Volatility and Error Transmission Spillover Effects: Evidence from Three European Financial Regions

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Abstract

This study uses the multivariate GARCH-BEKK modelling approach to examine the transmission of news (both volatility and error) between portfolios of cross-listed equities within three European financial regions, that is, the Scandinavian (Denmark, Sweden, Finland and Norway), the Germanic (Austria, Switzerland and Germany) and the French area (Brussels, France, Italy, Holland and Spain). We find that the Finnish and Danish portfolios of cross-listed equities are the main transmitters of volatility relative to the Swedish and Norwegian portfolios of cross-listed equities. On the other hand, the Swiss portfolio of cross-listed equities is the major exporter of volatility and error to the other portfolios of cross-listed equities in the Germanic stock market area. Finally, the Paris, Amsterdam and Brussels stock exchanges are the major exporters of volatility and error to the portfolios of cross-listed equities traded on the Milan and Madrid stock exchanges.

Keywords: Volatility transmission, GARCH models, spillover effects, cross-listings.

JEL classification: G15.

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1. Introduction

The abolishments of the last remaining barriers to the free flow of goods and capital, as well as the revolution in information technology, have been the main determinants for the growing international integration of financial markets during the last decades (Ane and Labidi, 2006). More specifically, the information technology revolution has had a tremendous impact on the structure of financial markets since the quick diffusion of information and the substantial deregulation and harmonisation which led to increasing free flow of capital across markets has fostered integration (Gallo and Otrando, 2008). Cross-listing of securities is another driver that fostered the market integration since a shock occurred in one market is quickly transmitted to the others. Also, the issue of interdependence among national stock markets has attracted significant research attention, especially in the wake of the October 1987 crash, which brought about correlated stock price movements across international stock markets (Kanas, 1998). The academic interest has been addressed to the investigation of stock market interdependence in terms of conditional second moments of the distribution of returns, alternatively known as volatility spillovers.

This study examines the existence of volatility and error spillover effects within three European financial regions, that is, the Scandinavian (comprising the stock markets of Copenhagen, Stockholm, Helsinki and Oslo), the Germanic (comprising the stock markets of Vienna, Zurich and Frankfurt) and the French area (comprising the stock markets of Brussels, Paris, Milan, Amsterdam and Madrid). The purpose of this paper is to find the exact spillover mechanism which exists in these stock exchanges within the three different European financial regions. We seek to explore whether there exists a fully or partially integrated stock market within the aforementioned three different European financial regions that are characterized by diverse structures.

Employing the GARCH-BEKK advanced technique, we find that the Finnish and Danish portfolios of cross-listed equities are the main transmitters of volatility with respect to the Swedish portfolios of cross-listed equities. Furthermore, in the Germanic stock market area, we evidence that the Swiss portfolio of cross-listed equities is the major exporter of volatility and error to the other portfolios of cross-listed equities. Finally, in the French stock market area, we observe that the Paris, Amsterdam and Brussels stock exchanges are the major exporters of volatility and error to the portfolios of cross-listed equities traded on the Milan and Madrid stock exchanges. However, the Spanish portfolio of cross-listed equities appears to receive negative volatility and error information from the other stock markets in the French area. This implies that negative news is more persistent on these stock markets that export volatility to the Spanish portfolio of cross-listed equities.

We believe that our results contribute to the ongoing debate about market interdependence by considering three financial regions that have not been previously examined together. Moreover, we apply an advanced econometric technique to address all issues raised. Our results suggest that volatility and error transmission depends on the dynamic nature of the cross-listed equities. Moreover, the results indicate that regulators should focus on cross-listed equities as they might produce different interactions between stock markets and lead to different conclusions than the results produced from the investigation of stock indices as previous studies did in the past.

This study was structured as follows. Section 2 presents a brief literature review. Section 3 outlines the research design and discusses the dataset and the sample selection process. Section 4 provides the empirical results and Section 5 contains the main conclusion of the study.

2. Literature review

In the literature, volatility clustering is very closely related to the volatility transmission and a number of studies have considered this phenomenon. More specifically, the studies of Von Furstenberg and Jeon (1989), Hamao et al. (1990), Neumark et al. (1991), Susmel and Engle (1994), King et al. (1994), Karolyi and Stulz, (1996), Kroner and Ng (1998), Jacobsen and Dannenburg (2003) and Fernadez-Izquierdo and Lafuente (2004) demonstrate this type of transmission of news between stock markets. In their analyses, they report that the transmission of volatility between markets is time-varying, that lags spillovers of price changes and price volatility exists between major stock markets and that, when volatility is high, price changes in major stock markets tend to become highly correlated.

