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ABSTRACT

This study examines the return (price) and volatility spillovers among the money, stock, foreign exchange and bond markets of the euro area, utilizing the forecast-error variance decomposition framework of a generalized VAR model proposed by Diebold and Yilmaz (2012) [Better to give than to receive: Predictive directional measurement of volatility spillovers. International Journal of Forecasting, 23, 57-66]. Our empirical results, based on a data set covering a twelve-year period (2000-2012), suggest a high level of total return and volatility spillover effects throughout the sample, indicating that, on average, more than the 50% of the forecast-error variance of the respective VAR model is explained by spillover effects. Moreover, the stock market is identified as the main transmitter of both return and volatility spillovers even during the current sovereign debt crisis. With the exception of the period 2011-2012, bonds of the periphery countries under financial support mechanisms are receivers of return spillovers, whereas, they transmit volatility spillovers to other markets diachronically. Finally, we identify the key role of money market in volatility transmission in the euro area during the outbreak of the global financial crisis.

Keywords: Asset markets, Spillovers, Vector Autoregressive, Euro area, Financial Crisis.

JEL Classifications: G01, G10, G20, C53.

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1. Introduction

The examination of the interconnectedness of financial markets is of crucial importance for the understanding of financial crises and their propagation mechanisms, while it is also critical in terms of systemic risk identification and financial stability preservation (Hartmann et al., 2004). It is also evident that exogenous output shocks are more likely to spread worldwide, if the transmission mechanism entails asset price spillovers or confidence channels, threatening the economies which are more vulnerable to adverse economic developments (IMF, 2007).

The recent developments in euro area economies and the unfolding sovereign debt crisis in southern Europe have highlighted the significance of measuring and monitoring the spillover effects across markets and asset classes. Ideally, a policy maker would like to have a macroprudential toolkit, which would enable him to answer questions such as: What is the current level of spillover effects in financial markets? How much of the spillover effects can be attributed to a specific market (or country) or to what extent does a specific market transmits (receives) spillover effects to (from) other market(s)? What is the behaviour of spillover effects during economic downturns and how can we use spillover measures to predict future evolution of specific market indicators? The answer to these questions could provide a useful guidance for policy actions which aim at monitoring, controlling or even predicting, through early warning indicators, contagion effects across markets or countries, which, in turn, may lead to financial instability and economic contraction (In, 2007).[1]

Spillover effects in financial markets have been extensively investigated in the extant literature. One strand of the literature examines return or volatility spillovers across countries but for identical assets. Although most studies concentrate on international equity markets (recent examples on equity volatility spillovers include Engle et al. (2012) for East Asia countries, Diebold and Yilmaz (2009) for a worldwide analysis), there are also a plenty of papers on other market sectors. Recently, Clays and Vasicek (2012) study the sovereign bond yield spillover effects in EU countries, Christiansen (2007) and Skinzti and Refenes (2006) study cross country bond market

[1] For a discussion on policy measures regarding financial contagion, see Dornbusch et al. (2001).

volatility spillovers, while In (2007) examines volatility spillover effects across international swap markets (UK, US, Japan). Currency markets have also been widely studied in terms of volatility spillover effects (e.g. see Antonakakis, 2012, Budak et al., 2011 and references therein).

In this study, we focus on spillover effects among different asset classes in the euro area, building on previous papers by Ehrmann et al. (2011) and, especially, Diebold and Yilmaz (2012), who examine spillover effects among different markets in the euro area and the US. In particular, the aim of this paper is to examine spillover effects among money, stock, FX and bond markets by constructing spillover indices, which depict both *total* and *directional* spillover effects. The methodology applied for the construction of the indices is based on the novel method of Diebold and Yilmaz (2012), which is a generalization of their own work in Diebold and Yilmaz (2009). This framework enables us to construct spillover indices on the basis of a generalized decomposition of the forecast-error variance of a Vector Autoregressive (VAR) model. A significant feature of this approach is that empirical results are independent of the ordering of the variables. We can also examine the direction of spillover effects among the different asset markets identifying the transmitters or the receivers of spillovers. Moreover, the time-dependent nature of the constructed indices enables us to extract periodizations of the spillover cycles.

Furthermore, since the current debt crisis in southern Europe has created large differences in the creditworthiness of the EMU countries, the use of a single bond index in the spillover analysis may be misleading. Therefore, we construct three market weighted sovereign bond indices, which reflect the credit quality of three groups of countries - two groups of periphery countries and one group of investment grade countries. In this way, we can examine the spillovers between each bond category with the remaining markets and draw conclusions regarding the way the different bond categories influence one another.

This study contributes to the growing literature of spillover effects in several ways. In particular, this is the first study that examines the spillovers effects among money market, stock, FX and bond markets in the euro area by implementing the methodology of Diebold and Yilmaz (2012). Moreover, with the exception of Diebold and Yilmaz (2009), the majority of studies focus either on return (price) or on volatility spillover effects. Here, we consider both return and volatility spillovers identifying possible similarities or differences in their patterns. Finally, this study provides spillover indices which cover a ten year period including both the 2007-2009 global financial crisis and the on-going economic crisis in southern Europe. Therefore, we examine the spillover effects during periods of both exogenous and endogenous shocks in the euro area.

The rest of the paper is organized as follows. Section 2 presents the econometric methodology implemented in the study. In Section 3, we provide the description of the data set and present the empirical results, which include the spillover indices. Finally, Section 4 summarizes and concludes this paper.

2. Econometric methodology

In this section, we present the econometric methodology for the estimation of the time-varying volatility (and correlations) of the series which are used subsequently in order to measure the volatility spillover effects. We also present the recently proposed method of Diebold and Yilmaz (2012) for analyzing both return and volatility spillover effects among the different markets in euro area.

2.1. Estimating time-varying volatility and correlation

We employ the Dynamic Conditional Correlation (DCC) model of Engle (2002) in order to model the conditional heteroscedastic behaviour of the financial variables under examination. Defining $\boldsymbol{r}_t = [r_{1,t}, r_{2,t}, ..., r_{N,t}]'$ as a N-variable vector of demeaned continuous compounded returns, the DCC model is formulated as:[2]

$$\mathbf{r}_t = \mathbf{H}_t^{1/2}\mathbf{u}_t \text{, with } \boldsymbol{u}_t \sim N(\boldsymbol{0}, \boldsymbol{I}) \tag{1a}$$

$$\boldsymbol{H}_t = \boldsymbol{D}_t \boldsymbol{R}_t \boldsymbol{D}_t \tag{1b}$$

[2] The continuous compounded returns for the i variable are calculated as: $r_{i,t} = 100 * \ln(P_{i,t} / P_{i,t-1})$ where $P_{i,t}$ is the observed price for the i variable.

where $\boldsymbol{I}$ is a $N \times N$ identity matrix and $\boldsymbol{H}_t$ is the $N \times N$ time-varying variance-covariance matrix and $\boldsymbol{u}_t$ is $N \times 1$ vector of innovations. The key feature of the DCC model is that $\boldsymbol{H}_t$ is written in the decomposed form of Eq. (1b), where $\boldsymbol{D}_t$ is a diagonal matrix with the square root of conditional variances in its diagonal, i.e. $\boldsymbol{D}_t = diag\left(h_{11,t}^{1/2}, h_{22,t}^{1/2}, ..., h_{NN,t}^{1/2},\right)$ and $\boldsymbol{R}_t$ is the dynamic correlation matrix. This decomposition ensures that the covariance matrix, $\boldsymbol{H}_t$, is positive definite and allows a two-step procedure in the estimation.

