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Working Paper

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Working Paper, No. 2015:30

Provided in Cooperation with:

Department of Economics, School of Economics and Management, Lund University

Suggested Citation: Asgharian, Hossein; Liu, Lu; Larsson, Marcus (2015) : Cross-Border Asset Holdings and Comovements in Sovereign Bond Markets, Working Paper, No. 2015:30, Lund University, School of Economics and Management, Department of Economics, Lund

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October 2015



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Cross-Border Asset Holdings and Comovements in Sovereign Bond Markets^{*}

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October 2015

Abstract

We analyze the importance of different types of asset holdings for the interdependence of the yield curves in the EMU using a spatial VAR model. We find that the cross-border holdings of long-term debt and bank lending are important for the interdependence. Our analysis of cross-sectional dispersion in sovereign-CDS-premium term structure shows that the differential in sovereign creditworthiness in the EMU is a main driver of the yield-curve divergence after 2008. The degree to which EMU countries' yield-curve slopes depend on the US slope decreases in the recent US recession, reflecting expectations during this period about future divergence of the US and EMU economies.

Keywords: yield-curve factors, cross-border asset holding, spatial dependence, EMU, sovereign credit default swap

JEL codes: E43, G15, C31

^{*} We thank Magnus Dahlquist, Jean Imbs, Stefan Mittnik, Konstantinos Tolikas, participants at CEQURA Conference on Advances in Financial and Insurance Risk Management 2014, Financial Management Association European Conference 2015 and International Finance and Banking Society's annual meeting 2015. We gratefully acknowledge funding from the Swedish Research Council and Torsten Söderberg Foundation.

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1. Introduction

The introduction of the Euro by the European Monetary Union (EMU) has eliminated exchange-rate risk and reduced the cross-border transaction costs in the union. The common currency should, therefore, enhance the possibilities of cross-border diversification and asset holdings, which in turn should increase financial-market comovements among countries in the union. One important aspect of the integration process of EMU countries is comovement and convergence of their interest-rate markets. Interest rates form a transmission channel between the monetary policy, real activity, inflation and asset prices and can, therefore, suggest future economic activity.

In this paper, we analyze the interaction and convergence of government-bond yield curves among EMU countries. We aim to address three main research questions. First, to what extent are cross-border asset holdings important for the comovement of government-bond yields? Second, has the harmonization among yields of EMU countries been (un)successful? Third, how are the interest-rate markets in the EMU influenced by the US market and the recent US economic recession?

We develop an international model for yield curves and their comovement. Specifically, by using spatial econometrics, we extend the vector autoregressive (VAR) model of the yield curve proposed by Diebold et al. (2006), which consists of the three yield-curve latent factors (i.e., level, slope and curvature), estimated in the Nelson and Siegel (1987) tradition, and macroeconomic variables. Our model can capture the contemporaneous cross-country interaction in the yield-curve factors associated with proximities among countries. We use different types of cross-border asset holdings to measure countries' proximities, as cross-border asset holdings proxy the extent of cross-border financial transactions, which create possibilities for interest-rate parity to hold. In this manner, we are able to analyze not only the level of yield curve comovement, but also to which extent cross-border asset holdings are important for the comovement.

First, we find strong evidence that cross-border holdings of long-term debt and bank lending are important for the systematic dependence in yield curves among EMU member countries, whereas holdings of short-term debt and equity are not. Further, while taking into account the spatial feedback loop through indirect asset-holding relationships, we find that Germany and France impose the largest impact on other countries.

Our study of the degree of integration over time shows that the degree of comovement in EMU declines considerably after 2008. This decrease is to some extent related to the difference among countries in reacting to outside shocks from the US financial crisis and it largely reflects the segmentation between Greece, Ireland, Italy, Portugal and Spain (GIIPS) and non-GIIPS countries. The integration among non-GIIPS countries also declines, although with a slower rate than that among all EMU countries. Furthermore, we investigate the role of differences in credit risk for divergence by extending our model and allowing the level of comovement to be a function of cross-country dispersion in sovereign credit risk. We find that the comovement of yield curve decreases significantly as cross-country dispersion in the term structure of credit-default-swap (CDS) premium rises.

Finally, we investigate the impact of the shocks to the US yield curve on the EMU countries' yield curve before, during and after the recent US recession from December 2007 to June 2009. We show, among other changes, that the degree to which EMU countries' slopes depend on the US slope decreases in the recent US recession. This reflects the markets' expectation of future divergence of the US and EMU economies, as slope of yield curve is believed to predict real economic activity and inflation.

Our study draws on two strands of literature. The previous literature on interest-rate convergence in the EMU area looks mainly at a certain point on the yield curve, especially long-term yields

such as 10-year government bond yields (see e.g., Codogno et al., 2003; Manganelli and Wolswijk, 2009; Bernoth and Erdogan, 2012; Antonakakis and Vergos, 2013; Costantini et al., 2014). There are a few exceptions; Baele et al. (2004) show that local yields with various maturities of all EMU member countries become more integrated with those of Germany and France in the period 1999–2003 than in 1995–1998. The degree of integration is higher in the 10-year maturity segment than in the two- and five-year segments. A more recent study by Ehrmann et al. (2011), uses yields of maturities between two and 10 years, ignoring the very short-end maturities, to investigate the convergence of the yields of Italy, Spain, France and Germany from 1997 to 2008. The paper looks at unconditional correlation of the yields and the contribution of first and second principal components (level and slope) to the cross-sectional variation of yields across the countries. Overall, study on the convergence or comovement in the whole yield curve is lacking. Additionally, the time period considered in previous studies is mostly limited to the period before the euro debt crisis starting in 2009.

Given that it studies the yield-curve contour, our paper also builds on works that model the whole yield curve based on latent factors (e.g., Nelson and Siegel, 1987; Knez et al., 1994; Duffie and Kan, 1996). The latent factors 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 yield-curve shape. In general, 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 economy and the required bond risk premiums.¹ Lund and Christensen (2005), for example, suggest that the

¹ See, for example, Laurent (1988), Estrella and Hardouvelis (1991), Estrella and Mishkin (1998), and Hamilton and Kim (2002), who show the predictability of slope for economic growth. Mishkin (1990a) and Mishkin (1990b), among others, show empirically that slope is a significant predictor of inflation. Estrella

curvature of the yield curve is related to interest-rate volatility. Recent studies have also explicitly related the latent factors to such macroeconomic variables as real activity, inflation and monetary policy (see, e.g. Ang and Piazzesi, 2003; Diebold et al., 2006; Dewachter and Lyrio, 2006; Hördahl et al., 2006; Wu, 2006; Evans and Marshall, 2007). This macrofinance strand of the literature typically studies a specific country and ignores cross-border interactions of yield-curve factors. 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. Also, Abbritti et al. (2013) establish a relationship between the yield-curve level and a global factor on expected inflation using a panel data approach for Canada, the UK, Japan, Germany, Australia, New Zealand and Switzerland.

To our knowledge, ours is the first analysis of the importance of cross-border asset holdings for the international dependence of the yield curves. Our spatial VAR model provides insights into the mechanism of yield-curve interactions among economies. We contribute to the literature by providing evidence for integration of the whole yield curve rather than just certain points on the curve, bridging the macrofinance literature on yield curves and the literature on government-bond-yield integration. In addition, we enrich spatial econometric models by allowing the spatial correlation parameter to vary with exogenous economic variables.

(2005) provides an analytical rational expectations model that explicitly relates the yield-curve slope to expectations of real activity and inflation.

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 section 5 concludes the paper.

2. The Empirical Model

We develop an international model for 16 countries' yield curves using latent factors and macroeconomic variables. Our model is an extension of the domestic VAR 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:

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

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

The factors consist of the three latent factors of yield curves—level, slope, and curvature—and three macroeconomic variables—industrial production growth, inflation, and policy rate—yielding six equations. The latent factors are constructed 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 nonstationary, we estimate the model with the first difference of the dependent and explanatory variables. In this paper, f_{kit} stands for the first difference of factor k for country i at time t .

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

Our model weights the effect of each country j on country i by 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 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 panel data specification with cross-sectional fixed-effect and year dummies. The model for each factor k at time t can be expressed in the matrix formation as

$$\mathbf{f}_{kt} = \rho_k \mathbf{W}_t \mathbf{f}_{kt} + \mathbf{X}_t \boldsymbol{\beta}_k + \mathbf{W}_t \mathbf{X}_t \boldsymbol{\theta}_k + \mathbf{D} \boldsymbol{\alpha}_k + \mathbf{D}^y \boldsymbol{\tau}_k + \boldsymbol{\varepsilon}_{kt}, \quad (3)$$

where the vector \mathbf{f}_{kt} contains N observations of the factor k at time t , \mathbf{X}_t is an $N \times K$ matrix containing the lagged observations (one lag) of all 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 . \mathbf{W}_t is the $N \times N$ time-varying spatial weight matrix. $\mathbf{W}_t \mathbf{f}_{kt}$ is called the spatial lag, as opposed to autoregressive lag. \mathbf{D} is an $N \times N$ matrix containing a $N \times 1$ vector of ones and $N - 1$ country-specific dummy variables, and $\boldsymbol{\alpha}_k$ is an $N \times 1$ vector containing the global constant and $N - 1$ fixed-effect parameters. \mathbf{D}^y is an $N \times (Y - 1)$ matrix containing $Y - 1$ year-specific dummies, where Y is the number of years, and $\boldsymbol{\tau}_k$ is the $(Y - 1) \times 1$ parameter vector for year fixed effects. $\boldsymbol{\varepsilon}_k$ is an $N \times 1$ vector of idiosyncratic error terms. To estimate the model in equation (3), we use a Bayesian estimation method (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 weight matrix \mathbf{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 in pairs of countries.

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

$$\mathbf{f}_{kt} = (\mathbf{I}_N - \rho_k \mathbf{W}_t)^{-1} (\mathbf{X}_t \boldsymbol{\beta}_k + \mathbf{W}_t \mathbf{X}_t \boldsymbol{\theta}_k + \mathbf{D} \boldsymbol{\alpha}_k + \mathbf{D}^y \boldsymbol{\tau}_k + \boldsymbol{\varepsilon}_k). \quad (4)$$

If ρ_k , which measures the degree of spatial dependence between factor k of various countries, is different from zero, $(\mathbf{I}_N - \rho_k \mathbf{W}_t)^{-1}$ is not an identity matrix, thus any unexpected shock ε to factor k of one country will trigger movements in that factor of the spatially related countries, which in turn will feed back to the country itself, thereby amplifying the shock's effect. Furthermore, changes in the explanatory variables \mathbf{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 the dependent variables 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 $\mathbf{W}_t \mathbf{X}_t \boldsymbol{\theta}_k$. 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 well spillover to other countries and become amplified by spatial feedback.

