. (2008), which constructs a hierarchical dynamic factor model, in which country yields are related to country factors, and country factors to global factors. The analysis is performed for the US, Germany, Japan, and the UK. The model decomposes the variation in country yields into two components, i.e. the global and the idiosyncratic components. Also, Abbriti et al. (2013) establish a relationship between the level of the yield curve and a global factor on expected inflation using a panel data approach for Canada, UK, Japan, Germany, Australia, New Zealand and Switzerland.

In the spirit of the domestic VAR model of Diebold et al. (2006), we develop an international model for yield curves using the spatial econometric approach. The VAR model of Diebold et al. (2006) consists of three latent yield factors and three macroeconomic variables, where the latent yield factors level, slope and curvature are constructed using the Nelson and Siegel (1987) approach. The spatial econometric method used in this paper follows the methodology of Asgharian et al. (2014). With the spatial econometric approach, the relationship between different entities is modeled based on their relative positions in a hypothetical space. We use data on 15 European countries and the US. Our main purpose is to analyze how the cross-border asset holdings among the countries affect the interaction of their yield curves. We focus mainly on the impact of the US on European countries and investigate if European countries' asset holdings in the US market affect their exposure to the changes in the US interest rate market, before, during and after the recent US recession from December 2007 to June 2009. The spatial econometrics approach allows us to investigate how shocks in interest rate factors and macroeconomic variables in the US affect other countries, while it takes into account feedback effects through the spatial relationships that amplify the impact of the shocks.

Our results show a strong degree of international dependence in the level of yield curves regardless of the choice of cross-country linkages, which is primarily generated by global co-movement in the interest rates. More importantly we show that the cross-border holdings of long-term debt cause spatial dependence among the slope of the yield curve, while both the cross-border lending between banks and the holdings of long-term debt results in a spatial relationship between curvature of the yield curves of different countries. Furthermore, we find that bank lending dominates other linkages in the effect of the US factors on corresponding factors of European countries. The degree to which the slopes of European countries depend on the US slope decreases in the recent US recession, while a reverse pattern is observed for curvature. Also, we also find that changes in the US policy rate have negative impact on the slope of the yield curve in the US and European countries.

To our knowledge, this is the first analysis that studies the importance of cross-border asset holdings for international dependence of yield curves. Our global VAR model provides insights into the mechanism of yield curve interactions in the global economy. Our study documents that the shock in yield curve factors and changes in policy rate in one country affect other countries and that the impact on the country itself is amplified by feedback. This has important policy implications, since the cross-border propagation can change the effectiveness of domestic monetary policies.

The remainder of our paper is organized as follows. Section 2 presents our model and describes the spatial econometric methodology. Section 3 contains the variable selection and data description. In section 4 we present our results and in section 5 we conclude the paper.

2. The Empirical Model

We develop an international model for yield curves of 16 countries using latent factors and macroeconomic variables. Our model is an extension of the domestic Vector Autoregressive model by Diebold et al. (2006). The domestic model for each country *i* relates the value of each factor *k* at time *t*, f_{kit}, to the lagged values of all the factors, including the factor *k* itself, in the same country

$$f_{kit} = \alpha_k + \sum_{l=1}^{K} \beta_{kl} f_{li,t-1} + \varepsilon_{kit} \,, \qquad (1)$$

for $k = 1, \ldots, K$, $i = 1, \ldots, N$ and $t = 1, \ldots, T$

The factors consist of three latent factors of yield curves, i.e. level, slope, and curvature and three macroeconomic variables, i.e. industrial production growth, inflation, and policy rate, which means that the model above consists of six equations. The latent factors are constructed by using the Nelson-Siegel approach (see Nelson and Siegel, 1987).

We extend the domestic model in equation (1) to an international factor model by using spatial Durbin regression. Specifically, our model relates the value of each factor for a country, not only to the lagged values of all the factors in that country but also to the contemporaneous values of that factor and the lagged values of all the factors in all the other countries. Since macroeconomic variables in most of the countries in our data are non-stationary, we estimate the model with the first difference of the dependent variable and the explanatory variables. In the rest of the paper, f_{kit} stands for the first-difference of factor k for country i at time t.

$$f_{kit} = \alpha_k + \rho_k \sum_{j \neq i}^{N} w_{ijt} f_{kjt} + \sum_{l=1}^{K} \beta_{kl} f_{li,t-1} + \sum_{l=1}^{K} \theta_{kl} \sum_{j \neq i}^{N} w_{ijt} f_{lj,t-1} + \varepsilon_{kit}. \tag{2}$$

Our model weighs the effect of each country j on country i by the country j:s relative closeness to country i, which we denote by w_{ij}. We will show later that this model can capture the cross-border transmissions of the shocks in both the dependent variable and the explanatory variables.

Since we have both cross-sectional and time-series variations in our data, we use a one-way fixed-effect panel data specification. Using the stacked matrix the model for each factor k can be expressed as:

$$\boldsymbol{f}_k = \rho_k \big(\boldsymbol{I}_T \otimes \boldsymbol{W}(t)\big) \boldsymbol{f}_k + \boldsymbol{X}\boldsymbol{\beta}_k + (\boldsymbol{I}_T \otimes \boldsymbol{W}(t))\boldsymbol{X}\boldsymbol{\theta}_k + \boldsymbol{D}\boldsymbol{\alpha}_k + \boldsymbol{\varepsilon}_k, \tag{3}$$

where the vector $\boldsymbol{f}_k$ contains NT observations of the factor k, $\boldsymbol{X}$ is an $NT \times K$ matrix containing the lagged observations (one lag) of all the K factors (including the factor k), and $\boldsymbol{\beta}_k$ and $\boldsymbol{\theta}_k$ are the corresponding $K \times 1$ vectors of parameters in the model for factor k. $\boldsymbol{W}(t)$ is the $N \times N$ time-varying spatial weighting matrix. $\big(\boldsymbol{I}_T \otimes \boldsymbol{W}(t)\big)\boldsymbol{f}_k$ is termed spatial lag, as opposed to autoregressive lag. $\boldsymbol{D}$ is an $NT \times N$ matrix containing N-1 country specific dummies and the global constant, and $\boldsymbol{\alpha}_k$ is the fixed effect parameter vector.

$\boldsymbol{\varepsilon}_k$ is an $NT \times 1$ vector of idiosyncratic error terms, $\boldsymbol{I}_T$ is an identity matrix of dimension T, and $\otimes$ denotes the Kronecker product. To estimate the model in equation 3 we use a Bayesian estimation methods (see, e.g., LeSage, 1997) which allows for heteroskedastic errors.

We use the cross-border holdings of debt and equities and cross-border bank lending to define the weighting matrix $\boldsymbol{W}(t)$. The elements in this matrix show the relative closeness of the countries to each other. More specifically, the element in row i and column j of the matrix shows the amount invested by country i in country j in period t relative to the total amount invested by country i in all the countries included to our sample. This element is therefore a measure of the exposure of the country i to shocks in country j. The matrix is not necessarily symmetric and allows for asymmetric dependence between any pair of countries.

