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Decomposing European Bond and Equity Volatility

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Decomposing European Bond and Equity Volatility

Abstract: The paper investigates volatility spillover from US and aggregate European asset markets into European national asset markets. A main contribution is that bond and equity volatility spillover is analyzed simultaneously. A new model belonging to the "volatility-spillover" class is suggested: The conditional variance of e.g. the unexpected German stock return is divided into separate effects from US bonds, US stocks, European bonds, European stocks, German bonds, and German stocks. Significant volatility-spillover effects are found. The national bond (stock) volatilities are mainly influenced by bond (stock) effects. After the introduction of the euro the European markets have become more integrated; bond markets more so than stock markets.

Keywords: European Asset Markets; Euro; GARCH; Integration of Financial Markets; International Finance; Volatility Spillover

JEL Classifications: C32; G12; G15

1 Introduction

Financial integration is high on the agenda these years. Financial integration appears to be a major concern of the policy makers in the European Union (EU) as the EU has launched several policy initiatives to obtain financial integration, cf. e.g. Hartmann, Maddaloni and Manganeli (2003). The introduction of the euro is also working in favor of financial integration of European markets. Several European stock exchanges have merged in the recent years. This paper is concerned with how the volatility of various European bond and stock markets is affected by volatility from other financial markets. The presented empirical analysis brings some light on the integration of the European financial markets.

In particular, this paper is based within what has become known as the "volatility-spillover" strand of the literature. The paper contains an analysis of volatility spillover into European national bond and stock markets. The variance of the unexpected return of e.g. the German equity market is divided into a part caused by US (global) bond effects, US (global) stock effects, European (regional) bond effects, European (regional) stock effects, pure German (local) bond effects, and pure German (local) stock effects. Global, regional, and several local bond and stock markets are investigated simultaneously, which is new to the volatility-spillover literature. Thereby we investigate if the analysis of stock and bond volatility can be conducted separately. Moreover, we contribute methodologically to the literature by suggesting a general volatility-spillover model. Regional effects should be stronger and local effects weaker, the more integrated the European financial markets are. When the importance of country specific effects are low, the potential benefits of diversification are small. So, volatility spillover effects and financial integration are also important for portfolio managers with respect to hedging and shifting between asset classes.

The previous analysis of volatility linkages between financial markets has mainly concentrated on international stock markets and to a lesser extend on foreign exchange markets, whereas bond markets have received only little attention. Engle, Ito and Lin (1990) find significant volatility-spillover effects at play at the foreign exchange market. Lin, Engle and Ito (1994) find signif-

ificant volatility-spillover effects between the US and Japanese equity markets. Bekaert and Harvey (1997) investigate how global volatility-spillover effects influence emerging stock market volatility. Ng (2000) breaks the variance of various Pacific Basin stock markets into US effects, Japanese effects, and local effects. Baele (2005) investigates how US and aggregate European volatility spills over into various European stock markets. Christiansen (forthcoming) finds significant volatility spillover from US and European bond markets into national European bond markets and that the introduction of the euro has strengthened the European volatility spillover effects and that it has made the bond markets of the EMS (European Monetary System) countries close to being fully integrated. The EMS countries are those EU countries that have adopted the euro as their common currency. Kim, Moshirian and Wu (2005) find that the introduction of the euro has caused a structural change in the integration between European stock markets and that volatility linkages have been strengthened by the introduction of the euro.

The volatility linkages between the US stock and bond markets are strong presumably due to information spillover, cf. Fleming, Kirby and Ost diek (1998). Fama and French (1993) find that the links between US stock and bond markets are mainly caused by term-structure factors. Connolly, Stivers and Sun (2005; forthcoming) use implied volatility indices (that measure stock market uncertainty) to explain the time variation in the (within country) correlation between stocks and bonds in the US and in various European countries. They find a negative relation between current implied equity volatility and the future correlation between US stocks and bonds. Cappiello, Engle and Sheppard (forthcoming) apply the dynamic conditional correlation model of Engle (2002) to investigate international bond and equity markets. For Europe, the conditional correlations have increased after the introduction of the euro, and the introduction of the euro appears to indicate a structural break. Hartmann et al. (2003) find that the European financial markets have become more integrated after the introduction of the euro, but they are still not fully integrated. Ilmanen (2003) investigates the correlation between US stocks and bonds (using rolling window correlation coefficients) and finds that it has turned from positive to negative since 1998.

We provide a new volatility-spillover model that covers several bond and

stock markets simultaneously. Our model extends Ng (2000) who divides the conditional variance of the unexpected stock return for country i into three effects; global effects, regional effects, and own market effects. Fleming et al. (1998) investigate the volatility spillover between three US asset markets (stock, bond, and money market). Here we combine the two types of volatility spillover analysis: On the one hand, spillover between the same asset type across countries/regions and on the other hand, spillover in one country across assets types. The model allows us to divide the conditional variance of the unexpected return of bonds (stocks) into separate proportions caused by global, regional, and local bond and stock market effects. The volatility-spillover effects are allowed to become stronger or weaker (independently of each other) after the launch of the euro in the beginning of 1999. We presume that the introduction of the euro causes the European financial markets to become more integrated, i.e. local effects have become weaker and regional effects have become stronger.

We investigate nine European Union member countries' bond and stock markets. Using the dynamic conditional correlation model of Engle (2002) and Tse and Tsui (2002) to the US and European bond and stock returns, we find that the conditional bond-stock correlations have gone from positive to negative in the last part of the sample. So, using time varying conditional volatility is important.

Before the euro, the main part of the conditional variances of the unexpected return on the bond markets are caused by aggregate European bond effects and own bond market effects. US bond market effects and US stock market effects are also fairly large. After the euro, the European bond market effects are strongest followed by US bond market effects. Own bond market effects have decreased dramatically. After the introduction of the euro, the local bond market effects have become weaker and the regional bond market effects have become stronger. Thus, the bond markets have become more integrated after the introduction of the euro. The non-EMS countries are not as integrated as the EMS countries indicating that the introduction of the euro has been effective for bond markets. Thus, the diversifications gains across European bond markets have been diminished after the introduction of the euro.

Before the euro, the own stock market effects and US stock market effects are the most important for the conditional variance of the unexpected return of the stock markets. The European stock effects and the US bond effects are small. After the euro, own stock market effects, US stock market effects, and European stock market effects are all strong. The local stock market effects are still sizeable. There appears to be room for further integration in the European equity markets. There are no differences between EMS and non-EMS countries, so for stock markets the euro is of less importance than for bond markets. There are more diversification gains for stock market investors than for bond market investors.

Particularly after the euro, our results indicate that bond (stock) market volatility is mainly influenced by bond (stock) market effects. This might suggest to analyze bond (stock) market variability separately from stock (bond) market variability.

The remaining part of the paper is structured as follows. In the next section the volatility-spillover model is described. Subsequently, the data are presented in Section 3, whereupon the empirical findings are discussed in Section 4. Finally, section 5 concludes.

2 The Volatility-Spillover Model

In this section we describe the new volatility-spillover model which offers a substantial generalization of previous volatility-spillover models.

For each country ($i = 1, 2, \dots, 9$) there are six return series of interest.