As mentioned earlier, β_k and θ_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 express equation (4) in the following form. For the sake of simplicity, index k is suppressed.

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

where $\mathbf{V}_t = (\mathbf{I}_N - \rho \mathbf{W}_t)^{-1}$ and $\mathbf{S}_{lt} = \mathbf{V}_t (\beta_l \mathbf{I}_N + \theta_l \mathbf{W}_t)$. It is important to know that \mathbf{V}_t can be written as a geometric series $\mathbf{I}_N + \rho \mathbf{W}_t + \rho^2 \mathbf{W}_t^2 + \dots$. The term $\rho \mathbf{W}_t$ captures the immediate effect of a unit shock to f_t on other countries, as \mathbf{W}_t describes direct asset-holding relationships. \mathbf{W}_t^2 describes the asset-holding relationship of the second order: Country i is related to country j through investing in a third country that invests in country j . In the same way, \mathbf{W}_t^3 is the asset-holding relationship of the third order, and so on. Therefore, the higher-order terms in the geometric series, $\rho^2 \mathbf{W}_t^2$, $\rho^3 \mathbf{W}_t^3$, ..., capture additional effects via indirect asset-holding relationships. It should also be noted that any country is also indirectly related to itself. Thus, any of the higher-order terms can also 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 other countries 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 immediate effect (i.e. the effect without considering feedback) of a shock to f_t in country j on f_t of country i at time t is given by $V_{ij,t}^*$, which is the element in row i and column j of

$$\mathbf{V}_t^* = \rho \mathbf{W}_t. \quad (6)$$

The total or marginal effect, of a shock to f_t in country j on f_t of country i at time t is given by $V_{ij,t}$, which is the element in row i and column j of

$$\mathbf{V}_t = (\mathbf{I}_N - \rho \mathbf{W}_t)^{-1}. \quad (7)$$

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 11 EMU countries and the US (see Table 1). We use monthly data from December 2001 to December 2012 for the yield-curve and macroeconomic factors and yearly data from 2001 to 2011 for the integration measures.

3.1. 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 2002 and ending in December 2012, with the least square method.

$$y_{mt} = b_{0t} + b_{1t} \frac{1 - \exp\left(-\frac{m}{\lambda}\right)}{\frac{m}{\lambda}} + b_{2t} \left(\frac{1 - \exp\left(-\frac{m}{\lambda}\right)}{\frac{m}{\lambda}} - \exp\left(-\frac{m}{\lambda}\right) \right) + e_{mt} \quad (8)$$

where y_{mt} is the interest rate with maturity m at time t . The parameter λ is the decay factor, which takes 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 three months to 15 years. Since b_{1t} has the highest/lowest loading at the shortest/longest maturities, it is negatively related to the slope factor. Therefore, we reverse the sign of all estimated values of b_{1t} before using them in the subsequent estimation steps. It must also be noted that the parameter b_{2t} has its highest loading on middle-term maturities. Consequently, a higher value of b_{2t} implies a more concave (or less convex) yield curve.

3.2. Macroeconomic factors

Following Diebold et al. (2006), we use three key macroeconomic variables: real economic activity, inflation rate, and monetary policy rate. These variables are also widely considered important economic fundamentals in other related literature (e.g., Kozicki and Tinsley, 2001; Dewachter and Lyrio, 2006; Rudebusch and Wu, 2008). Manufacturing capacity utilization used by Diebold et al. (2006) to represent real activity is not available for all the countries in our sample. Instead, we use industrial production growth, which is available for all the countries in our sample and reported at the monthly basis. 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. Monetary policy rate is the monthly policy rate of the European Central Bank for the EMU countries and the monthly federal funds rate. Data on CPI and policy rates are taken from national sources in DataStream. Data on monthly industrial production growth are collected from the OECD iLibrary.

3.3. Integration measures

We measure the closeness between countries using holdings of equities and holdings of debt securities separately. As for debt, we use holdings in long-term debt instruments and holdings in

short-term debt instruments. As the banking system greatly contributes to the global systemic risk, we also measure countries' closeness using cross-border lending between banks.

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

$$W_{ij,t} = \frac{holding_{ij,t}}{\sum_{k=1}^{k=N} holding_{ik,t}}, \quad (9)$$

where $holding_{ij}$ is the stock of investment holdings 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 and long- and short-term debt instruments are collected from the International Monetary Foundation's Coordinated Portfolio 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 banks² in individual economies on immediate borrowers.³

Table 1 shows that the summary statistics of the estimated yield factors for different countries. Overall, the average level of the yield curve is larger for all the GIIPS countries compared to other EMU countries and the US. Most of the GIIPS countries also have significantly positive excess

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 nonlocal 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.

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. The mean slope of the US is larger than that of the EMU countries excluding the GIIPS countries.

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 nonstationarity 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 and macroeconomic factors for the US and EMU countries. The US and the EMU yield-curve levels follow each other very closely from the beginning of the sample to 2008. The US level then drops considerably and reaches a trough at the end of 2008, one year after the start of the US recession. The drop may in part be caused by quantitative easing and decreased policy rate undertaken by the Federal Reserve to combat the credit crisis in 2008. From then on, the comovement between the US and EMU yield

curve levels is diminished. The US yield curve level has a decreasing trend since the recession and reaches half of its value prior to the 2012 recession. The mean of the EMU countries' interest-rate levels rises considerably from the beginning of 2010. Comparing the mean interest rate levels of EMU countries including and excluding GIIPS countries, we see that this rise is mainly caused by the increase in the GIIPS countries' interest rates, due to anxiety about their excessive national debt.

The slope factor of the EMU countries seems to follow that of the US until 2010. The mean value of the slopes of the EMU countries excluding the GIIPS remains stable, as does the slope of the US. Comparing this with the mean value of the EMU countries including the GIIPS shows that the average GIIPS slope rises dramatically from 2010 to 2011, indicating a sharp increase in the GIIPS sovereign risk premia. We can also see that the slopes are negatively correlated with their corresponding policy rates before 2010 when the policy rates become very low, which suggests a negative impact of the policy rate on slope. In addition, there seems also a lead-lag relationship between the federal funds rate and the ECB policy rate.

Like the slopes, the US and EMU curvatures are very similar until 2010, after which the GIIPS countries diverge from the rest of the EMU and the US. For the EMU countries and the US, industrial production growth drops considerably during the US financial crisis. We also observe a substantial negative growth for the GIIPS countries in 2012. Additionally, the inflation rate in the EMU, in contrast to the US inflation rate, is stable and close to the ECB's target inflation rate until the end of 2007, but it is slightly lower in the non-GIIPS countries. Unsurprisingly, the inflation rates of the EMU and the US drop to negative values in the recession period associated with the US financial crisis and return to normal levels after that.

(Insert Figure 1)

4. Results and Analysis

In this section, we first present the results of estimating our suggested model in equation (3) for the entire sample in order to see how different linkages between the countries affect interdependence in the yield-curve factors. Next, we investigate the importance of each EMU country for the comovement of the yield curve. The third subsection analyzes the degree of integration of EMU government-bond markets over time. The fourth subsection explores the role of credit risk for integration of the yield-curve factors. Finally, we analyze the US yield curve's effect on the EMU countries yield-curve factors before, during and after the global financial crisis.

4.1. The importance of cross-border asset holdings for yield-curve comovement

In this section, we analyze the estimated results of the model in equation (3). 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 2. The estimated coefficients for the country fixed effects and year dummies are not reported, but they are available upon request.

(Insert Table 2)

We start by analyzing the estimated ρ values, which show the degree of spatial dependence across countries. The first row of each panel shows the estimated ρ values for four different cross-border asset holdings. We also use a matrix with equal weights as the benchmark. The spatial correlation is highly statistically significant for all the latent factors, over all the choices of the weight matrices. However, as pointed out in Asgharian et al. (2013), the statistical significance of spatial correlation

may be caused primarily by global comovement and does not necessarily indicate that the selected closeness measures are important. If this is the case, the estimated values of ρ should be large, no matter how the relative weights in the matrix \mathbf{W} are chosen for each country. Hence, following Asgharian et al. (2013), we perform a simulation analysis where we randomly generate 200 spatial weight matrices and estimate the model for each matrix. This results in 200 different estimates of ρ . Figure 2 compares the estimated values of the spatial coefficients, ρ , from the selected closeness measures (the dots) with the 99% and 95% one-sided confidence intervals of the empirical distributions of the estimated ρ values from the randomly generated weight matrices. It shows that, although statistically significant, the estimated ρ values using the equity-investment and equal-weight matrices do not exceed 95% of the ρ values from the randomly generated closeness measures, for any factors. This indicates that the statistical significance and large value of ρ associated with these measures may primarily be caused by global comovement in interest-rate levels. The estimated ρ of the short-term debt is higher than the 95% one-sided confidence interval only for the curvature factor. Since the estimated ρ values using long-term debt and bank lending are above 95% of the ρ values from the randomly generated matrices for all the three factors (above 99% for level and slope), we may conclude that there exists systematic yield-curve spatial dependence in through these two cross-border asset holdings.

(Insert Figure 2)

It is possible that the holdings of short-term debt and equity by nature—perhaps due to the type of securities involved—do not affect interest-rate markets as strongly as the two other holdings do. Short-term debt involves securities with maturities less than one year, so transactions on these securities may not dramatically affect the whole term structure of the interest rates. Similarly, equity holdings do not directly imply transactions on fixed income securities. Another possible

explanation for why the short-term debt and equity holdings appear unimportant to the systematic spatial dependence in yield curve is reflected by the amount of these asset holdings among EMU countries. Shown in Figure 3, the yearly amounts of long-term debt holding and bank lending are considerably larger than the holdings of short-term debt and equity over the whole sample period. It is possible that the amount of cross-border short-term lending and equity holding is too small to affect the comovement of interest rates and, therefore, the weight structures imposed by these two types of asset-holding cannot properly capture the comovement among the interest rates.

(Insert Figure 3)

In what follows, we analyze the estimated values of vectors β and θ , 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 β and θ 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 the factors slope and curvature, regardless of the closeness measure. Since we estimate the regression on the first differences, the negative sign of this β implies that these two factors are mean reverting. Second, the β values 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. We also find a positive effect of lagged curvature on level, whereas Diebold et al. (2006) do 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 almost all cases, generally consistent with the Diebold et al. (2006) finding.