A bulk of the literature focuses on the transmission of news between the US and other major stock markets. For example, Hamao et al. (1990), Koutmos and Booth (1995) and Susmel and Engle (1994) focus on spillovers across New York and London, while Theodossiou and Lee (1993) examine spillovers across the US, Japan, Canada and Germany. Specifically, Hamao et al. (1990) find the existence of spillovers from the US and UK markets to Japan. Koutmos and Booth (1995) find that the transmission of volatility is asymmetric and is more pronounced when news is bad and coming from either the US or the UK market. Other evidence from Susmel and Engle (1994) find that volatility transmission is short and small between New York and London, in contrast to Theodossiou and Lee (1993) who also note that the US capital market is the major 'exporter' of volatility to the other financial markets. Also, Billio and Pelizzon (2003) find that volatility spillovers from both the world index and the German market have increased after the introduction to EMU for most European stock markets.

The literature review on transmission effects between European stock markets is relatively limited and tends to focus on the main world stock exchanges. For example, Kanas (1998) examines spillovers effects between European markets (i.e. London, Paris and Frankfurt) and shows that returns and noise spillovers across these markets vary more for those with diverse legal and operational features compared to those with similar structures. In another study, Kanas (2002) finds evidence of mean and variance spillovers from large to small firm portfolios, but not vice versa. The result holds for both weighting schemes and the existence of such spillovers suggests that profitable mean- and variance-based trading strategies exists in the UK stock market. A more recent study by Harris and Pisedtasalasai (2006) investigates return and spillover effects between the FTSE100, FTSE250 and FTSE Small Cap equity indices using a multivariate GARCH framework. They find that volatility transmission mechanism between large and small stocks in the UK is asymmetric.

Another strand of the pertinent literature focuses on the transmission of news between cross-listed equities in order to examine the validity of the information that is transmitted with this kind of dataset. Karolyi (1995), for instance, examines volatility spillover effects between the S&P 500 and the Toronto Stock Exchange index (TSE 300) and demonstrates that such spillovers on the portfolios of 'inter-listed' versus 'non-inter-listed' stocks are distinctly different. That is, the magnitude and persistence of S&P 500 stocks are greater for subsequent returns of 'inter-listed' stocks than 'non-inter-listed' stocks. Likewise, Eun and Jang (1997) find statistical evidence that there are dynamic interactions among the prices of stocks that are 'cross-listed' on the three major stock markets of the world, that is, New York, London, and Tokyo. However, the investigation on spillovers between cross-listed stocks in Europe remained underdeveloped[2].

Finally, the research methodology employed by most of the aforementioned studies typically involves the use of GARCH models to examine transmission patterns. Thus, we can conclude that the power of univariate GARCH models is relatively low and in their critique of such models Martens and Poon (1999) indicate that they are imprecise in estimating true spillover patterns and that systematic error that is related to factors like transmission smoothing patterns biased GARCH estimates. For instance, Hamao et al. (1990) does not confirm if their results are a ‘true spillover effect’ or a ‘non-dynamic correlation’ problem. Theodossiou, et al. (1997), Ng (2000) and Fernadez-Izquierdo and Lafuente (2004) use a multivariate GARCH modelling framework to address some of these limitations.

The aim of this paper is to advance the established literature on European volatility and error transmission by using a multivariate GARCH model to examine the transmission of news within three different European financial regions. The empirical analysis is conducted using data from the cross-listed equities on twelve European stock exchanges, details of which are outlined in the following section.

3. Data and Methodology

3.1 Sample selection

Tables 1 and 2 present the daily dataset of the stock prices for European cross-listed equities, which were obtained from the Datastream database over the period 1987 to 2006. It is noted that Austria and Finland have the smallest number of cross-listed equities (7) and also the smallest number of within sample inter-listed equities (11 and 4, respectively) while the maximum number (56) of cross-listed equities are found to be traded on the German stock market with 74 within sample inter-listed equities. In total, we identify 230 cross-listed equities and 336 within sample inter-listed equities which are controlled for the survivorship bias that might arise from mergers, delistings and de-mergers.