- R_{1t} : US bond return
- R_{2t} : US stock return
- R_{3t} : European bond return
- R_{4t} : European stock return
- R_{i5t} : Country i 's bond return
- R_{i6t} : Country i 's stock return

Below we omit i from the subscript when convenient. The model is estimated stepwise and we organize the presentation around these steps. The first two steps are identical for all countries and concern the returns of the US and European bond and stock markets, $R_{1t}, \dots, R_{4t}$. In contrast, the last two steps are estimated separately for each country. The third step concerns the return on country i 's bond market, R_{i5t} , and the fourth step concerns the return on country i 's stock market, R_{i6t} . By separately estimating the last two steps, we allow for volatility spillover from country i 's bond market to its stock market which would otherwise not be possible.

The volatility-spillover model is initiated by Bekaert and Harvey (1997). The literature applies multi-step estimation procedures; Ng (2000) applies two (and a half) steps: The first step specifies an ordinary bivariate GARCH model for the US and Japanese stock returns. The first step is similar to our first step. As an intermediate step, the residuals from the first step are orthogonalized (as we do here). In the last step, the US and Japanese orthogonalized residuals are applied as additional explanatory variables in univariate models for the national stock returns. The orthogonalized residuals provide the volatility spillover in that they make the variance of the unexpected return of the individual stock market a linear function of contemporaneous US idiosyncratic variance, Japanese idiosyncratic variance, and own market idiosyncratic variance. The last step is similar to our third step.

2.1 US and European Returns

First, we specify a multivariate model for the return of the US and European bond and stock returns, i.e. for $R_t = \{R_{jt}\}$ where $j = 1, \dots, 4$. To account for possible serial correlation, the conditional mean evolves according to a VAR(1) process.

$$R_t = \Phi_0 + \Phi_1 R_{t-1} + \epsilon_t \quad (1)$$

Φ_0 and Φ_1 are a 4×1 vector and a 4×4 matrix of constants, respectively. The residuals, ϵ_t , have mean zero and conditional covariance matrix H_t .

ϵ_t follows a multivariate GARCH model. To account for the recent changes in the sign of the correlation between stock and bond returns, cf. Ilmanen (2003), we apply a model with time-varying conditional correlation.

In particular, we apply the dynamic conditional correlation (DCC) model of Engle (2002) and Tse and Tsui (2002) as specified by the latter.¹ The DCC model extends the constant conditional correlation (CCCOR) model of Bollerslev (1990) as well as the asymmetric CCCOR of Kroner and Ng (1998) while preserving their simplicity.

The conditional covariance matrix is given as:

$$H_t = D_t \Gamma_t D_t \quad (2)$$

where D_t is a diagonal matrix with the square roots of the conditional variances in the diagonal ($\sqrt{h_{jt}}$). Γ_t is the time-varying conditional correlation matrix. The conditional correlation matrix evolves according to an autoregressive process resembling the GARCH(1,1) process:

$$\Gamma_t = (1 - \theta_1 - \theta_2)\Gamma + \theta_1\Gamma_{t-1} + \theta_2\Psi_{t-1} \quad (3)$$

where Γ is a positive definite 4×4 matrix of constants with unit diagonal elements. Ψ_{t-1} is the sample correlation matrix of the standardized residuals lagged 1 to 4 periods. The values of θ_1 and θ_2 are restricted equivalently to the parameters in the GARCH(1,1) model: $\theta_1, \theta_2 \geq 0$ and $\theta_1 + \theta_2 \leq 1$. In the CCCOR model the correlation matrix is constant: $\Gamma_t = \Gamma \forall t$ (i.e. $\theta_1 = \theta_2 = 0$). Thus, the CCCOR model is a testable restriction in the DCC model.

The conditional variances evolve according to the asymmetric GJR-GARCH(1,1) specification, cf. Glosten, Jagannathan and Runkle (1993);

$$h_{jt} = \omega_j + \alpha_j \epsilon_{j,t-1}^2 + \beta_j h_{j,t-1} + \alpha_j^* \epsilon_{j,t-1}^2 I_{j,t-1} \text{ for } j = 1, \dots, 4 \quad (4)$$

where $I_{j,t-1} = 1$ when $\epsilon_{j,t-1} < 0$ and 0 otherwise, $\omega_j > 0$, $\alpha_j, \beta_j, \alpha_j + \frac{1}{2}\alpha_j^* \geq 0$, and $\alpha_j + \beta_j + \frac{1}{2}\alpha_j^* \leq 1$. If α_i^* is positive it means that negative shocks have more effect than positive shocks, which is the prevailing asymmetry hypothesis (for equity markets).²

¹The main advantage of the Tse and Tsui (2002) version of DCC is that they - unlike Engle (2002) - explicitly model the time series evolution of the conditional correlation matrix. The main force of the Engle (2002) version of the DCC is that the conditional variance equations and conditional correlation equations can be estimated separately.

²Below, we set α_i^* equal to zero whenever it is insignificant.

2.2 Orthogonalization

In an intermediate step, we orthogonalize the residuals from the previous step using a Cholesky decomposition. The orthogonalized residuals are denoted the idiosyncratic shocks, e_t . The orthogonalization is conducted in the following order; US bonds, US stocks, European bonds, and European stocks. "Geographically", this is equivalent to the previous literature which puts global stock effects first followed by regional stock effects, cf. Ng (2000). Subsequently, we let bonds influence stocks. This is in accordance with the findings of Scruggs and Glabadanidis (2003) who apply the asymmetric dynamic covariance model of Kroner and Ng (1998) to the US stock and bond returns. The present value model also suggests that the influence goes from bond markets to stock markets.

At the two extremes, the order of orthogonalization implies that the US bond residuals only depend on own idiosyncratic shocks, and the European stock residuals depend on all four idiosyncratic shocks. The relation between the residuals (LHS) and the idiosyncratic shocks (RHS) is shown below:

$$\begin{aligned}
\epsilon_{1t} &= e_{1t} \\
\epsilon_{2t} &= k_{1,t-1}e_{1t} + e_{2t} \\
\epsilon_{3t} &= k_{2,t-1}e_{1t} + k_{3,t-1}e_{2t} + e_{3t} \\
\epsilon_{4t} &= k_{4,t-1}e_{1t} + k_{5,t-1}e_{2t} + k_{6,t-1}e_{3t} + e_{4t}
\end{aligned} \tag{5}$$

This is conveniently restated using matrix notation:

$$\epsilon_t = \begin{pmatrix} 1 & 0 & 0 & 0 \\ k_{1,t-1} & 1 & 0 & 0 \\ k_{2,t-1} & k_{3,t-1} & 1 & 0 \\ k_{4,t-1} & k_{5,t-1} & k_{6,t-1} & 1 \end{pmatrix} e_t = K_{t-1}e_t \tag{6}$$

The conditional covariance matrix of the idiosyncratic shocks is denoted Σ_t . Σ_t is a diagonal matrix, as the orthogonalized residuals are independent by construction. The variances are denoted σ_{jt}^2 .

