The Euro and European Financial Market Dependence

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Abstract

A time-varying copula model is used to investigate the impact of the introduction of the Euro on the dependence between seventeen European stock markets during the period 1994-2003. The model is implemented with a GJR-GARCH-MA-*t* model for the marginal distributions and the Gaussian copula for the joint distribution, which allows capturing time-varying, non-linear relationships. The results show that, within the Euro area, market dependence increased after the introduction of the common currency only for large equity markets, such as in France, Germany, Italy, the Netherlands and Spain. Structural break tests indicate that the increase in financial market dependence started around the beginning of 1998 when Euro membership was determined and the relevant information was announced. The UK and Sweden, but not other European countries outside the Euro area, are found to exhibit an increase in equity market co-movement, which is consistent with the interpretation that these countries may be expected to join the Euro in the future.

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The Euro and European Financial Market Dependence

Abstract

A time-varying copula model is used to investigate the impact of the introduction of the Euro on the dependence between seventeen European stock markets during the period 1994-2003. The model is implemented with a GJR-GARCH-MA-*t* model for the marginal distributions and the Gaussian copula for the joint distribution, which allows capturing time-varying, non-linear relationships. The results show that, within the Euro area, market dependence increased after the introduction of the common currency only for large equity markets, such as in France, Germany, Italy, the Netherlands and Spain. Structural break tests indicate that the increase in financial market dependence started around the beginning of 1998 when Euro membership was determined and the relevant information was announced. The UK and Sweden, but not other European countries outside the Euro area, are found to exhibit an increase in equity market co-movement, which is consistent with the interpretation that these countries may be expected to join the Euro in the future.

1 Introduction

The introduction of the Euro has been one of the most important events for global financial markets in the last decade. Detken and Hartmann (2000, 2002) and Perée and Steinherr (2001) show that the Euro has become one of the three major currencies in the world after its introduction, taking its place alongside the U.S. dollar and the Japanese yen. An immediate consequence of the adoption of the common currency has been the convergence of Euro-zone interest rates and the integration of fixed-income markets (Adjaouté and Danthine, 2003; Hartmann et al., 2003). Another important dimension of the elimination of exchange rate risk across countries within the Euro area, as a result of the adoption of a single currency, is its effect on the dependence or co-movement of equity markets within the Euro area. The impact of the introduction of the Euro on the dependence of equity markets within Europe is an important issue with significant implications for portfolio diversification and thus asset management, risk management and international asset pricing.

To assess this impact of the Euro, this paper provides a comprehensive analysis of the financial market co-movement of 17 European countries during the period 1994-2003 using a new econometric methodology.[1] In particular, we directly assess financial market dependence or co-movement across countries by estimating time-varying copula dependence models for stock market indices following the methodology of Patton (2006a). As shown by Patton and explained in more detail in Section 3, copulas offer significant advantages over other econometric techniques in analyzing the co-movement of financial time-series, consisting in the fact that they can model

[1] Previous work has studied market dependence and integration based on international capital mobility (Feldstein and Horioka, 1980; Frankel and MacArthur, 1988; Frankel, 1992; Lemmen and Eijffinger, 1998), asset pricing models (Ferson and Harvey, 1991; Bekaert and Harvey, 1995; Dumas and Solnik, 1995; Hardouvelis et al., 2001; Bekaert et al., 2002; Bekaert et al., 2005) or price and volatility spillovers or transmission (Eun and Shim, 1989; Kasa, 1992; Koutmos and Booth, 1995; Richards, 1995; Booth et al., 1997; Baele, 2005). Cappiello et al. (2004) and Bekaert et al. (2005) also look at the development of correlation coefficients over time.

dependence beyond linear correlation and provide a high degree of flexibility. In particular, marginal distributions and the joint distribution can be considered separately, while traditionally, either the marginals or the joint distribution are arbitrarily specified as normal distributions. Consequently, copulas have recently become increasingly popular in various finance applications, such as modeling default correlations for credit risk management (Li, 2000), modeling portfolio allocations (Hennessy and Lapan, 2002), pricing foreign exchange rate quanto options (Bennett and Kennedy, 2003), pricing multivariate contingent claims (Rosenberg, 2003), and modeling time-varying dependence (Patton, 2006a,b).

Our paper contributes to the literature by proposing a more direct and general copula model for modeling time-varying dependence between the prices of financial assets. Specifically, the model uses a GJR-GARCH-MA-*t* specification for the marginal distributions and the Gaussian copula for the joint distribution. The dependence parameter in the copula function is modeled as a time-varying process conditional on currently available information, allowing for time-varying, non-linear relationships. The proposed methodology can be extended to a multivariate model, which is useful for portfolio and risk management. We successfully apply our time-varying copula model to the investigation of whether the introduction of the Euro was associated with a structural increase in the level of dependence between the equity markets in the Euro area. We find an increase in equity market dependence in the Euro area after the introduction of the common currency, but only for relatively large markets, i.e. in France, Germany, Italy, the Netherlands and Spain. The increase in equity market dependence starts around the beginning of 1998, when Euro membership was determined and the relevant information was released.[2]

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[2] Our results are consistent with related work that, while not based on statistical tests of structural changes, also provides some support for increased correlation among major European stock markets using Vector Autoregression, Constant and Dynamic Conditional Correlation and EGARCH analyses (Billio and Pelizzon, 2003; Melle, 2003; Cappiello et al., 2004; Savva et al., 2004; Berben and Jansen, 2005; Friedman and Shachmurove, 2005).

Consistent with Bekaert et al. (2005) and Goetzmann et al. (2005), who document a positive causality from market integration to market dependence, a likely source of the observed increase in equity market dependence around 1998 consists of the higher degree of integration between European financial markets and economies, although even without foreign exchange rate risk several remaining capital market imperfections, such as regulation, taxes, and transaction costs still prevent full integration. In particular, higher transaction costs and lower market liquidity are the main reasons that render smaller equity markets less attractive to institutional investors and thus represent important barriers to investment in and thus stronger co-movement of these markets. For non-Euro European countries, we find a rise in the dependence of the British and Swedish equity markets with the aggregate Euro-zone stock market, which is consistent with the interpretation that these countries may be expected to join the Euro in the future.

The remainder of this paper is organized as follows. Section 2 discusses integration and dependence of financial markets in general and in the context of the Euro in particular, and it develops the hypotheses about the impact of the Euro on financial market dependence. Section 3 presents time-varying copula methodology in general, while Section 4 explains the implementation of the models used to test the hypotheses. The data used for the empirical analysis is presented in Section 5. Section 6 presents the empirical analysis and discusses the results. Finally, conclusions are stated in Section 7.

2 Integration and Dependence of European Financial Markets

The integration and dependence of financial markets has long been an issue of interest to financial economists in academia and investment practice alike, as it has consequences for the identification of opportunities for and barriers to international portfolio investment with important implications for portfolio allocation and asset pricing (Bartram and Dufey, 2001). In Europe, the harmonization of regulation and social welfare systems, most recently with the focus on pension arrangements, has been promoted as an important vehicle to reduce market frictions and barriers to cross-border mobility of all factors of production. In this context, the introduction of the Euro has been a milestone step, triggering heated and in part controversial debate of whether the launch of the common currency represents a sensible tool to force more integration in Europe, or whether, indeed, it would require a higher degree of harmonization prior to the event in order to ensure its success. In fact, the global economic downturn that coincided with the introduction of the Euro has emphasized the existing differences across European countries, and the lack of policy responses has contributed to slow economic growth in major economies (such as Germany and France) and Europe as a whole, culminating in violations of the Growth and Stability Pact.

In theory, if financial markets are not integrated, entailing differential investment and consumption opportunity sets across countries, investment barriers will affect investors' portfolio choices and companies' financing decisions. If purchasing power parity does not hold, exchange rates affect the cost of consumption across countries, and, thus, exchange rate risk influences the price of assets to foreign investors. International asset pricing models recognize these effects by including exchange rate risk as a systematic risk factor (e.g. Solnik, 1974; Stulz, 1981; Adler and Dumas, 1983) and can, thus, be used to empirically investigate the issue of financial market integration (Dumas and Solnik, 1995). In the same vein, the effect of the Economic and Monetary Union (EMU) on European stock market integration can be examined with a weighted average asset pricing model that includes the covariance between stock returns and exchange rate returns, suggesting that the forward interest differential between a country and Germany has played an important role for the degree of integration (Hardouvelis et al., 2001).