Specifically, in the first step, the conditional variances, $h_{ii,t}$, are modeled via a GARCH model, i.e.: $h_{ii,t} = \omega_i + \alpha_i r_{ii,t-1}^2 + \beta_i h_{ii,t-1}$ for i=1,2,…,N. In second step, the estimated conditional variances are used to estimate the standardized returns, $u_{i,t} = r_{i,t} \big/ h_{ii,t}^{1/2}$, which in turn are utilized in the modeling of $\boldsymbol{R}_t$ as follows:

$$\boldsymbol{R}_t = diag\left(q_{11,t}^{-1/2}, q_{22,t}^{-1/2}, ..., q_{NN,t}^{-1/2}\right)\boldsymbol{Q}_t\left(q_{11,t}^{-1/2}, q_{22,t}^{-1/2}, ..., q_{NN,t}^{-1/2}\right) \tag{2}$$

From Eq. (2), it can be seen that the ij^{th} element of $\boldsymbol{R}_t$ can be written as $\rho_{ij,t} = q_{ij,t} \big/ q_{ii,t}^{1/2}\, q_{jj,t}^{1/2}$ where $q_{ij,t}$ is the ij^{th} element of the symmetric positive definite matrix $\boldsymbol{Q}_t$, which is modeled as:

$$\boldsymbol{Q}_t = (1 - a - b)\overline{\boldsymbol{Q}} + a\boldsymbol{u}_{t-1}\boldsymbol{u}'_{t-1} + b\boldsymbol{Q}_{t-1} \tag{3}$$

Where $\boldsymbol{u}_t$ is the vector with standardized returns of step 1. The parameters of all models are estimated using quasi maximum likelihood techniques and assuming a Gaussian distribution.

2.2. Measuring spillover effects

We measure spillover effects using the variance decomposition approach introduced by Diebold and Yilmaz (2009) and recently generalized by the same authors in Diebold and Yilmaz (2012). Their method is based on the decomposition of the *H*-step-ahead forecast-error variance for each of the *N* variables of a N-dimensional Vector Autoregression (VAR) model. This enables us to examine the portion of the forecast-error variance of variable *i,* with *i*=1,2,…,N, which can be attributed to shocks of variable *j*, with *j*=1,2,…,N, $i \neq j$ and aggregate these measures in order to construct spillover indices.

In Diebold and Yilmaz (2012), the authors refined their own method employing the generalized VAR framework of Koop et al. (1996) and Pesaran and Shin (1998). In this way, they eliminate the dependence of the variance decomposition results on the ordering of the variables, which is not accounted for in the Cholesky factorization used in Diebold and Yilmaz (2009). Next we describe the spillover index framework of Diebold and Yilmaz (2012) implemented in this study.

Assume a *N*-variable vector $\boldsymbol{y}_t$ modeled as a p^{th}-order stationary VAR:

$$\boldsymbol{y}_t = \sum_{i=1}^{p} \boldsymbol{\Pi}_i \boldsymbol{y}_{t-i} + \boldsymbol{\varepsilon}_t \text{ , with } \boldsymbol{\varepsilon}_t \sim \text{i.i.d}\left(0, \boldsymbol{\Sigma}\right) \tag{4}$$

where $\boldsymbol{\Pi}_i$ are the $N \times N$ coefficient matrices, $\boldsymbol{\varepsilon}_t$ is the vector of identically and independently distributed errors and $\boldsymbol{\Sigma}$ is their variance-covariance matrix. To facilitate the analysis, the VAR(p) model is written as an infinite moving average model, i.e. $\boldsymbol{y}_t = \sum_{i=0}^{\infty} \boldsymbol{\Theta}_i \boldsymbol{\varepsilon}_{t-i}$, with $\boldsymbol{\Theta}_i$ being the $N \times N$ moving average coefficients matrix. The $\boldsymbol{\Theta}_i$ coefficient matrices can be estimated using the following recursion: $\boldsymbol{\Theta}_i = \boldsymbol{\Pi}_1 \boldsymbol{\Theta}_{i-1} + \boldsymbol{\Pi}_2 \boldsymbol{\Theta}_{i-1} + ... + \boldsymbol{\Pi}_p \boldsymbol{\Theta}_{i-p}$ with $\boldsymbol{\Theta}_0$ being a $N \times N$ identity matrix and $\boldsymbol{\Theta}_i = 0$ for $\forall i < 0$. Given this VAR framework, the *H*-step-ahead forecast-error variance decomposition is defined as:

$$d_{ij}^{g}(H)=\frac{\sigma_{jj}^{-1}\sum_{h=0}^{H-1}\left(\boldsymbol{e}_i'\boldsymbol{\Pi}_h\boldsymbol{\Sigma}\boldsymbol{e}_j\right)^2}{\sum_{h=0}^{H-1}\left(\boldsymbol{e}_i'\boldsymbol{\Pi}_h\boldsymbol{\Sigma}\boldsymbol{\Pi}_h'\boldsymbol{e}_i\right)} \qquad (5)$$

where σ_{jj} is the square root of the diagonal elements of the variance-covariance matrix $\boldsymbol{\Sigma}$, i.e. the standard deviation of the j error term and $\boldsymbol{e}_i$ is a selection vector, which its i^{th} element takes the value of one and all other elements are zeros. In the generalized VAR framework the shocks to each variable are not orthogonalized and, thus, the sum of each row of the variance decomposition matrix does not add to unity. Therefore, each element of the decomposition matrix can be normalized by dividing with the row sum, i.e.:

$$\tilde{d}_{ij}^{g}(H)=\frac{d_{ij}^{g}(H)}{\sum_{j=1}^{N}d_{ij}^{g}(H)}\text{, with }\sum_{j=1}^{N}\tilde{d}_{ij}^{g}(H)=1\text{ and }\sum_{i,j=1}^{N}\tilde{d}_{ij}^{g}(H)=N \qquad (6)$$