The model in equation 3 can be written in reduced form as:

$$\boldsymbol{f}_k = \left(\boldsymbol{I}_{NT} - \rho_k\big(\boldsymbol{I}_T \otimes \boldsymbol{W}(t)\big)\right)^{-1} (\boldsymbol{X}\boldsymbol{\beta}_k + (\boldsymbol{I}_T \otimes \boldsymbol{W}(t))\boldsymbol{X}\boldsymbol{\theta}_k + \boldsymbol{D}\boldsymbol{\alpha}_k + \boldsymbol{\varepsilon}_k). \quad (4)$$

If ρ_k, which measures the degree of spatial dependence between factor k of various countries, is different from zero, $\left(\boldsymbol{I}_{NT} - \rho_k\big(\boldsymbol{I}_T \otimes \boldsymbol{W}(t)\big)\right)^{-1}$ is not an identity matrix, thus any unexpected shock ε to factor k of one country will trigger movements in the factor k of the spatially related countries, which in turn will feed back to the country itself, thereby amplifying the effect of shock. Furthermore, changes in the explanatory variables $\boldsymbol{X}$ in one country may affect the dependent variable in the same country and its spatially related countries (see Anselin, 2006; LeSage and Pace, 2009). The values of the parameter vector $\boldsymbol{\beta}_k$ are interpreted as average *immediate* effects of changes in the explanatory variables on dependent variable of *the same country* (see, e.g., Kelejian *et al*., 2006). The effects are termed "immediate", as they do not include feedback effects among countries caused by spatial linkages. If ρ_k is significant and positive, each explanatory variable will *indirectly* affect the dependent variable of other countries due to spillover among dependent variables of spatially related countries. Also, the immediate effect $\boldsymbol{\beta}_k$ on the country itself will be increased by spatial feedback. Our model can also capture the *direct* effect of every explanatory variable on the dependent variable of other countries thanks to the presence of $(\boldsymbol{I}_T \otimes \boldsymbol{W}(t))\boldsymbol{X}\boldsymbol{\theta}_k$. If $\boldsymbol{\theta}_k$ is different from zero, changes in the explanatory variables of one country will directly affect the dependent variable of other countries. The effects may as well spillover to other countries and become amplified by spatial feedback.

As aforementioned, the parameters $\boldsymbol{\beta}_k$ and $\boldsymbol{\theta}_k$ are interpreted as the *immediate* effects of a change in the explanatory variables and not as the total marginal effect. To derive the total marginal effect we write the reduced form for a specific month *t* in the following equation. For the sake of simplicity, index k is suppressed.

$$\begin{aligned} \boldsymbol{f}_t &= \sum_{l=1}^{K} \boldsymbol{V}_t(\beta_l \boldsymbol{I}_N + \theta_l \boldsymbol{W}_t)\boldsymbol{x}_{lt} + \boldsymbol{V}_t\boldsymbol{D}\boldsymbol{\alpha} + \boldsymbol{V}_t\boldsymbol{\varepsilon}_t \\ &= \sum_{l=1}^{K} \boldsymbol{S}_{lt}\, \boldsymbol{x}_{lt} + \boldsymbol{V}_t\boldsymbol{D}\boldsymbol{\alpha} + \boldsymbol{V}_t\boldsymbol{\varepsilon}_t, \end{aligned} \tag{5}$$

where $\boldsymbol{V}_t = (\boldsymbol{I}_N - \rho\boldsymbol{W}_t)^{-1}$ and $\boldsymbol{S}_{lt} = \boldsymbol{V}_t(\beta_l\boldsymbol{I}_N + \theta_l\boldsymbol{W}_t)$. It is important to know that $\boldsymbol{V}_t$ can be written as a geometric series $\boldsymbol{I}_N + \rho\boldsymbol{W}_t + \rho^2\boldsymbol{W}_t{}^2 + \cdots$. The term $\rho\boldsymbol{W}_t$ captures the immediate effect of a unit shock of f_t to f_t of other countries, while the higher order terms describe the additional effect due to spatial feedback. More specifically, any of the higher order terms can be considered a spatial feedback loop, where a shock in country *i* affects country *j* and country *j* feeds back to country *i* directly as well as through a longer path from *j* to another country *k* and back to *i*. In a stationary spatial system, the feedback effect becomes smaller as the order of the loop increases. This dynamic process reaches a steady state within each time period *t*.

The average immediate effect (i.e. the effect without considering feedback) of a shock of f_t in country *j* on f_t of all other countries is given by

$$\bar{V}_j^{immediate} = \frac{1}{T}\sum_{t=1}^{T}\frac{\sum_{i\neq j}^{N} V_{ij,t}^{immediate}}{(N-1)} \tag{6}$$

where $V_{ij,t}^{immediate}$ is the element in row *i* and column *j* of $\boldsymbol{V}_t^{immediate} = \rho \boldsymbol{W}_t$.

The average total marginal effect of a shock of f_t in country *j* on f_t of all other countries is:

$$\bar{V}_j = \frac{1}{T}\sum_{t=1}^{T}\frac{\sum_{i\neq j}^{N} V_{ij,t}}{(N-1)}. \tag{7}$$

Similarly, the immediate effect of the explanatory variable x_l on the dependent variable in other countries is given by:

$$\bar{S}_{j,l}^{immediate} = \frac{1}{T}\sum_{t=1}^{T}\frac{\sum_{i\neq j}^{N} S_{ij,l,t}^{immediate}}{N-1} \tag{8}$$

where $S_{ij,l,t}^{immediate}$ is the element in row *i* and column *j* of

$$\boldsymbol{S}_{lt}^{immediate} = \boldsymbol{V}_t^{immediate}(\beta_l \boldsymbol{I}_N + \theta_l \boldsymbol{W}_t).$$

The marginal effect, i.e. total effect, of the explanatory variable $\boldsymbol{x}_l$ on the dependent variable in other countries is given by:

$$\bar{S}_{j,l} = \frac{1}{T}\sum_{t=1}^{T}\frac{\sum_{i\neq j}^{N} S_{ij,l,t}}{N-1} \tag{9}$$

3. Variable Selection and Data

This section provides a detailed description of the yield curve factors, macroeconomic factors, and selected measures of integration between markets. Our sample includes 15 European countries (see Table) and the US. The time span is from January 2001 to December 2012.

2.1. Yield curve latent factors

We use the Nelson and Siegel (1987) approach to construct the latent factors, level, slope and curvature. More specifically we estimate the following cross-sectional regression for each month *t*, starting in January 2001 and ending in December 2012, with the least square method:

$$y_{mt} = b_{0t} + b_{1t}\frac{1-\exp(-m/\lambda)}{m/\lambda} + b_{2t}\left(\frac{1-\exp(-m/\lambda)}{m/\lambda} - \exp(-m/\lambda)\right) + e_{mt} \tag{10}$$

where y_{mt} is the interest rate with maturity *m* at time *t*. The parameter λ is the decay factor, which takes the values between zero and one, where a small value corresponds to a slow decay. We use a grid search to find the value of λ that minimizes the sum of the squared residuals for each cross-sectional regression. The estimated parameters b_{0t}, b_{1t} and b_{2t} are used as the measure of the latent factors, level, slope and curvature, respectively. We use yield for government bills and bonds with all available maturities ranging from 3 months to 15 years.

2.2. Macroeconomic factors

We use three key macroeconomic variables: industrial production growth, inflation rate, and policy rate. We calculate yearly inflation rates as the average changes in the consumer price index (CPI) for every month of the year compared with the respective month in the preceding year. Data on monthly CPI[1] and policy rate are taken from national sources in DataStream. Data on monthly industrial production growth are collected from OECD iLibrary.

