Risk Contagion among International Stock Markets

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Keywords: Spillover; jump; stochastic volatility; wavelet; Markov Chain Monte Carlo

JEL classifications: C13; C15.

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Abstract

We develop a model of stochastic volatility with jump to analyze the risk spillover from the US market and the regional (European) market to the European equity markets. The key advantage of this approach comparing to the earlier approaches is that it enables us to identify jumps and investigate spillover of extreme events across borders. We find that a large part of the country jumps are due to the US and regional markets. The US contribution to the country variances is in general below the contribution from the regional market. Furthermore, we show that the identification of the jumps can be used as a useful signal for portfolio reallocation.

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1. Introduction

It is important for financial investors to understand how financial markets correlate and how country specific shocks are transmitted to other markets, because it affects their ability of risk hedging via international diversifications. Several aspects of the interactions between the international stock markets have been studied by previous literature. A part of literature has been concerned with return correlations or comovements between different markets (see for example Erb et al. (1994), Karolyi and Stulz (1996) and Longin and Solnik (1995)), while another part of the literature has focused on risk spillover between the markets. Bekaert and Harvey (1997) construct a volatility spillover model to analyze the impact of the world equity market on the emerging equity markets. Ng (2000) applies the same approach to analyze the volatility spillovers from Japan and the US to six Pacific–Basin equity markets. Related to this approach, Bekaert et al. (2005) analyze the equity market integrations in three different regions, Europe, South-East Asia and Latin America and measure proportion of volatility driven by global, regional, as well as, local factors. The paper also provides new insights on contagion, defined as correlation over what would be expected from economic fundamentals. Kim et al (2005) investigate the stock market integration among the European countries before and after the establishment of the European currency union. Baele (2005) studies the stock market integration between the US market and European countries using a regime switching GARCH model.

In recent years, there has been a growing interest toward modeling discontinuity in equity returns, so called return jumps, caused by large informational shocks or extreme events. The importance of modeling jumps in optimal portfolio selection, in a domestic or an international framework, has been shown by studies such as Wu (2003), Liu et al. (2003) and Das and Uppal

(2004). Asgharian and Bengtsson (2006) and Bengtsson (2006) apply a stochastic volatility model with jumps and analyze the spillover of jumps across borders and show that the dependencies between the jump processes in different markets are quite different from the dependencies between normal returns that are not jumps. This implies that international investors who use correlations among markets in their portfolio decisions may have no protection against event risk.

Our purpose is to analyze how the local equity markets of the European countries are affected by the regional equity market (other European equity markets) and the US equity market. Our approach simultaneously investigates all the three aspects of the interactions between markets, i.e. the correlation, the variance spillover and the jump spillover. We separate three sources of shocks to each European equity market; the shocks from the US market, the shocks from the regional market and the idiosyncratic or local shocks. Our approach is related to the model proposed by Bekaert and Harvey (1995, 1997). However, we extend the model in several ways. We use a more general volatility model, i.e. the stochastic volatility model, instead of a GARCH model. More importantly, our model allows for existence of jumps in returns and volatility. This enables us to capture extreme values in returns and achieve a better estimation of the parameters comparing to models assuming a normal distribution for returns. In addition, this approach makes it possible to identify jumps and directly model the contagion of extreme events across borders. Furthermore, allowing for jumps in volatility and considering the correlations between return and volatility make it possible to fully capture the asymmetry in the volatility (the leverage effect). Bekaert et al (2005) notify that a model that fails to capture the asymmetry in the volatility may misjudge the correlation between stock markets during crises.

We allow for time-varying coefficients by relating the spillover parameters to countries' degree of integration. It is rational to think about integration as a state variable that fluctuates smoothly over time. However, most of the variables applied in previous literature to measure the degree of integration are exposed to problems such as seasonality, short-term variability and estimation error. We use Wavelet to filter out all the short-term variations (frequencies up to one year) in the variables measuring country integration.

Our results show that the US contributions to the country variances lie in general below the contributions from the regional (European) market. The degree of integration among the European markets increases with the development of the European Union. We find that a large part of the country jumps are due to the US and regional markets. We cannot find any strong indications that spillover in jump days and in a period following jumps is different from other periods. Finally, we show a large benefit, in term of risk reduction, for the US investors from international diversification in the periods of large market volatility and more importantly in the periods following jump events. Therefore, the identification of the jump events can be used as an important signal for portfolio reallocation.

The rest of the paper is organized as follows: Section 2 presents the empirical models; data and econometric methods are described in Section 3; Section 4 contains the empirical results and the analyses; and Section 5 concludes the study.

2. The Empirical Models

2.1 The stochastic volatility model with correlated jumps (SVCJ)

The SVCJ model is a squared root volatility model with common jumps in the variance and the stock price processes. Allowing for jumps in volatility makes the model able to capture clusters of extreme returns (see Eraker et al (2003)). The model belongs to the continuous affine jump-diffusion model with stochastic volatility with correlated jumps proposed by Duffie et al (2000). In this paper we assume that the log stock returns follow a discrete time SVCJ model:

$$\begin{cases} Y_t = X_{t-1} + \sqrt{V_{t-1}}\varepsilon_t^y + \xi_t^y J_t \\ V_t = V_{t-1} + \alpha + \beta V_{t-1} + \sigma\sqrt{V_{t-1}}\varepsilon_t^v + \xi_t^v J_t, \end{cases} \tag{1}$$

Y_t and V_t are the log return and the return variance at time *t*, respectively. X_t is the expected log return which will be specified in the next section. The shocks ε_t^y and ε_t^v are two standardized normal variables with correlation ρ. A negative value of ρ means that the variance and the stock price are negatively correlated and the model captures what is commonly called volatility asymmetry. J_t is an independent Bernoulli distributed variable with $J_t = 1$ indicating a simultaneous jump in the stock price and variance at time *t*. The intensity of the jump events is constant and measured by the coefficient λ. The notations ξ_t^y and ξ_t^v are for the latent jump size in return and jump size in volatility respectively, with correlation coefficient ρ_J. The former variable is assumed to be normally distributed with mean $\mu_y + \rho_J E[V_t]$ and standard deviation σ_y (conditional on the information at time *t*-1) and the latter one is supposed to follow an exponential distribution with mean μ_v. The ratio -α/β is the mean reversion level of the variance process and $-\beta$ is the speed of adjustment to the mean reversion level. The parameter σ is the volatility of the squared root variance process (the volatility process).

2.2 The spillover model

Our purpose is to divide the total price variations of each European country into the components that are related to the US stock market and the regional stock market, and the country specific component. Since the impact of the other countries may be different between the normal news and when extreme events happen in the markets our model separates the returns into two parts, the normal returns and jumps. We allow a time-varying spillover by letting the coefficients be determined by the degree of integration between the countries.

To estimate the spillover from US and the European markets to each European country *i* we first estimate a SVCJ model for the US stock market as:

$$\begin{cases} Y_t^{us} = m + aY_{t-1}^{us} + \sqrt{V_{t-1}^{us}}\varepsilon_t^{y,us} + \xi_t^{y,us} J_t^{us} \\ V_t^{us} = V_{t-1}^{us} + \alpha + \beta V_{t-1}^{us} + \sqrt{V_{t-1}^{us}}\sigma\varepsilon_t^{v,us} + \xi_t^{v,us} J_t^{us} \end{cases} \tag{2}$$

We then include the unexpected return of the US market in the model for the regional market (European countries excluding country *i*). The unexpected return of the US market consists of two components, a normal component, e_t^{us}, and a jump component, x_t^{us}, where

$$e_t^{us} = Y_t^{us} - m - aY_{t-1}^{us} - x_t^{us} \tag{3}$$

$$x_t^{us} = \xi_t^{y,us} J_t^{us}$$

Consequently the SVCJ model for the spillover from the US market into the regional market (*eu*) is defined as:

$$\begin{cases} Y_t^{eu} = m + aY_{t-1}^{eu} + b_{1t}e_t^{us} + b_2x_t^{us} + \sqrt{V_{t-1}^{eu}}\varepsilon_t^{y,eu} + \xi_t^{y,eu}J_t^{eu} \\ V_t^{eu} = V_{t-1}^{eu} + \alpha + \beta V_{t-1}^{eu} + \sqrt{V_{t-1}^{eu}}\sigma\varepsilon_t^{v,eu} + \xi_t^{v,eu}J_t^{eu} \\ b_{1t} = b_{1,0} + b_{1,1}RI_{t-1}^{eu,us} + b_{1,2}FI_{t-1}^{eu,us} \end{cases} \tag{4}$$

Note that Y_t^{eu} is the European (regional) stock market index, where the country of interest, country *i*, is excluded. The economic integration variable, $RI_t^{eu,us}$ is the total trade (export plus import) of the regional market with the USA, divided by the GDP of the countries included in the regional market. The financial integration variable, $FI_t^{eu,us}$ is measured as the GDP-weighted average of the USD exchange rate volatilities of the currencies' included in the regional market.