Using the normalized elements of the decomposition matrix of Eq. (6), we construct the *Total Spillover* (TS) index, which captures the level of cross market spillovers by measuring the contribution of spillovers of shocks across all N variables to the total forecast-error variance. The Total Spillover index, based on H-step ahead forecasts, is given by:

$$TS^{g}(H)=\frac{\sum_{\substack{i,j=1\\ i\neq j}}^{N}\tilde{d}_{ij}^{g}(H)}{\sum_{i,j=1}^{N}\tilde{d}_{ij}^{g}(H)}\times 100=\frac{\sum_{\substack{i,j=1\\ i\neq j}}^{N}\tilde{d}_{ij}^{g}(H)}{N}\times 100 \qquad (7)$$

In a spillover analysis, it is also crucial to examine the direction of spillover effects from and towards a specific market. The employed generalized VAR framework enables us to compute *Directional Spillover* (DS) indices measuring the spillover effects received by market *i* *from* all other markets *j* for $i \neq j$:

$$DS^{g}_{i \leftarrow j}(H) = \frac{\sum_{j=1, i \neq j}^{N} \tilde{d}^{g}_{ij}(H)}{N} \times 100 \tag{8}$$

The corresponding index which measures the spillover effects transmitted by market *i* *to* all other markets *j* is:

$$DS^{g}_{i \rightarrow j}(H) = \frac{\sum_{j=1, i \neq j}^{N} \tilde{d}^{g}_{ji}(H)}{N} \times 100 \tag{9}$$

From Eq. (8) and (9) it is straightforward to calculate the *Net Spillover* (NS) index for market *i* as:

$$NS^{g}_{i}(H) = DS^{g}_{i \rightarrow j}(H) - DS^{g}_{i \leftarrow j}(H) \tag{10}$$

Positive values of the NS index imply that there are spillover effects from market *i* to all other markets while negative values indicate that market *i* is a receiver of spillover effects.

3. Empirical results

3.1. The data set, descriptive statistics and dynamic correlations

We examine the spillover effects in euro area financial markets using data from stock, money, currency and sovereign bond markets. Specifically, we use the Stoxx Europe 50 index, the 3-month Euribor index, the EURO/USD exchange rate and the total return sovereign bond indices of Bloomberg for the euro area periphery countries

(Greece, Ireland, Italy, Portugal and Spain) and investment grade countries (Austria, France, Germany and Netherlands), respectively.[3,4] The total return bond indices refer to maturities greater than ten years which are commonly used in similar studies (e.g. see Kim et al., 2006; Baur and Lucey, 2009). The time series, used in this study, span the period from 1.7.2000 to 7.13.2012, over a decade of financial history, which includes both the (2007-2009) subprime crisis commenced in US mortgage market and the ongoing (2010- …) sovereign debt crisis in southern European countries. The asset prices are sampled at a weekly frequency (Friday-to-Friday) to circumvent day-of-the-week and non-synchronous trading effects (Skintzi and Refenes, 2006).

Additionally, for the sovereign bond market, we construct three market value-weighted sub-indices based on common sovereign characteristics. In this way, we can categorize countries according to their credit quality and examine their spillover effects using a parsimonious - low dimension VAR setting, which also eases the interpretation of our results. Thus, the first bond sub-index consists of Greece, Ireland and Portugal, the three periphery countries currently under the support mechanism of the IMF/ECB/EU; the second sub-index comprises Italy and Spain, the periphery countries with debt problems but without financial aid; and the third sub-index consists of investment grade countries (Austria, France, Germany and Netherlands).

Table 1 presents the descriptive statistics for the weekly returns and the logarithmic volatility for the six indices as estimated by the multivariate DCC model. Stock market returns are the most volatile, as expected, followed by returns in Periphery 1 bonds and FX market. The 3-month Euribor index is the least volatile indicating the overall smooth functioning of the market. Sample estimates of skewness and kurtosis indicate rejection of normality assumption for both returns and logarithmic volatilities.

[Insert Table 1 about here]

[3] The tickers in Bloomberg for the Stoxx Europe 50 index, 3 the month euribor and the EURO/USD are SX5 Index, EUR003M index, EUR Currency, respectively.
[4] In the total return, bond indices are calculated assuming that coupon payments are reinvested in the bonds. The ticker for the Bloomberg bond indices for Greece, Ireland, Italy, Portugal, Spain, Austria, France, Germany and Netherlands are GCL5TR Index, IEL5TR Index, ITL5TR Index, PTL5TR Index, SPL5TR Index, ATL5TR Index, FRL5TR Index, GRL5TR Index, NEL5TR Index respectively.

Figure 1 depicts the weekly conditional volatility series for the six indices. The stock index, the 3-month Euribor interbank rate, the EUR/USD exchange rate and the investment grade sovereign bond indices take their maximum values during the period surrounding the collapse of Lehman Brothers on 15 September 2008. By contrast, the period April-May 2010, during which the Greek government signed the Memorandum of Understanding, is the most volatile for the Periphery 1 bond index (Greece, Ireland and Portugal) followed by the period July 2011-March 2012. The latter period is also highly volatile for the Periphery 2 bond index (Italy and Spain) approaching the levels of 2008-2009 volatility.

[Insert Figure 1 about here]

Dynamic correlations have been extensively used in order to examine interdependence and spillover effects among asset markets (e.g. see Baur and Lucey, 2009, Skintzi and Refenes, 2006). In Figure 2 we present the dynamic correlations produced by the DCC model from which we can draw interesting conclusions. First, the dynamic correlations between stocks and Periphery 1 (and 2) bonds indicate *negative* contagion from the late 2009 (2010) and onwards. According to the definition of Baur and Lucey (2009), we have *negative* contagion when we observe increasing stock-bond correlation coefficients, the correlation coefficient between bonds and stocks is positive (i.e. stock and bond prices co-move) and we have falling stock or bond markets.[5] It is evident that all three criteria are satisfied for the abovementioned period. Next, using the same definition, the estimated correlations imply contagion between stock and FX markets for the same period. By contrast, the decreasing correlation coefficient between Periphery 1 and investment grade bonds (from 2009 to 2012), the negative level of correlation coefficient, i.e. periphery 1 and investment grade bond prices do not co-move (from late 2010 and onwards) and the falling Periphery 1 bond prices indicate *flight-to-quality* from Periphery 1 to investment grade bonds form late 2010 to 2011 (Baur and Lucey, 2009). Similar behaviour, but only for the first months of 2011, is observed between Periphery 2 and investment grade bonds.

[5] We have *positive* contagion when we observe rising (stocks or bonds) markets.