[Insert Table 1 and 2 about here]

Table 3 contains the descriptive statistics for the portfolios of cross-listed equities. We observe that there is excess kurtosis in the whole dataset of the regional portfolios of cross-listed equities apart from those equities that are cross-listed on the Helsinki and Milan stock exchanges. There is also negative skewness in the whole European portfolio of cross-listed equities, except for the European cross-listed equities traded on the Milan and Helsinki stock

[2] see Karolyi (2004) for an excellent review of the cross listing literature

exchanges which display left fat tails. Moreover, the Oslo stock exchange appears to have the minimum mean value of return (0.00012) whereas the Helsinki stock exchange has the maximum value of return (0.00050).

[Insert Table 3 about here]

Table 4 provides the results of the first order difference for the residuals of an autoregressive conditional heteroskedastic model within a linear relationship between current residuals and previous day's residuals for the portfolios of European cross-listed equities. In this table we check for the existence of ARCH effects (heteroskedasticity) by comparing the critical value of the chi-squared statistic with 1 degree of freedom with the value of each portfolio of cross-listed equities. The results reject the null hypothesis of no heteroskedasticity for all portfolios of cross-listed equities. Therefore, the presence of strong heteroskedasticity (ARCH effects) in the whole dataset of cross-listed equities allows us to employ the GARCH-BEKK model to investigate the transmission of news between European portfolios of cross-listed equities.

[Insert Table 4 about here]

3.2. Modelling volatility and error transmission between cross-listed portfolios of equities

According to Berndt et al. (1974) and Engle and Kroner (1995), the multivariate GARCH-BEKK model takes the following form:

$$r_t = \alpha + \sum_{p=1}^{n} \Phi_p r_{t-n} + e_t, e_t \mid \Omega_{t-1} \sim N(0, H_t) \quad (1)$$

where,

r_t is the return series,

e_t is the error term of the return equation,

α is the constant term in the above return equation,

Φ_p is the matrix of coefficients with the p lagged values of r_t,

Ω_{t-1} is the matrix of conditional past information that includes the p lagged values of r_t.

and

$$H_{t+1} = CC' + \mathrm{B}'H_t B + A'\varepsilon_t * \varepsilon_t' \mathrm{A} \tag{2}$$

where the daily index returns, for example, for the Scandinavian portfolios of cross-listed equities are the logarithm of the stock price relative to the Danish portfolio of cross-listed equities (r_{1t}), the Swedish portfolio of cross-listed equities (r_{2t}), the Finnish portfolio of cross-listed equities (r_{3t}) and the Norwich portfolio of cross-listed equities (r_{4t}) where the returns vector is denoted by $r_t^{'} = [r_{1t}, r_{2t}, r_{3t}, r_{4t}]$. The residual vector is given by $\varepsilon_t^{'} = [e_{1t}, e_{2t}, e_{3t}, e_{4t}]$, with its corresponding conditional covariance matrix is $\{\mathrm{H}_{t+1}\}_{ij} = h_{ij,t+1}$. The parameter vectors of the mean returns in Equation (1) are defined as $\alpha^{'} = [a_1, a_2, a_3, a_4]$ for the constant and $\{\Phi_p\}_{ij} = \phi_{ij,p}$ for the matrix of coefficients with the p lagged returns. The parameter matrices for the variance in Equation (2) are defined as $\{\mathrm{C}\}_{ij} = \mathrm{c}_{ij,t}$ and free matrices are defined as $\{\mathrm{B}\}_{ij} = \beta_{ij,t}$ and $\{\mathrm{A}\}_{ij} = \mathrm{a}_{ij,t}$.

Equation (1) models the portfolios of cross-listed equities as an AR process. The aforementioned univariate return model allows us to measure the effects of an innovation in the stock returns of one market on its own lagged return. Equation (2) models the dynamic process of H_{t+1} as a linear function of its own t past values as well as t past values of squared innovations $(\varepsilon_t \varepsilon_t^{'})$ both of which allow for own-market and cross-market influences in the conditional variances. This model has been constructed by Baba, Engle, Kraft, and Kroner (1989), known as BEKK. The important characteristic of this model is that it allows the conditional variances and covariances of the four portfolios of cross-listed equities to influence each other and, at the same time, it does not require the estimation of many parameters. The BEKK model guarantees that the covariance matrices in the system are positive definite.

We justify the conditional mean returns and the conditional volatility equations using the optimal lag-length algorithm of Akaike information criterion. Thus, sequential testing procedures are employed to determine the order of the AR process as well as the conditional equation of the GARCH-BEKK process.