Finally we estimate the SVCJ model for the spillover from both the US market and the regional market to the country *i*.

$$\begin{cases} Y_t^{i} = m + aY_{t-1}^{i} + b_{1t}e_t^{us} + b_2x_t^{us} + c_{1t}e_t^{eu} + c_2x_t^{eu} + \sqrt{V_{t-1}^{i}}\varepsilon_t^{y,i} + \xi_t^{y,i}J_t^{i} \\ V_t^{i} = V_{t-1}^{i} + \alpha + \beta V_{t-1}^{i} + \sqrt{V_{t-1}^{i}}\sigma\varepsilon_t^{v,i} + \xi_t^{v,i}J_t^{i} \\ b_{1t} = b_{1,0} + b_{1,1}RI_{t-1}^{i,us} + b_{1,2}FI_{t-1}^{i,us} + b_{1,3}D_t^{us} \\ c_{1t} = c_{1,0} + c_{1,1}RI_{t-1}^{i,eu} + c_{1,2}FI_{t-1}^{i,eu} + c_{1,3}D_t^{eu} \end{cases} \tag{5}$$

where

$$e_t^{eu} = Y_t^{eu} - m - aY_{t-1}^{eu} - b_{1t}e_t^{us} - b_2x_t^{us} - x_t^{eu}, \tag{6}$$

$$x_t^{eu} = \xi_t^{y,eu}J_t^{eu},$$

and the economic integration variables, $RI_t^{i,eu}$ and $RI_t^{i,us}$, are the total trade (export plus import) of the country *i* with other European countries and with the USA respectively, divided by the countries' GDP. We assume that a large ratio of trade to GDP implies a higher dependence between the countries. Hence we believe that the spillovers are increasing with the economic integration variables. The financial integration variables, $FI_t^{i,eu}$ and $FI_t^{i,us}$, are measured as volatility of country i's exchange rate with Euro and with US dollar respectively. The time varying volatilities are measured by a applying a univariate AR(1)-GARCH(1,1) model on each exchange rate. An environment with stable exchange rates should reduce cross-currency risk premiums and imply more similar discounts rates. This should give a more homogenous valuation of equities and increase incentives to invest in foreign markets. Hence a less volatile exchange rate is expected to increase the spillover effects. Bekaert and Harvey (1995) and Baele (2005) found that countries with high export and import ratios and low exchange rate volatilities are in general more integrated with regional and world markets.

Since the country integration should depend on the fundamental economic variables, it is supposed to move smoothly over time. However, the variables commonly used to measure the degree of integration vary sharply within short-time intervals and are exposed to problems such as seasonality and estimation error. Therefore we use a smoothing technique by using the wavelet method and filter out all the variations in the integration variables up to one year.

To investigate if spillover after jumps is different from the normal periods we construct two dummy variables D_t^{eu} and D_t^{us}, which take the value one from week one up to week 12 (three months) after a jump occurrence in the regional market and in the US market respectively. The coefficients of these two variables measure the changes in spillover due to extreme events.

Due to a small number of jump occasions, allowing for time varying coefficients for jump components would result in poor parameter estimations. We therefore just let the coefficients of the normal shocks be related to the integration variables.

According to the model the expected return of the country i at time t is $(m + aY_{t-1}^{i})$ and the unexpected returns are divided to the normal returns, i.e. price variations due to normal chocks, and jumps or extreme returns. Excluding the jump component the unexpected return of country i at time t, η_t^i, can be defined as:

$$\eta_t^i = b_{1t}e_t^{us} + c_{1t}e_t^{eu} + e_t^i \tag{7}$$

$$e_t^i = Y_t^i - m - aY_{t-1}^i - b_{1t}e_t^{us} - b_2 x_t^{us} - c_{1t}e_t^{eu} - c_2 x_t^{eu} - x_t^i$$

$$x_t^i = \xi_t^{y,i} J_t^i$$

Condition on the information at time t-1, the variance of the unexpected normal return is:

$$\operatorname{var}_{t-1}\left(\eta_t^i\right) = b_{1t}^2 \operatorname{var}_{t-1}\left(e_t^{us}\right) + c_{1t}^2 \operatorname{var}_{t-1}\left(e_t^{eu}\right) + \operatorname{var}_{t-1}\left(e_t^i\right), \tag{8}$$

We can then compute the variance ratios

$$VR_{it}(us) = \frac{b_{1t}^2 \operatorname{var}_{t-1}\left(e_t^{us}\right)}{\operatorname{var}_{t-1}\left(\eta_t^i\right)} \tag{9}$$

$$VR_{it}(eu) = \frac{c_{1t}^2 \operatorname{var}_{t-1}\left(e_t^{eu}\right)}{\operatorname{var}_{t-1}\left(\eta_t^i\right)}$$

These ratios measure the percentage spillover effect of the US and the regional market on the country i's variance.

The covariance (conditional on the information at time t-1) between the unexpected normal returns of country i and the unexpected normal returns of the US market and the regional market are given by:

$$\operatorname{cov}_{t-1}(\eta_t^i, e_t^{us}) = b_{1t} \operatorname{var}_{t-1}\left(e_t^{us}\right) \tag{10}$$

$$\text{cov}_{t-1}(\eta_t^i, e_t^{eu}) = c_{1t}\ \text{var}_{t-1}\left(e_t^{eu}\right)$$

which implies that the variance ratio can be divided into three parts:

$$VR_{it}(us) = \frac{b_{1t}^2\ \text{var}_{t-1}\left(e_t^{us}\right)}{\text{var}_{t-1}\left(\eta_t^i\right)} = \underbrace{b_{1t}}_{1} \underbrace{\frac{b_{1t}\ \text{var}_{t-1}\left(e_t^{us}\right)}{\text{var}_{t-1}\left(\eta_t^i\right)^{1/2}\ \text{var}_{t-1}\left(e_t^{us}\right)^{1/2}}}_{2} \underbrace{\frac{\text{var}_{t-1}\left(e_t^{us}\right)^{1/2}}{\text{var}_{t-1}\left(\eta_t^i\right)^{1/2}}}_{3} \tag{11}$$

$$VR_{it}(eu) = \frac{c_{1t}^2\ \text{var}_{t-1}\left(e_t^{eu}\right)}{\text{var}_{t-1}\left(\eta_t^i\right)} = \underbrace{c_{1t}}_{1} \underbrace{\frac{c_{1t}\ \text{var}_{t-1}\left(e_t^{eu}\right)}{\text{var}_{t-1}\left(\eta_t^i\right)^{1/2}\ \text{var}_{t-1}\left(e_t^{eu}\right)^{1/2}}}_{2} \underbrace{\frac{\text{var}_{t-1}\left(e_t^{eu}\right)^{1/2}}{\text{var}_{t-1}\left(\eta_t^i\right)^{1/2}}}_{3}$$

where the component (1) is the degree of integration, component (2) is the time-varying correlation and component (3) is the volatility ratio.

It is important to note that the correlation given in equation (11) is between the normal shocks. Moreover, the correlation with the regional market is after filtering out the common effect of the US market on the regional and the local markets. To estimate the total time varying correlation between the returns we need to define the total conditional variances and covariances. The total conditional (conditional at the information at time t-1) covariances are:

$$\text{cov}_{t-1}(Y_t^{us}, Y_t^i) = b_{1t}^i V_{t-1}^{us} + b_2^i \lambda^{us} (\sigma_y^{us})^2 \tag{12}$$

$$\text{cov}_{t-1}(Y_t^{us}, Y_t^{eu}) = b_{1t}^{eu} V_{t-1}^{us} + b_2^{eu} \lambda^{us} (\sigma_y^{us})^2$$

$$\text{cov}_{t-1}(Y_t^{eu}, Y_t^i) = b_{1t}^{eu} b_{1t}^i V_{t-1}^{us} + c_{1t}^i V_{t-1}^{eu} + b_2^{eu} b_2^i \lambda^{us} (\sigma_y^{us})^2 + c_2^i \lambda^{eu} (\sigma_y^{eu})^2,$$

and the total conditional variances are:

$$\text{var}_{t-1}(Y_t^{eu}) = (b_{1t}^{eu})^2 V_{t-1}^{us} + V_{t-1}^{eu} + (b_2^{eu})^2 \lambda^{us} (\sigma_y^{us})^2 + \lambda^{eu} (\sigma_y^{eu})^2 \tag{13}$$

$$\text{var}_{t-1}(Y_t^i) = (b_{1t}^i)^2 V_{t-1}^{us} + (c_{1t}^i)^2 V_{t-1}^{eu} + V_{t-1}^i + (b_2^i)^2 \lambda^{us} (\sigma_y^{us})^2 + (c_2^i)^2 \lambda^{eu} (\sigma_y^{eu})^2 + \lambda^i (\sigma_y^i)^2$$

3. Data and Estimation Methodology

3.1 Data

The data are collected from DataStream. As the country specific stock indices we use the market indices composed by DataStream. These indices are supposed to represent countries' total stock market. The sample period begins in May 1982 and ends in May 2007. We are using weekly data with a total number of 1302 observations denominated in US dollars. We use the weekly data to avoid the problem of non-synchronized opening hours, due to the time differences between the US and the European markets. In addition to the USA, we use the following countries: Austria, Denmark, France, Germany, Ireland, Italy, Netherlands, Norway, Sweden, Switzerland and United Kingdom. The regional stock index is the weighted average of all the countries weekly log returns, where the weights are defined as the ratio between each country's market capitalization and the sum of all the countries market capitalisations. When calculating the spillover from the regional stock index to a specific country, the country in focus is excluded from the regional index.

3.2 Markov Chain Monte Carlo

The paper uses a Bayesian estimation methodology to estimate the parameters and the latent state variables of the spillover model. By the latent state variables, we mean the jump size, jump times and the volatility. In Bayesian statistics the researcher makes use of prior information and assumes that the true parameters of the model have a probability distribution and are not constant. Our prior information is economically motivated but still very uninformative. For example we assume that jumps are rare events, but we put a little weight to this assumption by giving a large standard deviation to the prior distribution of the jump intensity.

The spillover model is estimated in three steps. We first estimate the parameters of the SVCJ model for the US market. In the second step we estimate the SVCJ model for the regional market by including the unexpected return of the US market as an explanatory variable to the return equation. Finally, we estimate the SVCJ model for each European country by including the unexpected returns from the US and the regional markets as explanatory variables in the return equation. The estimation technique is the same in all the three steps. Hence, we only explain the estimation methodology for the general case.