2.3. Integration measures

The relative closeness of the countries to one another is measured by the stocks of cross-border asset holdings. Cross-border asset holdings indicate the vulnerability of a country to the economy of other countries, as it contains information about risk exposure associated with the default of a debtor, or fluctuations in asset values due to, for example, exchange rate changes or declines in equity prices). As the risk exposure tied with different types instruments are different, we measure the closeness between countries using holdings of equities and holdings of debt securities separately. Further, as for debt, we use holdings in long-term debt instruments and holdings in short-term debt instruments. As banking system greatly contributes to the global systemic risk, we also measure the closeness between countries using cross-border lending between banks.

The degree of relative closeness of country *j* to country *i* is calculated as

$$W_{ij,t} = \frac{holding_{ij,t}}{\sum_{k=1}^{k=N} holding_{ik,t}},$$

where $holding_{ij}$ is the stock of holdings of investment of country *i* in country *j*, which indicates the degree of risk exposure of country *i* in country *j*.

The data on cross-border holdings of equities, long-term debt instruments and short-term debt instruments are collected from the International Monetary Foundation's Coordinated Portfolio

[1] The CPIs for Australia and New Zealand are reported on a quarterly basis. We generate monthly values using linear interpolation.

Investment Survey (CPIS). The data on the stocks of cross-border lending between banks are collected from the Bank for International Settlements' International Banking Statistics (BIS IBS). The data are on year-end stocks of international claims of domestic banks[2] in individual economies on immediate borrowers[3].

Table 1 shows that the summary statistics of the estimated yield factors for different countries. Switzerland has the smallest average level of the yield curve (2.664), while Portugal has the largest value (5.853). In fact, the average level of the yield curve is larger for all the GIIPS countries, i.e. Greece, Italy, Ireland, Portugal and Spain, comparing to other countries in our sample. Most of the GIIPS countries also have significantly positive excess kurtosis and skewness, which indicates the existence of extreme interest rate values in some periods (see the column Max. for the maximum level for Greece, Ireland and Portugal).

(Insert Table 1)

The GIIPS countries have also a larger average slope comparing to the other countries. This reflects the relatively large spread between short- and long-term rates in the GIIPS countries due to their relatively high level of risk. In contrast, the yield curve has been quite flat for the UK. The mean slope of the US is larger than that of the European countries excluding the GIIPS.

[2] Domestic banks are those with a head office in the respective reporting country. A banking system's international claims on country A are comprised of cross-border claims in all currencies booked by all offices worldwide plus non-local currency claims on residents of country A booked by banks' foreign affiliates located in country A.

[3] The statistics of claims on an ultimate risk basis (consisting of claims on an immediate borrower basis and net risk transfers) can provide useful supplementary information about countries' external vulnerabilities but are available for fewer countries. Hence we choose to use the statistics of claims on an immediate borrower basis.

The sample statistics of the curvature of the yield curve shows that the mean value for Portugal and Greece is lower than that for other countries. However, judged from the minimum and maximum values it is clear that these two countries have had periods with extreme positive and negative kurtosis, indicating that their yield curve has switched between extreme convex and concave shapes.

As we can see from the last column of Table 1, the first-order autocorrelation is close to one for all the three factors in almost all the countries. This together with the unit root test shows non-stationarity in the data series. For this reason, we use the first-difference of the factors in our estimation.

For illustration, Figure 1 displays the evolution of the latent factors and macroeconomic factors for the US and different subsets of European countries. The yield curve levels of the US and the European countries follow each other very closely from the beginning of 2001 to November 2008, one year after the start of the US recession. The level of the US drops considerably after November 2008 and reaches a trough in December 2008. The drop is in part caused by quantitative easing undertaken by the Federal Reserve to combat the credit crisis in 2008 and the decrease of policy rate. From then, the degree of co-movement between the US and European yield curve levels decreases. The mean of the GIIPS countries' interest rate level rises considerably from the beginning of 2010 due to anxiety about the excessive national debt of GIIPS countries, whereas the mean of the other European countries remains fairly stable. The US yield curve level has a decreasing trend since the recession and reaches the half of its value prior to the recession in 2012. As for the factor slope, the slope of the US seems to lead the movement of the slopes of the European countries till 2010. The average value of GIIPS slopes rises dramatically from 2010 to 2011, indicating a sharp increase in the sovereign risk premia of

GIIPS. The mean value of the slopes of other European countries remains stable, so does the slope of the US. We can also see that the yield curve slopes have strong negative correlation with their corresponding policy rates before 2010 when the policy rates become very low, which suggests negative impact of policy rate on slope. In addition, there seems also a lead-lag effect between the US and European policy rate. Like slopes, the curvatures of the US and European countries are very similar till 2010, after which the GIIPS countries diverge from the rest of the European countries and the US. As for inflation rate and industrial production growth, European countries are very close to the US throughout the whole sample period.

(Insert Figure 1)

Table 2 summarizes, for every type of asset, the share of each selected European country invested in the US with respect to the total investment in the US and peer European countries, averaged over the whole sample period. The degree of preference for US asset is heterogeneous across asset classes. There is a strong preference for US equities rather than US debt: for all the selected European countries except Ireland and the UK, the relative share in US equities is larger than that in debt. The Netherlands, own more equities issued in the US than those issued in peer European countries. Greece, Sweden and the UK also have strong preference for U.S equities, with more than 40% of their equity investment in the US. The percentages of US bank claims owned by banks in the European countries are mild in general. This implies that the cross-bank lending takes place mainly between European countries. Furthermore, there is a big difference in the ownership of US assets across countries. Denmark, Ireland, Sweden, Switzerland, and UK have a large share of their investment in the US, while Austria, Belgium, Finland, Portugal and Spain have a weaker preference for US assets.

(Insert Table 2)

4. Results and Analysis

In this chapter we first present the estimation results of our suggested model in equation (2) for the entire sample in order to see how different linkages between the countries affect the interdependence in the yield curve factors. Next, we focus on the analysis of US effect on the European countries yield curve factors before, during and after the global financial crisis.

4.1 The estimation of the international model for yield curve factors

In this section, we analyze the estimated results of the model in equation (2). Our main purpose is to examine the importance of different cross-border asset holdings for the dependence of yield curve factors across countries. Since our main interest is only in the yield curve factors, we do not report the estimation with the macroeconomic factors as dependent variables. The estimated coefficients for the estimations with the latent factors as dependent variables are presented in different panels of Table 3.