[Insert Figure 2 about here]

3.2. Spillover tables

We produce the spillover measures presented in Section 3.2 using a VAR(2) model $(p = 2)$ and a forecast horizon of ten weeks $(H = 10)$. The lag specification of the VAR model is selected by minimizing the Bayesian Information Criterion, while the forecasting horizon is commonly used in similar studies (e.g. see Diebold and Yilmaz, 2012, Nikolakakis, 2012).

Tables 2 and 3 present the spillover effects for the returns and the volatility series, respectively, for the full sample. Each *ij* entry of the, so called, *spillover tables*, is an estimate for the contribution to i^{th} market's forecast-error variance generated by shocks to market j. The diagonal elements of the tables (*j*=*i*) are the *own variance shares* estimates, which show the fraction of the forecast-error variance of market *i* that is due to its own shocks. Summing up the off diagonal row elements of the tables, we estimate the spillovers effects received by market *i* from all other markets (column: Directional spillovers *from* other markets), while the sum of the off-diagonal column elements produce the spillover effects directed from market *i* to all other markets (row: Directional spillovers *to* other markets). The net spillover effects from market *i* to all other markets are calculated by subtracting the directional *from* spillovers from the directional *to* spillovers. The approximate total spillover index in percentage points is calculated as the grand sum of the off-diagonal elements of the table divided by the grand sum of all elements of the table.

[Insert Table 2 about here]

[Insert Table 3 about here]

The empirical results presented in Tables 2 and 3 reveal that the total spillover index is 59.44% and 55.67% for the returns and volatility series, respectively, indicating the high level of interconnectedness in euro area financial markets. In other words, more than the half of the total forecast-error variance across all six markets can attributed to spillover effects. Moreover, according to the "*Net* spillovers" row, the stock market is the main net transmitter of shocks in euro area financial markets in terms of both returns and volatility. In the case of returns spillovers (Table 2), all other markets are net receivers of shocks propagated through the stock market, while the volatility spillovers results (Table 3) show that Periphery 1 and 2 bonds are also net transmitters of shocks with Periphery 1 bonds lagging closely behind the stock market.

The examination of the gross directional return spillover measures also reveals the diversity of spillover effects among the different market segments (Table 2). In particular, 99.93% of the forecast-error variance for money market returns comes from the other markets, while at the same time only a 5.06% of the stock market forecast-error variance can be attributed to other markets (see column: "Directional spillovers *from* other markets"). A relatively high percentage (approximately 50% to 85% for all bonds categories) of the bonds forecast-error variance comes from the rest of the markets. By contrast, the stock market is the biggest contributor of spillovers towards other markets and the money market the smallest (see row: "Directional spillovers *to* other markets"). Bond markets are relatively close to each other regarding the spillovers directed to other markets.

Regarding the volatility series (Table 3), we do not observe such great deviations in the gross spillover effects. Specifically, approximately 90% of the forecast-error variance for the FX market and the investment grade bonds is explained by volatility spillovers from other markets. The corresponding percentage for the money market and Periphery 1 and 2 bonds ranges from 40% to 60%, while a 25.24% of the stock market forecast-error variance can be attributed to spillover effects from other markets. On the other hand, Periphery 1 bonds contribute the most to other markets forecast-error variances followed by the stock market, Periphery 2 and investment grade bonds and money market, while the FX market generates the smallest spillovers effects towards the rest of the markets.

3.3. Rolling sample spillover indices

Spillover tables give us an overview for the "average" spillover effects over the full sample. However, as pointed out in Diebold and Yilmaz (2009, 2012) the measures presented in spillover tables cannot reflect financial evolution or financial crises and, thus, the authors propose a rolling sample framework in order to construct time-varying spillover indices. Therefore, we use a 2-year (or 104 weekly observations) rolling sample in order to re-estimate the VAR(2) model on a weekly basis for both returns and logarithmic volatility and produce rolling spillover indices.

[Insert Figure 3 about here]

The time depended return spillover index depicted in Figure 3 reveals that the level of price spillover effects across euro area markets is quite high, fluctuating mostly between 60% and 80% during the full sample. Moreover, we locate several spillover cycles with the first one starting in 2002 and lasting until the mid-2004. The index value during this period was over 70% with a peak value close to 80% during the period surrounding the 2003 Iraq invasion. From March 2003 the index followed a downward trend taking its lowest value two years later. The period from mid-2005 until the first quarter of 2007 is characterized as a relatively “low” spillover phase of the cycle with the values of the index ranging between 58% and 65%, probably reflecting the underestimation of assets risks and the prosperous financial environment of that period (ECB, Financial Stability Review, 2005, 2006). The spillover index increased sharply mainly towards the middle of 2007 with the outbreak of the global financial crisis, starting another “high” spillover phase. The index exceeded 75% during the first months of 2008 reflecting the unfolding financial turmoil (Bearn Sterns bailout, Ireland/Iceland banking crisis). The spillover index reached its highest value (>80%) in the months after the collapse of Lehman Brothers and then decreased to 75% until the third quarter of 2010. We also observe a sharp rise in spillover effects in period April-May 2010, during which Greece signed the agreement for financial aid by the IMF/ECB/EU. In the first months of 2011, the spillover index decreased substantially to 2005-2006 levels. Nonetheless, the on-going sovereign debt crisis in southern European countries contributed to an upward movement of the index after the first half of 2011.

[Insert Figure 4 about here]

The pattern of the volatility spillover index presented in Figure 4 is more or less similar to that of Figure 3. In particular, the only visible difference is the increased volatility spillovers during 2005, which interrupt the downward trend started in mid-2004 and completed in the first quarter of 2007. The maximum value of the index is again reached during the Lehman's collapse and the periods of intensification of the Greek sovereign debt crisis.

From Figures 3 and 4, it is obvious that both returns and volatility spillovers intensify during periods of financial or economic stress, as expected. Nonetheless, the empirical results suggest some other interesting points. First, both indices are quite volatile and there is no clear cut upward or downward trend during our sample. Second, the ongoing southern European sovereign debt crisis has not increased the level of spillover effects more than the period following the Lehman Brothers collapse. Third, on average, the spillovers in 2008-2011 period are slightly greater compared to 2002-2005 spillover effects, indicating that even strong idiosyncratic shocks can only trigger temporary increases in spillovers above average. Therefore, a policy maker should expect strong spillover effects among the financial markets in euro area and short-termed increases during unexpected shocks. The next interesting step, from a policy making perspective, is to identify the directional spillover effects across the six classes of markets. This will enable policy makers to locate possible sources of imbalances and propagation channels in the financial system.