The posterior distribution of the parameters, Θ^i, the latent variances, V^i, the jump arrivals, J^i, and the jump sizes in the log returns and in the variance, $\xi^{y,i}$ and $\xi^{v,i}$, are according to the Bayes' rule given by

$$p(\Theta^i, V^i, J^i, \xi^{y,i}, \xi^{v,i} \middle| Y^i, Z^i) \propto p(Y^i \middle| \Theta^i, V \ , J^i, \xi^{y,i}, \xi^{v,i}, Z^i) p(\Theta^i, V^i, J^i, \xi^{y,i}, \xi^{v,i}),$$

where Y^i is a vector of the log returns of the country *i*'s stock market. Z^i is a matrix consistent of the integration variables for country *i*. The posterior distribution is split in two parts: the likelihood function, $p(Y^i \middle| \Theta^i, V \ , J^i, \xi^{y,i}, \xi^{v,i}, Z^i)$, and the prior distribution, $p(\Theta^i, V^i, J^i, \xi^{y,i}, \xi^{v,i})$. The posterior distribution is very complicated and not known in closed form. Therefore, we use a Markov Chain Monte Carlo (MCMC) algorithm to generate a sequence of draws of $\left\{\Theta^i_j, V^i_j, J^i_j, \xi^{y,i}_j, \xi^{v,i}_j\right\}_{j=1}^N$ with an equilibrium distribution equal to the posterior distribution. To generate samples we iteratively draw from the following conditional posteriors.

$$\text{parameters}: p(\Theta_k^i \mid \Theta_{-k}^i, V^i, J^i, \xi^{y,i}, \xi^{v,i}, Y^i), k = 1,...K$$
$$\text{jump times}: p(J_{t\Delta}^i = 1 \mid \Theta^i, \xi^{y,i}, \xi^{v,i}, V^i, Y^i), t= 1,...,T$$
$$\text{jump sizes 1}: p(\xi_t^{y,i} \mid \Theta^i, J_t^i, \xi_t^{v,i}, V^i, Y^i), t = 1,...T$$
$$\text{jump sizes 2}: p(\xi_t^{v,i} \| \Theta^i, J_t^i, \xi_t^{y,i}, V^i, Y^i), t = 1,...T$$
$$\text{variance}: p(V_t^i \mid V_{t-1}^i, V_{(t+1)\Delta}^i, \Theta^i, J^i, \xi^{v,i}, Y^i), t = 1,...,T,$$

where Θ_{-k}^i denotes the vector of the parameters excluding the parameter Θ_k^i , k = 1,…., K, and K is the number of parameters. Using appropriate prior distributions the conditional posteriors are in most cases known distributions. In these cases we can easily draw a sample from the posterior distributions using the Gibb's sampler. In the other cases, when the posterior distributions are not known distributions, we draw from the posterior distributions using a Metropolis Hasting algorithm, which is an acceptance/rejection method.

The vector of the parameters for country i, Θ^i, consists of the elements, $\{m, a, b, c, \alpha, \beta, \sigma, \rho, \rho_J, \lambda, \mu_y, \sigma_y, \mu_v\}$, where $b = \{b_{1,0}, b_{1,1}, b_{1,2}, b_{1,3}\}$ and $c = \{c_{1,0}, c_{1,1}, c_{1,2}, c_{1,3}\}$. The definitions of the parameters are given earlier related to the description of the spillover model (Section 2.2). To be able to draw most of the parameters through the Gibb's sampler, we must draw parameters values by sub blocks. Therefore we divide the parameters to the following sub blocks: $\Psi^1 = \{m, a, b, c\}$, $\Psi^2 = \{\alpha, \beta\}$, $\Psi^3 = \{\sigma^2\}$, $\Psi^4 = \{\rho\}$, $\Psi^5 = \{\rho_J\}$, $\Psi^6 = \{\lambda\}$, $\Psi^7 = \{\mu_y\}$, $\Psi^8 = \{\sigma_y^2\}$ and $\Psi^9 = \{\mu_v\}$.

The prior distributions of the parameters are:

$$\Psi^1 \sim N(0,25I\ ), \Psi^2 \sim N(0,I), \Psi^3 \sim IG(2.5,0.1), \Psi^4 \sim U(-1,1), \Psi^5 \sim N(0,4),$$

$$\Psi^6 \sim \beta(2,40),\ \Psi^7 \sim N(0,100), \Psi^8 \sim IG(5,20) \text{ and } \Psi^9 \sim IG(10,20),$$

where l is diagonal matrix of appropriate size. The prior distributions are standard conjugates except from the distributions of σ^2 and ρ. For these variables we use the independent Metropolis Hasting algorithm to draw from the posterior distributions. In the other cases we use the Gibb's sampler. The prior distribution of the latent state variables for jumps are $\xi_t^y \sim N(\mu_y, \sigma_y^2)$, $\xi_t^v \sim Exp(\mu_v)$ and $J_t \sim Ber(\lambda)$. The prior distribution of ξ_t^y and J_t are conjugate priors and the posterior distribution of ξ_t^v is a truncated normal distribution. Therefore we can use the Gibb's sampler in these three cases. The posterior distribution of V_t is not a well-known distribution. Therefore, we use the random Metropolis Hasting algorithm when we draw from its posterior. The prior distributions are very uninformative and are in line with Eraker et al (2003). The full posterior distributions of the parameters and the latent states variables are found in Asgharian and Bengtsson (2006) and a detailed explanation of the MCMC methodology can be found in Johannes and Polson (2004) and Tsay (2002).

3.3 Wavelet

Using a wavelet multi-scaling approach we divide the integration variables on a scale-by-scale basis into different frequency components. We then exclude all the components that belong to frequencies higher than approximately one year.

By applying a discrete wavelet transform (DWT) we project a time series process, x_t, on to a set of functions to generate a set of coefficients that capture information associated with different time scales. In contrast to the Fourier analysis, which uses the trigonometric functions and assumes regular periodicity, the DWT functions are local in time and can be used to present time series processes whose characteristics change over time.

Wavelet analysis divides a single signal into a set of components of different time frequencies. The smooth (low frequency) parts of a time series are represented by the father wavelet given by

$$A_J(t) = \sum_k a_{J,k} \theta_{J,k}(t) \tag{13}$$

$$a_{J,k} = \int_{-\infty}^{\infty} x(t)\, \theta_{J,k}(t) dt$$

$$\theta_{J,k}(t) = 2^{-\frac{j}{2}} \theta\left(2^{-J} t - k\right)$$

and the detailed (high-frequency) parts are represented by mother wavelets:

$$D_j(t) = \sum_k d_{j,k} \varphi_{j,k}(t)$$

$$d_{j,k} = \int_{-\infty}^{\infty} x(t) \varphi_{j,k}(t) dt \tag{14}$$

$$\varphi_{j,k}(t) = \frac{1}{\sqrt{s^j}} \varphi\left(\frac{t - kps^j}{s^j}\right)$$

where s is the scale factor, p is the translation factor and the factor $\sqrt{s^j}$ is for normalization across the different scales. The index j, $j = 1, 2, \ldots, J$, is for the scale, where J is the maximum scale possible given the number of observations for x_t, and k is the number of translations of the wavelet for any given scale. The notations $a_{j,k}$ and $d_{j,k}$ are the wavelet coefficients and $\theta_{j,k}$(t) and $\phi_{j,k}$(t) are corresponding wavelet functions.

The father wavelet integrates to one and the mother wavelet integrates to zero. The details and scaling functions are orthogonal and the original time series can be reconstructed as a linear combination of these functions and the related coefficients:

$$x(t) = A_J(t) + \sum_{j=1}^{J} D_j(t) \tag{15}$$

To be able to use j scales we should have at least 2^j observations.

To filter the integration variables we exclude all the details, mother wavelets $D_j(t)$, with $j \leq 6$. The scale $D_j(t)$ captures information with $2^{j-1}$and 2^j time intervals. Therefore, in our case with weekly data, the effect of filtering is to eliminate all the variations that belong to frequencies higher than 2^6 or 64 weeks.

See Gencay et al (2001) for a detailed discussion on the wavelet method.

4. Analysis

We start the analysis by looking at the descriptive statistics of the returns for countries included in the sample. Table 1 shows the descriptive statistics. The US market has the lowest standard deviation of the returns (15.4% in a yearly basis). The least volatile European countries are the Netherlands (16.5%) and Switzerland (16.7%), while Sweden (23.4%) and Norway (22.9%) have the most volatile returns among countries included in this study.

All the countries, except Germany, have a significant positive excess kurtosis, which reveals the existence of the extreme returns. This deviation from the normal distribution confirms relevance of the models that can capture jumps in the returns. The skewness parameter is not significant for any of the countries included in the sample.

4.1 The SVCJ model

Before going to the spillover analysis we estimate the country variances by applying the SVCJ model presented in Section 2. Table 2 presents the estimated coefficients from this model for all the countries. For most European countries the coefficient of the lagged return, a, is positive but, it is only significant for Austria and Italy. For US the coefficient of the lagged returns is significant and negative. The estimated parameters, ρ_j and ρ show the existence of a leverage effect for most of the countries. The estimated leverage effect in the normal shocks, i.e. the parameter ρ, is only significant for three countries, USA, France and UK. However, we find a much stronger leverage effect in the extreme returns: the estimated ρ_j are negative for nearly all countries and it is significant for Germany, Italy, Norway, Switzerland and the UK. For Norway the jump intensity is high and the average jump size is large and negative, which explains why the leverage effect is captured by ρ_j while ρ becomes positive.

The estimated jump intensities vary between one percent probability of a jump per week for US and nine percent jump probability per week for Ireland. Our parameter estimations deviate somewhat from estimations given by previous studies. This is due to the fact that the characteristics of daily and weekly data are not exactly the same. In weekly data we may identify less jumps comparing to the daily data due to the fact that some extreme shocks may revert during the week. Using daily data on a slightly shorter time horizon we estimate the daily jump probability for the US market to around 0.4 percent, which corresponds to approximately one jump per year. This should be compare with the estimated weekly jump probability on 1 percent, which corresponds to one jump every second year.

Figure 1 illustrates the variance series and jumps estimated for the US and the UK markets. We identify as jumps all the observations for which the probability of jump is larger than a threshold level that results in the number of jumps that is expected based on the estimated jump intensity, λ. As the figure shows we have identified 15 jumps for the US market. All the identified jumps are associated with negative returns and are mostly located around two extreme periods, i.e. 1987-1990 and 2000-2001. We have identified several jumps that are not associated with extreme returns. This depends on the low volatility during the periods under consideration. For the UK market we estimate 35 jumps, of which two are associated with positive returns.