Judged from the estimates of θ , we can see that yield-curve factors in one country can directly affect factors in other countries. Lagged level has a direct positive effect on the curvature of other

countries, which is significant for three out of five closeness measures. Slope has a positive effect on level and slope of other countries, but a negative effect on curvature. Curvature shows negative effects on level and slope, but the effect is not significant for all the closeness measures. However, curvature has a significant and positive effect on other countries' curvature. Furthermore, the estimated θ values for inflation are positive and significant for the level factor. This result, together with the insignificance of the estimated β values for lagged inflation may indicate that the domestic interest-rate level reacts more quickly to the domestic inflation than to that of the other countries and, therefore, we do not observe any significant impact of the inflation of a country on the interest-rate level of that country in the next period. Additionally, since the EMU countries have the same policy rate, the ECB rate, the value of θ for this variable is restricted to be zero and is thus not reported.

4.2. The importance of individual countries

In this part, we investigate the importance of each EMU country for comovement of the yield curve. We add an interaction term into the model in equation (3) to reveal how the degree of dependence on the focus country (hereby denoted as the *dominant* country) differs from the dependence on other countries:

$$\mathbf{f}_{kt} = \rho_k \mathbf{W}_t \mathbf{f}_{kt} + \rho_{k,\text{dom}} \mathbf{W}_t \mathbf{I}^{\text{dom}} \mathbf{f}_{kt} + \mathbf{X}_t \boldsymbol{\beta}_k + \mathbf{W}_t \mathbf{X}_t \boldsymbol{\theta}_k + \mathbf{D} \boldsymbol{\alpha}_k + \mathbf{D}^y \boldsymbol{\tau}_k + \boldsymbol{\varepsilon}_{kt}, \quad (10)$$

where \mathbf{I}^{dom} is a $N \times N$ matrix with the diagonal element corresponding to the dominant country equal to one and all the others equal to zero. In this case the total (i.e., marginal) effect of a shock to a latent factor of the dominant country j on the same of factor of country i at time t is given by $V_{ij,t}$, which is the element in row i and column j of

$$\mathbf{V}_t = (\mathbf{I}_N - \rho \mathbf{W}_t - \rho_{\text{dom}} \mathbf{W}_t \mathbf{I}^{\text{dom}})^{-1}. \quad (11)$$

We perform the analysis for all three latent factors using two choices of the cross-border asset holding—long-term debt and bank lending—which are shown to be systematically important linkages for the spatial correlation among the markets by the results of the previous section (see Figure 2). However, since the results from these two measures are fairly close to each other, we only present those obtained using bank lending.

Table 3 shows the total spatial effect of each country averaged over time, $\bar{V}_{i,j}$, for different countries, where j specifies the dominant country. The dominant countries are in the columns of the table. For all the latent factors, the effect of a shock in a country on itself is always larger than one. The reason is that, due to positive spatial dependence, a shock in a country affects other countries, which feed back positively to the country itself. This result reflects the dynamic nature of risk spillover. The last row for each latent factor shows the mean spatial effect of each dominant country, which can be used to assess the relative importance of that country. For all three latent factors, France and Germany are the most important countries: A one-unit shock to any of the three latent factors in these two countries can cause in average more than 0.50 unit change in the corresponding factor of the other EMU countries. Interestingly, the Netherlands is the third most important country with a mean spatial effect considerably higher than such larger countries as Italy and Spain. Greece, Ireland and Portugal have consistently the lowest mean spatial effects. France is, in addition to Germany and the Netherlands, affected largely by Italy and Belgium, while Austria is the most important country for Germany for all the three latent factors. The strong relationship between Austria and Germany is even more apparent when we look at the effect of Germany on Austria, where the spatial effect is slightly above one for all three factors, which means that a one-unit initial shock in Germany, after amplification through the spatial feedback process, will result in more than one unit of change in Austria's factor values.

(Insert Table 3)

As we can see in equation (11), the estimated spatial effect, $V_{ij,t}$, depends both on the cross-border asset holding, matrix \mathbf{W} , and the estimated spatial correlation, ρ . In Figure 4, we illustrate the relation between the cross-border bank lending and the estimated spatial effects. For each country, the figure shows the three countries that receive the largest volumes of bank lending from that country (arrows) and the mean spatial effect of the country according to Table 3 (the size of the ellipse). We choose only the level factor since, as Table 3 shows, the countries' spatial effects do not vary much from factor to factor in relative terms. Germany and France, as shown before, have the largest mean spatial effects and are at the same time the main recipients of the other countries' cross-border bank lending. However, for some countries, the relationship between spatial effect and cross-border bank lending is not so straightforward. For example, Austria has larger mean spatial effect than Spain and Italy (compare the size of the ellipse), but it is not among the main three recipients of any country's cross-border bank lending. In fact, according to Table 3, Austria has the largest spatial effect on Germany, while as the arrows of Figure 4 show, German banks lend more to Spain, France and the Netherlands than to Austria. This result is due to a relatively strong spatial correlation parameter, $\rho_{k,\text{dom}}$, for Austria.

(Insert Figure 4)

The analysis above is based on the average over time of the total spatial effect, which captures both the immediate effect (i.e. the effect of a shock through direct asset holdings),

$$\mathbf{V}_t^* = \rho \mathbf{W}_t + \rho_{\text{dom}} \mathbf{W}_t \mathbf{I}^{\text{dom}}, \quad (12)$$

and the entire spatial feedback loop through indirect asset-holding relationships (see section 2). To analyze the extent to which the feedback mechanism among EMU countries amplifies the

transmission of the shocks among the countries, we compare the average over time of the total effect with corresponding values for the immediate effect. As an example, we show immediate and total effects for the level factor in Figure 5. The figures for the other latent factors are similar. As Figure 5 shows, the indirect asset-holding relationships considerably increase the effect of shocks. The degree of amplification ranges between 44% (for France) and 90% for Portugal. There is a negative relationship between the value of the immediate shocks and the degree of amplification (a correlation of about -0.96). This indicates that the distribution of the total effect is smoother than that of the immediate effect. Therefore, it is important to take into account indirect asset-holding relationships when we assess countries' interconnectedness.

(Insert Figure 5)

4.3. Time variation in the degree of integration

In this section, we analyze to what extent the degree of integration of EMU government bond markets has changed over time. With all else held constant, we expect that the introduction of Euro, due to the elimination of the exchange-rate risk, would facilitate cross-border investments and accelerate the convergence of these markets. To study the degree of integration over the years, we estimate the spatial correlation coefficient ρ from the baseline model for each year from 2002 to 2012 (equation (3), without the year dummy). We present the yearly estimate and confidence interval of the spatial correlation coefficient for each latent factor, respectively, in Figure 6. The figures on the left are based on the sample with all the EMU countries. For brevity, we show the coefficient associated with bank lending only, as bank lending has been shown previously to be an important proximity measure for all the latent factors. For the level and slope factors, the estimated ρ has stable values and high statistical significance over the years between 2002 and 2007. For the curvature factor, the estimated ρ is highly statistically significant and increases gradually from

2002 to 2005. It drops considerably in 2006, but returns to its previous level in 2007. The estimates of ρ values from 2002 to 2007 largely indicate a strong degree of integration in all the latent factors during this period. This result is in line with the Ehrmann et al. (2011) study, which finds that the monetary union has unified government bond markets using the data from 1993 to 2008.

In contrast to convergence in the period between 2002 and 2007, the degree of EMU comovement starts to decline in 2008, as revealed by the decreasing trend of ρ from 2008 to 2012 for all factors. The decreasing trend is so remarkable that the estimate of ρ becomes insignificant at the 95% confidence interval for the level factor in year 2012, for slope from 2010 to 2012, and for curvature in 2010 and 2012.

(Insert Figure 6)

Our finding about the comovement among EMU government bond markets may have more than one interpretation. First, the decrease in the value of ρ after year 2007 may, in this case, indicate that the EMU bond markets become less sensitive to the shocks of other EMU bond markets. Alternatively, the comovement in EMU may be related to the degree of similarity among EMU markets in their reactions to external common shocks. For example, the decline in comovement starting from 2008 may reflect that EMU countries react differently to the US financial crisis. To investigate the integration among EMU markets further, we include the yield factors and macroeconomic variables of the US in the estimation. In order to control for the influence from the US, we augment the baseline model:

$$\begin{aligned}
f_{kit} = & \alpha_k + \rho_{k,EMU} \sum_{\substack{i \in EMU \\ j \in EMU}}^N w_{ij} f_{kjt} + \rho_k^* \sum_{\substack{i \in EMU, j=US \\ \{i=US, j \in EMU\}}}^N w_{ij} f_{kjt} + \sum_{l=1}^K \beta_{kl} f_{li,t-1} \\
& + \sum_{l=1}^K \theta_{kl} \sum_{j \neq i}^N w_{ij} f_{lj,t-1} + \varepsilon_{kit},
\end{aligned} \tag{13}$$

$$k = 1 \dots K, i = 1, \dots N + 1, j = 1, \dots N + 1, t = 1, \dots T,$$

which separates $\rho_{k,EMU}$, the spatial correlation among EMU countries from ρ_k^* the spatial correlation between EMU and the US. $\rho_{k,EMU}$ and ρ_k^* indicate, respectively, the degree of dependence among EMU countries and the degree of dependence between EMU and the US, both through direct cross-border asset holdings.

The diagrams in the middle of Figure 6 show the yearly estimates of ρ_{EMU} and their confidence intervals based on the sample including the US. By comparing the trends of these estimates with those based on the sample of EMU countries (figures in the left), we can see whether the dependence among EMU countries is influenced by the US market. As for the level factor, the trend of ρ_{EMU} is similar to that of ρ in the left figures. A difference is that ρ_{EMU} remains stable until year 2009 and starts increasing in 2010, implying that the decrease in the EMU comovement indicated by ρ in 2008 and 2009 comes mainly from the influence of the US market. Thus, the unification of the general level of bond yields within the EMU is high and stable until year 2009, but EMU countries may react to different extents to the US market during the US financial crisis in 2008 and 2009. For the slope factor, we can see a gradual increase in the unification among EMU countries from 2002 to 2005 when the influence of the US market is removed. Additionally, the drop of ρ_{EMU} in 2006 suggests divergence of slope among EMU countries in 2006. For curvature, the variation of ρ_{EMU} resembles that of ρ , indicating that the timing of convergence/divergence in this factor is not influenced by the US market. Furthermore, for all the latent factors, the estimates of ρ_{EMU} become

smaller and less significant in the last few years of our sample period. This suggests divergence in the EMU that is not explained by the US influence.