Given a sample of T observations of the returns vector, R_{t+1}, the parameters of the four-variable systems are estimated by computing the conditional log-likelihood function for each time period as follows:

$$L_t(\Theta) = -\log 2\pi - \frac{1}{2}\log|H_{t+1}| - \frac{1}{2}E(\varepsilon_t)'(\Theta)H_t^{-1}(\Theta)E(\varepsilon_t)(\Theta)$$

and

$$L(\Theta) = \sum_{t=1}^{T} L_t(\Theta) \quad (3)$$

where Θ is the vector of all parameters. Following Berndt et al's (1974) algorithm, numerical maximization of the log-likelihood function yields the maximum likelihood estimates and associates asymptotic standard errors.

4. Empirical Results

In this section we present the results from the transmission mechanism between different portfolios of cross-listed equities within three European regions (Scandinavian, Germanic and French area). For ease of exposition, we report only the results that appear to be statistically significant at the 5% significance level.

Table 5 reports the spillover effects between various portfolios of cross-listed equities within the Scandinavian area. In particular, the transmission of news between the portfolios of cross-listed equities traded on the Danish, Swedish, Finnish and Norwich stock exchanges is explored. Regarding the volatility transmission, we evidence that the Finnish portfolio of cross-listed equities influences both the Danish and Swedish portfolios of cross-listed equities. In particular, we find that the volatility transmission from the Helsinki to Copenhagen stock exchange is equal to 0.10 and that from the Helsinki to Stockholm stock exchange is equal to

0.08. These results imply that 1% increase in the volatility of returns of the Helsinki stock exchange transmits 10% volatility to the Copenhagen stock exchange and 8% to the Stockholm stock exchange. Moreover, the volatility transmission from the Copenhagen to Stockholm stock exchange is equal to 0.05. All the above figures are statistically significant, at least, at the 5% significance level.

As far as the error transmission results are concerned, we find that there is significant error transmission from the Copenhagen to Helsinki stock exchange being equal to 0.05 (5%) and from the Copenhagen to Oslo stock exchange being equal to 0.06 (6%). Last but not least, looking at the results of volatility persistence it is revealed that the stock exchanges of Copenhagen and Stockholm experience larger persistence in comparison to the stock exchanges of Oslo and Helsinki. This result implies that the transmitted news has significant impact on the stock exchanges of Copenhagen and Stockholm since their volatility persistence is close to one. For example, the Stockholm stock exchange presents the largest volatility persistence (0.94), among the Scandinavian stock exchanges which imply that the volatility of the previous day persists 94% in the next day.

The results within the Scandinavian area indicate that the major transmitter player between stock exchanges is that of Copenhagen as both volatility and error transmission of news are transferred to other Scandinavian capital markets. The second important transmitter player is the Helsinki stock market considering, however, only the volatility transmission part of news. Therefore, we can conclude that the rest of the Scandinavian stock exchanges are just receivers of the transmission of news from the Danish and Finnish portfolios of cross-listed equities. The Stockholm stock market, even though the greater stock market in the area in terms of market capitalization and number of stocks listed, seems not to influence the other stock markets. A potential explanation behind this result maybe its movement to a different regulatory direction with stricter trading rules that deprives the element of transmission to other stock markets.

[Insert Table 5 about here]

Table 6 presents the results of transmission of news between the Germanic stock exchanges. The stock exchange of Zurich seems to be the larger transmitter of news to the other two portfolios of cross-listed equities that are traded on the Vienna and Frankfurt stock exchanges. Moreover, we find bilateral transmission of volatility between the Zurich and Vienna stock exchanges. In particular, the volatility transmission from the Zurich to Vienna stock exchange is negative and equal to -0.02, while that from the Vienna stock exchange to Zurich stock exchange is positive and equal to 0.03. Regarding the error transmission, the Zurich stock exchange demonstrates a significant impact on the Vienna stock exchange (0.07) and to the Frankfurt stock exchange (0.08). On the other hand, the Frankfurt stock exchange seems to transmit significant error to the Vienna stock exchange (0.04), while the latter transmits a stronger error to the former (0.06).

Next, we consider the volatility persistence for the portfolios of cross-listed equities of the Vienna, Zurich and Frankfurt stock exchanges. Specifically, the volatility persistence of the Vienna stock exchange is 0.93 and reaches the value of 0.98 in the case of the Zurich stock exchange and 0.96 in the case of the Frankfurt stock exchange. These results support the view that the volatility persistence within stock exchanges remains in very high levels implying that the news from their own stock markets affects considerably the next period's volatility.