We start by analyzing the estimated ρ:s, which show the degree of spatial dependence across countries. From panel A, we can see that the spatial correlation among levels is strong and highly statistically significant for all types of asset holdings, with ρ-values around 0.7. As pointed out in Asgharian et.al (2013), the statistical significance of spatial correlation may be caused primarily by global co-movement and does not necessarily indicate that the selected linkages are important. If this is the case, the estimated values of ρ should be large, no matter how the relative weights in the spatial weighting matrix $\boldsymbol{W}$ are chosen for each country. Hence, following Asgharian et.al (2013), we perform a simulation analysis where we randomly generate 200 spatial weighting matrices and estimate the model for each matrix. This results in 200 different estimates of ρ. The analysis shows that, although significant in the statistical way, our selected linkage measures do not exceed 95% of the randomly generated closeness measures in terms of the value of ρ. This indicates that the statistical significance and large value of ρ associated with our measures may primarily be caused by global comovement in interest rate levels. Therefore, we cannot relate the average comovement in the level factor to the degree of cross-border asset holdings. Panel B contains results for the regression of the slope factor. The spatial correlation is still highly statistically significant for all the selected linkages. However, the simulation analysis suggests that cross-border holding of long-term debt is the only measure that outperforms more than 95% of the randomly generated closeness measures. This indicates that there exists systematic spatial dependence in yield curve slopes through cross-border holdings of long-term debt. Panel C shows the estimated results for the regression of curvature. Despite that ρ:s associated all the four linkages are statistically significant, the simulation analysis suggests that only cross-border bank lending and holdings of long-term debt capture the systematic spatial relationships in curvature across countries. It must be noted that our purpose is to examine the relevance of different types of cross-border asset holdings rather than analyzing all possible cross-border linkages and common factors important for the comovement in yield curve factors.

(Insert Table 3)

In what follows, we analyze the estimated values of vectors $\boldsymbol{\beta}$ and $\boldsymbol{\theta}$, the coefficients for the explanatory variables, which consist of the lag of the dependent variable and the lagged changes in the other factors and macroeconomic variables. It must be noted that the values of $\boldsymbol{\beta}$ and $\boldsymbol{\theta}$ measure the immediate effects rather than total marginal effects, see section 2. First, the β associated with the lagged dependent variable is negative and statistically significant for all the three factors regardless of our measures of closeness. Since we estimate the regression on the first differences, the negative sign of this β implies that the interest rate factors are mean reverting. Second, the β:s for the lagged changes in the other factors show that there exist cross-factor dynamics. As in Diebold et. al (2006), we find a negative effect of lagged slope on level. Similarly, we find a negative effect of lagged level on slope, but it is significant for one linkage measure only. We also find a positive effect of lagged curvature on level, whereas Diebold et. al (2006) does not find any significant relationship between these two variables. Furthermore, the impacts of macro factors on the yield curve factors of the same country appear insignificant in most cases, which is in general consistent with the finding in Diebold et. al (2006). The exception is the negative effect of policy rate on slope, which contradicts the positive effect documented in Diebold et. al (2006). The negative effect of policy rate on slope can be motivated by the asymmetric effects of policy rate on short-term and long-term interest rates. An increase in policy rate is expected to raise short-term interest rate. At the same time it may reduce the expectation for future inflation, which pushes down the long-term interest rate.

Judged from the estimates of $\boldsymbol{\theta}$, we can see that yield curve factors in one country can directly affect factors in other countries. Lagged level has direct negative effect on the curvature of other countries. The effect of slope is positive on level and slope of other countries, but is negative on curvature. Curvature shows negative effects on level and slope, but the effect is not significant for all the linkage measures. However, curvature has significant and positive effect on curvature of other countries. None of the macroeconomic variables exhibit statistically significant direct effect on the yield curve factors in other countries. However, as policy rate exhibits a negative effect on slope of the same country, it may still affect yield curve slope of other countries indirectly through spatial dependence in slope between countries.

4.2 The US effect

In this section, our purpose is to find out which type of the cross-border asset holdings is the most important linkage for the spatial dependence on the US and investigate the impact of the US on European countries through that linkage. For the latter purpose, we first investigate how shocks of the US yield factors affect the corresponding contemporaneous yield factors of European countries through the selected linkage. We then examine the effect of the US policy rate on the yield curve of European countries, since policy rate is the only macroeconomic variable that shows significant effect on yield curve (see Table 3).

As discussed in section 4.1, comparing the estimates of ρ*:s* with their empirical distributions (see Table 3) show that there exists a systematic spatial dependence in slope and curvature through some of our selected linkages, while such a systematic dependence cannot be confirmed for the factor level by any of the linkages. However, it should be pointed out that ρ is the average spatial correlation parameter, whereas this parameter may vary by the countries. Since our focus in this section is on the US effect we add an interaction term into the model in equation (2) to allow the degree of dependence on the US differs from that on European countries. Similarly, we release the restriction that the β coefficient for the US policy rate is the same as that for the policy rates in the European countries by adding an interaction term for this variable. We estimate the following model

$$f_{kit} = \alpha_k + \rho_k \sum_{j\neq i}^{N} w_{ij} f_{kjt} + \rho_{k,US} w_{ij} f_{kjt} d_{j=US} + \sum_{l=1}^{K} \beta_{kl} f_{li,t-1} +$$
$$\beta_{k,l=5,US} f_{l=5,i,t-1} d_{j=US} + \sum_{l=1}^{K} \theta_{kl} \sum_{j\neq i}^{N} w_{ij} f_{lj,t-1} + \varepsilon_{kit}, \quad (11)$$

where the dummy variable $d_{j=US}$ equals one when $j = US$ and zero otherwise, and $l = 5$ is the index for policy rate. Since equation (11) involves more parameters than equation (2), we impose two restrictions on the parameters. First, we assume the intercept to be the same for all the countries and drop the fixed effect dummies, since none of the fixed effect dummies are significant in the estimation of the model in equation (2). Second, since the estimates of θ:s for macroeconomic variables in equation (2) are all insignificant, we restrict them to be zero.

As we rely on spatial correlation parameters to assess the importance of linkages, we only report the estimates of these parameters in Table 4. The estimated ρ is the spatial correlation parameter for all the European countries, while ρ_{US} is the spatial correlation parameter for the US less that for all the European countries. All the estimated ρ:s are highly statistically significant, while the estimated ρ_{US}:s are positive in almost all cases but all of them are not significant. To select the most important linkage for the spatial dependence on the US, we rely on the empirical distribution of ρ estimated from 200 randomly generated spatial matrices. As for the factor level, no matter the cross-country linkages, the spatial correlation coefficient for the European countries ρ does not exceed the 95% quantile of the empirical distribution. This suggests that the selected linkages may not be the important drivers of the comovement in the level factors of the European countries. However, the value of the spatial correlation coefficient for the US, $\rho + \rho_{US}$, is significant in the case of bank lending, given the empirical distribution. This suggests that the level of the interest rate in European countries, which have a large amount of bank lending to the US, is sensitive to the changes in the US interest rate level.

(Insert Table 4)

As for the factor slope, none of the cross-country linkages are of importance for the dependence on the European countries. In contrast, all the debt linkages are shown to be important for the dependence on the US. These findings indicate that the importance of long-term debt documented in Table 3 may to a large extent be attributed to the effect exerted by the US. As for the factor curvature, the spatial correlation coefficient for the European countries is significant given the empirical distribution in the case long-term debt only, whereas the spatial correlation coefficient for the US is significant in all the cases.

Furthermore, it is noticeable that bank lending is associated with the largest spatial correlation coefficient for the US. This suggests that bank lending dominates other asset holdings in explaining spatial dependence on the US. Hence, in the following analysis of the US effect, we choose bank lending as the channel of interest.