As the introduction of the Euro means the elimination of exchange rate risk within the Euro area, it has further reduced the remaining differences of investment and consumption opportunities across the member countries of the Euro. As a result, there should be less regional preferences or discrimination between different national markets by investors given the risk and return characteristics of assets. Likewise, the absence of exchange rate risk allows corporations to raise funds across countries with fewer constraints and costs. In addition, the prices of assets in European markets are determined to a larger degree by common factors due to the reduction of exchange rate risk, so that country stock market returns should be more proportionally explained by their covariances with the regional stock market returns (Bekaert and Harvey, 1995; Bekaert et al., 2002; Baele, 2005; Bekaert et al., 2005).

Consequently, common factor risks in the form of market betas have moved in a similar direction for many stocks after the introduction of the Euro (Bartram and Karolyi, 2003), and the reduction and elimination of exchange rate volatility has been identified as a main driver of the integration of equity markets among EMU members (Fratzscher, 2002). At the same time, significant increases in trade between Euro countries as well as trade with outside countries have been observed after the introduction of the Euro, indicating stronger integration of the real sector (e.g. Barr et al., 2003; Micco et al., 2003). Since capital market integration and increased trade embed a prediction about the dependence between markets (Bekaert et al., 2005; Goetzmann et al., 2005), we conjecture that the degree of dependence between the equity markets of the countries in the Euro area has increased after the launch of the common currency.[3] Given that expectations about Euro membership were already formed before its determination, it is likely that an increase in the

[3] Previous work on model-endogenous, time-varying dependence employs either linear correlation coefficients in multivariate GARCH models (Bollerslev et al., 1988; Engle and Kroner, 1995; Alexander, 2001; Engle, 2002; Cappiello et al., 2004) or non-linear Kendall's tau or Spearman's rho in copula-based models (Rockinger and Jondeau, 2002; Rodriguez, 2003; Patton, 2006a,b). Few studies have applied these methods to analyze the development of market dependence for the last decade in Europe and most of them support increased dependence among major European stock markets (Billio and Pelizzon, 2003; Melle, 2003; Cappiello et al., 2004; Savva et al., 2004; Berben and Jansen, 2005; Patton, 2006b). However, our paper performs, for the first time, a truly comprehensive investigation of the impact of the introduction of the Euro, covering all member countries and dating the initiation of the effect.

dependence between Euro country equity markets can be observed in the years prior to January 1, 1999, if capital markets reflect all available information efficiently.[4]

Even without exchange rate risk, however, many differences between national markets for labor and capital in the Euro area currently remain, based on regulation, language, familiarity, transaction costs, etc.[5] In particular, estimates by Elkins McSherry indicate that after the introduction of the Euro trading costs, as measured by average market impact and total costs, in larger European equity markets are still significantly lower than in smaller Euro area markets. These significant differences in transaction costs across European equity markets suggest differential barriers to investment and integration of financial markets within the Euro area. As a result, we hypothesize a stronger increase in dependence between countries with large market capitalization, which may proxy for the remaining disparities between national markets in the Euro area.

For non-Euro European countries, especially the UK, Sweden and Denmark, which require a referendum for joining the Euro, it is interesting to investigate whether market participants believe that these countries are likely to adopt the Euro or not. If market participants expect that they will join the common European currency in the future, we conjecture that one should observe an increase in their market dependence with the Euro-zone equity market. Although increasing dependence is not a sufficient criterion to conclude that these countries will definitely join the Euro, it does reveal information about the expectations of market participants.

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[4] To illustrate, Danthine et al. (2001) document that there was already a consensus about Euro membership among financial and economic forecasters in January 1998.

[5] In addition to foreign exchange rate risk, other barriers to international portfolio investment (including taxes on foreign security holdings and ownership restrictions) are crucial factors that prevent market integration. Consequently, in partially integrated economies, investors' portfolios may be biased towards home assets because the benefits of international diversification are not large enough to offset its costs (Errunza and Losq, 1985; Eun and Janakiramanan, 1986; Cooper and Kaplanis, 2000). Still, the launch of the common European currency was clearly associated with reduced exchange rate volatility and convergence of interest rates, lower cost of cross-country transactions, improved liquidity, breadth and depth of European capital markets, which have been noted as important drivers of integration in the Euro area (Danthine et al., 2001; Fratzscher, 2002).

3 Time-varying Copula Dependence Theory

3.1 Conditional Copulas

Copula functions permit flexible modeling of the dependence between random variables, by enabling the construction of multivariate densities that are consistent with the univariate marginal densities. They therefore allow separation of the marginal distributions from the dependence structure that is entirely represented by the copula function. This separation enables researchers to construct multivariate distribution functions, starting from given marginal distributions, that avoid the common assumption of normality, for either the marginal distributions or their joint distribution function.

In this paper, we employ single-parameter conditional copulas to represent the dependence between two index returns, conditional upon the historical information provided by previous pairs of index returns. The parameter of the conditional copula, like the marginal densities of the separate index returns, depends upon the conditioning information. The general theory of copulas is covered in the books by Joe (1997) and Nelsen (1999) and finance applications are emphasized by Cherubini, Luciano and Vecchiato (2004). Important conditional theory has been developed and applied to financial market data by Patton (2006a, b).

Let X_t and Y_t be random variables that represent two returns for period t and let their conditional cumulative distribution functions (c.d.f.s) be $F_t(x_t|\Phi_{t-1})$ and $G_t(y_t|\Phi_{t-1})$ respectively, with Φ_{t-1} denoting all previous returns, i.e. $\{x_{t-i}, y_{t-i}, i>0\}$. Define two further random variables by $U_t = F_t(X_t|\Phi_{t-1})$ and $V_t = G_t(Y_t|\Phi_{t-1})$, whose marginal distributions are uniform on the interval from zero to one. Then the conditional, copula density function, denoted by $c_t(u_t, v_t|\Phi_{t-1})$, is defined by the time-varying, bivariate density function of U_t and V_t. Also, the conditional, bivariate density function of X_t and Y_t is given by the product of their copula density and their two marginal conditional densities, respectively denoted by f_t and g_t:

$$h_t(x_t, y_t \mid \Phi_{t-1}) = c_t(F_t(x_t \mid \Phi_{t-1}), G_t(y_t \mid \Phi_{t-1}) \mid \Phi_{t-1}) f_t(x_t \mid \Phi_{t-1}) g_t(y_t \mid \Phi_{t-1}). \quad (1)$$

3.2 Estimation of Parameters

The bivariate dynamics of the returns X_t and Y_t are determined by the three functions $f_t(x_t \mid \Phi_{t-1})$, $g_t(y_t \mid \Phi_{t-1})$ and $c_t(u_t, v_t \mid \Phi_{t-1})$. Parameter estimation is straightforward when separate parameters are used in the functions f_t, g_t and c_t, which we denote respectively by the vectors θ_x, θ_y and θ_c. The contribution to the log-likelihood of all the data made by the two observations at time *t* is then

$$\log h_t(x_t, y_t \middle| \Phi_{t-1}, \theta) = \log c_t(u_t, v_t \middle| \Phi_{t-1}, \theta_c) + \log f_t(x_t \middle| \Phi_{t-1}, \theta_x) + \log g_t(y_t \middle| \Phi_{t-1}, \theta_y), \quad (2)$$

with $\theta = [\theta_x; \theta_y; \theta_c]$. Summing these contributions across a set of times gives the log-likelihood of an observed time series of *n* pairs of returns $\{x_t, y_\mathrm{t}, 1 \le t \le n\}$, which can be stated as

$$L_{x,y}(\theta) = L_{u,v}(\theta_c) + L_x(\theta_x) + L_y(\theta_y) \quad (3)$$

with L_k denoting the sum of the log-likelihood function values across observations of the variable(s) *k*.

While it would be optimal to maximize $L_{x,y}(\theta)$, simultaneously for all the parameters, this is difficult to achieve in practice because the dimensions of the problem can be large. Drawing on the two-stage maximum likelihood framework of Newey and McFadden (1994) and White (1994), Patton (2006a) proposes a two-stage estimation procedure that is appropriate for large samples when the dependence vector θ_c does not have any impact upon the marginal distributions.