By recursively writing out equations, it is possible to express the elements of K_{t-1} as functions of elements in the covariance matrix of the residuals, H_t . The orthogonalized residuals are calculated from (6) as $e_t = K_{t-1}^{-1}\epsilon_t$. The

covariance matrix of the orthogonalized residuals is calculated as:

$$\Sigma_t = K_{t-1}^{-1} H_t K_{t-1}'^{-1} \quad (7)$$

2.3 Country i 's Bond Returns

We estimate a univariate model for the return on country i 's bond market, R_{i5t} (R_{5t}). The conditional mean is given as

$$\begin{aligned} R_{5t} = & c_0 + c_1 R_{1,t-1} + c_2 R_{2,t-1} + c_3 R_{3,t-1} + c_4 R_{4,t-1} + c_5 R_{5,t-1} \\ & + \gamma_{1t} e_{1t} + \gamma_{2t} e_{2t} + \gamma_{3t} e_{3t} + \gamma_{4t} e_{4t} + e_{5t} \end{aligned} \quad (8)$$

The conditional variance of the residual, $\text{Var}_{t-1}(e_{5t}) = \sigma_{5t}^2$, is assumed to evolve according to the GJR-GARCH(1,1) model, cf. (4) above.

To account for possible serial correlation, the one-period lagged own return is included in the mean. Moreover, the return on country i 's bond market depends on last period's return on the US and European stock and bond markets, $R_{1,t-1}, \dots, R_{4,t-1}$, hereby allowing for mean-spillover effects.

The return on the individual bond market also depends on the contemporaneous idiosyncratic shocks to the US and European bond and stock markets, $e_{1t}, \dots, e_{4t}$. As we shall see shortly, these terms represent volatility-spillover effects.

The volatility-spillover parameters, $\gamma_{1t}, \dots, \gamma_{4t}$, are time-varying; they take on different, yet constant, values before and after the launch of the euro on January 1, 1999:

$$\gamma_{lt} = \gamma_{0l} + \gamma_{1l} d_t \text{ for } l = 1, 2, 3, 4 \quad (9)$$

where d_t is an indicator function that equals zero before the euro and unity after. The sign of γ_{1l} determines whether the l 'th volatility-spillover effect has become weaker or stronger after the introduction of the euro. The volatility-spillover effects are individually allowed to become weaker or stronger after the euro, i.e. the γ_{1l} s do not have to be of the same sign. We expect the regional bond effects to have become stronger after the euro due to increased integration in the bond markets, i.e. $\gamma_{13} > 0$. This is a testable hypothesis. We expect that the euro mainly influences the EMS countries and that the non-EMS countries are less affected by other EU member countries adopting the euro. This is assessed in the empirical analysis.

Firstly, it is desirable that the volatility-spillover parameters change size at stochastic points in time. Secondly, it is preferable that the direction of the change may be different across the parameters. The present specification in (9) fulfills only the second requirement. The first requirement could be met by using a regime switching model where the regimes are determined by the size of the volatility-spillover parameters ($\gamma_{s_{it}=0} \leq \gamma_{s_{it}=1}$). For the second demand to be met the volatility-spillover effects should not necessarily be in the same regime at the same time, thereby yielding $2^4 = 16$ different states which makes estimation infeasible.

2.4 Country i 's Stock Returns

The return on country i 's stock index, R_{6t} , is described by a model equivalent to the one for country i 's bond market with added dependence on own bond market.

$$\begin{aligned} R_{6t} = & d_0 + d_1 R_{1,t-1} + d_2 R_{2,t-1} + d_3 R_{3,t-1} + d_4 R_{4,t-1} + d_5 R_{5,t-1} + d_6 R_{6,t-1} \\ & + \delta_{1t} e_{1t} + \delta_{2t} e_{2t} + \delta_{3t} e_{3t} + \delta_{4t} e_{4t} + \delta_{5t} e_{5t} + e_{6t} \end{aligned} \quad (10)$$

The conditional variance of the residual, $\text{Var}_{t-1}(e_{6t}) = \sigma_{6t}^2$, is assumed to evolve according to the GJR-GARCH(1,1) process as specified above in (4).

The return on country i 's stock market depends on own lagged return, and last period's return on the US and European bond and stock markets as well as on own bond market lagged return. The terms on the top right hand side of (10) represent the mean-spillover effects from the other bond and stock markets into the stock market of the country in question. The terms on the bottom right hand side of (10) represent the equivalent variance-spillover effects. Here the explanatory variables are the contemporaneous idiosyncratic shocks from the other markets, $e_{1t}, \dots, e_{5t}$.

Again, the volatility-spillover parameters are time varying

$$\delta_{lt} = \delta_{0l} + \delta_{1l} d_t \text{ for } l = 1, 2, 3, 4 \quad (11)$$

so that they take on different values before and after the euro. We expect the regional stock effects to have become stronger after the euro due to increased integration of the stock markets, i.e. $\delta_{14} > 0$. This is a testable hypothesis.

2.5 Volatility-Spillover Effects

The unexpected return on country i 's bond market is given as follows:

$$\epsilon_{5t} = \gamma_{1t}e_{1t} + \gamma_{2t}e_{2t} + \gamma_{3t}e_{3t} + \gamma_{4t}e_{4t} + e_{5t} \quad (12)$$

The first four terms are independent by construction, and the last term contains any remaining effects when we have taken account of the shocks from the US and European bond and stock markets, and is thus also independent here from. Therefore, the conditional variance of the unexpected return is simply the sum of the variances of the different terms:

$$h_{5t} = \gamma_{1t}^2\sigma_{1t}^2 + \gamma_{2t}^2\sigma_{2t}^2 + \gamma_{3t}^2\sigma_{3t}^2 + \gamma_{4t}^2\sigma_{4t}^2 + \sigma_{5t}^2 \quad (13)$$

Thus, the variance of the unexpected return of the individual national bond market depends on the idiosyncratic variances on US and European bond and stock markets as well as own idiosyncratic variance. Thus, the term volatility-spillover effects.

Equivalently, for country i 's stock index the unexpected return is

$$\epsilon_{6t} = \delta_{1t}e_{1t} + \delta_{2t}e_{2t} + \delta_{3t}e_{3t} + \delta_{4t}e_{4t} + \delta_{5t}e_{5t} + e_{6t} \quad (14)$$

By the same arguments, the conditional variance of the unexpected return depends on the idiosyncratic variances of US and European bond and stock markets as well as own idiosyncratic bond and stock variances.

$$h_{6t} = \delta_{1t}^2\sigma_{1t}^2 + \delta_{2t}^2\sigma_{2t}^2 + \delta_{3t}^2\sigma_{3t}^2 + \delta_{4t}^2\sigma_{4t}^2 + \delta_{5t}^2\sigma_{5t}^2 + \sigma_{6t}^2 \quad (15)$$

2.6 Variance Ratios

It is possible to calculate variance ratios using the estimated parameters. Using equation (13) we calculate the proportion of the variance of the unexpected return of country i 's bond return that is caused by the five different factors: US bond market effects, US stock market effects, European bond

market effects, European stock market effects, and own bond market effects.

$$\begin{aligned}
VR_{1t} &= \frac{\hat{\gamma}_{1t}^2 \hat{\sigma}_{1t}^2}{\hat{h}_{5t}} \\
VR_{2t} &= \frac{\hat{\gamma}_{2t}^2 \hat{\sigma}_{2t}^2}{\hat{h}_{5t}} \\
VR_{3t} &= \frac{\hat{\gamma}_{3t}^2 \hat{\sigma}_{3t}^2}{\hat{h}_{5t}} \\
VR_{4t} &= \frac{\hat{\gamma}_{4t}^2 \hat{\sigma}_{4t}^2}{\hat{h}_{5t}} \\
VR_{5t} &= \frac{\hat{\sigma}_{5t}^2}{\hat{h}_{5t}}
\end{aligned} \tag{16}$$