As we are especially interested in the impact of the recent US economic recession on yield curve interaction, we study three non-overlapping sub-sample periods: pre-recession period from 2001 March to 2007 November, recession period from 2007 December to 2009 June, and post-recession period from 2009 July to 2012 December. We estimate the model in equation (11) for each of the three sub-sample periods and use the estimated parameters to calculate the effects of the US yield factors and policy rate on the yield factors of European countries by using equations (6)-(9). We compare the US effect on two groups of European countries classified based on their bank lending to the US. One group consists of countries whose relative amount of bank lending to the US is above the median value of all the European countries. The other group consists of the rest of the countries. In this way, we can clearly see how much European countries' sensitivity to the US depends on their relative amount of bank lending to the US.

The estimated ρ:s are reported in Table 5 and the effects of the US yield factors and the US policy rate in Figure 2 and Figure 3, respectively. It must be noted that the estimated ρ:s for the sub-samples cannot be compared with the empirical distribution of ρ for the entire sample. Since the interest of this part of the study is the magnitude of the US effect rather than the significance of ρ, we do not use randomly generated weighting matrices to obtain the empirical distribution of this parameter for the sub-samples.

(Insert Table 5)

Subfigures on the left in Figure 2 show the immediate effects of the contemporaneous shock of the US yield factors calculated according to equation (6), and the ones on the right show the total marginal effects according to equation (7). The first observation is that the immediate effects on the "over median" group are larger than those on the "under median" group. In fact, the effects on the "over median" group are in most cases at least twice as large as those on the other group. This shows the cross-sectional difference in the immediate exposure of European countries due to their bank lending to the US.

(Insert Figure 2)

Comparing the immediate effects with the total effects, we can clearly see that the effects of shocks in the US yield factors to all the other countries (both "over median" and "under median" groups) are considerably amplified by spatial feedback for all the three factors. However, the relative difference between the effects on the "over median" group and the "under median" group reduces after amplification. This is because the countries in the "under median" group can be indirectly affected by the US due to their high bank lending to the countries in the "over median" group.

For the factor level, the immediate effect of the US increases gradually for the "over median" group, while the total effect reduces for both the groups. The decrease in the total effect over time is attributed to reduced feedback effects among European countries, which can be related to the decrease in the value of ρ as shown in the first column of Table 5. In fact, for all the three factors, the total effect is at least twice as large as the immediate effect before and during the US recession, but this is not the case in the post-recession period. This confirms the weakened feedback between European countries in the post-recession period. The magnitude of the feedback depends upon the degree of closeness among countries described by the weighting matrix $\boldsymbol{W}$ and the spatial correlation parameter measuring the strength of spatial dependence. From Table 5, we see that ρ is substantially lower in the post-recession period than in the other periods. This may be due to the divergence of European countries during the sovereign debt crisis.

Furthermore, the impact of the US slope on the slopes of European countries diminishes during the recent US recession. However, it increases dramatically after the recession especially to the European countries that hold a large amount of the US long-term debt. In contrast, the effect of the US curvature increases remarkably in the recession. After the recession, it drops back to the pre-recession level.

Since we have shown that a country's policy rate has a significant immediate effect on the slope of this country's yield curve, given the spatial dependence in slopes across countries, we would expect that a policy rate change in one country indirectly affects the slope of the yield curve of other countries. In this part of the analysis, we look at the total effects (see equation 9) of a change in the US policy rate on the slope of the yield curve of European countries in different periods. As in the previous analysis we only use bank lending as the channel of interest. Figure 3 illustrates the results for the where we sort countries based on the share of their lending to the US relative to the countries' total bank lending to all the countries in the sample. Since there are no changes in the US policy rate after 2009, we only plot the results for the first two sample periods. The effect of the US policy rate is negative in all the cases, which indicates that an increase in the FED rate, i.e. restraining liquidity in the economy, due to its anti-inflationary effect reduces the slope of the yield curve of the other countries. However, considering that the immediate effect of the US policy rate on the US slope is -0.016 and -0.281[4] in the pre-recession and recession, respectively, the effect of the US policy rate on European countries is small. In both sample periods, the UK Switzerland and Germany are affected strongly by a change in the US policy rate, which reflects their high relative bank lending to the US banks. We observe a much stronger effect of the US policy rate on the US slope and, through that, on the European slope factor in the second period comparing to the first period. It shows that the policy rate changes in the second period may have a strong signaling effect in the recession period. This might also be the case that the changes in the policy rate in this period were implemented together with other monetary policies.

(Insert Figure 3)

5. Conclusion

We construct a global VAR model for yield curves by applying the spatial Durbin model in order to analyze the importance of cross-border holdings of debt and equities and cross-border banking lending for the interaction of yield curve between countries. Moreover, we study to what extent shocks in yield curve and changes in macroeconomic variables such as policy rate in the US affect yield curves in 15 European countries.

Our results show a strong degree of international dependence in the level of yield curves regardless of the choice of cross-country linkages. However, the empirical distribution of spatial

[4]The immediate effect of the US policy rate on the US slope is the sum of β and β_{US} for policy rate. The estimated β:s are not reported in Table 5 but available upon request.

correlation estimated using randomly generated spatial weighting matrices verifies that the strong correlations among the level factor are primarily generated by global co-movement in the interest rates and are not due the spatial dependence through the our selected linkages. However, the results for the slope factor show that the cross-border holdings of long-term debt cause spatial dependence among the countries. For curvature, we find that both the cross-border bank lending and the holdings of long-term debt cause a spatial relationship across countries. Since the slope of the yield curve is considered to be a measure of the risk premium and the curvature may reflect the volatility of the interest rate markets, we may conclude that countries with a large amount of the cross-border bank lending and long-term loan to a country will be affected by the adverse interest rate market condition of that country.

In the second part of the analysis, we investigate how yield curve of the European countries are affected by the corresponding US factors. We find that that bank lending dominates other asset holdings in explaining spatial dependence on the US for all the yield factors. Further, we show that a shock in the US factors can affect corresponding factors of European countries and the effects get amplified because of spatial feedback among the countries. Moreover, the analysis of the effects of the US factors over three different periods shows that the patterns of the effects differ across the factors. For the factor level, we observe a gradual decrease in the effect of the US. For the factor slope, we find the effect of the US is very weak during the recent US recession. This can reflect divergence in markets' perception about the future economy between the US and Europe during this period. On the contrary, for the curvature factor, the effect of the US increases remarkably in the recession and drops back to the pre-recession level after the recession. This reflects that the uncertainty in the US interest rate market during the US recession spillovers to European countries, since the curvature is believed to be related to the interest rate volatility. Finally, we find that changes in the US policy rate have negative impact on the slope of the yield curve in the US and the European countries, which may indicate the anti-inflationary effect of an increase in the FED rate.

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Table 1. Summary statistics of the yield curve factors

The Table shows the summary statistics of the estimated yield factors, *level*, *slope* and *curvature*, for different countries. The factors are estimated based on the Nelson-Siegel model on yield for government bills and bonds with all available maturities ranging from 3 months to 15 years. Data covers the period starting January 2001 and ending December 2012.