Looking at the overall transmission results in the Germanic area, it is revealed that the second largest stock exchange in terms of market capitalization, the Zurich stock exchange, is the leader of volatility and error transmission compared to the largest stock exchange of the Germanic region, that is, Frankfurt and that of Vienna. The Vienna stock exchange and that of Frankfurt follows. Similar to the Scandinavian region (see Table 5), we find that the largest stock exchange (i.e. Frankfurt) is not the leader of transmission of news in the Germanic region. This should be attributed to the births or de-listings which are included in the dataset and, especially in the largest stock exchanges, and produce a relaxation in the distribution of returns. This results in a weaker influence of these portfolios of stock exchanges to the rest of Germanic area's portfolios of stock exchanges.

[Insert Table 6 about here]

Table 6 presents the transmission estimates within the French area which consists of the stock exchanges of Amsterdam, Brussels, Milan, Paris and Madrid. Regarding the volatility transmission estimates, it is revealed a bilateral spillover effect between the Amsterdam and Brussels stock exchanges. In particular, the volatility transmission from the Amsterdam stock exchange to the Brussels stock exchange is equal to 0.19, while for the opposite direction there is a volatility transmission equal to 0.13. Looking at the rest of volatility transmission estimates we can see that there is a volatility transmission effect from the Brussels stock exchange to the Milan stock exchange and to the Madrid stock exchange which are equal to 0.06 and -0.12 respectively being negative in the second case. There is also a similar size transmission from the Paris stock exchange to the Milan stock exchange (0.06) as well as from the Brussels stock exchange to the Milan stock exchange (0.06). In addition, the Paris stock exchange exerts a negative transmission effect to the Madrid stock exchange (-0.10). This means that an increase of 1% in the Paris portfolio of cross-listed equities results in volatility decrease of 10% in the Madrid portfolio of cross-listed equities.

With respect to the error transmission estimates we see that the exporters of error transmission are the portfolios of cross-listed equities traded on the Paris, Amsterdam and Brussels stock exchanges. On the other hand, the receivers of the error transmission are the portfolios of cross-listed equities traded on the Milan and Madrid stock exchanges. In particular, the French portfolio of cross-listed equities influences positively the Italian portfolios of cross-listed equities (0.05) and negatively the Spanish portfolios of cross-listed equities (-0.06). Similar result arises from the error transmission of the Amsterdam stock exchange to the Milan stock exchange (0.03) and to the Madrid stock exchange (-0.03) being negative in the latter, also the Brussels stock exchange affects negatively the Madrid stock exchange (-0.03). Looking at the overall results of the error transmission, we see that the Madrid stock exchange receives much of the negative error transmission (emanated from the other stock exchanges), while the Milan stock exchange receives positive error transmission (also emanated from the other stock exchanges).

In connection to the volatility persistence, this is found to be large for the cases of the Milan stock exchange (0.97) and the Paris stock exchange (0.84). The volatility persistence for the rest of stock exchanges is much lower. In particular, it is found to be equal to 0.69 for both the Dutch and Spanish portfolios of cross-listed equities and even smaller for the case of the Belgian portfolio of cross-listed equities (0.48). As it is expected, the volatility persistence for the portfolios of cross-listed equities of the large stock exchanges is found to be close to one. This means that the volatility persistence within large stock exchanges remains high from the previous period to the next period.

[Insert Table 7 about here]

5. Conclusions

This study examines the volatility and error transmission of news within three different European financial areas, namely the Scandinavian, the Germanic and the French area. In contrast to the literature review, we do not evidence that the leader of transmission news is always the largest stock exchange of the region. More specifically, Booth et al. (1997) examined the price and volatility spillovers for the Scandinavian stock markets using stock indices and found that both the stock price and volatility of Swedish equities spilled over to Finland ones. They also found some support for the reverse spillover effect (i.e. from Finland to Sweden). For the same region, however, our study finds that the Finnish and Danish portfolios of cross-listed equities are those that transmit volatility to the Swedish portfolios of cross-listed equities. Our results differ from those of Booth et al. (1997) because we use cross-listed equities rather than stock indices. In addition, we find that no a single pair of markets experience bilateral volatility or error spillovers. We believe that our findings shed new light on the ongoing debate of the spillover effects of the stock markets operating in the Scandinavian area.