For country i 's stock market the origin of the first four effects is unaltered, then there are own bond market effects, and own stock market effects. Otherwise, the variance ratios are calculated as for the bond market.

$$\begin{aligned}
VR_{1t}^* &= \frac{\hat{\delta}_{1t}^2 \hat{\sigma}_{1t}^2}{\hat{h}_{6t}} \\
VR_{2t}^* &= \frac{\hat{\delta}_{2t}^2 \hat{\sigma}_{2t}^2}{\hat{h}_{6t}} \\
VR_{3t}^* &= \frac{\hat{\delta}_{3t}^2 \hat{\sigma}_{3t}^2}{\hat{h}_{6t}} \\
VR_{4t}^* &= \frac{\hat{\delta}_{4t}^2 \hat{\sigma}_{4t}^2}{\hat{h}_{6t}} \\
VR_{5t}^* &= \frac{\hat{\delta}_{5t}^2 \hat{\sigma}_{5t}^2}{\hat{h}_{6t}} \\
VR_{6t}^* &= \frac{\hat{\sigma}_{6t}^2}{\hat{h}_{6t}}
\end{aligned} \tag{17}$$

3 Data Description

We obtain bond and stock indices for the US, Europe, and the following nine European Union countries: Belgium, Denmark, France, Germany, Italy, the Netherlands, Spain, Sweden, and the United Kingdom. All the countries are EMS member countries except for Denmark, Sweden, and the UK. Total

return indices imply that the received coupons (dividends) are reinvested into the bonds (stocks) of the index. Log-returns are calculated as the logarithmic growth rate of the indices.

As to bonds, we apply the J. P. Morgan government bond indices obtained from DataStream. The aggregate European index is a value weighted average of the indices of the nine individual indices. As to stocks, we apply the DataStream equity indices. The aggregate European index covers all 15 EU countries.

The returns are counted in local currency. There are a number of reasons for using local currency returns (in contrast to common currency returns). Local currency returns are equivalent to currency hedged returns, and it is both easy and inexpensive to hedge currency risk. Local currency returns are relevant for analyzing economic fundamentals. Miyakoshi (2003) in his study of volatility spillover on equity markets argues for local currency returns, because e.g. De Santis and Gérard (1998) find that currency risk is highly important for stock returns. Ilmanen (1995) argues that one should count bond returns in local currency to separate bond market predictability from foreign exchange market predictability, because exchange rates are more volatile than bond returns.

The weekly data (recorded on Wednesdays) cover the period from January 6, 1988 to December 3, 2003. Thus, there are 831 observations in our sample period. We use data of a fairly low (weekly) frequency, although they are available at a higher (daily) frequency, in order to remedy the potential problem of using non-synchronous data, cf. Burns and Engle (1998).

Table 1 contains various descriptive statistics for the bond and stock indices. Except for Italy, the average bond return is smaller than the average stock return, e.g. for aggregate Europe the average returns are 0.16% and 0.20% for bonds and stocks, respectively. Equivalently, the standard deviation is much larger for stock returns than for bond returns; for aggregate Europe compare 0.50% to 2.25%. As is usual for financial returns, the series are (with two exceptions) skewed to the left and show excess kurtosis. The return series show only weak signs of autocorrelation. The squared return series are significantly autocorrelated, i.e. providing signs of conditional heteroskedasticity.

The bond and stock markets of a given country are positively correlated (except for the Netherlands); the average correlation coefficient amounts to 0.14. The average correlation between the aggregate European bonds (stocks) and the countries' bonds (stocks) is 0.82 (0.80). The average correlation between the US bonds (stocks) and the individual bonds (stocks) is 0.45 (0.59). The correlations between the aggregate European bonds (stocks) and the individual stocks (bonds) are positive apart from the Netherlands (positive), averaging 0.08 (0.06). The correlations between the US bonds (stocks) and the individual stocks (bonds) are negative (positive), averaging -0.08 (0.05).

Overall, the simple correlation coefficients indicate that the relation between the individual European financial markets and the aggregate European markets is stronger than the relation between the individual European markets and the US markets. Moreover, the bond-stock relations are weaker than the bond-bond and stock-stock relations.

As we analyze the log-returns that are calculated as the first differences of the log-prices in a multivariate framework, we investigate if the log-prices cointegrate. Applying the Johansen procedure to the log-prices of the US bonds, US stocks, European bonds, and European stocks (the four series from the first estimation step) we find that there is one cointegrating relation, cf. Johansen (1991). For one country at a time, we investigate the cointegration between the four above-mentioned series as well as that country's stock and bond log-prices. For all countries, the six series cointegrate and furthermore there is evidence that we can leave out the country specific series from the cointegrating relation. Thus, in the empirical analysis we include the lagged cointegrating relation (z_{t-1}) as an additional explanatory variable in the mean equations, i.e. in equations (1), (8), and (10).³ The error correction term is included in the mean equations to account for the attraction between the log-price levels. The empirical results - yet to be presented - are robust to excluding z_{t-1} as explanatory variable.

³The cointegrating relation is given as $z_t = \ln(P_{1t}) - 2.487\ln(P_{2t}) - \ln(P_{3t}) + 2.941\ln(P_{4t}) + \text{constant}$. We cannot reject that the hypothesis of unit coefficients (of opposite signs) for the two bond series. The coefficients for the stocks are significantly different in absolute size.

4 Empirical Results

We open the empirical section by presenting the results from estimating the volatility-spillover model. Thereafter we discuss the empirical variance ratios.

4.1 Model Estimates

The volatility-spillover model described in Section 2 is estimated using the Quasi Maximum Likelihood method with Gaussian likelihood functions. The estimation is conducted using a combination of the Berndt, Hall, Hall and Hausman (1974) and the Newton-Raphson numerical optimization algorithm. The estimation is conducted in GAUSS using the Constrained Maximum Likelihood module.

Tables 2-4 report the results from estimating the volatility-spillover model.⁴ For brevity, only the parameter estimates are provided together with an indication of their significance based on the Bollerslev and Wooldridge (1992) robust standard errors. The volatility-spillover model appears to provide an adequate description of the data: The properties of the standardized residuals are investigated (separately for each estimation step) and there is no signs of remaining autocorrelation and heteroskedasticity.⁵

4.1.1 US and European Returns

Table 2 shows the parameter estimates of the multivariate GARCH model for the US bond return, the US stock return, the European bond return, and the European stock return laid out in equations (1)-(4).

Although we find only weak signs of autocorrelation in the summary statistics, cf. Table 1, we cannot assume constant means, because the dependence on lagged returns is significant; the robust Wald test of the null hypothesis that $\Phi_1 = 0$ is strongly rejected (i.e. the VAR(1) parameter matrix is not zero). Also, the cross effects are significant. We reject the null

⁴In the presented results the returns are not transformed into percentage returns.

⁵For the standardized residuals from the first step of the model we investigate the autocorrelation of the residuals, the squared residuals, and the cross-multiplied residuals. For the third and fourth step, we investigate the autocorrelation of the residuals and the squared residuals. In total, we only find significant autocorrelation in one instance.

hypothesis of an AR(1) model instead of the VAR(1) model (i.e. Φ_1 is not diagonal).

Asymmetry effects are present in the variance of the stock returns; negative shocks have more effect than positive shocks. For bonds, the variance processes are not significantly asymmetrical and therefore in the reported results, α_1^* and α_3^* are set equal to zero. The conditional variance processes are rather persistent, meaning that shocks to them die out slowly.