Another possible reason for the EMU divergence is segmentation among markets in the region. We investigate this by removing the GIIPS countries in the estimation of the baseline model (equation (3), without the year dummy), and look at the dependence among non-GIIPS countries (i.e., Austria, Belgium, Finland, France, Germany, and the Netherlands). The graphs on the right in Figure 6 show the yearly estimates of the spatial correlation coefficient and confidence intervals for the sample of non-GIIPS EMU member countries. As for the level factor, the spatial correlation coefficient for non-GIIPS countries is statistically significant throughout the period from 2002 to 2012. After reaching the peak in 2007, the spatial correlation decreases mildly, in contrast to the marked decrease in the parameter for the sample including GIIPS countries shown by the graphs on the left. Similarly, the spatial correlation of slope exhibits a slight decreasing trend from 2009. In contrast to the spatial correlation being statistically insignificant from 2010 to 2012 for the sample including GIIPS countries (graphs on the left), the spatial correlation for non-GIIPS countries is statistically significant throughout the whole sample period. In addition, integration among non-GIIPS countries drops in 2008, which may reflect that the risk premiums in the government bonds of non-GIIPS countries reacting to the US financial crisis to different extents. As for curvature, the trend of dependence among non-GIIPS countries looks similar to that among EMU countries. In all, the integration among non-GIIPS countries declines mildly, so the aforementioned divergence in the EMU reflects largely the segmentation between GIIPS and non-GIIPS countries. It should, however, be noted that the values of the estimates are not comparable across different samples due to the different numbers of markets included. As documented in

Asgharian et al. (2013), the estimated value of the spatial correlation coefficient depends on the number of related countries.

4.4. The role of sovereign creditworthiness

In the previous section, we showed that the degree of integration among yield factors of the EMU countries reduced after 2008. Since investors are generally compensated with a higher premium for holding government bonds issued in a country with higher sovereign credit risk, a possible explanation for the divergence in yields is the relative change in the sovereign credit risks.⁴ In order to analyze the effect of the credit risk we divide the government-bond yield of country i , Y_i , in two parts:

$$Y_i = Y_i^* + P_i$$

where Y_i^* is the part of the interest rate determined by the demand and supply of credits and such factors as inflation and exchange rate, and P_i is the risk premium due to sovereign credit risk. Both Y_i^* and P_i vary over maturities. Using the traditional method, the level, slope and curvature of the yield curve can be defined as:

$$\begin{aligned} Y_{level} &= \frac{1}{K} \sum_{k=1}^K Y_k = \frac{1}{K} \sum_{k=1}^K Y_k^* + \frac{1}{K} \sum_{k=1}^K P_k = Y_{level}^* + P_{level} \quad k = 1, \dots, K \\ Y_{slope} &= Y_l - Y_s = (Y_l^* + P_l) - (Y_s^* + P_s) = (Y_l^* - Y_s^*) + (P_l - P_s) \\ &= Y_{slope}^* + P_{slope} \end{aligned} \tag{14}$$

⁴ It should be pointed out that the decline of integration is not due to an inflation-rate differential since we control for the inflation rate of each country in the model. Neither is the decline explained by exchange-rate risk, as the EMU countries in our sample use the same currency and are subject to the same monetary policy executed by the European Central Bank.

$$\begin{aligned}
Y_{curv} &= \frac{1}{2}((Y_l - Y_m) - (Y_m - Y_s)) \\
&= \frac{1}{2}((Y_l^* + P_l) - (Y_m^* + P_m) - (Y_m^* + P_m) - (Y_s^* + P_s)) = Y_{curv}^* + P_{curv}
\end{aligned}$$

where k stands for a certain maturity, and s , m and l denote short, medium and long maturities, respectively. The cross-sectional covariance matrix of each factor is:

$$\Sigma_{Y_x} = \Sigma_{Y_x^*} + \Sigma_{P_x} + \Sigma_{Y_x^* P_x} \quad \text{for } x = \text{level, slope and curv} \quad (15)$$

where Σ_{Y_x} , $\Sigma_{Y_x^*}$ and Σ_{P_x} are $N \times N$ covariance matrices of Y_x , Y_x^* and P_x , and $\Sigma_{Y_x^* P_x}$ is the $N \times N$ covariance matrix of the two components of the yield across countries, in which each diagonal element is the covariance between the two components of the same country. According to equation (15), the comovement in the yield curve depends on that in the risk-premium term structure. To investigate this empirically, we analyze if the degree of spatial correlation of yield curve factors is related to the correlation of credit-risk factors. We follow Solnik and Roulet (2000) and use cross-sectional dispersion as a measure of the general correlation level in credit risk at each time point: The higher the dispersion, the lower the correlation. We use the sovereign credit default swap (CDS) premium as the measure of sovereign credit risk. We extend the model in equation (3) by defining a time-varying spatial correlation parameter as a function of the cross-sectional dispersion in the CDS premium:

$$\rho_t = \rho_0 + \rho_{\text{CDS}} \sigma_{\text{CDS}, t-1}, \quad (16)$$

where σ_{CDS} is the cross-sectional standard deviation of the sovereign-CDS-premium level, slope, and curvature, respectively, in the regression for yield-curve level, slope, and curvature.

A differential in sovereign creditworthiness has been suggested as an important determinant of yield differential by the previous literature (e.g. Codogno et al., 2003; Manganelli and Wolswijk,

2009; Costantini et al., 2014). However, these studies use sovereign credit ratings, debt to GDP ratio and government budget balance to GDP as measures of a country's creditworthiness. An advantage of using sovereign CDS premium is that sovereign CDSs are traded with several maturities, ranging from one year to 10 years, revealing market view of credit risk over different horizons. Therefore, by using sovereign CDS premium, we can relate the comovement of interest-rate term structure to that of risk-premium term structure.

We construct the level, slope, and curvature factors of sovereign CDS premium (in basis points)⁵, which correspond to the three yield-curve factors. The level factor of CDS premium is calculated as the average of CDS premiums with 10 different maturities, ranging from one to 10 years. Slope is the CDS premium with 10 years maturity minus the CDS premium with one year maturity. Curvature is the difference between the CDS premiums with 10 years and five years maturities minus the difference between the CDS premiums with five years and one year maturities. For illustration, we depict the cross-sectional dispersion of sovereign-CDS-premium factors of the EMU countries (with and without GIIPS countries) in Figure 7. Dispersion is measured as the cross-sectional standard deviation of the CDS-premium factor in each month. The figure shows that the dispersion of all the CDS-premium factors is very small before year 2008 and increases after the US financial crisis. The dispersion among all EMU countries accelerates in the European financial crisis, with a notably larger rate than the dispersion among non-GIIPS countries. Although increasing in general, the trend in dispersion differs from factor to factor. For example, the dispersion in level reaches its peak in 2011, whereas the dispersions in slope and curvature, respectively, reach their peaks in the start of 2012 and towards the end of 2012. This reveals that

⁵ Data on sovereign CDS premium cover 10 different maturities, ranging from one to 10 years, and are collected from Capital IQ. The data are available for the period from 2006.

the comovement of credit risk differs across maturities and suggests the necessity of delving into credit-risk term structure.

(Insert Figure 7)

We report the parameters of the spatial correlation function for different latent factors and asset holdings in Table 4. We demean $\sigma_{\text{CDS},t-1}$ in order to capture the average spatial correlation by the parameter ρ_0 , which makes it comparable with the estimation of time-invariant ρ values in the other parts of the study. The estimated ρ values are all highly significant and show the same relative pattern as the time-invariant ρ values in Table 2, but all are slightly lower than the corresponding values in Table 2. The lower values should be due to the fact that the sample, due to unavailability of the CDS premium data, starts in 2006 and the average degree of spatial dependence is lower in the later part of the sample. The estimated ρ_{CDS} are all negative and highly significant. This verifies that the degree of yield-factor comovement is negatively related to the differences in the countries' sovereign risk. As we illustrated in Figure 7, the dispersion of credit-risk factors has increased after 2008, even among non-GIIPS countries. Therefore, we can conclude that the divergence of the yield curve of the EMU countries (both with and without GIIPS countries) after 2008, illustrated in Figures 6–8, should be mostly related to the cross-sectional divergence in the credit risk during this period.

(Insert Table 4)

4.5. The US effect

In this section, our purpose is to investigate how the EMU countries' yield factors are affected by the contemporaneous shocks to the corresponding US yield factors, through the selected cross-border linkages.

Table 5 summarizes, for every type of asset, the share of each selected EMU country invested in the US with respect to the total investment in the US and peer EMU 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 over US debt: For all of the selected EMU countries except Ireland, the relative share in US equities is larger than that in debt. Greece and the Netherlands have a strong preference for US equities, with more than 40% of their equity investment in the US. The percentages of US bank claims owned by banks in the EMU countries are mild in general, implying that cross-border bank lending takes place mainly between EMU countries. Furthermore, there is a big difference in the ownership of US assets across countries.

(Insert Table 5)

We include the US yield factors and macroeconomic variables in the model and estimate equation (10), where \mathbf{I}^{dom} is an $N \times N$ matrix with the diagonal element corresponding to the US equal to one and all the other elements equal to zero, and N is the number of countries including the US. As we are especially interested in the impact of the recent US economic recession on yield-curve interaction, we study three nonoverlapping subsample periods: prerecession from January 2002 to November 2007, recession period from December 2007 to June 2009, and postrecession period from July 2009 to December 2012.

We estimate the model for each of the three subsample periods and use the estimated parameters to calculate the effects of the US yield factors on the EMU yield factors using equation (11). Table 6 reports the sum of estimated ρ and ρ_{dom} , which indicates the spatial correlation coefficient for the US. Since the interest of this part of the study is the magnitude of the US impact rather than the spatial correlation coefficient itself, we do not use randomly generated weight matrices to obtain the empirical distribution of this parameter for the subsamples. We calculate the marginal

effects of the US factors, which depend on both the estimated spatial correlation and the weight matrix \mathbf{W} . Figure (8) depicts the marginal effects of the US factors averaged over the EMU countries in different periods.

As for the level factor, that spatial correlation coefficient for the US is statistically significant in all cases except for the short-term-debt holding in the postrecession period, which indicates that the levels of the EMU countries comove with that of the US in all periods. The time trend of the spatial correlation parameter is not consistent across all the cross-border linkages. However, the marginal effect of the US level factor depicted in Figure 8 appears to have a decreasing trend in all the cases.