		Mean	Stdev	Min	Max	Kurt.	Skew.	Autocor.
	Austria	4.389**	0.705	2.546	5.808	-0.257	-0.260	0.948**
	Belgium	4.535**	0.651	2.677	5.859	-0.201	-0.143	0.920**
	Denmark	4.158**	0.980	1.428	5.657	0.568**	-0.962*	0.972**
	Finland	4.270**	0.768	2.230	5.808	0.073	-0.299	0.955**
	France	4.325**	0.687	2.616	5.753	-0.182	-0.087	0.944**
	Germany	4.030**	0.918	1.642	5.635	0.167	-0.618	0.967**
Level	Greece	5.744**	1.723	3.686	11.659	3.174**	1.811**	0.958**
	Ireland	5.524**	1.518	3.470	10.249	1.659**	1.336**	0.960**
	Italy	5.015**	0.702	3.666	7.220	0.515*	0.515	0.933**
	Netherlands	4.243**	0.814	2.096	5.666	0.072	-0.640	0.950**
	Portugal	5.853**	2.567	3.468	16.536	4.296**	2.149**	0.972**
	Spain	4.927**	0.864	3.398	7.786	0.108	0.533	0.946**
	Sweden	4.039**	1.105	1.420	5.974	-0.288	-0.460	0.972**
	Switzerland	2.664**	0.813	0.719	3.935	-0.008	-0.801*	0.973**
	UK	4.465**	0.715	2.145	5.358	2.478**	-1.659**	0.946**
	US	4.289**	0.986	1.691	5.922	0.632**	-1.042**	0.946**
	Austria	1.520**	1.289	-1.703	5.027	-0.317	-0.269	0.908**
	Belgium	2.220**	1.226	0.015	4.539	-1.159**	0.093	0.941**
	Denmark	1.326**	1.047	-1.993	3.333	-0.078	-0.370	0.867**
	Finland	1.154**	1.043	-1.661	2.952	-0.420*	-0.594	0.934**
	France	2.055**	1.046	-0.096	4.032	-0.840**	-0.018	0.950**
	Germany	1.852**	0.968	-0.290	3.752	-0.596**	-0.047	0.926**
Slope	Greece	2.779**	3.153	-1.169	16.499	6.484**	2.417**	0.924**
	Ireland	2.979**	3.243	-1.284	15.013	2.092**	1.414**	0.952**
	Italy	2.697**	1.547	0.362	6.547	-0.941**	0.456	0.954**
	Netherlands	1.904**	1.059	-0.030	4.126	-0.784**	0.094	0.948**
	Portugal	3.610**	3.791	-0.154	21.061	4.158**	2.012**	0.923**
	Spain	2.493**	1.771	-0.272	8.006	-0.073	0.719	0.957**
	Sweden	1.554**	1.130	-0.919	4.990	-0.369	0.140	0.917**
	Switzerland	1.246**	0.946	-1.336	3.205	-0.745**	-0.100	0.954**
	UK	0.866**	1.598	-1.134	4.956	-0.432*	0.954*	0.926**
	US	2.352**	1.432	-0.820	4.620	-0.923**	-0.375	0.951**

Table1. Summary statistics of the yield curve factors (continued)

		Mean	Stdev	Min	Max	Kurt.	Skew.	Autocor.
Curvature	Austria	-4.181**	2.625	-10.933	0.772	-0.224	-0.214	0.903**
	Belgium	-3.493**	2.097	-8.639	0.451	-0.941**	0.232	0.833**
	Denmark	-3.474**	2.642	-10.243	1.428	-0.475*	-0.265	0.891**
	Finland	-4.656**	3.009	-11.755	0.294	-0.851**	-0.273	0.943**
	France	-3.494**	2.117	-7.106	0.571	-0.900**	0.393	0.942**
	Germany	-3.019**	2.000	-6.495	1.209	-0.854**	0.562	0.929**
	Greece	-0.001	12.422	-8.167	71.003	19.085**	4.180**	0.945**
	Ireland	-3.366**	6.581	-16.039	29.979	10.877**	2.802**	0.620**
	Italy	-2.965**	2.014	-6.542	4.086	-0.433*	0.400	0.823**
	Netherlands	-3.512**	1.994	-6.803	0.153	-1.030**	0.464	0.926**
	Portugal	-1.766*	9.651	-31.422	37.818	7.133**	1.532**	0.759**
	Spain	-3.117**	1.965	-8.895	0.488	-0.331	0.006	0.752**
	Sweden	-2.468**	1.964	-7.434	1.637	-0.114	-0.043	0.792**
	Switzerland	-3.144**	1.597	-6.302	0.294	-0.808**	0.109	0.876**
	UK	-3.314**	3.482	-11.333	1.908	-0.876**	-0.415	0.912**
	US	-3.454**	2.503	-7.427	1.682	-0.781**	0.526	0.947**

Table 2. Mean relative investment in the US

The Table shows the average over time investment of the countries in the US relative to their total investment in the countries included in the sample. Data covers the period starting January 2001 and ending December 2012.

	Bank Lending	*Long Debt*	*Short Debt*	*Equity*
Austria	4.4%	9.8%	11.1%	21.4%
Belgium	6.9%	6.0%	8.7%	14.4%
Denmark	10.9%	20.6%	18.7%	39.2%
Finland	6.8%	5.8%	2.1%	20.4%
France	11.2%	12.0%	11.0%	19.9%
Germany	11.8%	11.0%	19.5%	22.5%
Greece	4.1%	13.5%	4.1%	43.1%
Ireland	7.0%	28.0%	44.0%	36.7%
Italy	5.5%	18.3%	4.1%	20.3%
Netherlands	11.2%	17.9%	12.2%	51.4%
Portugal	2.9%	8.1%	2.0%	16.4%
Spain	5.0%	10.0%	4.7%	15.7%
Sweden	9.5%	28.2%	19.3%	42.5%
Switzerland	10.5%	23.6%	9.1%	36.1%
UK	10.7%	41.5%	24.1%	41.0%

Table3. Estimation results from the SDM with one spatial lag

This table presents the estimated results of the panel data SDM with one spatial lag and with country-specific effects:

$$\boldsymbol{f}_k = \rho_k\big(\boldsymbol{I}_T \otimes \boldsymbol{W}(t)\big)\boldsymbol{f}_k + \boldsymbol{X}\boldsymbol{\beta}_k + (\boldsymbol{I}_T \otimes \boldsymbol{W}(t))\boldsymbol{X}\boldsymbol{\theta}_k + \boldsymbol{D}\boldsymbol{\alpha}_k + \boldsymbol{\varepsilon}_k,$$

where the vector $\boldsymbol{f}_k$ contains *NT* observations of the factor *k*, $\boldsymbol{X}$ is an $NT \times K$ matrix containing the lagged observations (one lag) of all the *K* factors (including the factor *k*), and $\boldsymbol{\beta}_k$ and $\boldsymbol{\theta}_k$ are the corresponding $K \times 1$ vectors of parameters in the model for factor *k*. $\boldsymbol{W}(t)$ is the $N \times N$ time-varying spatial weighting matrix according to various form of investments, i.e. *bank lending*, *long-term debt*, *short-term debt*, and *equity*. $\boldsymbol{D}$ is an $NT{\times}N$ matrix containing *N*-1 country specific dummies and the global constant, and $\boldsymbol{\alpha}_k$ is the fixed effect parameter vector. $\boldsymbol{I}_T$ is an identity matrix of dimension *T*, and $\otimes$ denotes the Kronecker product. The estimations are based on monthly values for 16 countries over the period from January 2001 to December 2012. The parameters marked with one asterisk are significant at the 5% level and those with two asterisks are significant at the 1% level.