The conditional correlations are time-varying according to equation (3). The point estimates of the weighting parameters for the conditional correlation matrix (θ_1 and θ_2) equal 0.975 and 0.022, respectively. They are of about the same size as in the four empirical applications in Tse and Tsui (2002). The large value of θ_1 (close to unity) implies that the correlation process is highly persistent. The hypothesis that $\theta_1 = \theta_2 = 0$ is strongly rejected, in other words the conditional volatilities are not constant as specified by the CCCOR model. The constant part of the correlation matrix, Γ , includes only positive correlations, but only half of them are significant; (US stocks; US bonds), (US bonds; European bonds), and (US stocks; European stocks).

Figure 1 shows the time-series evolution of the conditional correlations. For the entire sample period the conditional correlation between the US bond return and European bond return is positive and the same applies for the stock-stock correlation. In the beginning and end of the sample the bond-bond and stock-stock correlations are fairly high (around 0.70), whereas they are somewhat smaller in the middle period (around 0.45 and 0.55, respectively). They reach a local minimum around 1993 where the bond-bond correlation drops to a lower level than the stock-stock correlation, minimum values are 0.17 and 0.42, respectively. The four time series of bond-stock correlations all start out being positive and then begin to decrease around 1997. Beginning in 1999, the stock-bond correlations turn negative. Thus, the conditional correlations from the DCC model provide results that are consistent with the moving window correlations in Ilmanen (2003).

4.1.2 Country i 's Bond Returns

Table 3 shows the parameter estimates arising from estimating the model for the individual countries' bond returns given in equation (8).

The variance processes are not significantly asymmetric, so this feature is excluded in the presented results, (i.e. $\alpha^* \equiv 0$). The GARCH processes are highly persistent.

The expected bond returns are influenced by lagged returns - both own lagged returns and lagged returns for the US and European bond and stock markets. The dependence of today's bond return on lagged US and European returns is denoted mean-spillover effects in the literature. Not all the mean-spillover parameters ($c_{i1}, \dots, c_{i4}$) are significant for all countries, but all parameters are significant for some countries. There does not seem to be a pattern for the structure of the mean-spillover effects, i.e. which countries receive mean-spillover effects from which markets.

In equation (8) the lagged cointegrating relation, z_{t-1} is added as explanatory variable to take account of the attraction of the log-price levels. The coefficients are negative, significant, and numerically small.

There are significant volatility-spillover effects at play at the bond markets. For the period before the euro, there are positive and strongly significant volatility-spillover effects to the individual bond markets from the US bond market, the US stock market, and the European bond market. This applies to all the countries under investigation. The volatility spillover parameters for the European stock market (γ_{04}) are very small, negative and some insignificant, thereby indicating that there is no volatility-spillover from the aggregate European stock market into the individual bond markets.

The nature of the volatility spillover has changed by the introduction of the euro: The hypotheses that $\gamma_{11} = \gamma_{12} = \gamma_{13} = \gamma_{14} = 0$ are strongly rejected for all countries. After the euro, there are significant volatility-spillover effects to the individual bond markets from the US bond market and the European bond market; the hypotheses that $\gamma_{01} + \gamma_{11} = 0$ and $\gamma_{03} + \gamma_{13} = 0$ are rejected for all countries. The volatility-spillover effect from the US stock market has ceased to be important ($\gamma_{02} + \gamma_{12}$ is small and negative) and the volatility-spillover effect from the European stock market

is still insignificant. The influence from the US bond market has increased for Belgium, Germany, Italy, and Spain and it has remained unchanged for Denmark, France, the Netherlands, Sweden and the UK. The influence from the European bond market is strengthened by the introduction of the euro for all countries except for Denmark, Sweden, and the UK, namely for the non-EMS countries. Thereby it confirms our expectations of stronger integration of the EMS countries' bond markets after the introduction of the euro as their common currency.

4.1.3 Country i 's Stock Returns

Table 4 provides the parameter estimates of the model for the individual stock returns in equation (10).

Many of the patterns from the bond markets are recovered. There are significant mean-spillover effects into the individual stock markets. The mean spillover parameters $(d_{i1}, \dots, d_{i5})$ are not all significant for all countries. The returns depend significantly and negatively on the lagged cointegrating equation and therefore the variance processes are highly persistent and show no signs of asymmetry. Therefore the reported results include symmetric volatility processes.

For the period before the euro, there are significant volatility-spillover effects into the individual stock markets from the US bond market, the US stock market, the European bond market, and from own bond market.

The volatility-spillover effects are significantly influenced by the introduction of the euro; we strongly reject that $\delta_{11} = \delta_{12} = \delta_{13} = \delta_{14} = \delta_{15} = 0$ by robust Wald tests. After the euro, there is significant volatility-spillover from the US stock market and the European stock market into the individual stock markets. The post-euro volatility-spillover coefficients are negative for the US bond market, the European bond market, and own bond market; $(\hat{\delta}_{0i} + \hat{\delta}_{1i} < 0)$ for $i = 1, 3, 5$. The volatility-spillover effects from the US stock market are diminished and significantly so for all countries. The effects from the European stock market are increased significantly for Belgium, the Netherlands, Sweden and the UK and has remained unchanged for the remaining countries. So, there are signs of further integration for some of the

countries. Notice, that the country results are not identical for the bond and stock markets.

4.2 Empirical Variance Ratios

From the significance of the volatility-spillover coefficients we conclude above that until 1999 there are significant volatility-spillover effects from the US bond, US stock, and European bond markets into the individual bond markets and after 1999 only from the US bond and European bond markets. Similarly, before 1999 there are significant volatility-spillover effects from the US bond, US stock, European bond, and own bond markets into the national stock markets and after 1999 only from the US stock and European stock markets. However, so far we have not discussed the order of magnitude of the spillover effects. The variance ratios described in Section 2.6 enable us to measure the importance of the various markets in this respect. Table 5 shows the average variance ratios, at the top for the bond markets and at the bottom for stock markets. The averages have been calculated for the two sub periods divided by the introduction of the euro.

First we analyze the individual bond markets in the period before the euro. The volatility-spillover effects from the aggregate European bond market and the own bond market are the largest effects; on average the variance of the European idiosyncratic shock accounts for between 27% (Spain) and 44% (the Netherlands) of the variance of the unexpected returns for the individual bond markets; the average of the averages across the countries is 36%. The average own bond market effects provide around 37% of the variance of the unexpected return for the various bond markets, ranging from 25% (France) to 57% (Italy). The proportion of the bond variances caused by US bond effects are also fairly large, and lies between 6% (Italy) and 20% (the Netherlands), on average 15%. The US stock market effects are somewhat smaller, around 12% on average. The European stock market effects are negligible.

After the euro only the bond markets play a role: The European bond markets on average account for around 44% of the variance of the unexpected return for the national bond markets, ranging from 33% for Sweden to 50%

for the Netherlands. The US bond market effect is slightly lower, around 41%, spreading from 36% for Sweden to 43% for Belgium. The own bond market effect has decreased dramatically from an average of 37% to around 9% for the EMS countries and to between 18% and 30% for the non-EMS countries. So, European bond markets appear to have become more integrated. And, as expected, this is particularly the case for the EMS countries which have adopted the euro as common currency.