Figure 2 plots the estimated variances of the European countries as well as the European regional market and compares these variances with the estimated variance of the US market. According to the figure, nearly all the markets have a higher variance than the US market over the entire period except the period surrounding year 2000. However, the variance of the value-weighted index of these country indices is in general lower than the US variance. During this period the US market variance is very close to the variances estimated for the other markets except for Sweden. The movements in the variance series for France and the Netherlands seem to be very close to that for the US variance over the entire period. Almost all the countries experience an apparent increase in the volatility around year 2000. Finally, Norway seems to experience a relatively large variance after 2003.

4.2 The spillover model

In this section we present the results of the spillover model described in Section 2.

Wavlet filtering of the integration variables

We first, in Figure 3, illustrate the effect of filtering the variables used to measure the countries' integration by using the wavelet approach. As illustration we choose only the series representing the integration between the US and the UK markets. The figure plots the original series and the filtered series by Wavelet that have been used as the instruments in the model. The filtered series separate out all the variation with frequencies approximately up to one year (64 weeks). There are several apparent advantages with the filtered series. This series captures all the long-term changes of the integration level without being affected by the short-term shocks in the value of the variables or seasonal characteristics of variables.

Variance spillover

Table 3 shows the estimated coefficients of the mean and variance equations of the SVCJ spillover model, and the related test statistics. The coefficients b_1 and c_1, which measure the average spillover from the US and the regional market respectively, are significant for all the countries. The coefficients $b_{1,1}$, which relates the spillover to the import and export with US, is positive for all countries except for Norway and significant in six out of eleven cases, while $b_{1,2}$, the parameters of the USD exchange rate volatility, is negative for all countries except for Sweden and is significant in seven out of eleven cases. The corresponding coefficients for the spillover from the regional market also support a time-varying pattern in the spillover for most countries; the parameter $c_{1,1}$ is positive in eight cases and significant for five countries and $c_{1,2}$ is negative for seven countries and significant in only two cases. The results support earlier works who find that the spillover from the regional market has increased over time (see for instance Kim et al (2005), Baele (2005) and Christianssen (2007)).

The time varying spillover coefficients, b_t and c_t, are plotted in Figure 4. The impact of the US market on the European markets seems to be time-varying, which is in accordance with the discussion above. For Austria, France, Germany, Netherlands and Switzerland there is a tendency that the US spillover has increased by the time. Inside Europe, the spillover seems to have increased over time, particularly after the Maastricht Treaty 1992. In the Maastricht Treaty the economic convergence criteria for EMU membership was set, which might explains why a large proportion of the increased integration occurred before the EMU start 1998. For all EMU countries together with Denmark and Sweden the increased integration is evident. For Norway, Switzerland and UK there is no tendency of increased integration.

To examine to what extent the time-varying variance of a country can be explained by our spillover model, we compute the part of each country's variance which is due to the US and the regional market respectively as a percentage of the countries total variance. As Figure 5 illustrates, Austria, Denmark and Norway have consistently larger idiosyncratic variances, which shows a low degree of integration or/and a higher volatility than the US market and the other European countries. In general, for most countries we observe an increase in the regional variance ratio around 1992 and afterward, which might be related to the development of the European Union (the Maastricht Treaty, 1992).

Figure 6 shows the average variance components for each country. The result, in accordance with Figure 5, shows that, Austria, Denmark and Norway have the lowest spillover from the other European countries. On the other hand, France, Germany, Netherlands and Switzerland are the most integrated countries. The US contributions to the country variances lie in general below the contribution from the European markets. This result is partly supported by Bekaert et al (2005) who find that the regional variance component is higher than the US variance component for small European countries. However, Baele (2005) and Christiansen (2007) find that the US variance component is higher than the regional variance component. This divergence in the results might be related to the length of the data employed by these studies. Our sample contains the recent period with a high integration among the European countries, which implies a higher average spillover within Europe.

Jump spillover

There are three questions that we aim to answer regarding the jump spillover. The first question is the impact of jumps in the US and the European region on the local market returns. As shown in Table 3, the coefficients for the jump spillover from both the US market and the regional market, b_2 and c_1, are positive and significant in all the cases, revealing that extreme shocks spillover to the local markets. To compare the relative impact of the extreme shocks with the normal shocks we have estimated the difference between the jump spillover and the spillover from normal shocks, i.e. b_2-b_1 and c_2-c_1. The difference between b_2 and b_1 is positive in seven out of eleven cases, but it is only significantly positive for UK. The difference between c_2 and c_1 is positive for eight cases and is significant in four out of these eight cases.

The second question is to what extend the jumps in a local market can be explained by the outside shocks. The estimated jump intensities, λ, in the spillover model (Table 3) are considerably lower than the jump intensities estimated by SVCJ models (see Table 2) for all the countries. This suggests that a large part of the country jumps is now explained by the US and European markets return shocks.

The last question is whether the spillover after jumps is different from other periods. This effect is measured by the dummy variables, D_t^{us} and D_t^{eu}, which take the value one from week one up to week 12 (three months) after a jump occurrence in the US market and in the regional market respectively. The coefficient $b_{1,3}$, which measures the effect of D_t^{us} is positive in seven cases and significant in two cases. The coefficient $c_{1,3}$, which measures the effect of D_t^{eu} is positive in six out of eleven cases but not significant in any case. These two results indicate that the spillover after jumps is in general not higher from other periods.

Correlation and international diversification

According to the correlation matrix of the returns in Table 4, Netherlands and UK have the highest correlation with the US market (0.57 and 0.51 respectively). The least correlated European market with the US market is Austria with a correlation of only 0.18 followed by Denmark (0.29). All of the European countries have in average a higher correlation with other European countries than with the USA. The correlation with the regional constructed stock index, where the country under focus is dropped from the index, ranges between 0.52 (for Austria) and 0.84 (Netherlands).

The estimated time-varying correlations, given by equation (11) are presented in Figure 7. It is important to note that in estimating the correlation between the local countries and the regional market the US effect on the regional market is filtered out. In this way we can easier see the dynamics of the correlation, which depends solely on the European factors. In general the correlation between the European countries' stock returns and the US stock returns decreases in the early 1980's and rises again in the beginning of the 1990's. As shown by equation (11) the correlation between the US and the local markets is affected by the spillover coefficient $b_{t,}$ the US variance and the countries' total variance. The spillover coefficient b_t decreases during the 1980's for most country indices (see Figure 4), however not to such extent that it can explain the drops in the correlations illustrated in Figure 7. The lower correlation between US and Europe seems rather be due to an increasing variance amongst the European countries (see Figure 5).

The correlations between the European countries and the regional market have increased during the time period under consideration except for Netherlands, Norway and Switzerland. However, the correlation for the latter countries doesn't seem to be decreasing either.

An interesting question coming up often in the context of the international diversification is the link between volatility and correlation. Hedging is mostly needed when uncertainty increases. Therefore, the benefit of international diversification shrinks if correlation between markets increases in high volatility periods. It must be noted that according to equation (12) there is a direct link between the variance and the correlation; if the variance of the US market increases, everything else the same, the correlation will increase. However, since an increase in the US market variance increases the variances in other countries, the outcome is not given. In Figure 8 we plot the time varying volatility of the US market and the European market as well as the conditional correlation between these markets (estimated according to the equations (12) and (13)). From the figure we can see that the correlation between these markets is high in the periods of high volatility, particularly when the US volatility is high. In fact the US (European) market volatility and the correlation between the US market and the European market have a correlation coefficient equal to 0.69 (0.47).

This relatively large positive comovement between variance and correlation implies that when the US market variance increases it largely contaminates other markets. One may therefore wonder if a US investor can gain from diversification abroad in the period of high volatility. To analyze this issue we estimate the weights of the minimum variance portfolio when a US investor confronts a bivariate portfolio choice: the US equity market and the European equity market. The weight of the US market and the percentage reduction in the volatility if investors hold the minimum variance portfolio are plotted in the two last diagrams of the Figure 8. The figures show that weights of the US market falls from 60% to –20% when the US market volatility is high. This reduction in weight may decrease the volatility up to 50%. Therefore, despite the high correlation between the markets in periods of high volatility, US investors can benefit largely by decreasing their holding on the US market and invest abroad when the US market undergoes a volatile period. When the volatility is low in both markets, e.g. the period 1992-1998, an approximately equal holding in both markets can decrease the volatility with about 30% for investors from both equity markets.

Finally, we look at the correlations and volatility around jumps and analyze their implication for portfolio selection. As in above, we perform this analysis for the bivariate case with the US market and the European regional market and we look at the portfolio selection from viewpoint of a US investor. We use a three-month window (12 weeks) before a jump and a three-month window after a jump, while the jump day is excluded from these windows. Table 5 shows the average variance and correlation as well as the weight of the minimum variance portfolio for the periods around jumps and the entire sample. The first column of the table shows that the volatility of the US market before jumps (2.25%) is slightly higher comparing to volatility over the entire period (2.66%), but it increases to 2.66% in the period following jumps. This higher volatility after jumps is associated with an increase in the correlation between these markets. These results are extremely interesting for risk management. As we see in the last column of the table, the optimal weight of the US market in the minimum variance portfolio decreases from 19% before jumps to 13% after jumps (compare to 26% for the entire period). This means that identifying a jump can be an important signal to a US investor for a portfolio reallocation.

5. Conclusion

In this study we investigate the risk spillover to the equity markets of the European countries during the period 1982-2007. We analyze both the continuous part of the price fluctuations, i.e. the return variance, and the discontinuous price changes due to extreme shocks, i.e. the jumps in returns. The model considers three sources of shocks to each local equity market, i.e. the shocks from the US market, the shocks from the regional market (the other European markets) and the idiosyncratic or local shocks. We extend the model by Bekaert and Harvey (1997) by applying the stochastic volatility model instead of GARCH and allowing for jumps in returns and volatility. This makes it possible to analyze both variance spillover and the spillover of extreme events among the international markets.

We find that almost all of the European markets have a higher variance than the US market over the entire period except the period surrounding year 2000. However, the variance of a value-weighted index of these country indices is, in general, lower than the US market variance. We compute the part of each country's variance that is due to the US market and the regional market as a percentage of the countries total variance. Austria, Denmark and Norway have consistently larger idiosyncratic variances, which shows a low degree of integration or/and a higher volatile markets than the US market and the other European countries. In general, for most countries we observe an increase in the impact from the regional market in pace with the development of the European Union. The US contributions to the country variances lie in general below the contribution from the European markets.