We perform a simulation analysis where we randomly generate 200 spatial weights matrices and estimate the model for each matrix separately. The table also reports if the parameter ρ is significant at the 5% level using a one-sided test based on the empirical distribution of the 200 estimated $\boldsymbol{\rho}$:s. The parameters marked with “sig” (“insig”) is significant (insignificant) at the 5% level using a one-sided test based on the empirical distribution of the 200 estimated ρ:s.

			Bank Lending	*Long Debt*	*Short Debt*	*Equity*
Level	$\boldsymbol{\rho}$		0.775**	0.774**	0.692**	0.722**
	Emp. Dist.		Insig	Insig	Insig	Insig
	$\boldsymbol{\beta}$**:s**	Level	-0.062**	-0.066**	-0.050*	-0.048*
		Slope	-0.036**	-0.042**	-0.050**	-0.046**
		Curvature	0.025**	0.024**	0.026**	0.026**
		Ip growth	0.000	0.000	0.000	-0.001
		Policy rate	0.003	-0.024	-0.025	-0.030
		Inflation	1.827	1.478	1.173	1.062
	$\boldsymbol{\theta}$**:s**	Level	-0.013	0.014	0.001	0.046
		Slope	0.063**	0.062**	0.070**	0.031
		Curvature	-0.011*	-0.009	-0.012*	-0.007
		Ip growth	0.001	0.002	0.001	0.002
		Policy rate	0.009	0.031	0.024	-0.010
		Inflation	1.116	1.353	1.846	2.243

Table3. Estimation results from the SDM with one spatial lag (continued)

			Bank Lending	*Long Debt*	*Short Debt*	*Equity*
Slope	$\boldsymbol{\rho}$		0.530**	0.576**	0.416**	0.488**
	Emp. Dist.		Insig	Sig.	Insig	Insig
	$\boldsymbol{\beta}$:s	Level	-0.055	-0.114*	-0.080	-0.062
		Slope	-0.129**	-0.094**	-0.109**	-0.136**
		Curvature	0.009	-0.017	-0.010	0.003
		Ip growth	0.002	0.002	0.002	0.002
		Policy rate	-0.139**	-0.135**	-0.108*	-0.147**
		Inflation	0.735	1.425	0.431	0.056
	$\boldsymbol{\theta}$:s	Level	-0.010	0.008	-0.011	0.063
		Slope	0.255**	0.266**	0.241**	0.211**
		Curvature	-0.032*	-0.005	-0.011	-0.039**
		Ip growth	-0.001	0.004	0.000	0.001
		Policy rate	0.102	0.119	0.081	-0.014
		Inflation	-2.716	-0.872	-1.066	1.542
Curvature	$\boldsymbol{\rho}$		0.460**	0.504**	0.283**	0.388**
	Emp. Dist.		Sig.	Sig.	Insig	Insig
	$\boldsymbol{\beta}$:s	Level	-0.016	-0.003	-0.034	0.110
		Slope	-0.152	-0.146	-0.124	-0.216*
		Curvature	-0.103**	-0.122**	-0.113**	-0.078**
		Ip growth	0.005	0.004	0.004	0.005
		Policy rate	0.091	0.085	0.163	0.101
		Inflation	1.152	-0.604	-0.873	-2.433
	$\boldsymbol{\theta}$:s	Level	0.835**	0.574**	0.681**	0.675**
		Slope	-0.380**	-0.156	-0.329**	-0.266*
		Curvature	0.130**	0.162**	0.144**	0.063*
		Ip growth	0.001	0.006	-0.003	0.000
		Policy rate	-0.229	-0.266	-0.344	-0.322
		Inflation	-5.053	2.275	-4.490	7.809

Table 4. The spatial dependence on the European countries and the US

The table reports the estimated ρ, i.e. the degree of dependence of the European countries on the European countries' yield curve factors and the estimated ρ_{US}, i.e. degree of dependence of the European countries on the US yield curve factors less the degree of dependence on the European countries. The estimations are based on monthly values for 16 countries over the period from January 2001 to December 2012. The parameters marked with one asterisk are significant at the 5% level. The parameters marked with "sig" is significant at the 5% level using a one-sided test based on the empirical distribution of the 200 estimated ρ:s.

		Long Debt	*Short Debt*	*Equity*	*Bank Lending*
Level	ρ	0.773**	0.684**	0.729**	0.765**
	ρ_{US}	0.007	0.079	-0.032	0.096
	$\rho+\rho_{US}$	0.780	0.763	0.696	0.861 sig
Slope	ρ	0.556**	0.375**	0.460**	0.483**
	ρ_{US}	0.113	0.380**	0.083	0.438**
	$\rho+\rho_{US}$	0.669 sig	0.755 sig	0.543	0.921 sig
Curvature	ρ	0.453** sig	0.228**	0.300**	0.401**
	ρ_{US}	0.513**	0.868**	0.472**	0.748**
	$\rho+\rho_{US}$	0.966 sig	1.096 sig	0.772 sig	1.148 sig

Table 5. The spatial dependence on the European countries before, during and after the US recession

The table reports the estimated ρ, i.e. the degree of dependence of the European countries on the European countries' yield curve factors and the estimated ρ_{US}, i.e. degree of dependence of the European countries on the US yield curve factors less the degree of dependence on the European countries. The coefficients are reported in the case of cross-border bank lending for three non-overlapping sub-sample periods: the period before the US recession from 2001 March to 2007 November, the US recession period from 2007 December to 2009 June, and the post-recession period from 2009 July to 2013 December. The parameters marked with one asterisk are significant at the 5% level and those with two asterisks are significant at the 1% level.

Bank Lending

		Level	*Slope*	*Curvature*
Pre-recession	ρ	0.872**	0.540**	0.505**
	ρ_{US}	-0.119	0.359**	0.244*
	$\rho + \rho_{US}$	0.752	0.899	0.749
Recession	ρ	0.770**	0.558**	0.561**
	ρ_{US}	0.069	-0.294	1.540**
	$\rho + \rho_{US}$	0.839	0.263	2.101
Post-recession	ρ	0.540**	0.197**	0.145*
	ρ_{US}	0.652**	1.502**	0.768
	$\rho + \rho_{US}$	1.192	1.700	0.912

Figure 1. Yield curve latent factors and macroeconomic factors of the US and European countries

The figure shows the changes in the estimated latent factors and the macroeconomic factors for the US as well as for different subsets of European countries, i.e. all the European countries, the GIIPS countries and finally all the European countries except the GIIPS. The factors are estimated based on the Nelson-Siegel model on yield for government bills and bonds with all available maturities ranging from 3 months to 15 years. Data covers the period starting January 2001 and ending December 2012.