For the stock markets the magnitudes of the volatility-spillover effects are quite different from the bond markets. Before the euro, the own stock market effects are largest (around 57% on average, ranging from 47% for the UK to 75% for Italy) followed by the US stock market effects (on average 31%, ranging from 17% for Denmark to 41% for the UK). The European and US bond markets also account for a small fraction of the variance of the unexpected stock returns, 8% and 3% on average). Both the European stock effects and the own-country bond effects are negligible. After the introduction of the euro, only the stock market effects are relevant; the own stock market effects is the dominant factor (48% on average; with a minimum of 35% for Germany and a maximum for 69% in Belgium), the US stock market effects are also strong (31% on average, with a minimum of 22% for Denmark and a maximum of 43% for Germany), and the European stock market effects are much stronger than before the euro (13% on average, ranging from 6% for Belgium to 20% for the Netherlands). Thus, European stock markets are not as integrated as European bond markets as the regional effects are not so dominant as for the bond markets. There are no discernible differences between EMS and non-EMS countries. These findings are not surprising because many relevant news items for stock markets are firm specific.

Overall, the sizes of the variance ratios tell us that after the introduction of the euro the countries' bond markets work almost autonomously from the world and regional stock markets with respect to variance. Similarly, after the euro the countries' stock markets are hardly influenced by the world and regional bond markets with respect to variance. For the period before the euro, the results are less clear-cut. For the bond markets, the own market effects have decreased dramatically after the launch of the euro making the bond markets more integrated, especially for the EMS countries. In contrast,

the decrease in own market effects has been weaker for the stock markets and they are not as integrated as the bond markets.

5 Conclusion

We have added to the literature model-wise as well as empirically by analyzing bond and equity volatility-spillover effects simultaneously.

We have applied a new volatility-spillover model. The model has included volatility spillover into national European bond and equity markets from the US and aggregate European bond and equity markets. The conditional variance of the unexpected return of country i 's bond market has been decomposed into separate effects caused by contemporaneous idiosyncratic US bond variance, idiosyncratic US stock variance, idiosyncratic European bond variance, idiosyncratic European stock variance, and own bond market idiosyncratic variance. The conditional variance of the unexpected return of country i 's stock market has been decomposed into the same five effects as well as idiosyncratic own stock market variance.

We have investigated nine European countries' bond and stock markets. We have found significant volatility-spillover into the individual bond and equity markets from the global and regional bond and equity markets. Our results have indicated that bond (stock) market volatility is mainly influenced by bond (stock) market effects. Local, regional, and global effects have all been found to be of importance for European bond and stock volatility. We have accounted for the structural break caused by the introduction of the euro. The European financial markets have become much more integrated after the introduction of the euro, this is particularly the case for the bond markets, and even more so for the EMS countries' bond markets.

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– Bonds –						
	Mean	Stdev.	Skew.	Kurt.	AC(1)	AC ² (1)
US	0.15	0.61	-0.33	3.69	0.00	0.09
Eu	0.16	0.50	-0.67	4.70	0.01	0.12
Be	0.15	0.50	-0.53	5.03	-0.01	0.19
De	0.17	0.56	-0.47	6.49	0.06	0.18
Fr	0.16	0.56	-0.35	4.55	-0.01	0.12
Ge	0.12	0.49	-0.71	4.84	0.03	0.11
It	0.21	0.64	-0.56	8.39	0.04	0.17
Ne	0.13	0.50	-0.76	5.11	0.04	0.09
Sp	0.19	0.60	-0.26	8.18	0.02	0.18
Sw	0.18	0.71	-0.19	11.39	-0.03	0.09
UK	0.17	0.78	0.00	4.55	-0.01	0.07

– Stocks –						
	Mean	Stdev.	Skew.	Kurt.	AC(1)	AC ² (1)
US	0.23	2.23	-0.26	4.80	-0.09	0.17
Eu	0.20	2.25	-0.38	6.15	-0.07	0.33
Be	0.18	2.35	-0.16	9.26	-0.08	0.39
De	0.26	2.29	-0.15	4.50	0.04	0.17
Fr	0.23	2.74	-0.21	5.46	-0.09	0.31
Ge	0.17	2.70	-0.55	5.71	-0.07	0.25
It	0.15	3.04	-0.19	3.95	0.01	0.18
Ne	0.22	2.48	-0.54	9.24	-0.12	0.39
Sp	0.21	2.67	-0.42	4.42	-0.03	0.17
Sw	0.25	3.40	-0.18	5.80	-0.06	0.12
UK	0.19	2.14	0.13	6.37	-0.05	0.28

The table reports summary statistics for the weekly returns (in %) of the J. P. Morgan government bond indices and the DataStream stock indices from 1988 to 2003 for the US, Europe (Eu), Belgium (Be), Denmark (De), France (Fr), Germany (Ge), Italy (It), the Netherlands (Ne), Spain (Sp), Sweden (Sw), and the UK. The following statistics are reported: Mean, standard deviation, skewness, kurtosis, first order autocorrelation, and first order autocorrelation of the squared variable.

Table 1: Summary Statistics

		R_{1t}	R_{2t}	R_{3t}	R_{4t}
Φ_0		0.002	-0.001	-0.009***	-0.014
Φ_1	R_{1t-1}	-0.036	0.207	0.080***	0.117
	R_{2t-1}	-0.007	-0.147***	-0.017	-0.008
	R_{3t-1}	0.074	0.187	-0.005	0.111
	R_{4t-1}	-0.015	0.065	0.015	0.009
Φ_2	z_{t-1}	0.0005	-0.001	-0.005***	0.008
ω		$2 \cdot 10^{-6}$ ***	0.002**	$7 \cdot 10^{-7}$ ***	0.002**
α		0.060***	0.000	0.047***	0.043*
α^*			0.161***		0.089**
β		0.887***	0.856***	0.918***	0.850***
Γ	R_{2t}	0.361**			
	R_{3t}	0.757***	0.110		
	R_{4t}	0.048	0.810***	0.208	
θ_1			0.975***		
θ_2			0.022***		

The table reports the results from estimating the first step of the volatility-spillover model. R_{1t} , R_{2t} , R_{3t} , and R_{4t} , are the US bond return, US stock return, European bond return, and the European stock return, respectively. $R_t = \Phi_0 + \Phi_1 R_{t-1} + \epsilon_t$, where ϵ_t , have mean zero and conditional covariance matrix $H_t = D_t \Gamma_t D_t$. D_t is a diagonal matrix with the square roots of the conditional variances in the diagonal ($\sqrt{h_{jt}}$). $\Gamma_t = (1 - \theta_1 - \theta_2)\Gamma + \theta_1 \Gamma_{t-1} + \theta_2 \Psi_{t-1}$ is the time-varying conditional correlation matrix and $h_{jt} = \omega_j + \alpha_j \epsilon_{j,t-1}^2 + \beta_j h_{j,t-1} + \alpha_j^* \epsilon_{j,t-1}^2 I_{j,t-1}$ for $j = 1, \dots, 4$. Based on Bollerslev and Wooldridge (1992) robust standard errors, */**/** indicates that the parameter is significant at the 10%/5%/1% level of significance.