In the first stage, the parameters of the marginal distributions parameters are estimated from univariate time series as:

$$\hat{\theta}_x \equiv \arg\max \sum_{t=1}^{n} \log f_t(x_t | \Phi_{t-1}, \theta_x),$$
$$\hat{\theta}_y \equiv \arg\max \sum_{t=1}^{n} \log g_t(y_t | \Phi_{t-1}, \theta_y). \tag{4}$$

The second stage then estimates the dependence parameter(s) as:

$$\hat{\theta}_c \equiv \arg\max \sum_{t=1}^{n} \log c_t(u_t, v_t | \Phi_{t-1}, \theta_c, \hat{\theta}_x, \hat{\theta}_y). \tag{5}$$

Patton (2006a) shows that the two-stage ML estimates $\hat{\theta} = [\hat{\theta}_x ; \hat{\theta}_y ; \hat{\theta}_c]$ are asymptotically as efficient as one-stage ML estimates. The variance-covariance matrix of $\hat{\theta}$ has to be obtained from numerical derivatives. We have only been able to obtain satisfactory first derivatives, from which the fully efficient two-stage estimator $(n\hat{B})^{-1}$ of the variance-covariance matrix is given by

$$\hat{B} = n^{-1} \sum_{t=1}^{n} \hat{s}_t \hat{s}_t{}',$$

where the score vector $\hat{s}_t = \partial \log h_t / \partial \theta$ is evaluated at $\theta = \hat{\theta}$.

4 Empirical Methodology

4.1 Models for Marginal Distributions

The conditional densities of equity index returns are leptokurtic and have variances that are asymmetric functions of previous returns (Nelson, 1991; Engle and Ng, 1993; Glosten et al, 1993). Consequently, we obtain our marginal distributions by fitting appropriate ARCH models that have conditional Student's *t*-distributions.

Let $R_{i,t}$ and $h_{i,t}$ respectively denote the return from equity index i and its conditional variance for period t. The ARCH model for the returns from index i is defined by:

$$\begin{aligned} R_{i,t} &= \mu_i + \varepsilon_{i,t} + \Theta_i \varepsilon_{i,t-1}, \\ h_{i,t} &= \omega_i + \beta_i h_{i,t-1} + \alpha_{i,1}\varepsilon_{i,t-1}^2 + \alpha_{i,2} s_{i,t-1}\varepsilon_{i,t-1}^2, \\ \varepsilon_{i,t} \mid \Phi_{t-1} &\sim t_{\nu_i}(0, h_{i,t}), \end{aligned} \tag{6}$$

with $s_{i,t-1} = 1$ when $\varepsilon_{i,t-1}$ is negative and otherwise $s_{i,t-1} = 0$. In the first stage of parameter estimation, all of the parameters, including the degrees of freedom ν_i, are estimated separately for each equity index by maximizing the log-likelihood for each time series of index returns.

4.2 Models for Bivariate Distributions

The estimated marginal ARCH c.d.f.s provide numerical values of $u_t = F_t(R_{x,t} \mid \Phi_{t-1})$ and $v_t = G_t(R_{y,t} \mid \Phi_{t-1})$. These values are used to estimate a time-varying copula dependence parameter ρ_t that is a conditional quantity determined by Φ_{t-1} and the parameter vector θ_c. We first describe the conditional copula density function $c_t(u_t, v_t \mid \rho_t)$, which only depends on the single parameter ρ_t.

The cited textbooks describe a variety of copula density functions that have different mathematical properties. Malevergne and Sornette (2003) demonstrate that returns from most pairs of major stock indices are compatible with the Gaussian copula. Accordingly, we employ the conditional Gaussian copula.[6]

[6] Estimates have also been obtained for the Clayton copula, suggested by a referee, but the log-likelihoods obtained are usually much lower than for the Gaussian copula.

The Gaussian copula density function is the density of (u_t, v_t) when the variables (x_t, y_t) are bivariate Gaussian with correlation ρ_t between x_t and y_t. With $\psi(.)$ the c.d.f. of the standard normal distribution, $a_t = \psi^{-1}(u_t)$ and $b_t = \psi^{-1}(v_t)$, the Gaussian copula density is:

$$c_t\,(u_t, v_t \mid \rho_t) = \frac{1}{\sqrt{1-\rho_t^2}} \exp\left\{ -\frac{1}{2(1-\rho_t^2)}[a_t^2 + b_t^2 - 2\rho_t a_t b_t] + \frac{1}{2}[a_t^2 + b_t^2] \right\}. \qquad (7)$$

4.3 The Specification for the Dependence Parameter

Conditional copulas typically contain a time-varying dependence parameter, such as ρ_t in the equation above. A few studies have already investigated how to model this time-varying process, including Rodriguez (2003), Jondeau and Rockinger (2005) and Patton (2006a, b). Based on the observation that high correlation is associated with high volatility, Rodriguez (2003) uses a mixed copula. He lets the weights and the marginal distributions follow two-state switching processes. Jondeau and Rockinger (2005) assume that dependence is either a function of its historical values or a deterministic function of time. Patton (2006a) proposes that the current dependence is explained by the previous dependence and the historical average difference of cumulative probabilities for the two assets. A common issue in these studies is an arbitrary choice of the number of regimes or lagged periods.

We follow Patton (2006a) and suppose that ρ_t depends on the previous dependence ρ_{t-1}, to capture persistence, and historical absolute differences, $|u_{t-i} - v_{t-i}|$, $i > 0$, to capture variation in the dependence process. We estimate the following dependence process:

$$(1-\beta_1 L)(1-\beta_2 L)\rho_t = \omega + \gamma |u_{t-1} - v_{t-1}|. \qquad (8)$$

The intuition for the use of $|u_{t-1} - v_{t-1}|$ is that the smaller (larger) the difference between the realized cumulative probabilities, the higher (lower) is the dependence.[7] Equation (8) describes an AR(2) model when extra assumptions are made, namely that a linear function of the previous absolute difference, $|u_{t-1} - v_{t-1}|$, provides a white noise innovation term.

The copula parameter vector is $\theta_c = (\beta_1, \beta_2, \omega, \gamma)'$, which is estimated in the second stage by maximizing the sum of terms $\log c_t(u_t, v_t | \Phi_{t-1}, \theta_c, \hat{\theta}_x, \hat{\theta}_y)$. We apply the constraints $0 \le \beta_2 \le \beta_1 \le 1$. As (8) does not guarantee $|\rho_t| < 1$, we set the maximum and the minimum of ρ_t in the estimation software as 0.9999 and –0.9999, respectively. However, the upper bound is rarely touched in the empirical implementation and the lower bound is never required.

5 Data and Summary Statistics

The empirical investigation is conducted for twelve Euro-zone countries (France, Germany, Italy, the Netherlands, Spain, Finland, Belgium, Greece, Ireland, Portugal, Austria and Luxembourg) and five non-Euro European countries (U.K., Switzerland, Sweden, Denmark and Norway). For each country, we obtain ten years of daily values of the stock market index from Datastream. The sample period is from January 1, 1994 to October 31, 2003 and excludes holidays. We also use a Euro-zone stock market index from Datastream for the tests of the dependence between the Euro-zone stock market and the equity market in the non-Euro countries. All the indices exclude foreign (cross-listed) stocks and are denominated in U.S. dollars, but we also study results for local currency returns in order to investigate the effect of different numeraires.

For every Euro-zone country, we calculate a modified Euro-zone stock market index by excluding the equities of that country from the Euro-zone index. This is done in order to avoid

[7] A logical alternative to the term $|u_{t-1} - v_{t-1}|$ in (8) is the "sample covariance" $(u_{t-1} - 0.5)(v_{t-1} - 0.5)$. We have obtained similar empirical results from this alternative specification.

mechanical relationships created by overlaps between the country indices and the Euro-zone regional index.[8]

In order to avoid interpreting global trends as regional trends, we also investigate the time-varying dependence of European equity markets with a U.S. stock market index. As shown in Martens and Poon (2001), it is essential to have time-synchronized prices when studying equity market co-movements. Therefore, we use values of the S&P500 index at 16:00 London time recorded by Datastream to represent the U.S. stock market index.[9]

The summary statistics of the returns, defined by changes in the logarithms of these indices, are shown in Table 1. As anticipated from previous research, most of the series of returns are negatively skewed, leptokurtic and do not have a high first-lag autocorrelation coefficient (independent of the currency denomination). Nevertheless, there are minor differences in skewness and kurtosis between the returns in U.S. dollars and in local currency, which may imply that the numeraire could matter in the analysis of inter-market dependence.