Our analysis of the jump spillover shows that the impact of outside jumps is significant on all the local markets. However, the percentage spillover effect of the extreme shocks is in general not significantly different from the percentage spillover of the normal shocks. We can not find a significant difference in market dependencies during the normal periods and periods after jumps. However, we show that a large part of the country jumps can be explained by the US and European markets return shocks.

We conclude the analysis by looking at implication of our model for risk management. We find a relatively large positive comovement between variance and correlation, which indicates that a large US market volatility contaminates in general to other markets. Despite this fact, we show a large benefit, in term of risk reduction, for the US investors from international diversification in the periods of large market volatility. More importantly, we show that the volatility of the US market increases largely in the period following jumps. This implies considerable changes in the minimum variance portfolio weights. Consequently, the identification of the jump events can be used as an important signal for portfolio reallocation.

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Table 1. Summary statistics

The table shows the summary statistics of the countries' stock markets. The sample period is from May 1982 to May 2007. The data is sampled on a weekly basis, which gives a total number of 1302 observations for each series.

	USA	Aus	Den	Fra	Ger	Ire	Ita	Neth	Nor	Swe	Switz	UK
Mean %	0.20	0.29	0.27	0.24	0.20	0.29	0.19	0.24	0.27	0.27	0.26	0.19
St.dev. %	2.13	2.74	2.60	2.57	2.60	2.80	3.12	2.30	3.19	3.26	2.32	2.38
St.dev. yearly %	15.4	19.9	18.7	18.6	18.7	20.2	22.5	16.5	22.9	23.4	16.7	17.0
p-value (mean)	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00
Excess kurtosis	4.57	3.90	2.15	2.15	1.51	3.71	3.30	2.96	2.83	3.23	3.45	6.96
p-value (kurtosis)	0.00	0.00	0.03	0.03	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Skewness	-0.63	0.14	-0.19	-0.36	-0.31	-0.67	-0.15	-0.49	-0.52	-0.30	-0.39	-0.64
p-value (skewness)	0.53	0.89	0.85	0.72	0.76	0.50	0.88	0.63	0.60	0.76	0.70	0.52

Table 2. Coefficients of the SVCJ model estimated on the country indices

The table shows the posterior estimates of the SVCJ model and the related test statistics. The sample period is from in May 1982 to in May 2007. Data is sampled on a weekly basis, which gives 1302 observations. The returns are scaled by a factor of 100. *The* parameter *m* is the constant expected return, *a* is effect of the one period lagged return on the return, μ_Y is the constant expected jump size in the return, σ_y is the standard deviation of the jump size in the return conditional on the jump size in the variance, ρ_J is the correlation between the jump size in the return and in the variance, $\kappa = -\alpha / \beta$ is the mean reversion level in the variance and $-\beta$ is the speed to the mean reversion level, ρ is the correlation between the returns and the variance generated by the normal shocks, μ_v is the expected jump size in the variance, λ is the jump intensity, σ is the standard deviation of the squared root variance process. The values marked with one asterix are significant at the 5% level and with two asterices are significant at the 1% level.

Coefficients

	US	*Aus*	*Den*	*Fra*	*Ger*	*Ire*	*Ita*	*Neth*	*Nor*	*Swe*	*Switz*	*UK*
m	0.29**	0.04	0.38**	0.33**	0.29**	0.48**	0.18	0.46**	0.56**	0.62**	0.29**	0.25**
a	-0.10**	0.11**	0.00	0.04	0.02	0.05	0.07**	-0.02	0.05	0.01	0.01	-0.04
μ_y	-9.07**	0.24	0.28	-3.83	1.03	-1.89	3.75	-1.60	-0.57	-1.97	2.62	0.90
σ_y	5.03*	6.51*	9.36	5.50	4.07*	5.44*	6.14	3.42**	4.42*	4.38*	4.31*	4.40*
ρ_J	0.97	-0.01	-1.35	0.66	-0.98*	-0.87	-0.75**	-0.47	-1.00**	-0.50	-0.99*	-2.17**
λ	0.01**	0.04*	0.06*	0.04*	0.05*	0.06**	0.05**	0.07**	0.09**	0.07*	0.05**	0.03
β	-0.03**	-0.05**	-0.03**	-0.06**	-0.05**	-0.05*	-0.06**	-0.08**	-0.05**	-0.06**	-0.14**	-0.06**
κ	2.58**	2.30**	2.72*	4.03**	3.13**	3.19**	3.77**	1.87**	2.52	3.56	3.21**	3.94**
ρ	-0.55**	0.50	0.27	-0.52**	0.00	0.04	0.15	-0.13	0.61**	-0.33	-0.22	-0.30*
μ_v	2.63**	5.06**	1.69**	2.45**	3.02**	2.42**	5.11**	2.83**	2.80**	4.30**	3.64**	2.09**
σ	0.17**	0.18**	0.22**	0.24**	0.26**	0.24**	0.21**	0.20**	0.19*	0.28*	0.25**	0.33**

Standard errors

	US	*Aus*	*Den*	*Fra*	*Ger*	*Ire*	*Ita*	*Neth*	*Nor*	*Swe*	*Switz*	*UK*
m	0.05	0.23	0.07	0.08	0.08	0.08	0.09	0.07	0.09	0.16	0.07	0.07
a	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
μ_y	1.78	3.37	1.73	2.19	1.76	2.27	2.24	0.85	1.30	2.56	1.45	2.92
σ_y	2.40	2.69	5.53	2.81	1.80	2.67	4.00	1.32	1.90	2.07	1.98	2.13
ρ_J	0.62	0.43	0.78	0.74	0.39	0.76	0.22	0.31	0.26	0.30	0.44	0.76
λ	0.00	0.02	0.03	0.02	0.02	0.02	0.02	0.03	0.03	0.03	0.02	0.02
β	0.01	0.01	0.01	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.04	0.02
κ	0.56	0.78	1.08	0.56	0.94	1.04	0.93	0.49	1.33	1.83	0.38	0.99
ρ	0.11	0.27	0.21	0.19	0.16	0.17	0.18	0.18	0.19	0.19	0.20	0.14
μ_v	0.98	1.98	0.44	0.84	0.96	0.73	1.42	0.98	0.56	1.35	1.34	0.75
σ	0.05	0.06	0.05	0.06	0.09	0.09	0.07	0.05	0.07	0.11	0.09	0.07

Table 3. Coefficients of the spillover model

The table reports the posterior estimates of the spillover model and the related test statistics. We use weekly data from in May 1982 to in May 2007. Data is sampled on a weekly basis, which gives 1302 observations on each series. The coefficient $b_{1,0}/c_{1,0}$ is the constant spillover effect from US/regional market, $b_{1,1}/c_{1,1}$ is the spillover effect from economic integration with US/regional market, $b_{1,2}/c_{1,2}$ is the spillover effect from financial integration with US/regional market, $b_{1,3}/c_{1,3}$ is the coefficient of a dummy variable capturing the spillover up to three months after a jump event in US/regional market, b_1/c_1 is the mean spillover estimated at the average values of the integration variables, b_2/c_2 is the spillover effect from jumps in US/regional market, m is the constant expected return, a is effect of the one period lagged return on the return, μ_y is the constant expected jump size in the return, σ_y is the standard deviation of the jump size in the return conditional on the jump size in the variance, ρ_J is the correlation between the jump size in the return and in the variance, λ is the jump intensity, $\kappa = -\alpha / \beta$ is the mean reversion level in the variance and $-\beta$ is the speed to the mean reversion level, ρ is the correlation between the returns and the variance generated by the normal shocks, μ_v is the expected jump size in the variance and σ is the standard deviation of the variance process. The values marked with one asterix are significant at the 5% level and with two asterices are significant at the 1% level.