Table 2: Model Estimates: US and European Bond and Stock Returns

	Be	De	Fr	Ge	It	Ne	Sp	Sw	UK
c_0	-1.274***	-1.202***	-1.456***	-1.298***	-1.575***	-1.367***	-1.630***	-1.902***	-1.693***
c_1	0.081***	0.058***	0.083***	0.088***	0.079***	0.092***	0.084***	0.034	0.109***
c_2	-0.013***	-0.011*	-0.014***	-0.012***	-0.016***	-0.016***	-0.014***	-0.013*	-0.021**
c_3	0.042	0.122**	0.023	-0.052	-0.037	-0.015	0.027	0.149**	-0.080
c_4	0.012***	0.013***	0.011***	0.011***	0.018***	0.015***	0.013***	0.017**	0.018**
c_5	-0.047	-0.104*	-0.021	0.045	0.066	0.010	-0.039	-0.089*	0.034
$c_6 (z_{t-1})$	-0.003***	-0.003***	-0.004***	-0.003***	-0.004***	-0.004***	-0.004***	-0.005***	-0.005***
γ_{01}	0.361***	0.410***	0.474***	0.381***	0.227***	0.417***	0.329***	0.455***	0.599**
γ_{11}	0.116***	-0.010	-0.008	0.083**	0.233***	0.042	0.143**	-0.009	0.013
γ_{02}	0.103***	0.152***	0.140***	0.103***	0.089***	0.110***	0.063***	0.126***	0.202***
γ_{12}	-0.111***	-0.169***	-0.146***	-0.112***	-0.089***	-0.116***	-0.068***	-0.140***	-0.217***
γ_{03}	0.657***	0.855***	0.834***	0.673***	0.604***	0.747***	0.591***	0.829***	1.101***
γ_{13}	0.272***	-0.102	0.109*	0.253***	0.308***	0.188***	0.339***	-0.029	0.068
γ_{04}	-0.000***	-0.000***	-0.000***	-0.000***	-0.000	-0.012***	-0.015***	-0.008***	-0.006
γ_{14}	-0.003	0.004	-0.003	0.001	0.004	-0.002	-0.001	0.004	0.008
ω	$4 \cdot 10^{-8}$	$6 \cdot 10^{-8}$	$4 \cdot 10^{-8}$	$5 \cdot 10^{-8}$ *	$3 \cdot 10^{-8}$	$2 \cdot 10^{-8}$	$3 \cdot 10^{-8}$ *	$6 \cdot 10^{-8}$	$3 \cdot 10^{-8}$
α	0.107	0.126***	0.118*	0.103***	0.116***	0.102***	0.106***	0.065*	0.082**
β	0.890***	0.873***	0.879***	0.673***	0.880***	0.895***	0.893***	0.933***	0.906***

The table reports the results from estimating the third step of the volatility-spillover model for country i 's bond returns (R_{i5t}). $R_{5t} = c_0 + c_1 R_{1,t-1} + c_2 R_{2,t-1} + c_3 R_{3,t-1} + c_4 R_{4,t-1} + c_5 R_{5,t-1} + \gamma_{1t} e_{1t} + \gamma_{2t} e_{2t} + \gamma_{3t} e_{3t} + \gamma_{4t} e_{4t} + e_{5t}$. $\text{Var}_{t-1}(e_{5t}) = \sigma_{5t}^2 = \omega_5 + \alpha_5 \epsilon_{5,t-1}^2 + \beta_5 \sigma_{5,t-1} + \alpha_5^* \epsilon_{5,t-1}^2 I_{5,t-1}$. The volatility spillover parameters: $\gamma_{lt} = \gamma_{0l} + \gamma_{1l} d_t$ for $l = 1, 2, 3, 4$ where d_t is an indicator function that equals zero before the euro and unity after. Based on Bollerslev and Wooldridge (1992) robust standard errors, */**/** indicates that the parameter is significant at the 10%/5%/1% level of significance.

Table 3: Model Estimates: Country i 's Bond Returns

	Be	De	Fr	Ge	It	Ne	Sp	Sw	UK
d_0	-0.985***	-0.899***	-1.070***	-0.404**	-1.784***	-1.959***	-2.415***	-4.239***	-2.918***
d_1	-0.002	0.228	-0.033	0.072	-0.188	0.043	0.083	-0.041	0.113
d_2	-0.042	-0.054	-0.005	0.030	-0.060	0.029	0.067	-0.056	0.021
d_3	0.152	-0.167	0.072	-0.081	-0.436	0.151*	0.048	0.215	0.083
d_4	0.102**	0.169***	-0.015	0.084	-0.102	0.119**	0.048	0.086	-0.012
d_5	0.133	0.050	0.215	0.016	0.396	0.012	0.288*	-0.178	0.119
d_6	-0.003	-0.022	-0.045	-0.087	0.148***	-0.117**	-0.079*	-0.070*	-0.032
$d_7 (z_{t-1})$	-0.003***	-0.002***	-0.003***	-0.001**	0.005***	-0.005***	-0.006***	-0.011***	-0.008***
δ_{01}	0.578***	0.820***	0.832***	0.598***	0.926***	0.521***	0.675***	0.693***	0.536***
δ_{11}	-1.003***	-1.483***	-1.580***	-1.505***	-1.864***	-1.317***	-1.569***	-1.828***	-1.020***
δ_{02}	0.577***	0.518***	0.943***	0.824***	0.724***	0.704***	0.814***	1.023***	0.742***
δ_{12}	-0.135*	-0.035	-0.227	-0.010	-0.080	-0.118*	-0.195**	-0.012	-0.235***
δ_{03}	0.890***	1.139***	1.732***	1.341***	1.597***	0.889***	1.439	1.280***	1.175***
δ_{13}	-0.565	-1.582***	-3.240***	-2.491***	-4.325***	-1.838***	-3.159***	-3.230***	-1.856***
δ_{04}	$2 \cdot 10^{-4}$ ***	$5 \cdot 10^{-5}$	$-2 \cdot 10^{-4}$ **	$-5 \cdot 10^{-5}$	$9 \cdot 10^{-4}$	$-3 \cdot 10^{-4}$	$-1 \cdot 10^{-4}$	$-1 \cdot 10^{-4}$	0.003***
δ_{14}	0.272**	0.299***	0.570***	0.595***	0.591***	0.606***	0.498***	0.609***	0.462***
δ_{05}	0.003***	0.004***	0.004***	0.003***	0.008***	0.001*	0.006***	0.006***	0.004***
δ_{15}	-0.004**	-0.004**	-0.007***	-0.006***	-0.011***	-0.004***	-0.008***	-0.007***	-0.006***
ω	$4 \cdot 10^{-5}$ **	$1 \cdot 10^{-5}$	$4 \cdot 10^{-5}$ **	$4 \cdot 10^{-5}$ **	$3 \cdot 10^{-7}$ ***	$1 \cdot 10^{-5}$ ***	$9 \cdot 10^{-6}$ *	$2 \cdot 10^{-5}$ *	$9 \cdot 10^{-6}$ **
α	0.280***	0.058**	0.220***	0.191***	0.025***	0.185***	0.060***	0.085**	0.104***
β	0.614***	0.911***	0.649***	0.676***	0.975***	0.759***	0.915***	0.883***	0.856***

The table reports the results from estimating the fourth step of the volatility-spillover model for country i 's stock returns (R_{i6t}). $R_{6t} = d_0 + d_1 R_{1,t-1} + d_2 R_{2,t-1} + d_3 R_{3,t-1} + d_4 R_{4,t-1} + d_5 R_{5,t-1} + d_6 R_{6,t-1} + \delta_{1t} e_{1t} + \delta_{2t} e_{2t} + \delta_{3t} e_{3t} + \delta_{4t} e_{4t} + \delta_{5t} e_{5t} + e_{6t}$. $\text{Var}_{t-1}(e_{6t}) = \sigma_{6t}^2 = \omega_6 + \alpha_6 \epsilon_{6,t-1}^2 + \beta_6 \sigma_{6,t-1} + \alpha_6^* \epsilon_{6,t-1}^2 I_{6,t-1}$. The volatility spillover parameters: $\delta_{lt} = \delta_{0l} + \delta_{1l} d_t$ for $l = 1, 2, 3, 4$ where d_t is an indicator function that equals zero before the euro and unity after. Based on Bollerslev and Wooldridge (1992) robust standard errors, */**/** indicates that the parameter is significant at the 10%/5%/1% level of significance.