6 Empirical Results

Modelling dependence by conditional copula densities first requires appropriate specifications for the marginal densities. We use the diagnostic test of Berkowitz (2001) to evaluate the goodness-of-fit of our marginal return densities, specified by the GJR-GARCH-MA-*t* model given by (6). The residual series pass the goodness-of-fit test at the 10% level for all 17 European countries indices, the S&P500 index and the Euro-zone index.

[8] The definition of the modified Euro-zone index $MPI_{i,t}$ for country i in period t is given by

$$MPI_{i,t} = MPI_{i,t-1}[(\sum_{j\neq i} MV_{j,t} \cdot PI_{j,t})/(\sum_{j\neq i} MV_{j,t} \cdot PI_{j,t-1})]$$

where MV is the market value of stocks in the country and PI is the country price index expressed in dollars.

[9] The S&P500 is the only time-synchronized U.S. index available.

6.1 The Euro-zone Equity Markets

Table 2 shows the estimates of the copula dependence model for the twelve Euro-zone countries. The time-varying dependence model is estimated for each country index and the Euro-zone stock market index excluding the examined country. For the purpose of comparison, we also include each country's dependence with the synchronized S&P500 index. All the indices are converted to the same numeraire, namely U.S. dollars. Across all countries and indices, β_1 is always larger than 0.9 and even as high as 0.99 in some cases, which indicates high dependence persistence. The other autoregressive parameter, β_2, is much smaller than β_1 and it is rarely significantly different from zero. As expected, the parameter γ is always negative; it is also highly significant, indicating that the latest absolute difference of returns is consistently a relevant measure when modeling market dependence. Overall, the copula log-likelihood function of specifications with the Euro-zone regional index is higher than that with the S&P500 index.

Figure 1 shows the time-varying conditional dependence, ρ_t, for the parameter estimates listed in Table 2. Overall, the level of dependence within the Euro-zone market is higher than the association of the Euro national markets with the U.S. market. The dependence of the indices of France, Germany, Italy, the Netherlands and Spain with the Euro-zone regional index exhibits an increase during our sample period, while the dependence for Finland, Belgium, Greece and Portugal does not display a regime shift, and that for Ireland, Austria and Luxembourg has actually decreased. Interestingly, some countries, especially Finland, have experienced a higher degree of dependence with the U.S. market.

To test whether there are regime changes in the process generating the conditional correlations, that are statistically significant, and to determine the timing of any such regime shifts, we evaluate five ways to add a regime term λD_t into the conditional dependence process (8). Specifically, the dummy variables D are equal to 0 before the first day of one of 1996, 1997, 1998, 1999 and 2000, otherwise they are equal to 1. *T*-tests and likelihood-ratio tests are employed to assess the significance of these dummy variables. The results indicate that France, Germany, Italy, the Netherlands and Spain have experienced an increase in their dependence with the equity markets of other Euro-zone countries, which most probably started in late 1997 or early 1998 when the membership of the EMU was determined and the relevant information was announced.[10]

To verify that this phenomenon is unique for the Euro area, we also implement tests that include the same dummy variables in the dependence process (8) for all Euro-zone stock market indices with the S&P500 index. The results indicate that although the dependence for some indices increases during our sample period, the timing is not consistent across countries and does not match the timing of the introduction of the Euro.

Importantly, the findings for changes of dependence with the U.S. market also suggest that the introduction of the Euro is the economic driver of higher market dependence within the Euro area, as opposed to other events that happened at other points in time during the sample period, such as the Asian crisis or the burst of the internet bubble. Note, also, that higher volatility caused by these events does not necessarily entail higher correlation (Bartram and Wang, 2005; Longin and Solnik, 2001)[11]. This is also confirmed by unreported results documenting that, in contrast to market dependence, volatility increased significantly in almost all markets, including small ones, in 1997 and/or 1998. Similarly, while different economies follow different economic/business cycles, there is no obvious link between business cycles and market dependence.

The empirical results largely confirm the hypothesis that only some Euro-zone countries, specifically France, Germany, Italy, the Netherlands and Spain, experienced a rise in their de-

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[10] All statistical results for the alternative dummy specifications and tests are available upon request.

[11] In particular, Longin and Solnik (2001) use extreme value theory to derive the distribution of extreme returns and find that correlation is not related to market volatility per se.

pendence with the other Euro-zone countries.[12] Although some of these countries also exhibit an increasing co-movement with the U.S. market, for most countries the relative degree of the increase is higher for the dependence with the other Euro-zone countries.

Nonetheless, there is no evidence of increases in financial market dependence for the remaining Euro-zone countries. We deduce that other significant barriers still play a crucial role for the lower co-movement of smaller markets. As stated earlier (Section 2), significant differences in transactions costs remain after the introduction of the Euro even across Euro-zone equity markets. The correlation coefficient between market capitalization and total transaction costs (market impact) is about –0.64 (–0.49) for the period 1998-99, which, in line with our findings, indicates that transaction costs and market liquidity are likely to remain the main concern of institutional investors regarding investment in smaller Euro-zone markets.[13] To this end, we estimate a logit model where the left hand side variable indicates whether the stock market in a country shows a significant increase in dependence with the Euro-zone market. After controlling for other country effects such as GDP per capita, legal environment and Euro membership, variables proxying for transactions cost, especially market impact, show a significant negative relationship to the likelihood of increased market dependence. Consequently, country factors may still determine the degree of regional integration and financial market co-movement (Guiso et al., 2003), as institutional investors focus on large European equity markets with low transactions cost and high liquidity.

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[12] Instead of investigating the dependence with the regional stock index, Westermann (2004) uses a GARCH-M framework to analyze the co-movement between France, Germany, Italy and US stock market indices and shows that price changes have less impact on other markets on the following day after the introduction of the euro. Then, he uses a feedback trading strategy to interpret this as evidence of more integration.

[13] Because the data frequencies of transaction costs and stock market returns are different, transaction costs are not modeled directly in the dependence dynamics of our model.

6.2 Non-Euro European Equity Markets

In order to investigate whether equity market dynamics say anything about beliefs that non-Euro European countries will adopt the Euro, we model the time-varying conditional dependence between the equity indices of these countries and the Euro-zone regional stock market index. For comparison, we provide estimates for these national indices with the S&P500 index as well. All indices are denominated in U.S. dollars. As shown in Table 3, the basic properties of the estimated parameters are the same as in Table 2. Figure 2 displays the estimated dependence with the Euro-zone regional index and with the S&P500 index. Although there is no obvious regime change compared to Euro countries, it appears that the U.K. and Sweden also experienced a slight increase in their dependence with the Euro-zone market, while there is no structural change in co-movement with the U.S. market. On the other hand, Switzerland, Denmark and Norway do not exhibit a clear regime shift, neither with the Euro-zone market nor with the U.S. market.[14]

The U.K. and Sweden are potential candidates for introducing the Euro. Nevertheless, while we find increased dependence of their stock market indices with the Euro-zone stock market index, the evidence is not sufficiently strong and thus the future development of the dependence in all financial markets still needs to be studied further before firm conclusions can be drawn. We leave these issues for future research. At present, what we can suggest is that the co-movement of the British and Swedish stock markets with the Euro-zone equity market has increased in the second half of the 1990s even though they are not part of the currency union, which

[14] We also run the dummy-variable tests as before. For the dependence with the Euro area, the dummy variable for the UK is significant for a regime change in 1999 or 2000, while the dummy variable for Sweden is significant for 1996 or 1997. However, there is no significant dependence increase for the remaining non-Euro countries. For the dependence with the S&P500 index, an increased dependence for both the Swedish and U.K. index is found early in the sample period. This does not match the introduction of the Euro and might rather be the result of the high-tech boom or the emergent globalization of financial markets during the 1990s.

may reflect the expectations of market participants’ about the adoption of the Euro in these countries in the future.

6.3 Robustness Tests

When investigating the consequence of the Euro introduction on market dependence in the above analysis, the perspective of the same investor is adopted and, thus, all of the indices are denominated in U.S. dollars. In order to investigate the sensitivity of the results to different base currencies, we discuss the influence of the numeraire by changing the currency of reference. To this end, we first repeat the estimations by using the Euro (EUR) as the common measure to assess the dependence between the Euro-zone regional index and the Euro-zone national stock market indices and compare the fitted dependence processes with the results using the indices in U.S. dollars. A typical result, shown in Figure 3, indicates that there is little difference between these two dependence processes, since the average level, the patterns and the development over time of the correlations are very similar, which may imply that the choice of numeraire does not matter as long as the same currency is chosen for a pair of markets.