Coefficient

	Aus	*Den*	*Fra*	*Ger*	*Ire*	*Ita*	*Neth*	*Nor*	*Swe*	*Swi*	*UK*
m	0.23^{**}	0.39^{**}	0.39^{**}	0.34^{**}	0.42^{**}	0.30^{**}	0.35^{**}	0.46^{**}	0.49^{**}	0.31^{**}	0.28^{**}
a	0.09^{**}	0.00	-0.04^{**}	0.01	0.04^{*}	0.03	-0.03^{*}	0.03	-0.01	-0.01	-0.07^{**}
$b_{1,0}$	0.75^{**}	0.54^{*}	1.12^{**}	0.25	0.53^{**}	0.90^{**}	1.16^{**}	0.50	0.00	1.15^{**}	0.76
$b_{1,1}$	6.20^{*}	9.64^{*}	15.69^{**}	14.87^{**}	0.29	1.04	7.68^{**}	-0.04	8.50^{*}	2.41	0.77
$b_{1,2}$	-0.49^{**}	-0.37^{*}	-0.64^{**}	-0.18	-0.11	-0.26^{*}	-0.74^{**}	-0.04	0.21	-0.54^{**}	-0.22
$b_{1,3}$	-0.16^{*}	0.08	-0.06	-0.06	0.09	0.00	0.01	-0.03	0.15	0.01	0.15^{*}
$c_{1,0}$	-0.41	-0.55	0.16	1.03^{**}	1.96^{**}	0.99	0.83^{**}	2.20^{**}	-0.12	0.83^{*}	1.34^{*}
$c_{1,1}$	2.30^{**}	3.13^{**}	3.49^{**}	0.21	-1.66^{**}	0.12	0.24	-1.46	3.67^{**}	0.39	-0.86
$c_{1,2}$	0.53^{**}	0.23	0.02	-0.10	0.07	-0.25^{**}	-0.17	-0.80	-0.14	-0.07	-0.10
$c_{1,3}$	-0.13	0.00	-0.02	0.05	0.13	0.02	-0.05	-0.15	0.01	0.00	-0.06
b_1	0.18^{**}	0.31^{**}	0.64^{**}	0.55^{**}	0.43^{**}	0.55^{**}	0.55^{**}	0.44^{**}	0.71^{**}	0.42^{**}	0.51^{**}
c_1	0.82^{**}	0.75^{**}	1.02^{**}	1.06^{**}	0.87^{**}	0.88^{**}	0.89^{**}	0.88^{**}	0.88^{**}	0.93^{**}	1.04^{**}
b_2	0.30^{**}	0.46^{**}	0.59^{**}	0.48^{**}	0.54^{**}	0.50^{**}	0.63^{**}	0.61^{**}	0.44^{**}	0.53^{**}	0.63^{**}
c_2	0.60^{**}	1.38^{**}	1.24^{**}	1.36^{**}	1.10^{**}	1.16^{**}	0.83^{**}	1.01^{**}	1.13^{**}	0.92^{**}	1.05^{**}
$b_2 - b_1$	0.12	0.15	-0.05	-0.07	0.11	-0.05	0.08	0.17	-0.27^{**}	0.11	0.12^{*}
$c_2 - c_1$	-0.23	0.63^{**}	0.22	0.30^{**}	0.23^{*}	0.28^{*}	-0.06	0.12	0.26	-0.01	0.02
μ_y	1.69	4.52	-1.12	-1.45	-4.68	3.11	0.95	-2.90	-1.63	1.52	-2.01
σ_y	6.12^{*}	5.31	6.77^{*}	5.18	5.98^{*}	8.10	4.61^{*}	4.96	4.45^{*}	4.14^{*}	11.67^{*}
ρ_J	-0.24	-0.48	0.97	0.03	1.02^{*}	-0.78	0.08	0.75	-1.34^{**}	0.00	0.13
λ	0.04^{**}	0.02	0.02^{*}	0.01	0.03^{*}	0.02^{*}	0.01^{**}	0.04	0.03^{*}	0.02	0.02^{*}
β	-0.09^{**}	-0.03^{*}	-0.02^{**}	-0.01^{*}	-0.03^{**}	-0.01^{**}	-0.04^{**}	-0.04^{**}	-0.02^{**}	-0.03^{**}	-0.01^{*}
κ	1.69^{**}	3.12^{*}	0.62^{**}	1.47	1.82^{**}	1.34	0.83^{**}	4.00^{**}	1.99^{*}	1.35^{**}	1.07
ρ	0.22	-0.01	-0.02	0.20	0.02	0.28	0.15	-0.10	-0.07	-0.26	-0.50
μ_v	5.59^{**}	2.08^{**}	2.16^{**}	1.84^{*}	2.48^{**}	2.76^{**}	1.80^{**}	2.35^{*}	2.27^{**}	1.36^{**}	1.38^{**}
σ	0.17^{**}	0.27^{**}	0.10^{**}	0.12^{**}	0.15^{**}	0.14^{**}	0.13^{**}	0.30^{**}	0.18^{**}	0.15^{**}	0.10^{**}

Table 3. Coefficients of the spillover model (continued)

	Standard errors										
	Aus	*Den*	*Fra*	*Ger*	*Ire*	*Ita*	*Neth*	*Nor*	*Swe*	*Swi*	*UK*
$\boldsymbol{m}$	0.05	0.05	0.03	0.04	0.05	0.04	0.03	0.07	0.06	0.04	0.08
$\boldsymbol{a}$	0.02	0.02	0.01	0.01	0.02	0.02	0.01	0.02	0.02	0.02	0.02
$\boldsymbol{b}_{1,0}$	0.20	0.24	0.15	0.18	0.17	0.18	0.13	0.31	0.26	0.28	0.58
$\boldsymbol{b}_{1,1}$	2.87	3.96	2.94	2.09	0.78	3.78	1.16	4.41	3.94	1.94	2.70
$\boldsymbol{b}_{1,2}$	0.14	0.17	0.11	0.11	0.11	0.12	0.09	0.21	0.16	0.14	0.42
$\boldsymbol{b}_{1,3}$	0.07	0.08	0.05	0.05	0.08	0.07	0.04	0.09	0.09	0.06	0.07
$\boldsymbol{c}_{1,0}$	0.25	0.45	0.36	0.29	0.33	0.61	0.23	0.84	0.46	0.38	0.65
$\boldsymbol{c}_{1,1}$	0.42	0.89	1.22	0.78	0.50	2.36	0.31	1.80	0.76	0.69	2.46
$\boldsymbol{c}_{1,2}$	0.17	0.31	0.17	0.14	0.09	0.09	0.09	0.42	0.15	0.14	0.36
$\boldsymbol{c}_{1,3}$	0.08	0.07	0.06	0.06	0.08	0.08	0.04	0.10	0.08	0.06	0.09
$\boldsymbol{b}_1$	0.03	0.03	0.02	0.02	0.03	0.03	0.02	0.04	0.03	0.02	0.03
$\boldsymbol{c}_1$	0.04	0.04	0.03	0.03	0.04	0.04	0.02	0.04	0.04	0.03	0.04
$\boldsymbol{b}_2$	0.07	0.08	0.04	0.05	0.10	0.06	0.05	0.09	0.08	0.05	0.05
$\boldsymbol{c}_2$	0.12	0.17	0.11	0.10	0.11	0.11	0.08	0.15	0.16	0.09	0.12
$\boldsymbol{b}_2 - \boldsymbol{b}_1$	0.08	0.09	0.05	0.06	0.10	0.07	0.05	0.10	0.09	0.06	0.05
$\boldsymbol{c}_2 - \boldsymbol{c}_1$	0.13	0.18	0.11	0.11	0.12	0.12	0.08	0.16	0.17	0.10	0.13
μ_y	1.65	3.61	1.72	3.24	2.80	3.88	3.79	2.61	2.19	1.47	2.29
σ_y	2.64	3.06	2.81	2.76	2.65	6.02	2.17	3.18	2.13	1.98	5.59
ρ_J	0.21	1.55	0.53	1.04	0.52	0.74	1.64	1.16	0.49	1.08	1.13
λ	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01
β	0.02	0.01	0.01	0.00	0.01	0.00	0.01	0.01	0.01	0.01	0.00
κ	0.28	1.51	0.24	1.00	0.42	1.10	0.14	1.48	0.80	0.47	0.69
ρ	0.19	0.18	0.19	0.16	0.30	0.15	0.16	0.20	0.16	0.22	0.28
μ_v	1.39	0.80	0.68	0.82	0.72	0.80	0.55	1.02	0.76	0.44	0.47
σ	0.04	0.07	0.02	0.02	0.04	0.04	0.02	0.10	0.04	0.03	0.02

Table 4. Correlation matrix of the returns

The table shows the correlation between the returns of the European countries. The last column shows the correlation with the regional market index where the European country under the consideration is excluded from the index. We use weekly data from in May 1982 to in May 2007.

	USA	*Aus*	*Den*	*Fra*	*Ger*	*Ire*	*Ita*	*Neth*	*Nor*	*Swe*	*Switz*	*Region. market*
USA												0.49
Aus	0.18											0.52
Den	0.29	0.42										0.58
Fra	0.49	0.46	0.48									0.75
Ger	0.47	0.55	0.54	0.71								0.76
Ire	0.38	0.39	0.47	0.51	0.53							0.66
Ita	0.34	0.38	0.45	0.56	0.56	0.43						0.60
Neth	0.57	0.44	0.54	0.71	0.76	0.58	0.53					0.84
Nor	0.33	0.40	0.45	0.46	0.50	0.49	0.36	0.57				0.59
Swe	0.46	0.34	0.45	0.56	0.62	0.46	0.48	0.57	0.48			0.64
Switz	0.42	0.52	0.54	0.66	0.73	0.56	0.50	0.74	0.51	0.55		0.77
UK	0.51	0.37	0.45	0.60	0.58	0.62	0.47	0.71	0.50	0.50	0.62	0.69

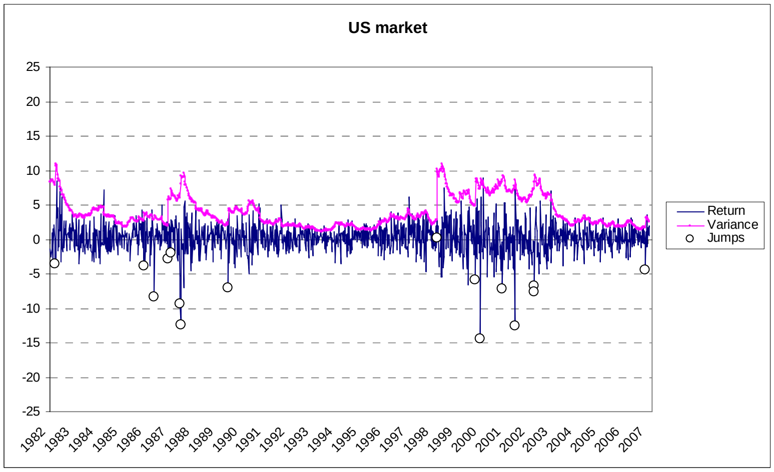
Table 5. Jumps and diversification

The table shows US volatility, the correlation between the US market and the European market, and the US weight in the minimum variance portfolio (MVP). The values are shown for a three-month period before and after jumps as well as for the entire period. We use weekly data from in May 1982 to in May 2007.

	Volatility US	Correlation US vs Europe	MVP weight US
Before Jump	2.25	0.54	0.19
After Jump	2.66	0.57	0.13
Entire period	2.00	0.49	0.26

Figure 1. Return, variance and jumps

The figure shows the returns and the estimated spot variance and jump times on the US market and the UK market. We use weekly data from in May 1982 to in May 2007. The spot variance and the jump times are estimated by assuming that the stock price returns follow a SVCJ model.