3.3.1. Directional rolling sample net spillover indices

In this section we examine the net directional spillover effects among the different markets using the abovementioned rolling sample methodology. The examination of directional spillover effects will enable us to identify the net transmitters and receivers of spillovers and the main contributors to total spillovers. Figure 5 presents the net return spillovers for the six markets examined in this study. The net spillover index for the i market, NS_i^g, is calculated as in Eq. 10 with positive (negative) values indicating that market i transmits (receives) spillovers to (from) the rest of the j markets.

[Insert Figure 5 about here]

Figure 5 confirm the results of Table 2 indicating that the stock market is the key net transmitter of returns spillovers throughout our sample. By contrast, the money market is the only aspect of euro area financial system that is net receiver of return spillovers throughout the sample. For the bond market, we can clearly discern two phases for the Periphery 1 countries, which are currently under a support mechanism. The first phase spans from 2002 until the end of 2010, during which the Periphery 1 bonds are net receivers of spillovers. The picture, however, is reversed towards the end of 2010 with the diffusion of the debt-economic crisis to southern Europe. From this point in time and till the end of our sample (July 2012) Periphery 1 bonds are converted to net transmitters of return spillovers. Nonetheless, it is worth noting that even during the latter period of debt crisis the level of spillover effects directed from the sovereign bonds under pressure to other markets did not exceed 20%, while at the same time the average stock market spillover effects during this specific period was about 25%. This implies that stock market is the main net transmitter of spillovers in euro area financial markets throughout our sample even during periods of increased sovereign risk.

For the other two bond sub-indices, i.e. Periphery 2 countries (Italy and Spain) and investment grade countries, their net spillover index is almost always negative implying that these bond categories are mainly receivers of return spillovers. The FX market transmits return spillovers only during the 2005-2006 period, probably reflecting the weakening of the Euro against the U.S. Dollar during this period.

[Insert Figure 6 about here]

The picture is slightly different with regard to net volatility spillovers presented in Figure 6. The most sticking feature of Figure 6 is that money market is a net transmitter of volatility for a two year period spanning from mid-2006 to mid-2008. This reflects the uncertainty regarding the interest rate increases from the FED and the ECB in May 2006 and the subsequent liquidity squeeze in 2007 that led to widespread tensions in the interbank markets before and during the global financial crisis (Louzis and Vouldis, 2012). It is also worth noting that the interbank market along with Periphery 1 and 2 bonds are the main transmitters of volatility spillovers during a four months period towards the end of 2006, with the stock market being a receiver of volatility for that period. These results indicate the importance of the smooth functioning of money market for the stability of the financial system, since it can contribute considerably to the increase of volatility and thus uncertainty, in other aspects of the financial system. Therefore, regardless its smooth functioning history, the recent financial crisis has taught both policy makers and academic researchers that interbank markets should not be neglected (Holthausen and Pill, 2010).

Another interesting result emerging from Figure 6 is that the Periphery 1 bond index is a net transmitter of volatility spillovers throughout the sample, taking its highest values during the debt crisis in southern Europe, as expected. However, it is worth noting that the values of the index during the latter period are only slightly higher compared to the values of the index during the 2003-2007 period. This points out that periphery bond markets have been, historically, a possible source of volatility transmission in the Euro-area markets and this phenomenon is not only a consequence of the current debt crisis. This is a quite significant result from a policy making perspective, since actions should be taken promptly in order to control the propagation of uncertainty from the periphery bond markets to other elements of the financial system. Furthermore, it should also be noted that even during the sovereign debt crisis the spillover effects directed from the Periphery 1 bonds to the other countries are more or less to the same level with the stock market spillovers.

Regarding the remaining markets, the stock market is again the main transmitter of volatility spillovers across the six markets. By contrast, the FX market does not transmit volatility spillovers to other markets throughout the sample, while investment grade bonds are also net receivers of volatility for the most of the time. Finally, Periphery 2 bonds are net receivers of volatility spillovers during the years 2002-2003, 2007 and the second half of 2011.

3.3.2. Net pairwise spillover indices: The case of Periphery 1 bonds

In this section, we provide empirical results regarding the net pairwise spillover effects for Periphery 1 bonds. Although the analysis can also be extended to the other markets, the choice for the Periphery 1 bonds is justified on the grounds of the ongoing economic crisis in the underlying countries of the index. The net pairwise spillovers (NPS) between market i and market j are calculated as: $NPS_{ij}^{g}(H) = \left\{\left(\tilde{d}_{ji}^{g}(H) - \tilde{d}_{ij}^{g}(H)\right)/N\right\} \times 100$. Positive (negative) values of this index indicate that market i is a net transmitter (receiver) of spillovers to (from) market j. Figure 7 depicts the net pairwise return spillovers for the five pairs of Periphery 1 bonds with the rest of the markets.

[Insert Figure 7 about here]

For all five pairs, Periphery 1 bond index transmits spillovers during the 2011-2012 period. Nonetheless, the spillover effects transmitted to the stock market can be considered negligible. Moreover, Periphery 1 bonds are net transmitters of spillover effects towards teh money market throughout the sample period and almost always receive return spillovers from the stock market. Another interesting result is that Periphery 1 bonds are net receivers of spillovers from the other two categories of bond indices for a period of almost 6 years (2005-2010). This result implies that during non-stress periods or during periods of external global shocks (such as the sub-prime crisis in U.S.) the price movements of the sovereign bonds of large euro area economies are more likely to be transmitted to periphery countries than the opposite.

In Figure 8, we present the pairwise volatility spillovers for Periphery 1 bonds. The picture is clear regarding the money market, the FX and the investment grade sovereign bonds, which receive volatility spillovers from Periphery 1 bonds throughout the sample period. On the contrary, stock market and Periphery 2 bonds present a more “volatile” pattern of net volatility spillovers including periods of both receiving and transmitting spillover effects, implying bi-directional net volatility spillovers in these markets.

[Insert Figure 8 about here]

4. Conclusions

This study examines the return and volatility spillover effects among the main markets of the financial system in the euro area, i.e. among the money, stock, FX and bond markets. In particular, we construct total and directional spillover indices for a ten-year period (2002-2012) by implementing the forecast-error variance decomposition approach of Diebold and Yilmaz (2012).

The empirical results indicate a high level of total return and volatility spillovers throughout our sample period with sharp but temporary increases being observed during external (Lehman Brother collapse) and idiosyncratic (Greek debt crisis) shocks to the euro area. The spillovers seem to follow a more general pattern which is more likely to be affected by the corresponding phase of the business cycle. The main contributor to total return and volatility spillovers is the stock market, since it is almost always a net transmitter of return and volatility spillover effects.