Regarding the other two European stock market areas, the results are similar to those of the Scandinavian area. In the Germanic stock market area, we find that the Swiss portfolio of cross-listed equities is the major exporter of volatility and error to the other portfolios of cross-listed equities. To the best of our knowledge, this area has not been previously examined and, therefore, we can claim that our results fill the research gap. With respect to the French stock market area, we observe that the Paris, Amsterdam and Brussels stock exchanges are the major exporters of volatility and error to the portfolios of cross-listed equities traded on the Milan and Madrid stock exchanges. Thus, we find that for some cases the largest stock exchange (the Paris) plays the role of major exporter of volatility and error to the other stock exchanges for their own portfolios of cross-listed equities. In addition, we evidence that the Spanish portfolio of equities receives much of the negative volatility and error information from the other stock markets of the French area, while the Italian receives positive information from the other stock markets within the French area. Further research could simply address the issue of asymmetry or leverage effect on volatility spillovers in order to see if bad news has a greater impact on volatility spillovers than good news. However, we leave this approach to be examined in the future.

Overall, the results indicate that regulators should focus on cross-listed equities as they might produce different interactions between stock markets and lead to different conclusions than the results produced from the investigation of stock indices. Thus, cross-listed equities are assumed to be very specific case within stock exchanges and need a sophisticated attention from regulators and investors for different kind of investment purposes. In particular, investors could take advantage of the findings of this study as they could easily arbitrary in their decisions taking into account both investments on indices and cross-listed equities. The one investment that is based on indices should not be mixed with the other ones (e.g. cross-listed equities), but keep them separately as it seems to be in the literature review of transmission of news between markets, in order to take advantage investors from the one which does produce more benefits in comparison to the other.

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Table 1. The distribution of the European cross-listed equities

Markets	Firms	Equities
Austria	6	7
Belgium	7	8
Denmark	7	9
Finland	4	7
France	32	34
Germany	26	56
Netherlands	26	30
Italy	12	14
Norway	6	11
Spain	20	23
Sweden	13	20
Switzerland	7	11
Total	166	230

Notes: This table provides the number of firms that are used in the study and also the number of equities that have been chosen. The number of firms and the corresponding number of equities differ because we use more than one equity for each firm. More specifically, one company might have ordinary shares and also other type of shares. Here, we consider both cases in order to deal with a big number of shares that are present in a company.

Table 2. Within sample-inter-listing of stock prices

Markets	Firms	Equities	Vienna	Brussels	Copenhagen	Helsinki	Paris	Frankfurt+	Milan	Amsterdam	Oslo	Madrid	Stockholm	Zurich	Total
Austria	6	7	0	2	0	0	1	8	0	0	0	0	0	0	11
Belgium	7	8	0	0	0	0	6	4	0	2	0	0	0	2	14
Denmark	7	9	0	0	0	0	0	5	0	0	1	0	0	2	8
Finland	4	7	0	0	0	0	1	3	0	0	0	0	0	0	4
France	32	34	0	8	1	0	0	31	2	1	0	2	1	7	53
Germany	26	56	11	8	0	0	14	0	2	8	0	3	0	28	74
Netherlands	26	30	3	13	0	0	12	30	0	0	0	0	1	17	76
Italy	12	14	0	0	0	0	7	12	0	1	0	0	0	0	20
Norway	6	11	0	0	7	0	1	6	0	1	0	0	1	0	16
Spain	20	23	0	0	0	0	4	19	0	0	0	0	0	1	24
Sweden	13	20	0	0	3	0	3	13	1	0	0	0	0	0	20
Switzerland	7	11	0	1	0	0	3	10	0	1	0	0	1	0	16
Total	166	230	14	32	11	0	52	141	5	14	1	5	4	57	336

Notes: Frankfurt+ comprises Berlin, Dusseldolf, Stuttgart, Munich, Xet, and Frankfurt. The sample includes ordinary shares, ‘A’ shares, ‘B’ shares, registered shares, but not Redeemable shares (regarded as a preference share and therefore as non-equity share).

Table 3. Descriptive statistics for European cross-listed equities

Stock exchanges	Mean	St.Dv.	Skewness	Kurtosis
Amsterdam	0.00026	0.008	-0.34	14.36
Brussels	0.00036	0.009	-0.30	13.94
Copenhagen	0.00024	0.011	-0.28	6.33
Frankfurt	0.00035	0.012	-0.31	6.40
Helsinki	0.00050	0.015	0.01	2.85
Madrid	0.00038	0.013	-0.03	3.83
Milan	0.00013	0.015	0.10	1.09
Oslo	0.00012	0.016	-0.34	3.48
Paris	0.00019	0.011	-0.44	6.00
Stockholm	0.00027	0.013	-0.30	6.10
Zurich	0.00039	0.012	-0.40	7.88
Vienna	0.00018	0.013	-0.34	8.93

Notes: At this table it is reported the mean, the standard deviation, the skewness and of the dataset in order to comment with a first glance at the distribution of the returns.