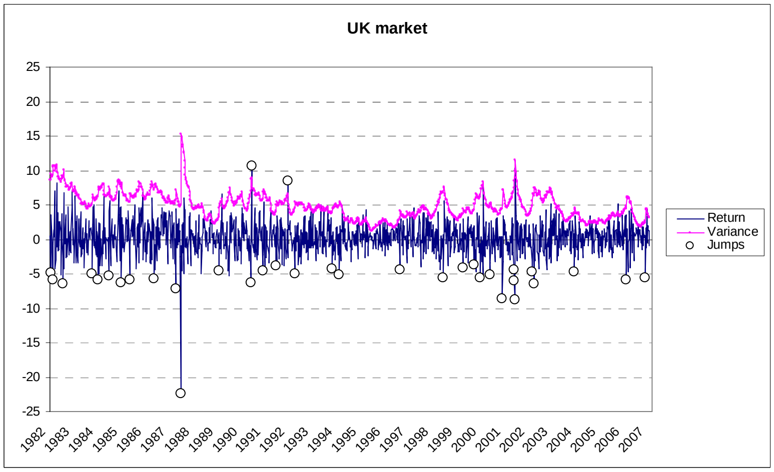


Figure 2. The variance series estimated by the SVCJ model for European countries

The figure illustrates the estimated variance process for the European countries together with the variance process for US. We use weekly data from in May 1982 to in May 2007.

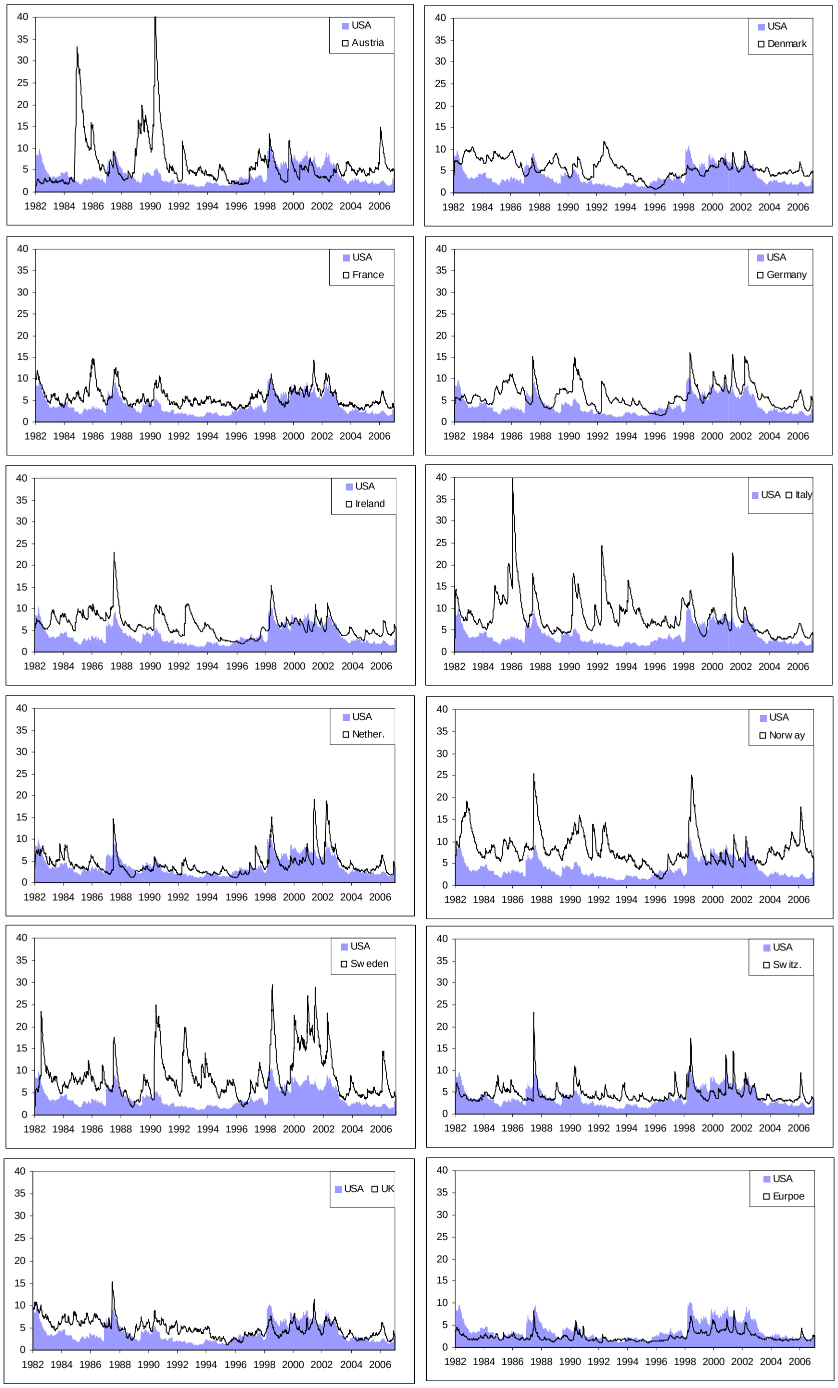
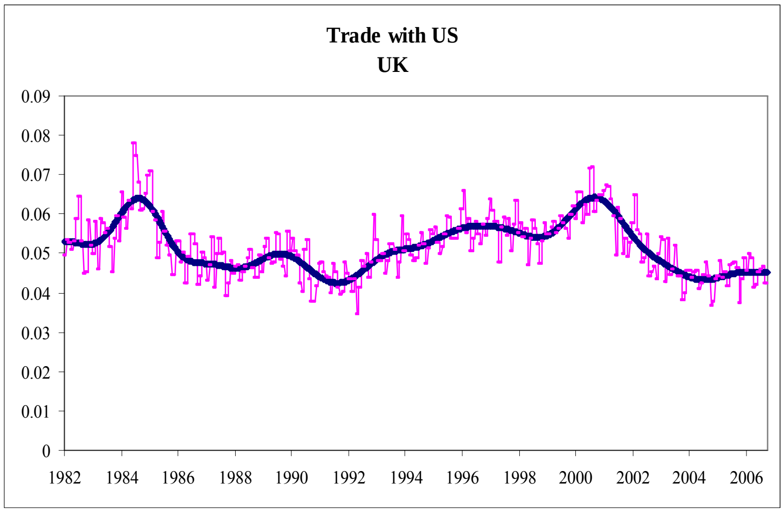


Figure 3. The effect of filtering the instrumental variables by Wavelet

The figure shows effects of filtering the integration variables, i.e. the relative trade and the exchange rate volatility. To save space we show only the series for the UK. The variable trade is the ratio between import plus export and GDP. The exchange rate volatility is estimated by an AR-GARCH(1,1) model.



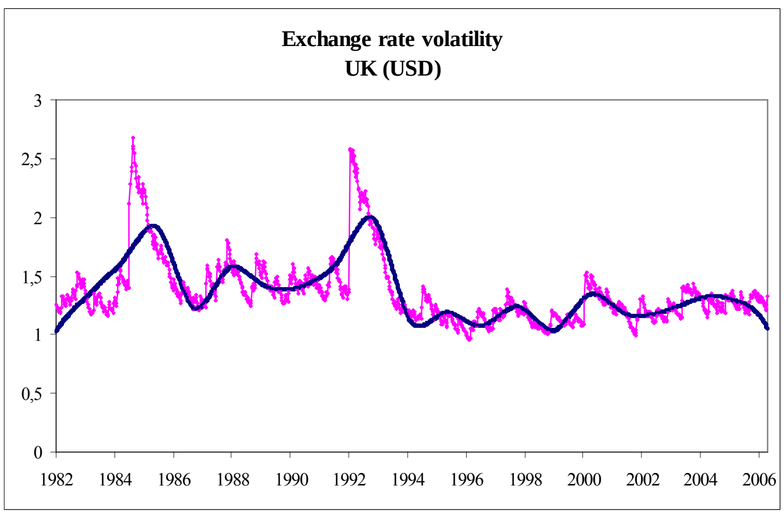


Figure 4. Degree of integration with the US and regional market

The figure shows the time-varying degree of integration estimated by the spillover model. The degree of integration is measured by the time-varying coefficients $b_{1,t}$, for the US market, and $c_{1,t}$, for the regional market (see equation 5).