By contrast, sovereign bonds of Greece, Ireland and Portugal were transmitting return spillovers to the rest of the markets only during 2011 and 2012. Nonetheless, the level of their directional spillover effects does not exceed the corresponding level of the stock market spillovers, even during the latter period of debt crisis. Moreover, the pattern of volatility spillovers is different for the bond series, with the results indicating that periphery countries, especially those under a support mechanism, have always been transmitters of volatility spillovers throughout the sample. However, the level of volatility transmission for the periphery countries during the last three years has only marginally increased compare to the period 2003-2007. Our study has also identified the key role money market in volatility transmission to other market segments during periods of liquidity squeeze.

The results of our study are of particular interest for both policy makers and investors. For a policy maker, it is important to know that euro-area financial markets are highly integrated and thus, shocks to one market will possibly create spillovers to other market segments. This is crucial for the preservation of the stability of the financial system, which in turn ensures the smooth funding of the real economy. Moreover, it is important to know that shocks to stock markets are more likely to be transmitted to the rest of the markets. Thus, stock markets should be closely monitored and possibly used in an early warning indicator system. Furthermore, the fact that the periphery bond market (along with the stock market) plays a crucial role in the transmission of uncertainty to the rest of the financial markets enhance the idea of central policy actions, e.g. see the recent ECB's rescue plan for buying sovereign bonds through Outright Monetary Transactions (OMT), ECB (2012), in order to limit widespread contagion effects. Finally, investors can also improve their hedging and portfolio diversification strategies exploiting the increased knowledge regarding the way the markets influence one another (In, 2007).

This study could be extended in several ways including the examination of cross-country spillover effects in the euro area as well as spillover effects between the euro area and other economies. It is also of particular interest to investigate how spillover indices can be used as early warning tools and how they are connected with domestic business cycles and global economic trends.

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APPENDIX

Table 1 Descriptive statistics of returns and logarithmic volatility for the six indices

Returns	Money market	Stocks	FX	Periphery 1 Bonds	Periphery 2 Bonds	Investment Grade Bonds
Mean	0.005	-0.093	0.030	0.010	0.096	0.155
St.devation	0.104	3.161	1.475	1.617	1.299	1.215
Max	0.895	12.548	4.992	13.252	6.555	3.969
Min	-0.380	-24.540	-6.048	-9.928	-6.748	-4.928
Skewness	2.066	-0.978	-0.266	0.081	0.025	-0.082
Kurtosis	16.870	6.689	0.919	14.741	3.589	0.959
Logarithmic volatility						
Mean	-1.021	0.448	0.155	0.061	0.062	0.058
St.devation	0.144	0.162	0.077	0.229	0.122	0.094
Max	-0.533	1.078	0.398	0.850	0.523	0.404
Min	-1.287	0.165	-0.031	-0.339	-0.115	-0.116
Skewness	0.574	0.885	0.351	1.109	1.429	1.014
Kurtosis	0.399	0.962	0.116	0.515	1.954	0.973

Notes: Periphery 1 Bonds index consists of Greece, Ireland and Portugal bond indices, Periphery 2 Bonds index consists of Italy and Spain bond indices and Investment Grade Bond index consists of Austria, France, Germany and Netherlands bond indices.

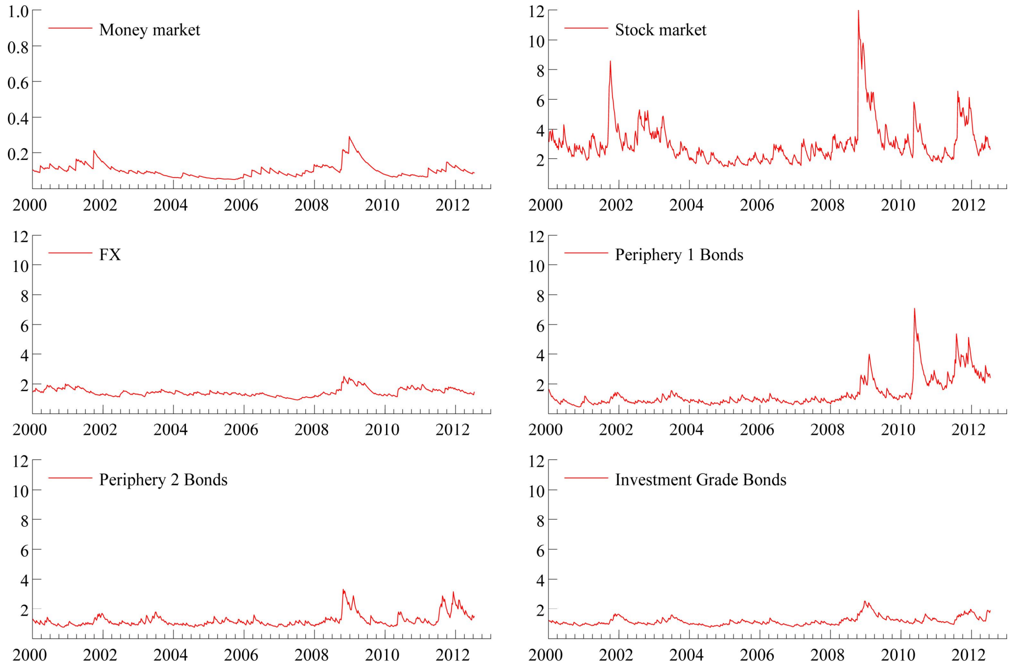
Table 2 Returns spillover table for the six markets

	Money market	Stocks	FX	Periphery 1 Bonds	Periphery 2 Bonds	Investment Grade Bonds	Directional spillovers ***from*** other markets
Money market	*0.07*	41.87	2.12	29.26	18.55	8.13	**99.93**
Stocks	0.15	*94.94*	0.26	0.43	0.41	3.81	5.06
FX	0.03	14.19	*76.51*	4.33	3.44	1.50	23.49
Periphery 1 Bonds	0.05	26.30	2.41	*51.34*	15.39	4.51	48.66
Periphery 2 Bonds	0.14	69.44	1.83	6.25	*13.76*	8.58	86.23
Investment Grade	0.12	53.14	1.46	4.34	11.63	*29.32*	70.68
Directional spillovers ***to*** other markets	0.48	**204.93**	8.08	44.61	49.40	26.54	***Total*** Spillover index (334.06/600=) 55.67%
Net spillovers	-99.44	**199.87**	-15.40	-4.05	-36.83	-44.14	

Table 3 Volatility spillover table for the six markets

	Money market	Stocks	FX	Periphery 1 Bonds	Periphery 2 Bonds	Investment Grade Bonds	Directional spillovers ***from*** other markets
Money market	*40.21*	30.45	0.70	12.18	12.12	4.33	59.79
Stocks	4.72	*74.76*	0.87	7.78	8.82	3.05	25.24
FX	19.31	20.29	*11.29*	22.14	19.54	7.42	88.71
Periphery 1 Bonds	0.72	4.72	1.10	*58.06*	23.34	12.06	41.94
Periphery 2 Bonds	0.15	8.19	1.00	28.00	*48.29*	14.36	51.71
Investment Grade Bonds	6.83	27.35	2.01	35.57	17.51	*10.73*	**89.27**
Directional spillovers ***to*** other markets	31.74	91.00	5.68	**105.67**	81.32	41.23	***Total*** Spillover index 59.44%
Net spillovers	-28.05	**65.77**	-83.02	63.74	29.61	-48.04	

Figure 1. Weekly volatility series



Note: The scaling in money market volatility is from 0 to 1. In all other markets is from 0 to 12.