Table 4. ARCH test effects results for European cross-listed equities

Home portfolios of equities	Chi-squared (1)
Amsterdam	83.26
Brussels	55.30
Copenhagen	106.07
Frankfurt	294.16
Helsinki	79.33
Madrid	66.36
Milan	71.84
Oslo	173.02
Paris	100.93
Stockholm	160.24
Zurich	442.37
Vienna	106.52

Notes: Critical level of Chi-squared (1) is: 3.84. The ARCH test is important in this study in order to comment on the acceptance or rejection of an ARCH type model.

Table 5. Volatility and error spillovers for cross-listed equities within the Scandinavian area

$$r_t = \alpha + \sum_{p=1}^{n} \Phi_p r_{t-n} + e_t, e_t \mid \Omega_{t-1} \sim N(0, H_t)$$

and

$$H_{t+1} = CC' + B' H_t B + A' \varepsilon_t * \varepsilon_t' A$$

Notes: This table reports the volatility and error transmission results for the portfolios of cross-listed equities in the Scandinavian area. It is also reported the results of volatility persistence. Only statistical results that are significant at the 5% level are reported. P-values are in parentheses. The above two equations express the return and variance equations for the European portfolios of cross-listed equities. r_t is the return series, e_t is the error term of return equation, α is the constant term in the return equation, Φ_p is the matrix of coefficients with the p lagged values of r_t, Ω_{t-1} is the matrix of conditional past information that includes the p lagged values of r_t. The first portfolio of cross-listed equities (r_{1t}), the second portfolio of cross-listed equities (r_{2t}), the third portfolio of cross-listed equities (r_{3t}) and the fourth portfolio of cross-listed equities (r_{4t}), the returns vector is denoted by $r_t' = [r_{1t}, r_{2t}, r_{3t}, r_{4t}]$. The residual vector is given by $\varepsilon_t' = [e_{1t}, e_{2t}, e_{3t}, e_{4t}]$, with its corresponding conditional covariance matrix is $\{H_{t+1}\}_{ij} = h_{ij,t+1}$. The parameter vectors of the mean returns Equation (1) are defined as $\alpha' = [a_1, a_2, a_3, a_4]$ for the constant and $\{\Phi_p\}_{ij} = \phi_{ij,p}$ for the matrix of coefficients with the p lagged returns. The parameter matrices for the variance Equation (2) are defined as $\{C\}_{ij} = c_{ij,t}$ which is restricted to be upper triangular, and free matrices $\{B\}_{ij} = \beta_{ij,t}$ and $\{A\}_{ij} = a_{ij,t}$.

Period: 28/3/88-31/12/06	Denmark Sweden Finland Norway
Volatility Transmission from Helsinki to Copenhagen	0.10
	(0.05)
Volatility Transmission from Copenhagen to Stockholm	0.05
	(0.02)
Volatility Transmission from Helsinki to Stockholm	0.08
	(0.03)
Error Transmission from Copenhagen to Helsinki	0.05
	(0.02)
Error Transmission from Copenhagen to Oslo	0.06
	(0.02)
Volatility persistence	
Copenhagen	0.88
Helsinki	0.50
Oslo	0.54
Stockholm	0.94
Log-Likelihood	41628.42

Table 6. Volatility and error spillovers for cross-listed equities within the Germanic area

$$r_t = \alpha + \sum_{p=1}^{n} \Phi_p r_{t-n} + e_t, e_t \mid \Omega_{t-1} \sim N(0, H_t)$$