Table 4: Model Estimates: Country i 's Stock Returns

– Bonds –					
Pre euro					
	$\bar{V}R_1$	$\bar{V}R_2$	$\bar{V}R_3$	$\bar{V}R_4$	$\bar{V}R_5$
	US-bond	US-stock	Eu-bond	Eu-stock	Own-bond
Be	0.166	0.124	0.392	0.0006	0.317
De	0.130	0.156	0.407	0.0001	0.307
Fr	0.189	0.146	0.419	0.0004	0.245
Ge	0.189	0.124	0.418	0.0003	0.269
It	0.059	0.090	0.281	0.0004	0.569
Ne	0.195	0.122	0.443	0.0005	0.239
Sp	0.126	0.047	0.273	0.0006	0.554
Sw	0.120	0.088	0.279	0.0001	0.512
UK	0.148	0.148	0.364	0.00006	0.341

Post euro					
	$\bar{V}R_1$	$\bar{V}R_2$	$\bar{V}R_3$	$\bar{V}R_4$	$\bar{V}R_5$
	US-bond	US-stock	Eu-bond	Eu-stock	Own-bond
Be	0.432	0.001	0.471	0.0002	0.095
De	0.399	0.011	0.402	0.0005	0.188
Fr	0.416	0.001	0.487	0.0002	0.096
Ge	0.426	0.002	0.487	0.000008	0.085
It	0.425	0.000005	0.480	0.0003	0.095
Ne	0.415	0.001	0.495	0.0001	0.089
Sp	0.430	0.001	0.478	0.00005	0.090
Sw	0.363	0.005	0.331	0.0003	0.300
UK	0.342	0.003	0.352	0.0006	0.302

– Stocks –						
Pre euro						
	$\bar{V}R^*_1$	$\bar{V}R^*_2$	$\bar{V}R^*_3$	$\bar{V}R^*_4$	$\bar{V}R^*_5$	$\bar{V}R^*_6$
	US-bond	US-stock	Eu-bond	Eu-stock	Own-bond	Own-stock
Be	0.032	0.257	0.061	0.0002	0.0000002	0.649
De	0.050	0.170	0.077	0.000007	0.0000005	0.703
Fr	0.037	0.383	0.126	0.00007	0.0000002	0.453
Ge	0.024	0.365	0.095	0.000006	0.0000001	0.516
It	0.030	0.156	0.068	0.0009	0.000002	0.745
Ne	0.028	0.397	0.064	0.0003	0.00000002	0.510
Sp	0.045	0.300	0.113	0.0001	0.000002	0.542
Sw	0.020	0.346	0.052	0.00002	0.000002	0.583
UK	0.028	0.411	0.093	0.0002	0.000002	0.468

Post euro						
	$\bar{V}R^*_1$	$\bar{V}R^*_2$	$\bar{V}R^*_3$	$\bar{V}R^*_4$	$\bar{V}R^*_5$	$\bar{V}R^*_6$
	US-bond	US-stock	Eu-bond	Eu-stock	Own-bond	Own-stock
Be	0.018	0.231	0.003	0.055	0.00000001	0.693
De	0.032	0.223	0.004	0.059	0.00000001	0.682
Fr	0.034	0.385	0.041	0.160	0.00000004	0.380
Ge	0.043	0.430	0.021	0.153	0.00000003	0.353
It	0.039	0.240	0.094	0.146	0.00000002	0.480
Ne	0.047	0.319	0.019	0.204	0.00000003	0.411
Sp	0.048	0.290	0.056	0.127	0.00000001	0.450
Sw	0.040	0.398	0.039	0.103	0.00000001	0.420
UK	0.024	0.338	0.014	0.169	0.00000001	0.456

The table reports the average variance ratios based on the parameter estimates in Tables 2-4. For the bond markets the following average variance ratios applicable before and after the euro are reported: US bond effects ($\bar{V}R_1$), US stock effects ($\bar{V}R_2$), European bond effects ($\bar{V}R_3$), European stock effects ($\bar{V}R_4$), and own bond effects ($\bar{V}R_5$). For the stock markets the following variance ratios applicable before and after the euro are reported: US bond effects ($\bar{V}R^*_1$), US stock effects ($\bar{V}R^*_2$), European bond effects ($\bar{V}R^*_3$), European stock effects ($\bar{V}R^*_4$), own bond effects ($\bar{V}R^*_5$), and own stock effects ($\bar{V}R^*_6$).

Table 5: Variance Ratios

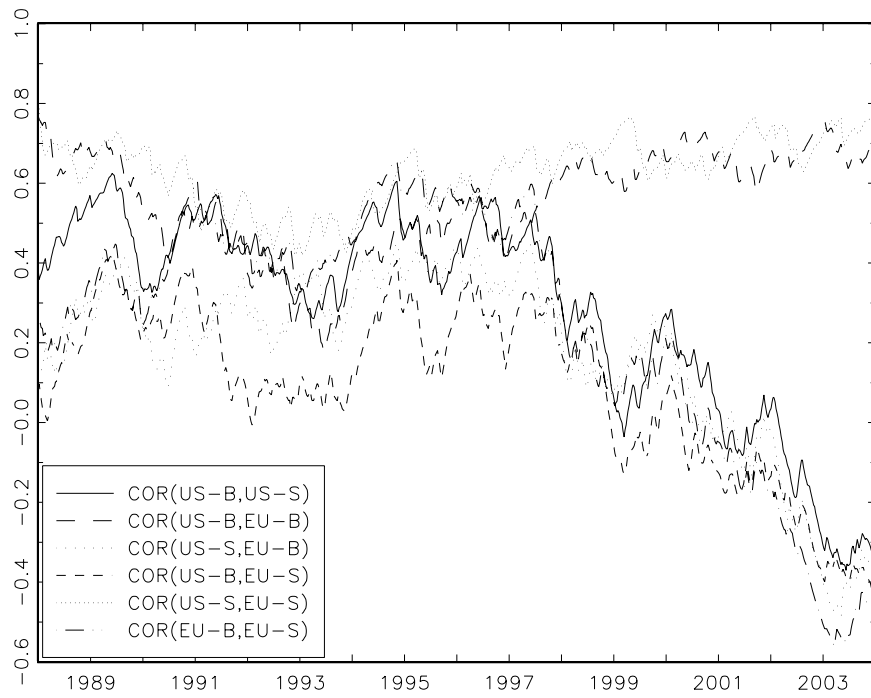


Figure 1: DCC Correlations

The figure shows the estimated time series of the conditional correlations between US and European bonds and stocks. The following abbreviations are applied. US-B: US bonds, US-S: US stocks, EU-B: European bonds, and EU-S: European stocks.

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