(Insert Table 6 and Figure 8)

The spatial correlation parameters for the US slope are significant in the pre- and postrecession periods but not in the recession. This is in line with the change in the marginal effect of the US slope, which is at trough during the recent US recession. The slope of the yield curve is a strong predictor of the economic growth and inflation, and is also related to the risk premium incorporated in the yield. Therefore the weak effect of the US slope on the slope of EMU during the US recession may reflect the perception of the divergence between the US and the EMU regarding future economic growth or the riskiness of the bonds in this period. In contrast, the spatial correlation parameter for the US curvature and the marginal effect of the US increase markedly in the recession, reflecting that the uncertainty in the US interest-rate market during the US recession spills over to the EMU countries, since the curvature is believed to be related to interest-rate volatility. After the recession, the spatial correlation parameter turns statistically insignificant and the marginal effect also drops considerably.

5. Conclusion

We construct a spatialVAR 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 bank lending for yield-curve interactions among EMU countries. We also investigate to what extent shocks in the US yield curve affect yield curves of these countries.

Our results show a systematic spatial dependence in yield curve through cross-border long-term debt and bank lending, while the short-term debt and equity holdings appear unimportant. For all the three latent factors of the yield curve, the spatial correlation parameters resulted from long-term debt and bank lending are statistically significant and are also above the 95% one-sided confidence interval of the spatial correlation parameters from a simulation study with 200 randomly generated weight matrices.

We investigate the role of each EMU country for the comovement of the yield curve within the EMU and find that France and Germany are the most important countries in this regard. More specifically, a one-unit shock to any of the three latent factors in these two countries can cause on average about 0.50 unit change in the corresponding factor of the other countries. France itself is largely affected by Italy and Belgium, while Austria is the most important country for Germany. Furthermore, we show that the feedback mechanism among EMU countries, due to indirect asset-holding relationships, considerably amplifies the transmission of the shocks among the countries.

The elimination of the exchange-rate risk, as a result of the introduction of Euro, should facilitate cross-border investments and accelerate the convergence of these markets. However, our study of the degree of integration over time shows that the degree of comovement in EMU declines considerably after 2008. This decrease may either indicate that the EMU bond markets become

less sensitive to the shocks from other EMU bond markets, or that different EMU countries have reacted differently to outside shocks, such as the US financial crisis. To analyze this, we include the US factors in our model. Our results show that the lower EMU comovement in 2008 and 2009 resulted partly from the influence of the US market, but the US effect cannot explain the divergence in the EMU after 2009. Our further analysis shows that the divergence in the EMU in the latter period largely reflects segmentation between GIIPS and non-GIIPS countries. The integration among non-GIIPS countries also declines, with a slower rate than that among all EMU countries.

A possible explanation for this divergence may be the divergence in the sovereign credit risks. We observe a substantial cross-sectional dispersion in sovereign CDS premium of the EMU countries after the US financial crisis, which is mostly due, but not limited, to the GIIPS countries. We extend, therefore, the model by defining a time-varying spatial correlation parameter as a function of the cross-sectional dispersion in the CDS premium. We find a strong negative relation between the degree of a yield factors' comovement and the dispersion in the countries' CDS-premium term structure.

Finally we analyze how the EMU yield factors are affected by contemporaneous shocks to the corresponding US yield factors, before, during and after the US financial crisis. We find a decreasing trend in the effect of the US level factor on the EMU level factors. The effect of the US slope is small and insignificant during the recession, which may reflect markets' perception about divergence in the future economy between the US and the EMU countries during this period. The effect of the US curvature on that of the EMU countries is considerably stronger in the recession than in the other periods, which may indicate spillover of the uncertainty in the US interest-rate market to the EMU countries during the US recession.

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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 monthly yields for government bills and bonds with all available maturities ranging from three months to 15 years. Data covers the period from December 2001 to December 2012.

		Mean	Stdev	Min	Max	Kurt.	Skew.	Autocor.
Level	Austria	4.299**	0.655	2.546	5.620	−0.071	−0.349	0.938**
	Belgium	4.452**	0.604	2.677	5.796	0.075	−0.207	0.904**
	Finland	4.177**	0.723	2.230	5.808	0.395	−0.336	0.947**
	France	4.238**	0.636	2.616	5.667	0.079	−0.156	0.934**
	Germany	3.932**	0.884	1.642	5.635	0.302	−0.636	0.964**
	Greece	5.741**	1.792	3.686	11.659	2.727**	1.748**	0.959**
	Ireland	5.541**	1.578	3.470	10.249	1.273**	1.258**	0.961**
	Italy	4.971**	0.710	3.666	7.220	0.728**	0.674	0.933**
	Netherlands	4.156**	0.784	2.096	5.666	0.165	−0.663	0.945**
	Portugal	5.888**	2.669	3.468	16.536	3.668**	2.035**	0.972**
	Spain	4.876**	0.878	3.398	7.786	0.270	0.690	0.945**
	US	4.198**	0.970	1.691	5.922	0.583**	−1.046*	0.943**
Slope	Austria	1.573**	1.322	−1.703	5.027	−0.332	−0.372	0.908**
	Belgium	2.313**	1.223	0.015	4.539	−1.127**	−0.034	0.940**
	Finland	1.183**	1.070	−1.661	2.952	−0.426*	−0.660	0.937**
	France	2.153**	1.018	−0.096	4.032	−0.735**	−0.106	0.950**
	Germany	1.958**	0.919	−0.290	3.752	−0.438*	−0.084	0.920**
	Greece	4.674**	5.341	−1.169	16.499	0.245	1.334**	0.976**
	Ireland	3.165**	3.305	−1.284	15.013	1.782**	1.307**	0.950**
	Italy	2.816**	1.546	0.362	6.547	−1.003**	0.347	0.953**
	Netherlands	2.005**	1.031	−0.030	4.126	−0.688**	0.011	0.945**
	Portugal	3.707**	3.929	−0.154	21.061	3.532**	1.886**	0.923**
	Spain	2.607**	1.792	−0.272	8.006	−0.199	0.608	0.956**
	US	2.405**	1.447	−0.820	4.620	−0.899**	−0.435	0.955**
Curvature	Austria	−4.239**	2.714	−10.933	0.772	−0.389	−0.151	0.904**
	Belgium	−3.481**	2.167	−8.639	0.451	−1.056**	0.217	0.833**
	Finland	−4.766**	3.098	−11.755	0.294	−0.971**	−0.176	0.943**
	France	−3.487**	2.185	−7.106	0.571	−1.011**	0.379	0.944**
	Germany	−2.979**	2.058	−6.495	1.209	−0.987**	0.515	0.932**
	Greece	9.950**	27.061	−8.167	71.003	1.158**	1.713**	0.989**
	Ireland	−3.373**	6.844	−16.039	29.979	9.899**	2.706**	0.620**
	Italy	−2.951**	2.078	−6.542	4.086	−0.566**	0.382	0.826**
	Netherlands	−3.528**	2.051	−6.803	0.153	−1.091**	0.484	0.928**
	Portugal	−1.845*	10.041	−31.422	37.818	6.439**	1.500**	0.759**
	Spain	−3.075**	2.021	−8.895	0.488	−0.436*	−0.036	0.750**
	US	−3.455**	2.596	−7.427	1.682	−0.922**	0.513	0.949**

Table 2. Estimation results from the spatial Durbin model (SDM) with one spatial lag

This table presents the estimated results of the panel data SDM model:

$$f_{kt} = \rho_k W_t f_{kt} + X_t \beta_k + W_t X_t \theta_k + D \alpha_k + D^y \tau_k + \varepsilon_{kt},$$

where the vector f_{kt} contains N observations of the factor k at time t , X_t is an $N \times K$ matrix containing the lagged observations (one lag) of all factors, and β_k and θ_k are the corresponding parameter vectors. W_t is the $N \times N$ spatial weight matrix. D is an $N \times N$ matrix containing a vector of ones and country-specific dummies, and α_k is an $N \times 1$ vector containing the global constant and fixed-effect parameters. D^y is an $N \times (Y - 1)$ matrix of year dummies, where Y is the number of years, and τ_k is the vector for year fixed effects. ε_{kt} is an $N \times 1$ vector of error terms. The estimations are based on monthly values for 11 EMU countries over the period from January 2002 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.

		Long-term debt	Short-term debt	Equity	Bank lending	Equally weighted
Level	ρ	0.789**	0.712**	0.753**	0.798**	0.779**
	Level	-0.012	-0.005	-0.016	-0.006	0.027
	Slope	-0.068**	-0.059**	-0.057**	-0.072**	-0.063**
	β Curvature	0.032**	0.028**	0.025**	0.031**	0.031**
	IP growth	0.001	0.000	0.000	0.001	0.000
	Policy rate	-0.039	-0.086**	-0.054	-0.031	-0.072*
	Inflation	0.618	1.165	0.596	0.750	0.891
	Level	-0.017	0.029	0.004	-0.032	0.044
	Slope	0.071**	0.022	0.044	0.081**	-0.004
	θ Curvature	-0.020**	-0.015**	-0.017**	-0.020**	-0.013**
	IP growth	0.001	0.000	0.000	0.001	0.001
	Inflation	4.106*	3.457*	4.414**	3.906*	3.556*
	ρ	0.645**	0.549**	0.555**	0.655**	0.554**
	Level	0.044	0.003	0.117*	0.042	0.027
Slope	Slope	-0.166**	-0.178**	-0.192**	-0.168**	-0.217**
	β Curvature	-0.006	-0.005	0.020*	-0.008	0.016
	IP growth	0.003	0.002	0.003	0.002	0.002
	Policy rate	-0.045	-0.103	-0.140*	-0.040	-0.122
	Inflation	-2.725	-3.352	-3.181	-2.636	-1.680
	Level	-0.062	0.064	-0.048	-0.045	0.137
	Slope	0.199**	0.163**	0.165**	0.197**	0.121*
	θ Curvature	-0.017	-0.022	-0.035**	-0.018	-0.031**
	IP growth	0.003	0.001	0.000	0.002	0.004
	Inflation	5.862	7.923*	6.557	5.992	6.442
	ρ	0.514**	0.396**	0.305**	0.505**	0.324**
	Level	0.033	0.045	-0.132	0.072	0.198
	Slope	0.009	-0.027	0.028	-0.025	-0.164
	β Curvature	-0.141**	-0.140**	-0.131**	-0.142**	-0.106**
Curvature	IP growth	0.004	0.007	0.004	0.004	0.004
	Policy rate	-0.062	-0.036	-0.124	-0.049	0.010
	Inflation	-0.039	1.178	0.130	0.686	1.250
	Level	0.423	0.612**	1.063**	0.464	0.562*
	Slope	-0.280*	-0.311*	-0.623**	-0.299*	-0.259
	θ Curvature	0.147**	0.116**	0.137**	0.143**	0.080**
	IP growth	-0.004	-0.011	-0.005	-0.007	-0.003
	Inflation	-0.098	7.004	7.306	-0.278	0.349

Table 3. Total spatial effects

The table shows the total (i.e., marginal) effect of a shock to the latent factor of each country averaged over time. The countries where shocks originate are in the columns of the table. The countries that receive the effects of the shocks are in the rows. The values of the effects are calculated according to equation (11). The spatial correlations are estimated from equation (10). Cross-border bank lending is used as the closeness measure. The last row for each latent factor shows the average of the effects of each country on other countries.