Figure 2. Dynamic correlations

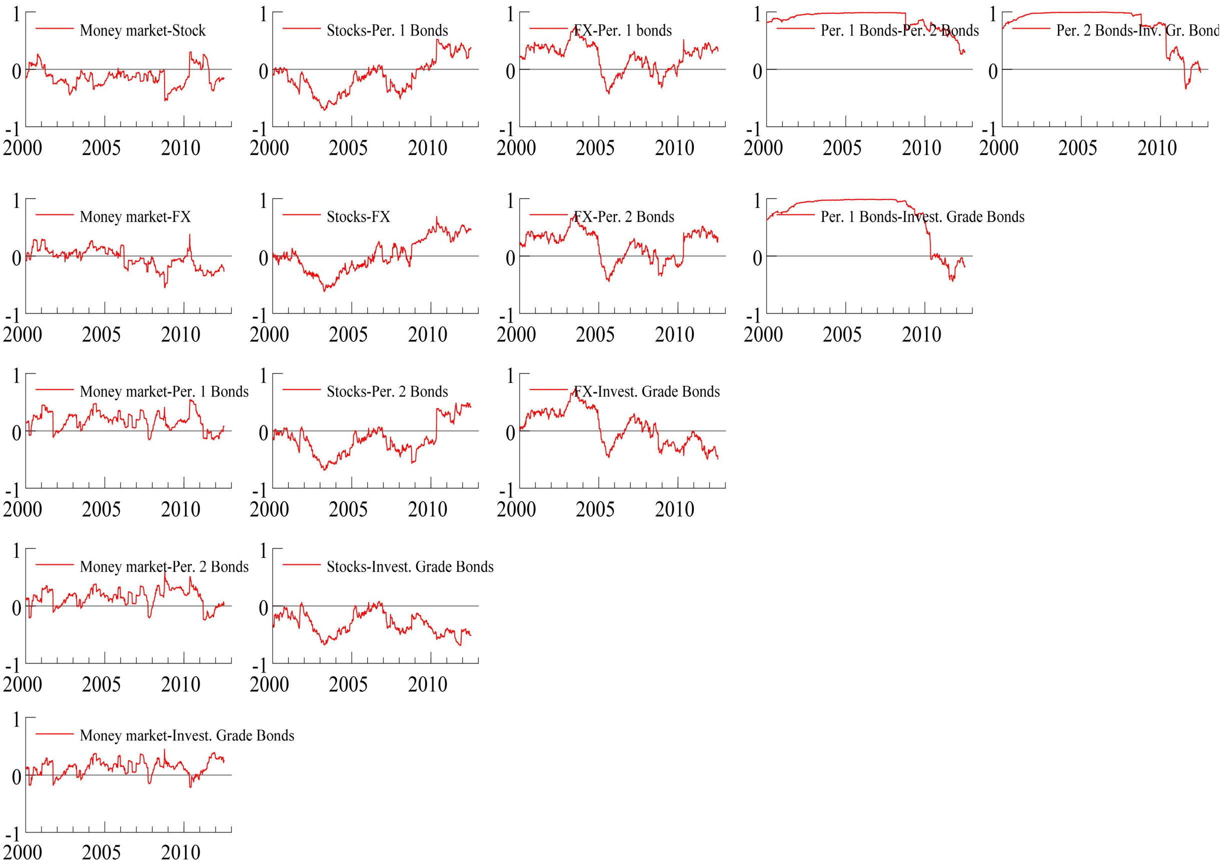
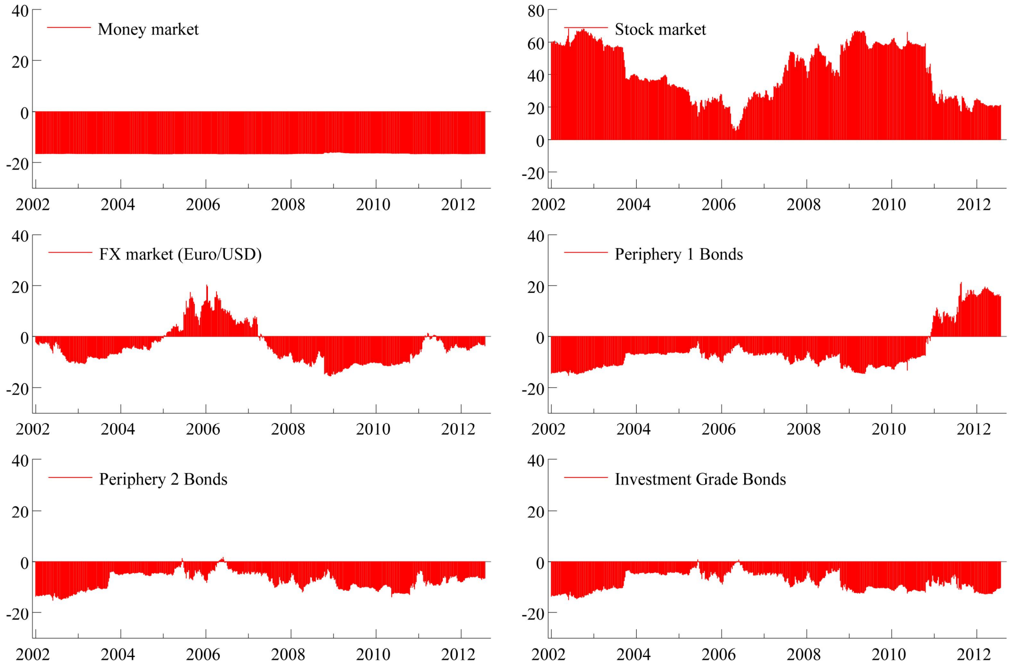


Figure 3. Total return spillover index

Figure 4. Total volatility spillover index

Figure 5. Net directional return spillovers



Note: The scaling in stock market is from -30 to 80. In all other markets is from -30 to 40.