Next, we repeat the estimations by using the individual local currency for the non-Euro equity indices, but keeping the Euro-zone stock index in U.S. dollars. We compare the fitted dependence processes for these national indices in their local currencies and in dollars and show a typical result in Figure 4. The gap between these two processes becomes larger than that using the same currency for a pair of indices (e.g. Figure 3) and the magnitude of the gap varies across countries. We suggest that this result is due to the different local currencies and the gap size may depend on the development of the exchange rate. However, for the purposes of this study, the numeraire has no effect on the conclusions.

Another potential concern is that we use price indices in our empirical implementations, rather than total return indices, and thus neglect the effect of dividends. Nonetheless, we observe that the time series of daily dividends for indices do not vary much and will not have a significant impact on our results. To validate this point, we compare the estimates of the dependence between the Euro-zone index returns and the non-Euro country returns calculated first from the price indices and second from the total return indices. We find that for all pairs of markets, the values of marginal and copula likelihood functions are almost unchanged when we use total return indices instead of price indices. All of the differences in the log-likelihood are smaller than 1. In addition, the estimated dependence processes from price indices and total return indices almost overlap for all pairs of markets.

In the framework of the copula method, there is no analytical relationship between the copula parameter ρ_t and the conditional correlation between two index returns when at least one marginal distribution is non-Gaussian. The correlation can only be calculated numerically from a double integral involving the bivariate density. Unreported numerical results show that when the marginal distributions follow Student's *t*, as assumed in this paper, the Gaussian copula dependence parameter is almost equal to the correlation. This is also confirmed by the very similar dependence processes estimated using our conditional copula model and the dynamic conditional correlation (DCC) model of Engle and Sheppard (2001), which is illustrated by Figure 5.

7 Concluding Remarks

In this paper, we propose a general time-varying copula dependence model in order to study market linkages. Subsequently, we use this model to investigate the impact of the introduction of the Euro on the dependence of equity markets in Europe. In particular, we investigate whether there are significant changes in the time-varying dependence structure of markets within the Euro area as well as between equity markets of countries in the Euro area and non-Euro European countries. We find that market dependence within the Euro area increased only for some countries, like France, Germany, Italy, the Netherlands and Spain, which are characterized by relatively large equity market capitalization, comprehensive regulations, high liquidity, and low transaction and information costs. When testing for alternative structural breaks in market dependence, we find that the increase in dependence started in late 1997 or early 1998 when Euro membership was determined and announced. The results suggest that the introduction of the Euro increased financial market dependence in the Euro area as a likely result of increased European integration.

In contrast, most of the remaining European countries continue to lack significant dependence with the Euro area. Nevertheless, we do find that the co-movement of the British and Swedish stock markets with the Euro-zone market slightly increased. This may indicate that at least some market participants actually expected the adoption of the Euro in these countries. However, we suggest further research on the development of non-Euro financial markets since the existing evidence is not of sufficient strength to draw firm conclusions. Our approach can be extended to a multivariate model, which is useful for portfolio and risk management. Future research may apply this model to study changes in the dependence of other asset markets in order to provide a broader basis for conjectures about whether and when these countries may join the Euro.

References

Adjaouté, K., and J.-P. Danthine, 2003. "European financial integration and equity returns: A theory-based assessment." In: V. Gaspar, P. Hartmann and O. Sleijpen (Eds.), The Transformation of the European Financial System, Chapter 5, 185-245, 2003.

Adler, M. and Dumas, B. 1983. "International portfolio selection and corporation finance: A synthesis." Journal of Finance 46, 925-984.

Alexander, C. O. (2001). "Orthogonal GARCH." Measuring Risk Volume 2, Prentice-Hall, 21-38.

Baele, L. 2005. "Volatility spillover effects in European equity markets." Journal of Financial and Quantitative Analysis 40, 373-401.

Barr, D., F. Breedon, and D. Miles, 2003. "Life on the outside: Economic conditions and prospects outside Euroland." Economic Policy 18, 573-613.

Bartram, S. M. and Dufey, G. 2001. "International portfolio investment: theory, evidence, and institutional framework." Financial Markets, Institutions & Instruments 10 (3), 85-155.

Bartram, S.M., and G.A. Karolyi 2003. "The impact of the introduction of the Euro on foreign exchange rate risk exposures." Working Paper, Ohio State University.

Bartram, S.M., and Wang, Y.-H. 2005. "Another look at the relationship between cross-market correlation and volatility." Finance Research Letters 2 (2), 75-88.

Bekaert, G. and Harvey, C.R. 1995. "Time-varying world market integration." Journal of Finance 50, 403-444.

Bekaert, G., Harvey, C.R. and Lumsdaine, R.L. 2002. "Dating the integration of world equity markets." Journal of Financial Economics 65, 203-247.

Bekaert, G., Harvey, C.R. and Ng, A. 2005. "Market integration and contagion." Journal of Business 78, 39-69.

Bennett, M. N. and Kennedy, J. E. 2004. "Quanto pricing with copulas." Journal of Derivatives 12, 26-45.

Berben, R.-P., and Jansen, W.J. 2005. "Comovement in international equity markets: A sectoral view." Journal of International Money and Finance 24, 832-857.

Berkowitz, J. 2001. "Testing density forecasts, with applications to risk management." Journal of Business and Economic Statistics 19, 465-474.

Billio, M. and Pelizzon, L. 2003. "Volatility and shocks spillover before and after EMU in European stock markets." Working paper, GRETA, Venice.

Bollerslev, T., Engle, R. F. and Wooldridge, J. M. 1988. "A capital asset pricing model with time-varying covariances." Journal of Political Economy 96, 116-131.

Booth, G. G., Martikainen, T. and Tse, Y. 1997. "Price and volatility spillovers in Scandinavian stock markets." Journal of Banking and Finance 21, 811-823.

Cappiello, L., Engle, R. F., and Sheppard, K. 2004. "Asymmetric dynamics in the correlations of global equity and bond markets." Working paper, European Central Bank.

Cherubini, U., Luciano, E. and Vecchiato, W. 2004. Copula Methods in Finance. Chichester, John Wiley.

Cooper, I. and Kaplanis, E. 2000. "Partially segmented international capital markets and international capital budgeting." Journal of International Money and Finance 43, 287-307.

Danthine, J.-P., F. Giavazzi, and E.-L. von Thadden, 2001. "European financial markets after EMU: A first assessment." In C. Wyplosz, ed. EMU: Its Impact on Europe and the World, Oxford University Press.

Detken, C. and Hartmann, P. 2000. "The Euro and international capital markets." International Finance 3, 53-94.

Detken, C. and Hartmann, P. 2002. “Features of the Euro’s role in international financial markets.” Economic Policy 24, 555-575.

Dumas, B. and Solnik, B. 1995. “The world price of foreign exchange risk.” Journal of Finance 50, 445-479.

Engle, R. F. 2002. “Dynamic conditional correlation: A simple class of multivariate generalized autoregressive conditional heteroskedasticity models.” Journal of Business and Economic Statistics 20, 339-350.

Engle, R. F. and Kroner, K. F. 1995. “Multivariate simultaneous generalized arch.” Econometric Theory 11, 122-150.

Engle, R.F. and Ng, V.K. 1993. Measuring and testing the impact of news on volatility, Journal of Finance 48, 1749-1778.

Engle, R. F. and Sheppard, K. 2001. “Theoretical and empirical properties of dynamic conditional correlation multivariate GARCH.” Working Paper, University of California at San Diego.

Errunza, V. and Losq, E. 1985. “International asset pricing under mild segmentation: Theory and test.” Journal of Finance 40, 105-124.

Eun, C. S. and Janakiramanan, S. 1986. “A model of international asset pricing with a constraint on the foreign equity ownership.” Journal of Finance 41, 897-914.

Eun, C. S. and Shim, S. 1989. “International transmission of stock market movements.” Journal of Financial and Quantitative Analysis 24, 241-256.

Feldstein, M. and Horioka, C. 1980. “Domestic saving and international capital flows.” Economic Journal 90, 314-329.

Ferson, W. and Harvey, C. 1991. “The variation of economic risk premiums.” Journal of Political Economy 99, 385-415.

Frankel, J.A. 1992. “Measuring international capital mobility: A review.” American Economic Review 82, 197-202.