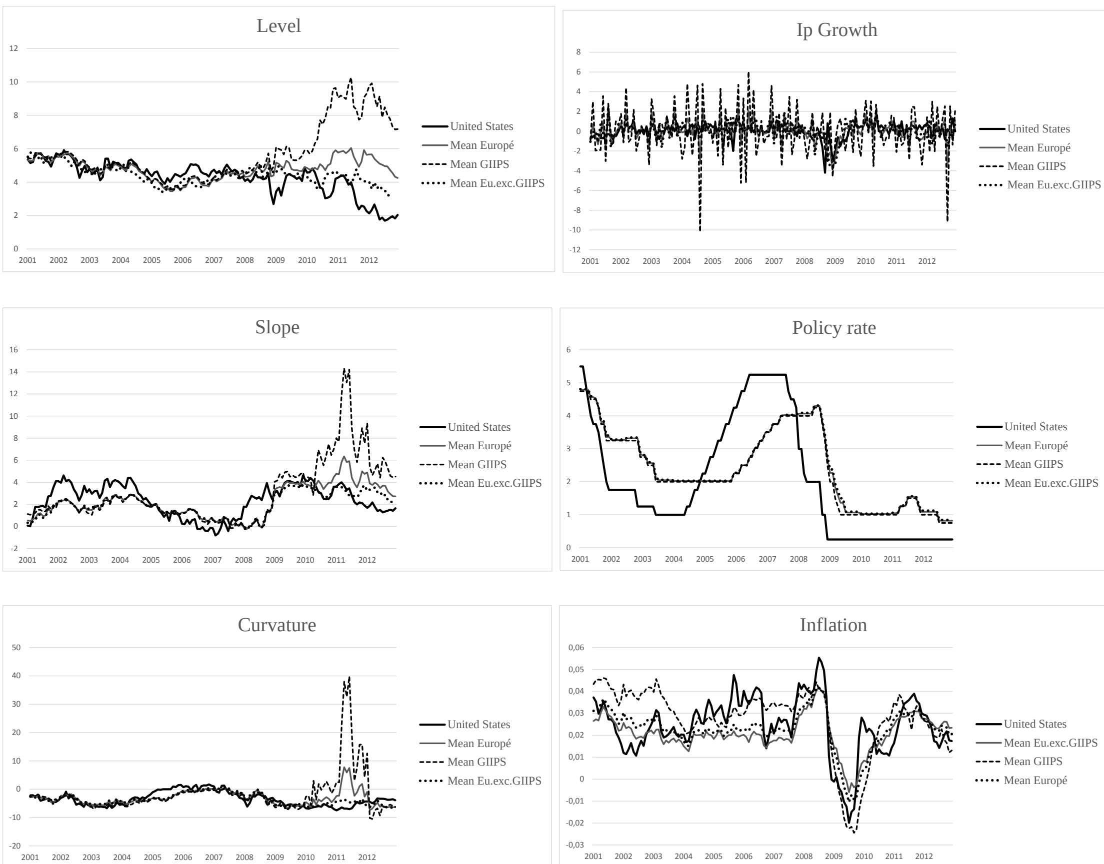

Figure 2. The impact of US factors on the European yield curve factors with bank lending regarded as the cross-country linkage

This figure shows the effects of US factors on the yield curve factors of two groups of European countries. One group consists of countries that hold the share of investment in US assets over the median of all the European countries. The other group consists of the rest of the countries that are less close to the US through portfolio investment. The linkage being considered is bank lending. Subfigures to the left present the immediate effects of the US an subfigures to the right display the total marginal effects of the US, which take the spatial feedback into account. We plot the effects for three non-overlapping sub-sample periods: the period before the US recession from 2001 March to 2007 November, the US recession period from 2007 December to 2009 June, and the post-recession period from 2009 July to 2013 December.

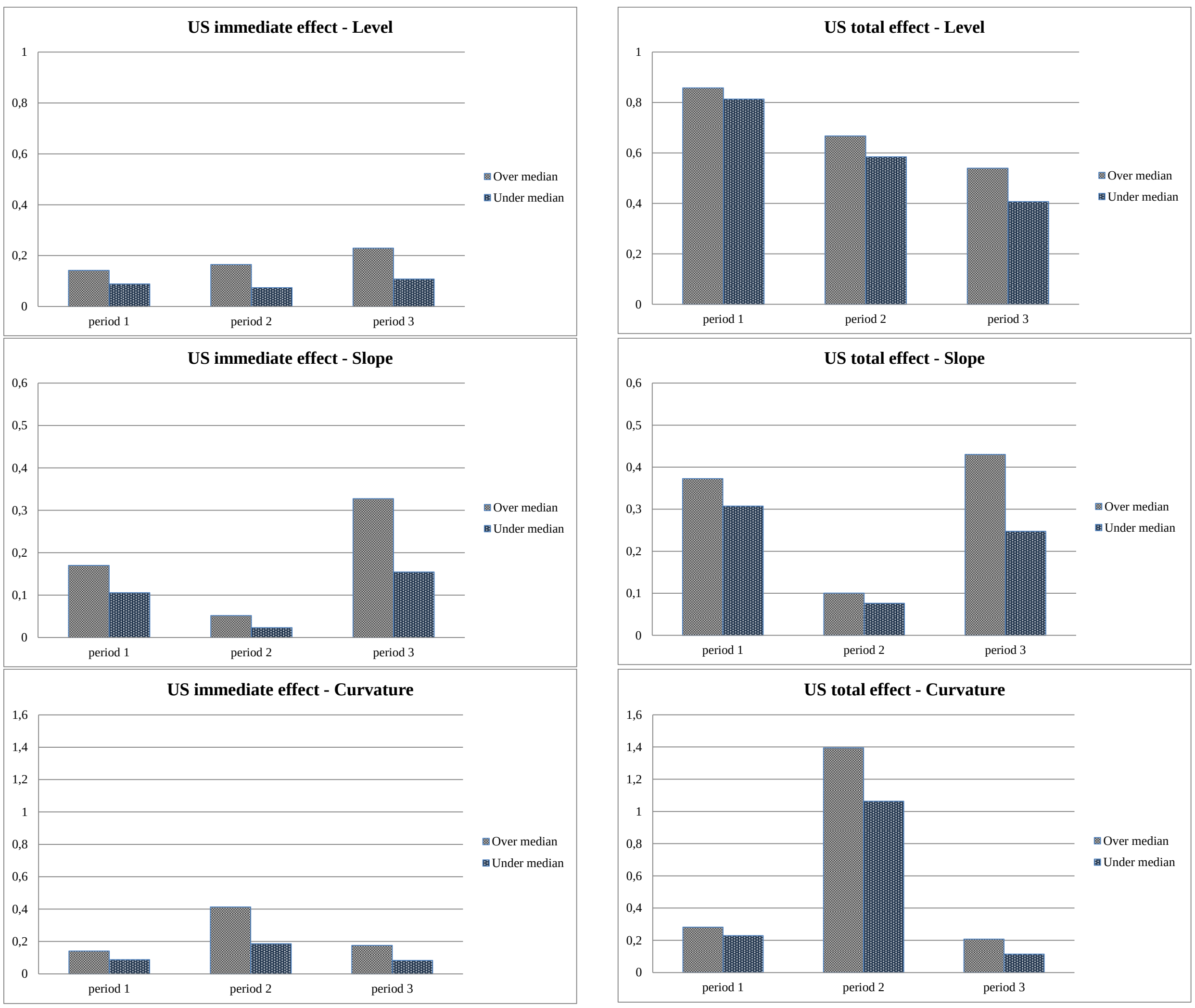

Figure 3. The total impact of US policy rate on the slope of the European slope

This figure shows the effects of the US policy rate on the yield curve factors of the European countries. We use bank lending as the cross-country linkage when forming the weighting matrix in the spatial regression model. The countries are sorted based on the share of the lending to the US relative to the countries' total bank lending to all countries in the sample. The figures display the total marginal effects of the US, which take the spatial feedback into account. We plot the effects for two non-overlapping sub-sample periods: period 1 is before the US recession from 2001 March to 2007 November and period 2 is the US recession period from 2007 December to 2009 June.