		Aust.	Belg.	Finl.	Fran.	Germ.	Gree.	Irel.	Italy	Neth.	Port.	Spain
Level	Austria	1.168	0.250	0.384	0.407	1.109	0.167	0.172	0.503	0.512	0.064	0.238
	Belgium	0.336	1.139	0.274	0.767	0.470	0.124	0.213	0.543	0.583	0.067	0.309
	Finland	0.242	0.141	1.064	0.485	0.343	0.038	0.084	0.165	0.335	0.042	0.196
	France	0.285	0.516	0.310	1.146	0.561	0.119	0.141	0.554	0.483	0.066	0.333
	Germany	0.640	0.288	0.342	0.486	1.141	0.119	0.170	0.371	0.424	0.065	0.318
	Greece	0.730	0.551	0.164	0.540	0.562	1.046	0.109	0.228	0.420	0.035	0.121
	Ireland	0.417	0.219	0.089	0.391	0.559	0.120	1.060	0.482	0.264	0.065	0.321
	Italy	0.860	0.578	0.243	0.664	0.766	0.115	0.183	1.154	0.484	0.100	0.318
	Netherl.	0.291	0.621	0.293	0.595	0.571	0.119	0.124	0.397	1.137	0.059	0.305
	Portugal	0.278	0.295	0.200	0.610	0.424	0.157	0.338	0.390	0.558	1.045	0.583
	Spain	0.272	0.458	0.324	0.698	0.479	0.083	0.182	0.508	0.512	0.156	1.126
	Mean	0.435	0.392	0.262	0.564	0.584	0.116	0.172	0.414	0.458	0.072	0.304
Slope	Austria	1.126	0.200	0.354	0.346	1.019	0.016	0.059	0.343	0.486	0.017	0.143
	Belgium	0.238	1.105	0.248	0.755	0.386	0.012	0.074	0.371	0.566	0.018	0.192
	Finland	0.170	0.114	1.050	0.483	0.297	0.003	0.028	0.111	0.322	0.011	0.121
	France	0.203	0.426	0.286	1.067	0.488	0.011	0.048	0.379	0.465	0.018	0.209
	Germany	0.441	0.234	0.320	0.465	1.076	0.012	0.060	0.252	0.409	0.018	0.201
	Greece	0.505	0.456	0.144	0.528	0.493	1.004	0.037	0.153	0.404	0.009	0.070
	Ireland	0.292	0.176	0.070	0.356	0.491	0.012	1.019	0.329	0.235	0.018	0.203
	Italy	0.591	0.477	0.215	0.638	0.678	0.011	0.063	1.100	0.455	0.028	0.197
	Netherl.	0.206	0.515	0.268	0.574	0.502	0.011	0.042	0.270	1.092	0.016	0.191
	Portugal	0.198	0.237	0.174	0.572	0.337	0.015	0.121	0.264	0.534	1.011	0.374
	Spain	0.194	0.375	0.299	0.685	0.400	0.008	0.063	0.347	0.492	0.046	1.070
	Mean	0.304	0.321	0.238	0.540	0.509	0.011	0.060	0.282	0.437	0.020	0.190
Curvature	Austria	1.078	0.147	0.328	0.327	1.103	0.012	0.030	0.341	0.504	0.010	0.117
	Belgium	0.228	1.071	0.226	0.735	0.395	0.008	0.039	0.372	0.598	0.010	0.164
	Finland	0.170	0.085	1.036	0.471	0.314	0.002	0.014	0.103	0.339	0.007	0.103
	France	0.188	0.329	0.266	1.052	0.515	0.008	0.024	0.387	0.488	0.011	0.182
	Germany	0.491	0.177	0.303	0.450	1.056	0.009	0.032	0.250	0.430	0.011	0.176
	Greece	0.570	0.353	0.125	0.513	0.523	1.002	0.019	0.140	0.424	0.005	0.054
	Ireland	0.304	0.131	0.051	0.341	0.521	0.009	1.008	0.334	0.231	0.011	0.178
	Italy	0.651	0.368	0.189	0.618	0.721	0.008	0.033	1.073	0.469	0.018	0.167
	Netherl.	0.198	0.401	0.248	0.557	0.532	0.008	0.021	0.266	1.063	0.009	0.165
	Portugal	0.184	0.176	0.151	0.551	0.339	0.011	0.066	0.252	0.559	1.005	0.333
	Spain	0.178	0.287	0.278	0.666	0.413	0.005	0.033	0.346	0.515	0.030	1.049
	Mean	0.316	0.245	0.216	0.523	0.538	0.008	0.031	0.279	0.456	0.012	0.164

Table 4 Spatial correlation dependent on the cross-sectional dispersion in sovereign CDS premium

The table presents the estimated ρ_0 and ρ_{CDS} in equation (16), which extends the model in equation (3) by allowing a time-varying spatial correlation parameter as a function of the cross-sectional dispersion in the term structure of sovereign CDS premium basis points: $\rho_t = \rho_0 + \rho_{\text{CDS}}\sigma_{\text{CDS},t-1}$. σ_{CDS} is the cross-sectional standard deviation of the sovereign CDS premium level, slope, and curvature, respectively, in the regression for yield-curve level, slope, and curvature. ρ_{CDS} is multiplied by 10,000 in this table. The estimations are based on monthly values for 11 EMU member countries over the period from January 2002 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.

		Long-term debt	Short-term debt	Equity	Bank lending
Level	ρ_0	0.731**	0.617**	0.674**	0.729**
	ρ_{CDS}	-5.940**	-13.399**	-10.702**	-6.639**
Slope	ρ_0	0.494**	0.436**	0.463**	0.498**
	ρ_{CDS}	-35.134**	-28.176**	-39.026**	-37.178**
Curvature	ρ_0	0.442**	0.353**	0.381**	0.424**
	ρ_{CDS}	-112.458**	-133.458**	-121.456**	-130.563**

Table 5. Cross-border asset holdings

The table shows the time-average 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 2011.

	Long-term debt	Short-term debt	Equity	Bank lending
Austria	9.8%	11.1%	21.4%	4.4%
Belgium	6.0%	8.7%	14.4%	6.9%
Finland	5.8%	2.1%	20.4%	6.8%
France	12.0%	11.0%	19.9%	11.2%
Germany	11.0%	19.5%	22.5%	11.8%
Greece	13.5%	4.1%	43.1%	4.1%
Ireland	28.0%	44.0%	36.7%	7.0%
Italy	18.3%	4.1%	20.3%	5.5%
Netherlands	17.9%	12.2%	51.4%	11.2%
Portugal	8.1%	2.0%	16.4%	2.9%
Spain	10.0%	4.7%	15.7%	5.0%

Table 6. Spatial correlation parameter of the US yield-curve factors

The table reports the sum of ρ and ρ_{dom} , which indicates the spatial correlation coefficient for the US, estimated from the model in equation (10). The estimations are based on monthly values for 11 EMU member countries and the US over the period from January 2002 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.

		Long-term debt	Short-term debt	Equity	Bank lending
Period 1	Level	0.679**	0.564**	0.566**	0.699**
	Slope	0.544**	0.414**	0.402**	0.455**
	Curvature	0.485**	0.449**	0.314**	0.299**
Period 2	Level	1.226**	0.786**	0.740**	1.020**
	Slope	-0.051	-0.203	-0.003	0.509
	Curvature	2.036**	1.411**	1.111**	2.385**
Period 3	Level	0.610*	0.366	0.704**	1.242**
	Slope	1.402**	1.114*	0.759**	1.555**
	Curvature	-0.138	0.538	0.423	0.583

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

The figure shows the changes in the estimated latent factors and the macroeconomic factors for the US as well as for the EMU member countries with and without the GIIPS countries. The factors are estimated based on the Nelson–Siegel model on yield for government bills and bonds with all available maturities ranging from three months to 15 years. Data covers the period starting from December 2001 and ending in December 2012.