Frankel, J.A. and MacArthur, A.T. 1988. “Political vs. currency premia in international real interest differentials: A study of forward rates for 24 countries.” European Economic Review 32, 1083-1114.

Fratzscher, M. 2002. “Financial market integration in Europe: On the effects of EMU on stock markets.” International Journal of Finance and Economics 7, 165-194.

Friedman, J and Shachmurove, Y. 2005. “European stock market dynamics before and after the introduction of the Euro.” Working Paper, PIER, University of Pennsylvania.

Glosten, R. T., Jagannathan, R., and Runkle, D. 1993. "On the relation between the expected value and the volatility of the nominal excess return on stocks." Journal of Finance 48, 1779-1801.

Goetzmann, W.N, Li, L. and Rouwenhorst, K.G. 2005. "Long-term global market correlations." Journal of Business 78, 1-37.

Guiso, L., Haliassos, M., and Jappelli, T. 2003. "Household stockholding in Europe: where do we stand and where do we go?" Economic Policy 36, 123-170.

Hardouvelis, G., Malliaropulos, D., and Priestly, R. 2001. "EMU and European stock market integration." Discussion Paper, Centre for Economic Policy Research.

Hartmann, P., Maddaloni, A., and Manganelli, S. 2003. "The Euro area financial system: Structure, integration and policy initiatives." Oxford Review of Economic Policy 19, 180-213.

Hennessy, D. A., and Lapan, H. 2002. "The use of Archimedean copulas to model portfolio allocations." Mathematical Finance 12, 143-154.

Joe, H. 1997. Multivariate Models and Dependence Concepts. London, Chapman & Hall.

Jondeau, E. and Rockinger, M. 2005. "The Copula-GARCH model of conditional dependencies: An international stock-market application." Journal of International Money and Finance, forthcoming.

Kasa, K. 1992. "Common stochastic trends in international stock markets." Journal of Monetary Economics 29, 95-124.

Koutmos, G. and Booth G. 1995. "Asymmetric volatility transmission in international stock markets." Journal of International Money and Finance 14, 747-762.

Lemmen, J.J.G. and Eijffinger, S.C.W. 1998. "The quality approach to financial integration: The Feldstein-Horioka criterion revisited." In: J.J.G. Lemmen (ed.) Integrating Financial Markets in the European Union, Chapter 3, Edward Elgar.

Li, D. X. 2000. "On default correlation: A copula function approach." Journal of Fixed Income 9, 43-54.

Longin, F. and Solnik, B. 2001. "Extreme correlation of international equity markets." Journal of Finance 56, 649-676.

Malevergne, Y. and Sornette, D. 2003. "Testing the Gaussian copula hypothesis for financial assets dependences." Quantitative Finance 3, 231-250.

Martens, M. and Poon, S.H. 2001. "Returns synchronization and daily correlation dynamics between international stock markets." Journal of Banking and Finance 25, 1805-1827.

Melle, M. 2003. “The Euro effect on the integration of the European stock markets.” Working Paper, Universidad Complutense de Madrid.

Micco, A., E. Stein, and G. Ordoñez, 2003. “The currency union effect on trade: Early evidence from the European union.” Economic Policy 18:37, 315-356.

Nelsen, R. B. 1999. An Introduction to Copulas. New York, Springer.

Nelson, D.B. 1991. “Conditional heteroskedasticity in asset returns: a new approach.” Econometrica 59, 347-370.

Newey, W. K. and McFadden D. 1994. “Large sample estimation and hypothesis testing”, in Engle, R.F. and McFadden eds. Handbook of Econometrics 4, North-Holland, Amstertam.

Patton, A. J. 2006a. “Modelling asymmetric exchange rate dependence.” International Economic Review 47, 527-556.

Patton, A. J. 2006b. “Estimation of multivariate models for time series of possibly different lengths.” Journal of Applied Econometrics 21, 147-173.

Perée, E. and Steinherr, A. 2001. “The Euro and capital markets: a new era.” The World Economy 24, 1295-1308.

Richards, A. J. 1995. “Comovements in national stock market returns: Evidence of predictability but not cointegration.” Journal of Monetary Economics 36, 631-654.

Rockinger, M. and Jondeau, E. 2002. “Conditional dependence of financial series: An application of copulas.” Working Paper, HEC, University of Lausanne.

Rodriguez, J. C. 2003. “Measuring financial contagion: A copula approach.” Working Paper, Tilburg University.

Rosenberg, J. V. 2003. “Non-parametric pricing of multivariate contingent claims.” Journal of Derivatives 10, 9-26.

Savva, C.S., Osborn, D.R., and Gill, L. 2004. “Volatility, spillover effects and correlations in U.S. and major European markets.” Working Paper, University of Manchester.

Solnik, B. 1974. “An equilibrium model of the international capital market.” Journal of Economic Thoery 8, 500-524.

Stulz, R. M. (1981). “On the effects of barriers to international investment.” Journal of Finance 36, 923-934.

Westermann, F. 2004. “Does the Euro affect the dynamics interactions of stock markets in Europe? Evidence from France, Germany and Italy.” European Journal of Finance 10, 139-148.

White, H. 1994. Estimation, Inference and Specification Analysis. New York, Cambridge University Press.

Table 1: Summary Statistics

Summary statistics of the returns of the Euro-zone stock market index, S&P500 index, 12 Euro-zone country stock market indices and 5 non-Euro European country stock market indices. All of the indices are denominated in alternatively USD or local currency. The sample period covers January 1, 1994 to October 31, 2003 and has 2319 daily observations excluding holidays. Markets are sorted by region and decreasing market capitalization.

	Index	Currency	Mean	Std. Dev.	Skewness	Kurtosis	AR(1)*	AR(2)*
Euro area	Euro-zone	USD	0.000255	0.0112	-0.0913	5.3113	0.0934	-0.0401
		EUR	0.000249	0.0121	-0.1699	5.2681	0.0501	-0.0177
	France	USD	0.000254	0.0127	-0.0246	4.9854	0.0732	-0.0463
		EUR	0.000234	0.0135	-0.0629	5.1835	0.0490	-0.0290
	Germany	USD	0.000157	0.0128	-0.1267	4.9708	0.0620	-0.0175
		EUR	0.000144	0.0132	-0.3158	5.2785	0.0556	-0.0132
	Italy	USD	0.000263	0.0144	-0.0533	4.8467	0.0612	-0.0010
		EUR	0.000252	0.0144	-0.1479	4.9206	0.0370	0.0323
	Netherlands	USD	0.000247	0.0124	-0.1251	8.1302	0.0450	-0.0429
		EUR	0.000237	0.0132	-0.1693	8.1485	0.0227	-0.0248
	Spain	USD	0.000347	0.0130	-0.0849	5.0074	0.0772	-0.0459
		EUR	0.000348	0.0132	-0.2301	5.1015	0.0339	-0.0309
	Finland	USD	0.000698	0.0224	-0.3690	9.0046	0.0361	-0.0130
		EUR	0.000645	0.0232	-0.3545	8.8999	0.0241	-0.0048
	Belgium	USD	0.000220	0.0108	0.1719	6.3110	0.1662	-0.0079
		EUR	0.000202	0.0104	0.2110	7.7974	0.1781	0.0018
	Greece	USD	0.000356	0.0183	-0.0873	8.3628	0.1151	-0.0036
		EUR	0.000411	0.0174	-0.1109	9.8499	0.1309	-0.0012
	Ireland	USD	0.000407	0.0114	-0.3315	6.8231	0.1117	0.0022
		EUR	0.000387	0.0113	-0.5823	8.7496	0.1124	0.0210
	Portugal	USD	0.000222	0.0109	-0.0702	6.3178	0.1450	0.0164
		EUR	0.000212	0.0102	-0.5372	9.6835	0.1359	0.0158
	Austria	USD	0.000094	0.0093	-0.1968	4.6855	0.0722	0.0187
		EUR	0.000081	0.0080	-0.7150	8.3091	0.0682	0.0068
	Luxembourg	USD	0.000181	0.0121	-0.0706	10.2988	0.0755	0.0322
		EUR	0.000164	0.0110	-0.1806	15.3306	0.1260	0.0763
Non-Euro Europe	UK	USD	0.000180	0.0105	-0.0557	5.3958	0.0328	-0.0440
		GBP	0.000120	0.0108	-0.1406	5.5838	0.0217	-0.0365
	Switzerland	USD	0.000303	0.0112	-0.0850	5.8229	0.0837	0.0014
		SWF	0.000257	0.0117	-0.2473	6.4344	0.0684	0.0185
	Sweden	USD	0.000403	0.0165	-0.0763	5.8585	0.0995	-0.0267
		SEK	0.000374	0.0158	0.0340	5.8404	0.0572	-0.0062
	Denmark	USD	0.000417	0.0112	-0.1149	8.2294	0.0370	0.0033
		DMK	0.000390	0.0107	-0.3742	11.1635	0.0651	0.0098
	Norway	USD	0.000250	0.0126	-0.4716	7.1171	0.0651	0.0263
		NOK	0.000224	0.0120	-0.4373	7.1770	0.0565	0.0320
United States	SP500	USD	0.000348	0.0117	-0.1184	5.5530	-0.0318	-0.0219

*AR(*i*) represents the i^{th}-lag autocorrelation coefficient of returns.