Figure 6. Net directional volatility spillovers

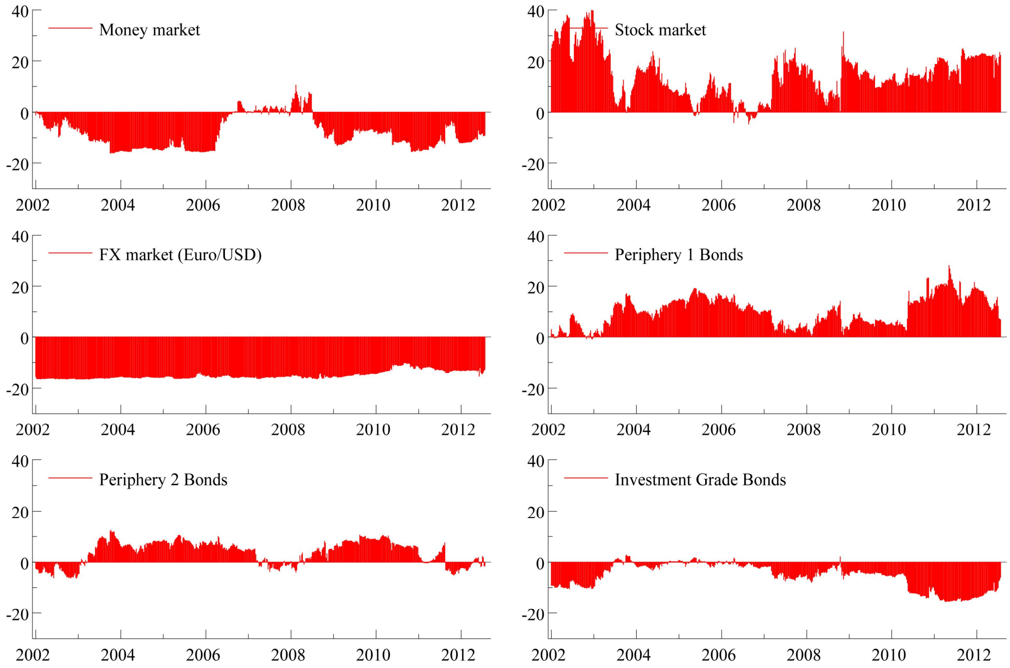
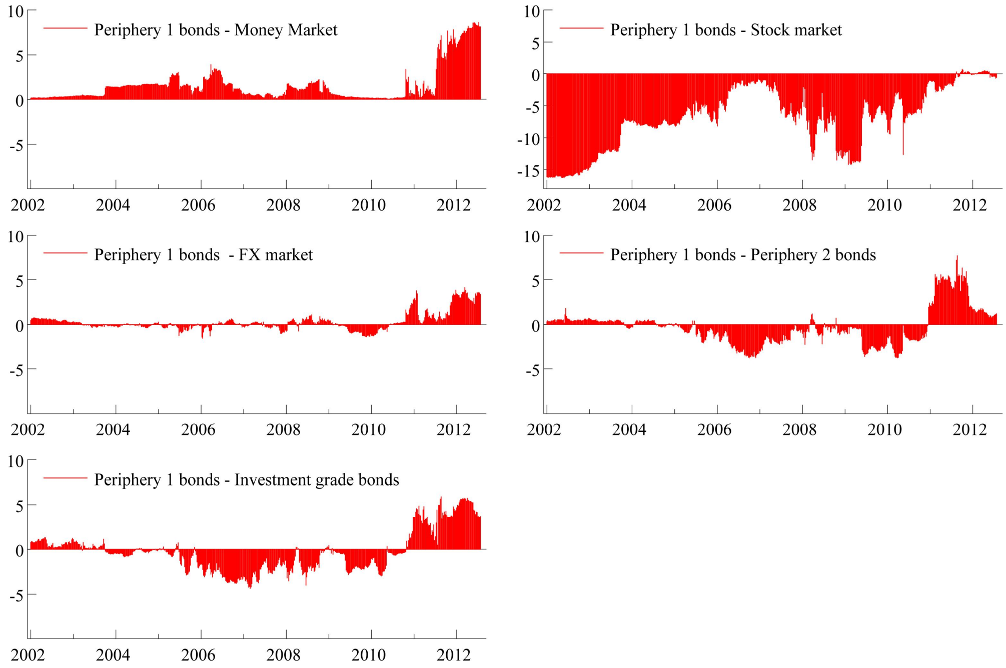
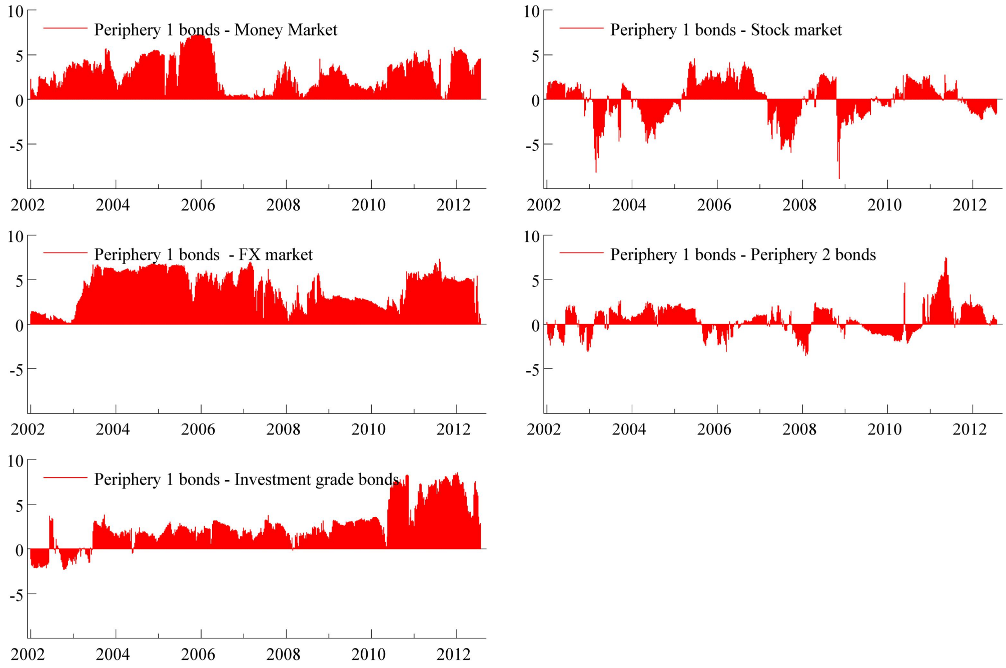


Figure 7. Net pairwise return spillovers



Note: The scaling in stock market is from -18 to 10. In all other markets is from -10 to 10.

Figure 8. Net pairwise volatility spillovers



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