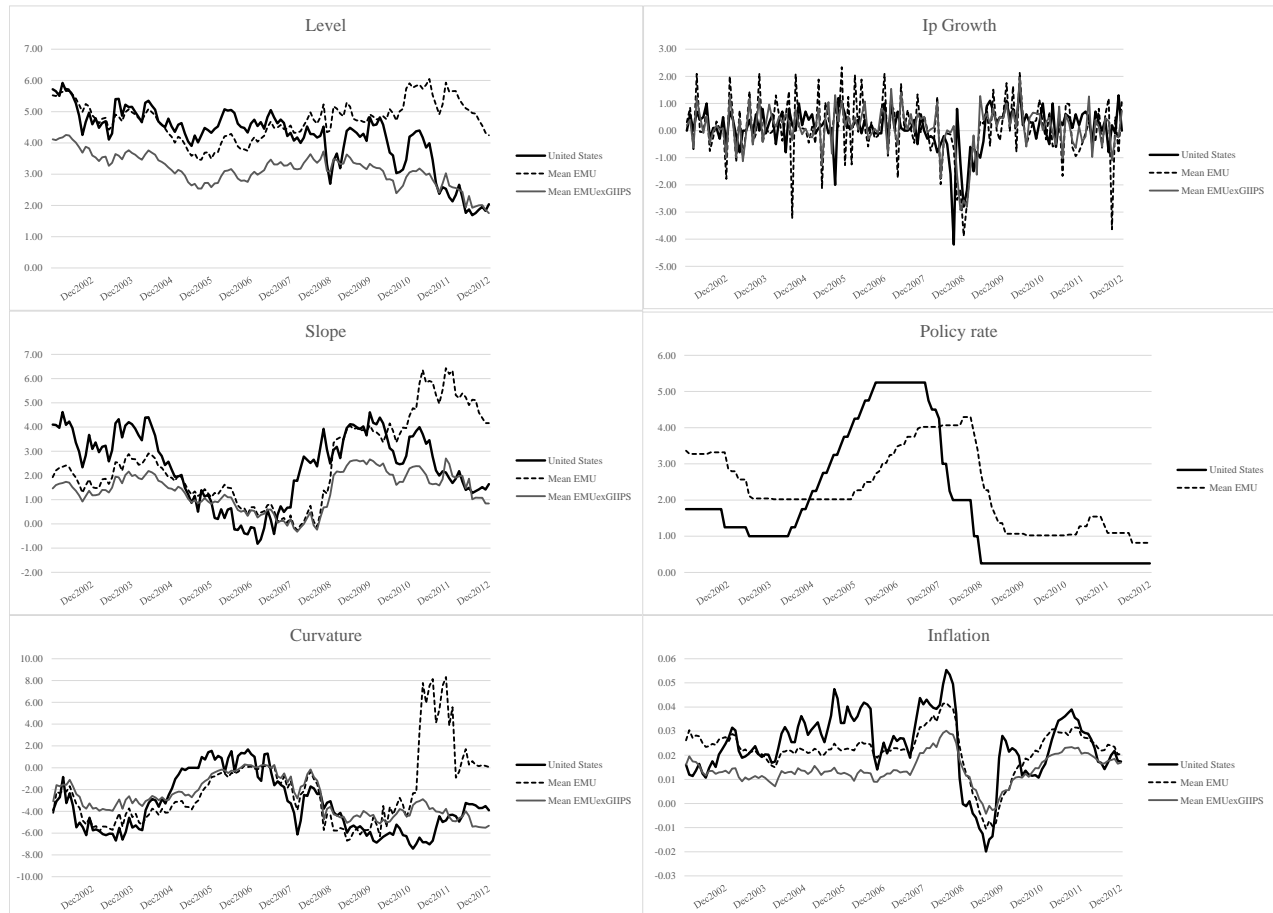


Figure 2. Estimated spatial correlations from the closeness measures compared with the empirical distributions of the spatial correlations

The figure compares the estimated values of the spatial correlation coefficients ρ from our selected closeness measures (the dots) with those from randomly generated weight matrices. The estimated spatial coefficients are obtained from the panel data spatial Durbin model with one spatial lag and with country-specific effects and year dummies (equation 3). The estimations are based on monthly data covering 11 EMU countries over the period from January 2002 to December 2012. The spatial weight matrix is defined according to cross-border long- and short-term debts, equity investment and bank lending, as well as a matrix with equal weights. The lines show the 99% and 95% one-sided confidence interval of the empirical distribution of the estimated ρ values from 200 randomly generated spatial weight matrices.

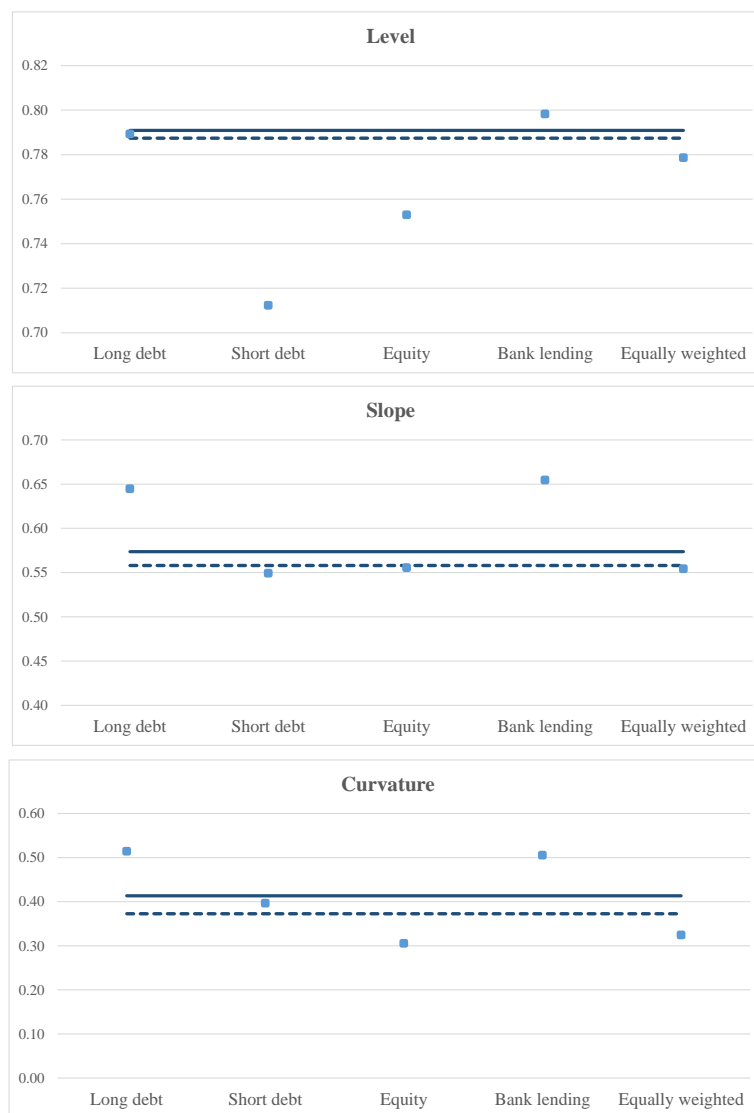


Figure 3. Asset holdings among EMU member countries

The figure shows the total amount of cross-border asset holdings among the 11 EMU member countries included in the sample over time. Data covers the period starting January 2001 and ending December 2011.

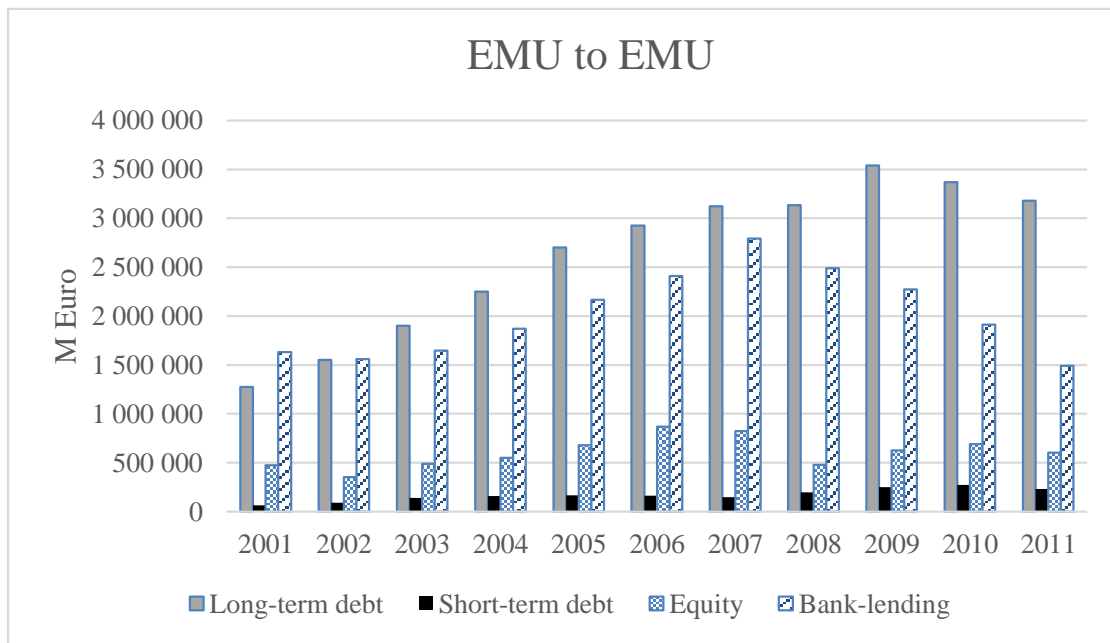


Figure 4. Cross-border bank-lending and spatial effects

For each country, arrows point to three countries that receive the largest volumes of bank lending from the country being considered. The data on the volumes of bank lending covers the period from January 2001 to December 2011. The size of the ellipse for each country indicates the average spatial effect of the country's level factor on the level factor of other countries shown in Table 3.

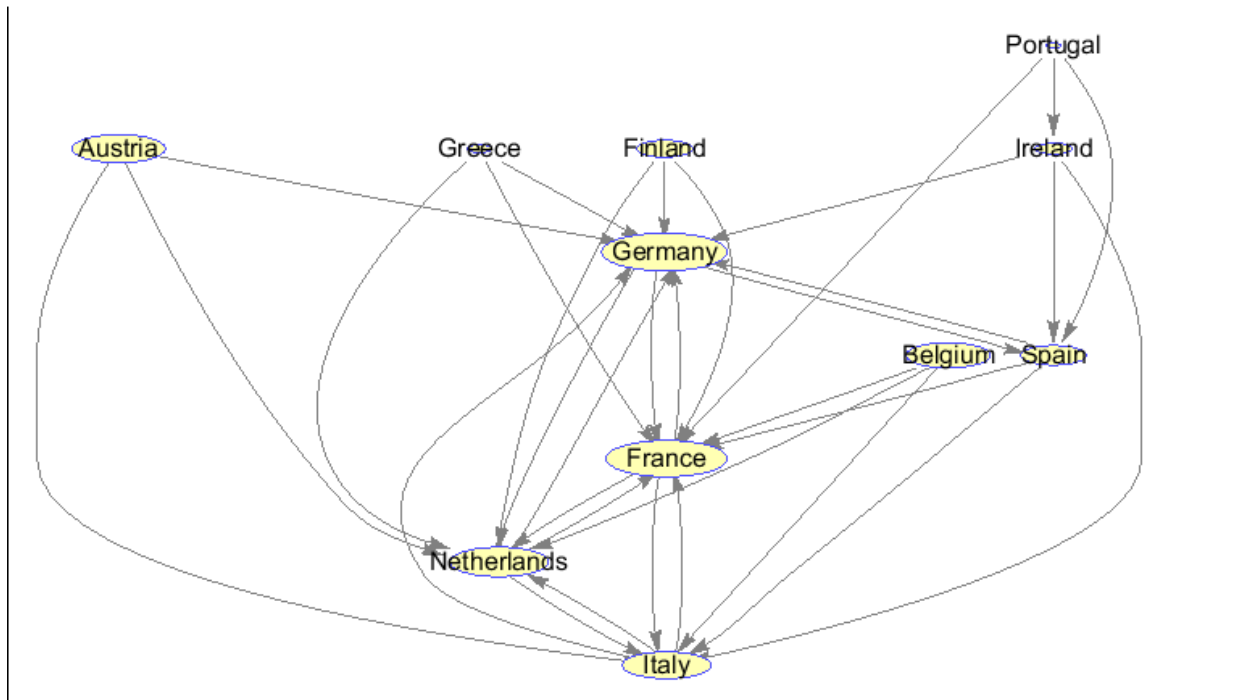


Figure 5. Immediate effect and total effect

The figure shows, for each country, the average immediate and total effects of a shock to the level factor on the level factor of other countries. The values of the effects are constructed according to equations (11) and (12) using the spatial correlation coefficients estimated from the model in equation (10). Cross-border bank lending is considered as the closeness measure.