Table 2: Estimates of Dependence Models for Euro-zone Stock Market Indices

Estimates of the dependence of 12 Euro-zone country stock market indices with the Euro-zone stock market index and with the S&P500 index, using the following model settings. All indices are denominated in USD. Markets are sorted by decreasing market capitalization. The bivariate density $h(x,y)$ is given by (1) and depends on the Gaussian copula function $c(u,v)$ defined by (7) with correlation parameter ρ_t given by

$$(1-\beta_1 L)(1-\beta_2 L)\rho_t = \omega + \gamma \mid u_{t-1} - v_{t-1} \mid .$$

Country	with	ω	β_1	β_2	γ	LLF(c)
France	Euro	0.0238	0.9777	0.0000	-0.0412	1438.18
		(0.0000)	(0.0000)	(0.9997)	(0.0000)	
	SP500	0.0345	0.9623	0.1684	-0.0782	470.91
		(0.0001)	(0.0000)	(0.2125)	(0.0000)	
Germany	Euro	0.0970	0.9064	0.0000	-0.1574	1208.52
		(0.0000)	(0.0000)	(0.9998)	(0.0000)	
	SP500	0.0784	0.9217	0.0000	-0.1727	322.13
		(0.0052)	(0.0000)	(0.9999)	(0.0056)	
Italy	Euro	0.0625	0.9441	0.0000	-0.1380	910.10
		(0.0000)	(0.0000)	(0.9999)	(0.0000)	
	SP500	0.0325	0.9730	0.0000	-0.0852	271.14
		(0.0092)	(0.0000)	(0.9999)	(0.0085)	
Netherlands	Euro	0.0276	0.9737	0.0110	-0.0454	1432.55
		(0.0000)	(0.0000)	(0.8114)	(0.0000)	
	SP500	0.0243	0.9686	0.3133	-0.0576	470.70
		(0.0000)	(0.0000)	(0.0002)	(0.0000)	
Spain	Euro	0.0642	0.9398	0.0000	-0.1174	1054.05
		(0.0000)	(0.0000)	(0.9999)	(0.0000)	
	SP500	0.0390	0.9274	0.4192	-0.0767	318.62
		(0.0000)	(0.0000)	(0.0000)	(0.0000)	
Finland	Euro	0.0540	0.9446	0.0539	-0.1024	642.16
		(0.0003)	(0.0000)	(0.8145)	(0.0001)	
	SP500	0.0466	0.9353	0.3156	-0.1008	433.23
		(0.0000)	(0.0000)	(0.0284)	(0.0000)	
Belgium	Euro	0.0736	0.9235	0.0880	-0.1382	843.39
		(0.0000)	(0.0000)	(0.5859)	(0.0000)	
	SP500	0.0580	0.9469	0.0000	-0.1585	135.44
		(0.0274)	(0.0000)	(0.9999)	(0.0287)	
Greece	Euro	0.0952	0.8990	0.0000	-0.2199	153.56
		(0.0087)	(0.0000)	(0.9999)	(0.0101)	
	SP500	0.0603	0.9421	0.0000	-0.1853	22.96
		(0.0926)	(0.0000)	(0.9999)	(0.0890)	
Ireland	Euro	0.0095	0.9898	0.2356	-0.0239	378.66
		(0.0073)	(0.0000)	(0.0014)	(0.0075)	
	SP500	0.0254	0.9559	0.4758	-0.0664	142.04
		(0.0022)	(0.0000)	(0.0054)	(0.0023)	
Portugal	Euro	0.0423	0.9647	0.0000	-0.1017	487.95
		(0.0012)	(0.0000)	(0.9999)	(0.0010)	
	SP500	0.0211	0.9876	0.0000	-0.0688	76.54
		(0.1114)	(0.0000)	(0.9999)	(0.1108)	
Austria	Euro	0.0205	0.9767	0.2953	-0.0534	407.13
		(0.0000)	(0.0000)	(0.0005)	(0.0000)	
	SP500	0.0094	0.9953	0.0480	-0.0309	32.18
		(0.1669)	(0.0000)	(0.9249)	(0.1591)	
Luxembourg	Euro	0.0274	0.9767	0.0005	-0.0788	134.05
		(0.0014)	(0.0000)	(0.9993)	(0.0016)	
	SP500	0.0289	0.7436	0.0436	-0.0549	3.15
		(0.0700)	(0.0000)	(0.2626)	(0.0685)	

The numbers in brackets ( ) are P values and 0.0000 means that the value is less than 0.00005.
LLF(c) is the maximum of the copula component of the log-likelihood function.

Table 3: Estimates of Dependence Models for Non-Euro, European Stock Market Indices

Estimates of the dependence of 5 non-Euro country stock market indices with the Euro-zone stock market index and with the S&P500 index, using the following model settings. All indices are denominated in USD. Markets are sorted by decreasing market capitalization. The bivariate density *h*(*x*,*y*) is given by (1) and depends on the Gaussian copula function *c*(*u*,*v*) defined by (7) with correlation parameter ρ_t given by

$$(1-\beta_1 L)(1-\beta_2 L)\rho_t = \omega + \gamma\,|u_{t-1} - v_{t-1}|.$$

Country	with	ω	β_1	β_2	γ	LLF(*c*)
UK	Euro	0.0761	0.9282	0.0000	-0.1435	835.51
		(0.0000)	(0.0000)	(0.9999)	(0.0000)	
	SP500	0.0123	0.9862	0.0993	-0.0275	464.16
		(0.0300)	(0.0000)	(0.4132)	(0.0165)	
Switzerland	Euro	0.1001	0.9006	0.0000	-0.1532	947.89
		(0.0000)	(0.0000)	(0.9999)	(0.0000)	
	SP500	0.0477	0.9277	0.3088	-0.1064	234.43
		(0.0065)	(0.0000)	(0.2451)	(0.0079)	
Sweden	Euro	0.0339	0.9700	0.0000	-0.0726	851.52
		(0.0000)	(0.0000)	(0.9999)	(0.0000)	
	SP500	0.0781	0.9159	0.0420	-0.1530	414.12
		(0.0013)	(0.0000)	(0.8798)	(0.0013)	
Denmark	Euro	0.0284	0.9594	0.3404	-0.0598	399.42
		(0.0004)	(0.0000)	(0.0001)	(0.0004)	
	SP500	0.0132	0.9537	0.6447	-0.0326	62.66
		(0.0143)	(0.0000)	(0.0000)	(0.0241)	
Norway	Euro	0.0391	0.9326	0.3813	-0.0629	528.10
		(0.0003)	(0.0000)	(0.0000)	(0.0002)	
	SP500	0.0162	0.9545	0.5339	-0.0283	189.30
		(0.0224)	(0.0000)	(0.0000)	(0.0412)	

The numbers in brackets ( ) are P values and 0.0000 means that the value is less than 0.00005.
LLF(c) is the maximum of the copula component of the log-likelihood function.

Figure 1: Dependence of Euro-zone Country Stock Indices with the Euro-zone Stock Index and with the S&P500 Index

The figure shows the time-varying conditional dependence of 12 Euro-zone country stock indices with the Euro-zone regional stock index and with the S&P500 index. All indices are denominated in USD. The Euro-zone stock index excludes the examined country. The S&P500 index is observed at 16.00 London time. The dark line shows the dependence with the Euro-zone stock index, the light line shows the dependence with the S&P500 index.