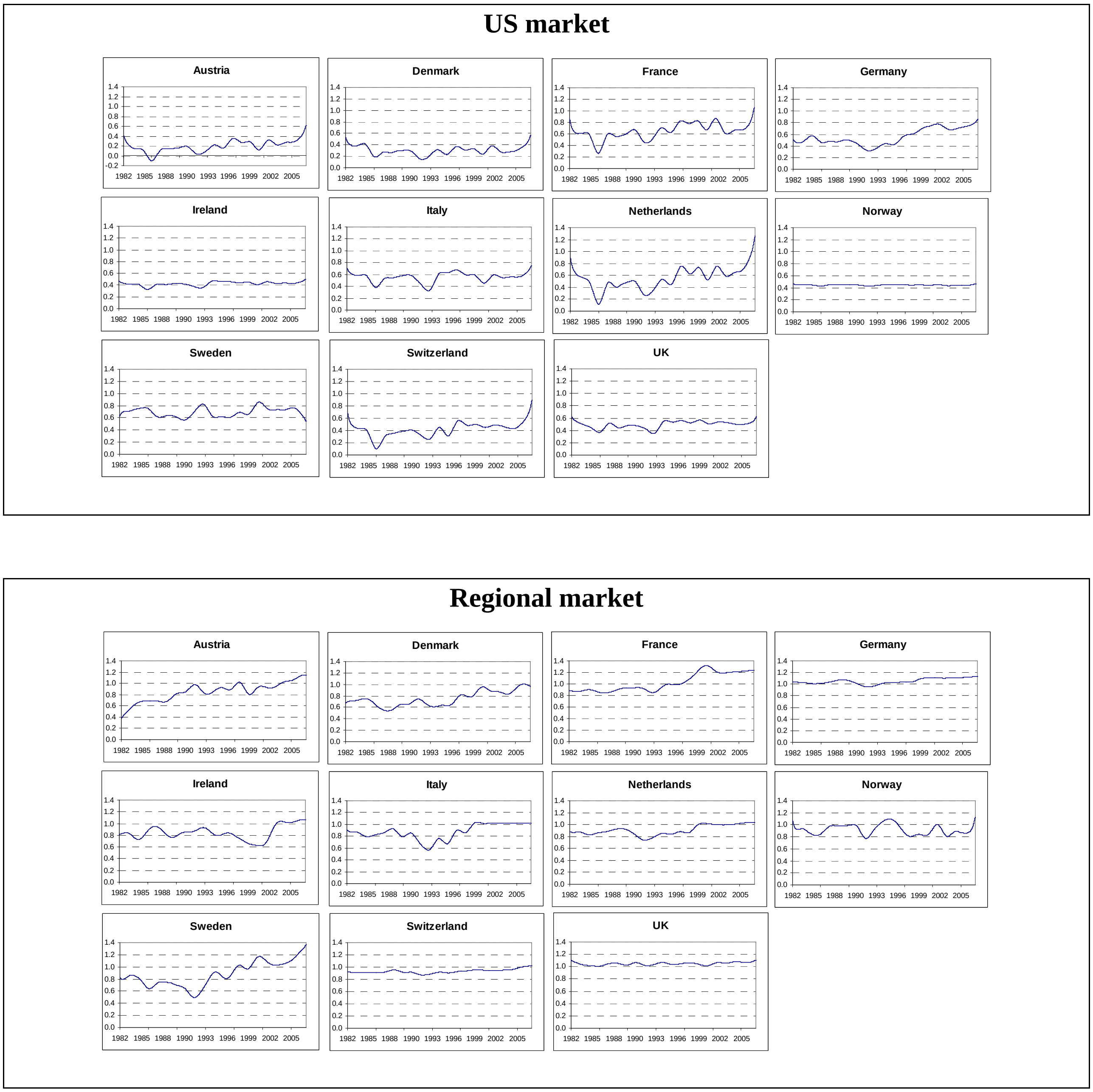


Figure 5. Percentage contribution of the US and the regional market to the country variance

The figure reports the percentage contribution of the European countries variances decomposed in three categories: US variance, regional variance and idiosyncratic variance. The variances are estimated by the spillover model.

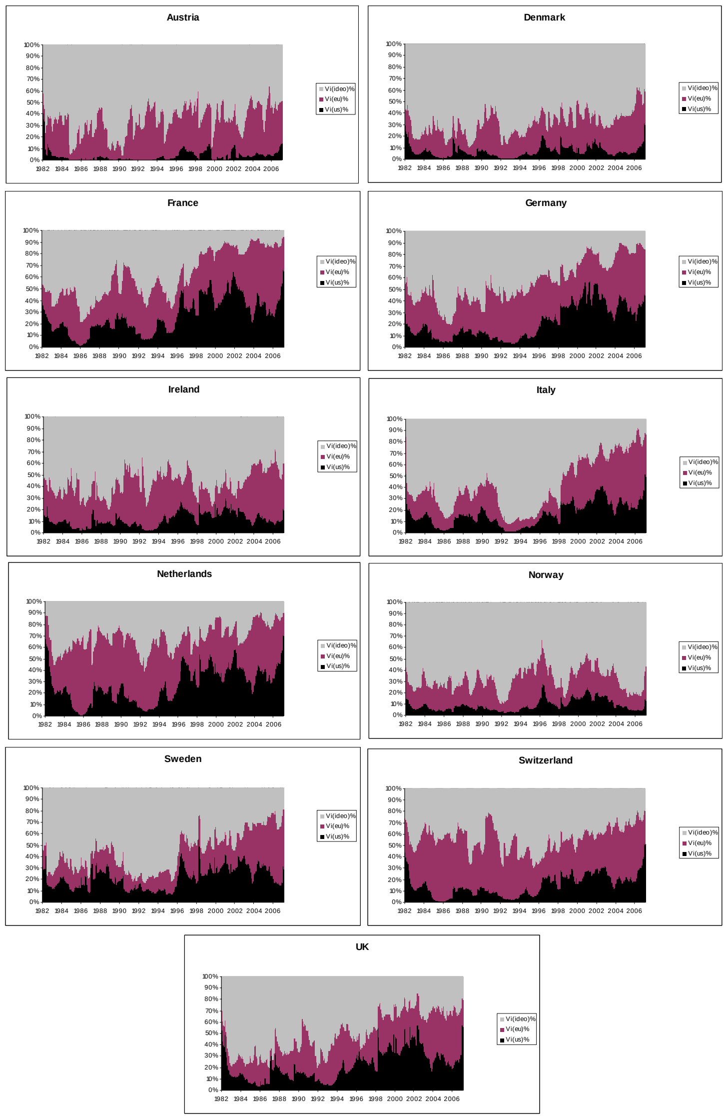


Figure 6. Average percentage variance components

The figure shows the average of the time-varying variance components. The variance components are divided into three components: US, regional and idiosyncratic variance. The components are estimate by the spillover model.

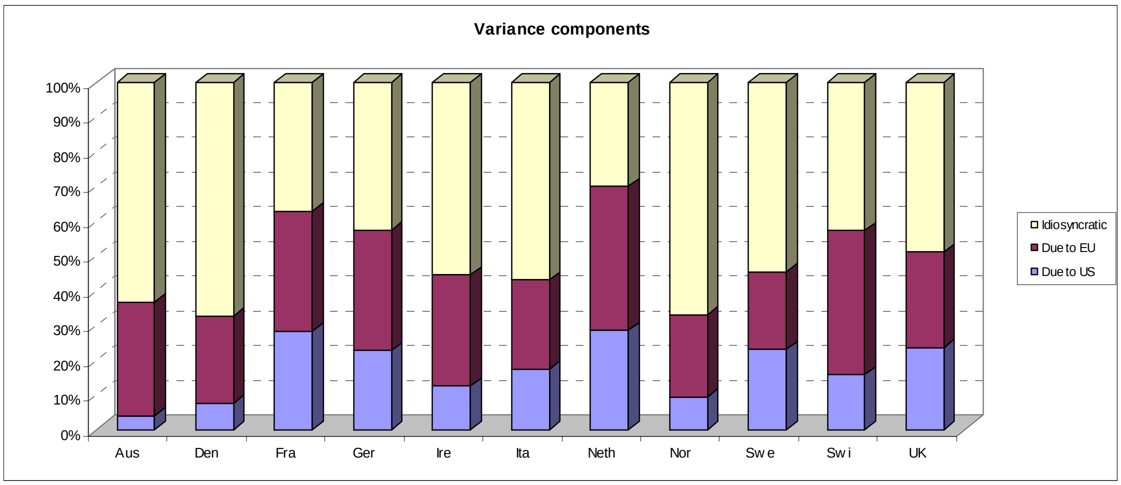


Figure 7. Estimated time-varying correlations

The figure shows the time-varying correlation between the normal shocks of the local markets with those of the US market and regional market. The correlations are estimated by the spillover model.

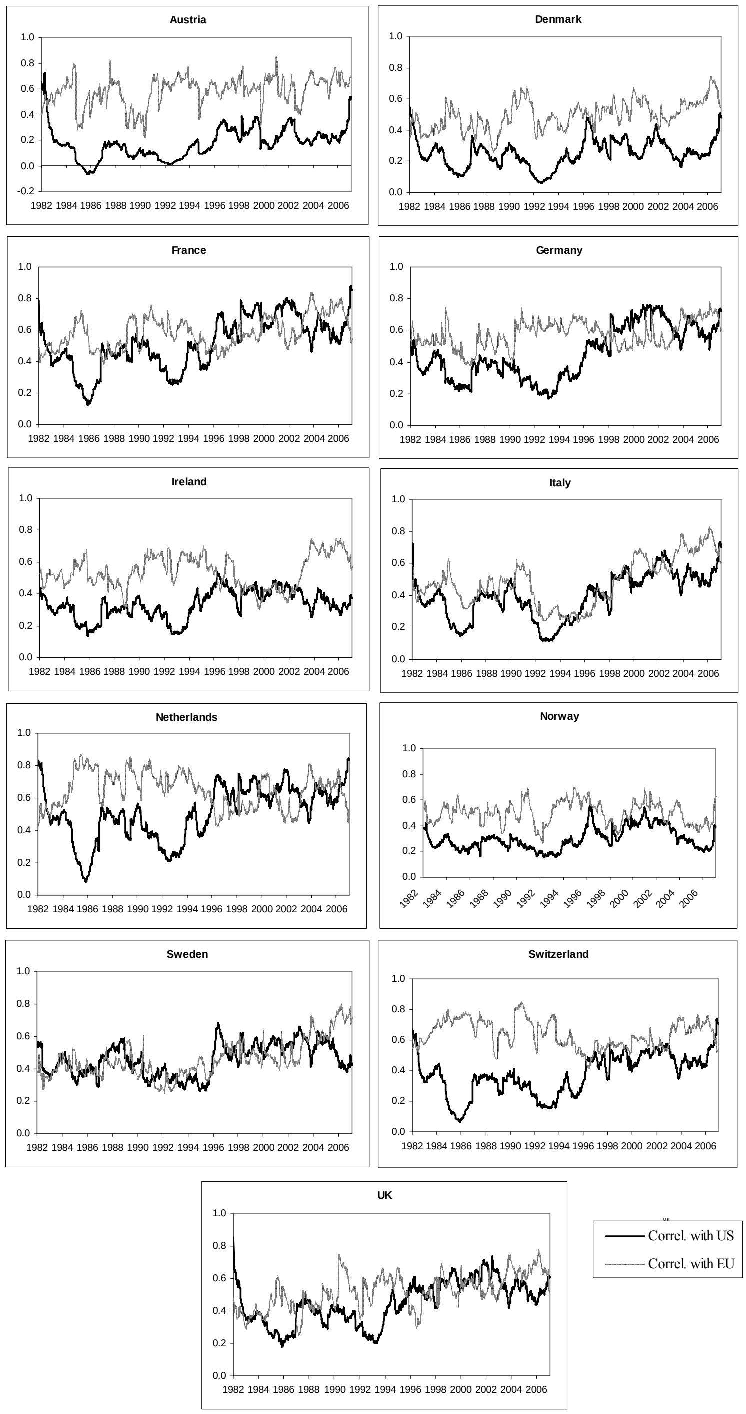


Figure 8. Volatility, correlation and diversification

The figure plots volatility of the US and the European markets, the correlation between these markets, as well as the weight of the minimum variance portfolio (MVP). In addition, it illustrates the risk reduction by investing in the MVP. The data sample is from May 1982 to May 2007.