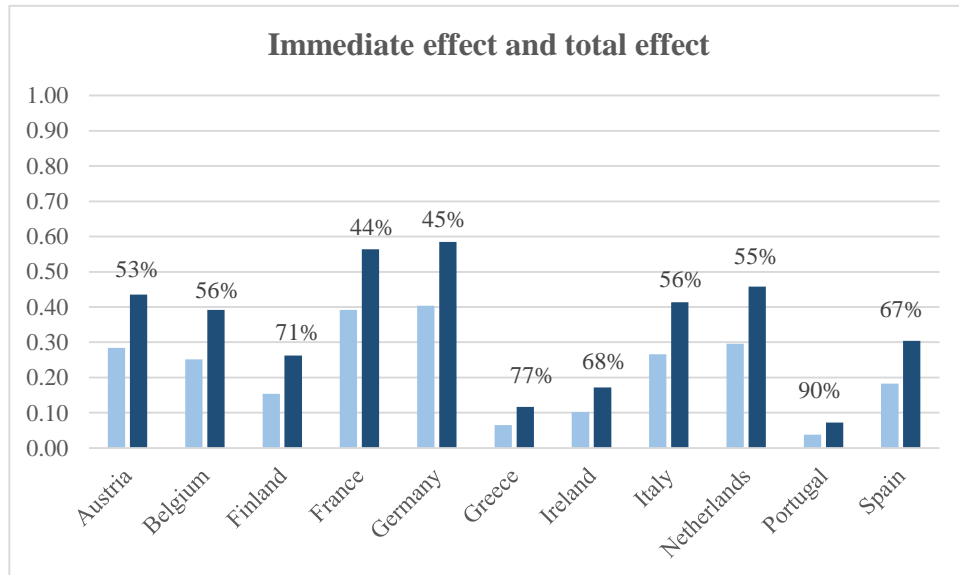


Figure 6. The estimates of spatial correlation coefficient

The figure presents the yearly estimated values and 95% confidence intervals of the spatial correlation coefficient ρ of EMU member countries in each year from January 2002 to December 2012. The dots show each estimate of ρ . The intervals are the 95% confidence interval of the estimated ρ values. The graphs on the left and right show ρ values estimated from equation (3) based on the sample with 11 EMU member countries and the sample of non-GIIPS EMU member countries, respectively. The graphs in the middle show the ρ values for 11 EMU member countries estimated from equation (12) based on the sample including the US. The spatial weight matrix is defined according to cross-border bank lending in all cases.

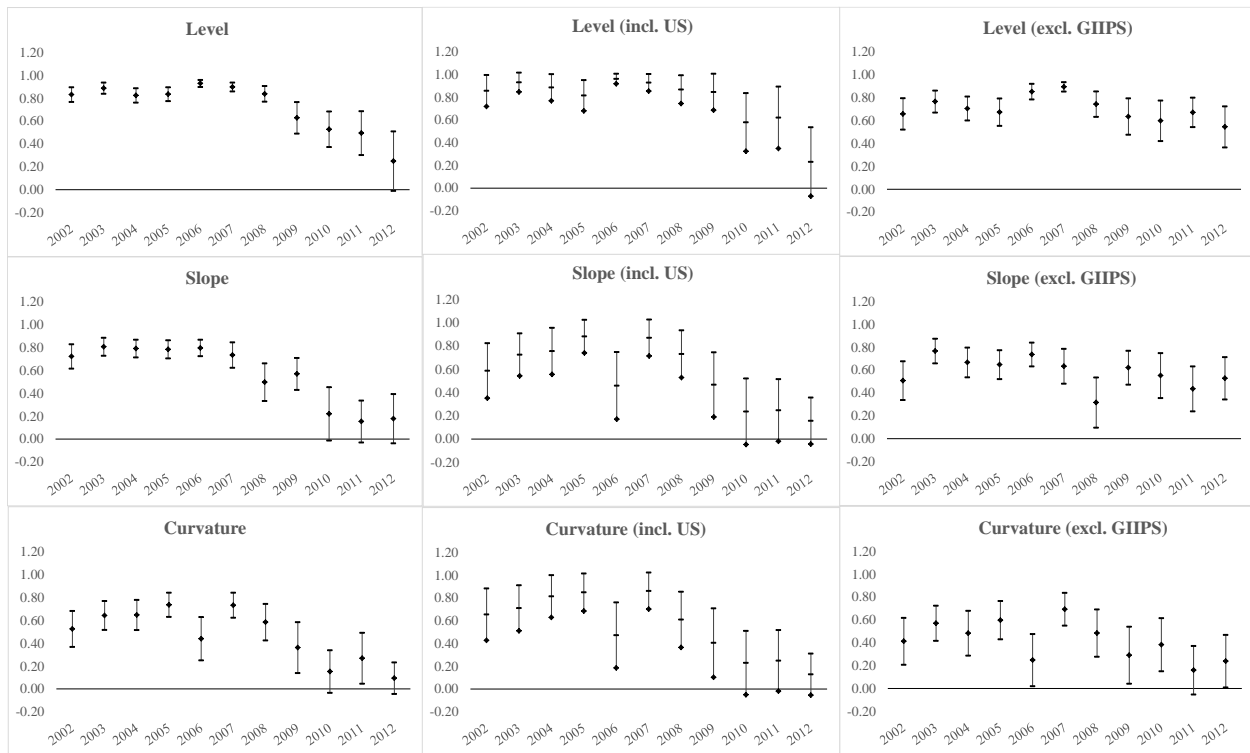


Figure 7. Dispersion of CDS premium factors

The figure shows the cross-sectional dispersion of the level, slope and curvature of sovereign credit default swap (CDS) premium (in basis points) of 11 EMU countries (with and without GIIPS countries).

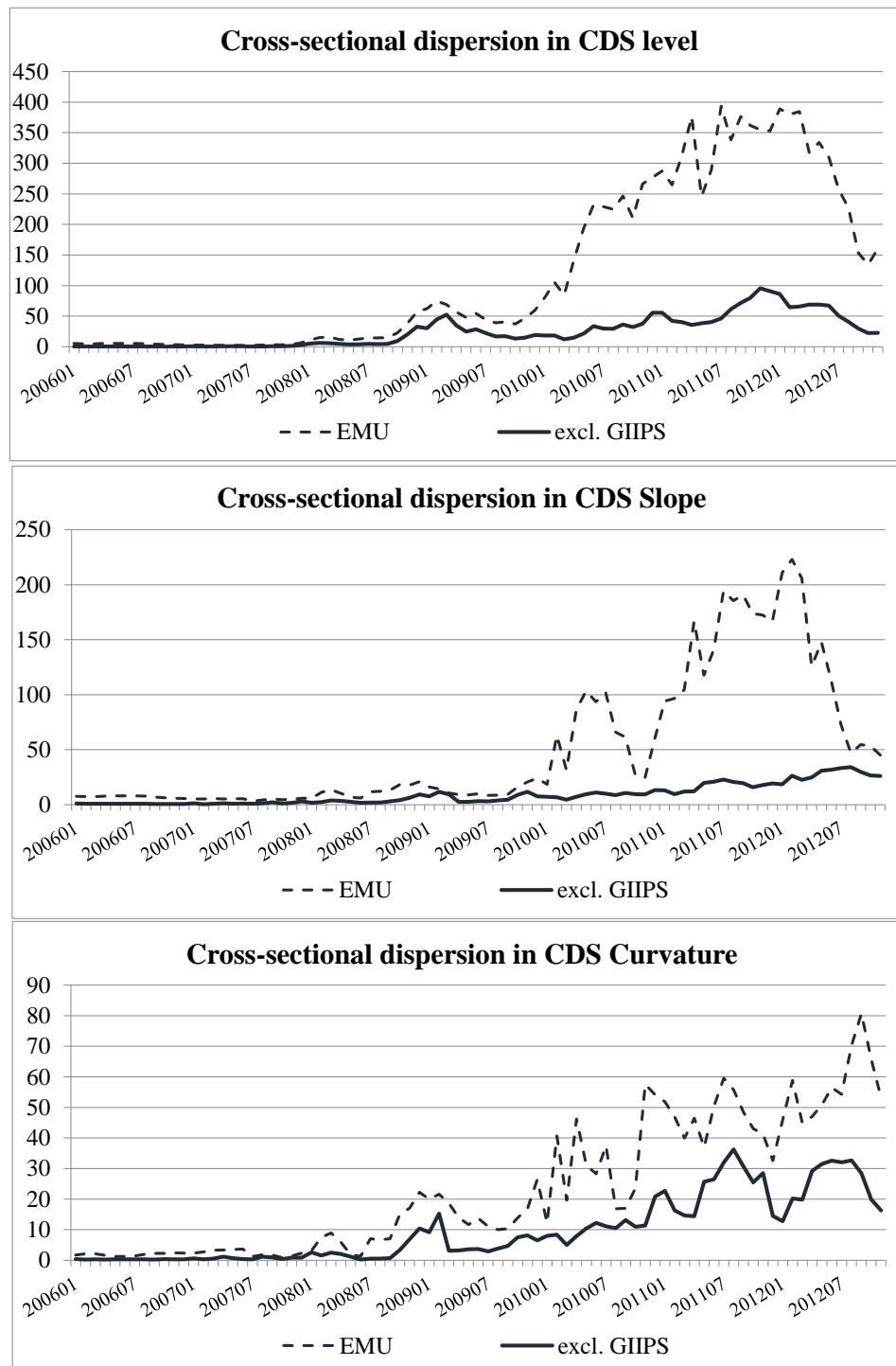


Figure 8. The impact of shocks to US yield-curve factors on corresponding EMU factors

This figure shows the immediate and total effects of shocks to US yield-curve factors on the corresponding EMU factors. The values of the effects are constructed according to equations (11) and (12) using the estimates from equation (10). We plot the effects for three nonoverlapping subsample periods: the period before the US recession from January 2002 to November 2007, the US recession period from December 2007 to June 2009, and the postrecession period from July 2009 to December 2012.