(continued)

Figure 1: Dependence of Euro-zone Country Stock Indices with the Euro-zone Stock Index and with the S&P500 Index (continued)

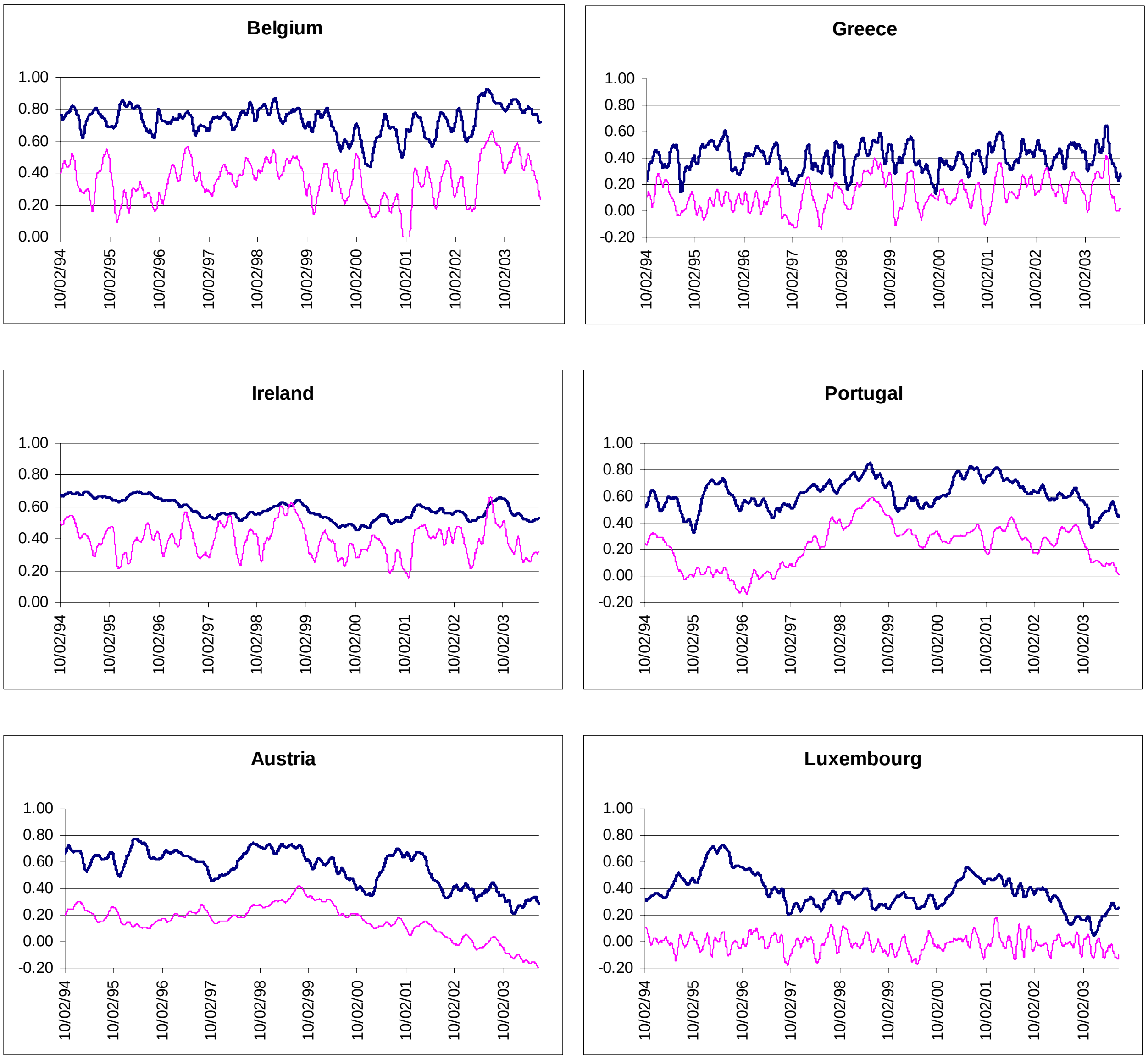

Figure 2: Dependence of Non-Euro Country Stock Indices with the Euro-zone Stock Index and with the S&P500 Index

The figure shows the time-varying conditional dependence of 5 non-Euro country stock indices with the Euro-zone stock index and the S&P500 index. All indices are denominated in USD. The S&P500 index is observed at 16.00 London time. The dark line shows the dependence with the Euro-zone stock index, the light line shows the dependence with the S&P500 index.

Figure 3: Dependence of a Euro-zone Country Index with the Euro-zone Stock Index in EUR and in USD

The figure shows the time-varying conditional dependence of the French stock index with the Euro-zone stock index in EUR and in USD. The Euro-zone stock index excludes the examined country. The dark line represents returns denominated in EUR. The light line represents returns denominated in USD.

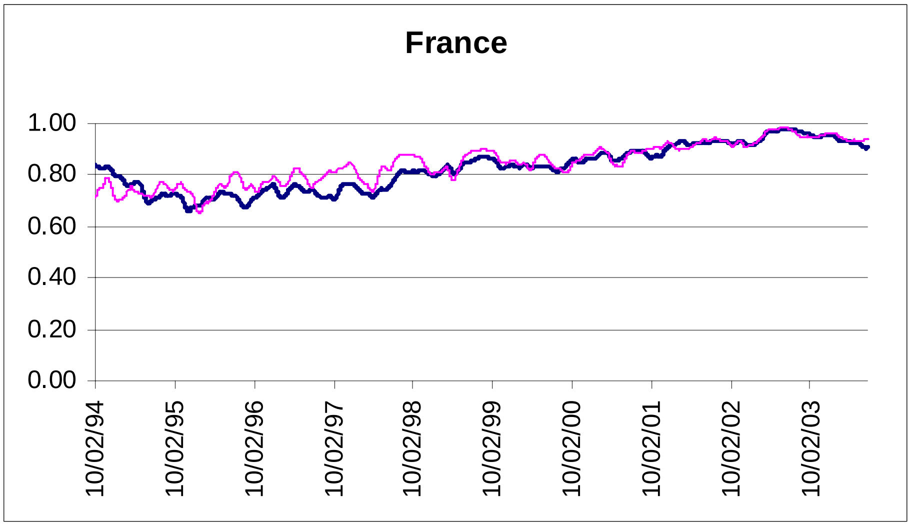

Figure 4: Dependence of a Non-Euro Country Index with the Euro-zone Stock Index in Different Currencies

The figure shows the time-varying conditional dependence of the Swiss stock index in local currency and in USD with the Euro-zone stock index in USD. The dark line represents the dependence for the Swiss returns in local currency. The light line represents the dependence for the Swiss returns in USD.

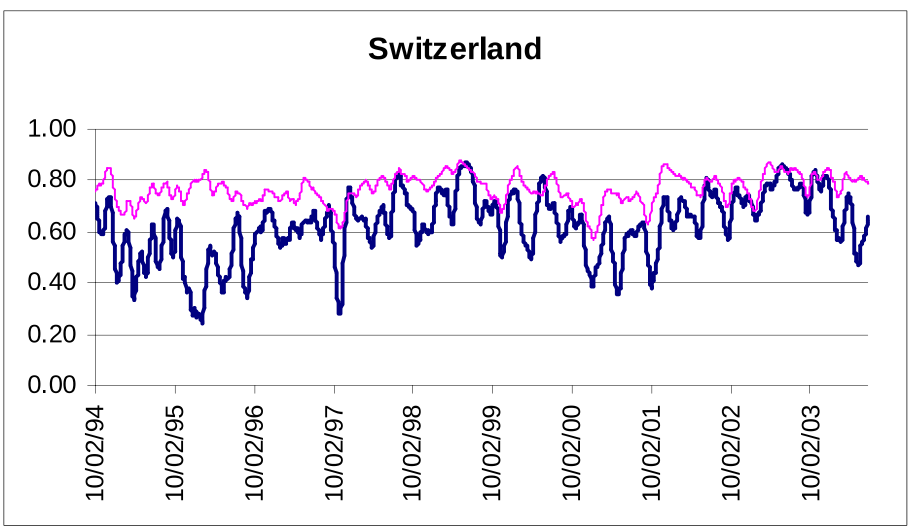

Figure 5: Gaussian Copula Dependence and Dynamic Conditional Correlation

The figure shows the time-varying dependences of the Dutch stock index with the Euro-zone stock index in USD, estimated by the conditional Gaussian copula method and the dynamic conditional correlation (DCC) model of Engle and Sheppard (2001). The dark line represents the dependence estimated by the Gaussian copula method. The light line represents the correlation estimated by the DCC model.