and

$$H_{t+1} = CC' + B' H_t B + A' \varepsilon_t * \varepsilon_t' A$$

Notes: The following table reports the volatility and error transmission results for the portfolios of cross-listed equities in the Scandinavian area. It is also reported the results of volatility persistence. Only statistical results that are significant at the 5% level are reported. P-values are in parentheses. The above two equations express the return and variance equations for the European portfolios of cross-listed equities. r_t is the return series, e_t is the error term of return equation, α is the constant term in the return equation, Φ_p is the matrix of coefficients with the p lagged values of r_t, Ω_{t-1} is the matrix of conditional past information that includes the p lagged values of r_t. The first portfolio of cross-listed equities (r_{1t}), the second portfolio of cross-listed equities (r_{2t}), the third portfolio of cross-listed equities (r_{3t}), the returns vector is denoted by $r_t' = [r_{1t}, r_{2t}, r_{3t}]$. The residual vector is given by $\varepsilon_t' = [e_{1t}, e_{2t}, e_{3t}]$, with its corresponding conditional covariance matrix is $\{H_{t+1}\}_{ij} = h_{ij,t+1}$. The parameter vectors of the mean returns Equation (1) are defined as $\alpha' = [a_1, a_2, a_3]$ for the constant and $\{\Phi_p\}_{ij} = \phi_{ij,p}$ for the matrix of coefficients with the p lagged returns. The parameter matrices for the variance Equation (2) are defined as $\{C\}_{ij} = c_{ij,t}$ which is restricted to be upper triangular, and free matrices $\{B\}_{ij} = \beta_{ij,t}$ and $\{A\}_{ij} = a_{ij,t}$.

Period: 6/1/87-31/12/06	Austria Switserland Germany
Volatility Transmission from Zurich to Vienna	-0.02
	(0.00)
Volatility Transmission from Vienna to Zurich	0.03
	(0.00)
Error Transmission from Zurich to Vienna	0.07
	(0.01)
Error Transmission from Frankfurt to Vienna	0.04
	(0.01)
Error Transmission from Vienna to Frankfurt	0.06
	(0.02)
Error Transmission from Zurich to Frankfurt	0.08
	(0.02)
Volatility persistence	
Vienna	0.93
Zurich	0.98
German	0.96
Log-Likelihood	36691.64

Table 7. Volatility and error spillovers for cross-listed equities within the French area

$$r_t = \alpha + \sum_{p=1}^{n} \Phi_p r_{t-n} + e_t, e_t \mid \Omega_{t-1} \sim N(0, H_t)$$

and

$$H_{t+1} = CC' + B' H_t B + A' \varepsilon_t * \varepsilon_t' A$$

Notes: The following table reports the volatility and error transmission results for the portfolios of cross-listed equities in the Scandinavian area. It is also reported the results of volatility persistence. Only statistical results that are significant at the 5% level are reported. P-values are in parentheses. The above two equations express the return and variance equations for the European portfolios of cross-listed equities. r_t is the return series, e_t is the error term of return equation, α is the constant term in the return equation, Φ_p is the matrix of coefficients with the p lagged values of r_t, Ω_{t-1} is the matrix of conditional past information that includes the p lagged values of r_t. The first portfolio of cross-listed equities (r_{1t}), the second portfolio of cross-listed equities (r_{2t}), the third portfolio of cross-listed equities (r_{3t}) and the fourth portfolio of cross-listed equities (r_{4t}), the fifth portfolio of cross-listed equities (r_{5t}), the returns vector is denoted by $r_t' = [r_{1t}, r_{2t}, r_{3t}, r_{4t}, r_{5t}]$. The residual vector is given by $\varepsilon_t' = [e_{1t}, e_{2t}, e_{3t}, e_{4t}, e_{5t}]$, with its corresponding conditional covariance matrix is $\{H_{t+1}\}_{ij} = h_{ij,t+1}$. The parameter vectors of the mean returns equation (1) are defined as $\alpha' = [a_1, a_2, a_3, a_4, \alpha_5]$ for the constant and $\{\Phi_p\}_{ij} = \phi_{ij,p}$ for the matrix of coefficients with the p lagged returns. The parameter matrices for the variance equation (2) are defined as $\{C\}_{ij} = c_{ij,t}$ which is restricted to be upper triangular, and free matrices $\{B\}_{ij} = \beta_{ij,t}$ and $\{A\}_{ij} = a_{ij,t}$.

Period: 3/3/87-31/12/06	Belgium France Italy Netherlands Spain
Volatility Transmission from Brussels to Milan	0.06 (0.03)
Volatility transmission from Paris to Milan	0.06 (0.02)
Volatility Transmission from Amsterdam to Brussels	0.19 (0.07)
Volatility Transmission from Brussels to Amsterdam	0.13 (0.05)
Volatility Transmission from Brussels to Madrid	-0.12 (0.04)
Volatility transmission from Paris to Madrid	-0.10 (0.04)
Error Transmission from Paris to Milan	0.05 (0.02)
Error Transmission from Amsterdam to Milan	0.03 (0.01)
Error Transmission from Brussels to Madrid	-0.03 (0.01)
Error Transmission from Paris to Madrid	-0.06 (0.02)
Error Transmission from Amsterdam to Madrid	-0.03 (0.01)
Volatility persistence	

Brussels	0.48
Paris	0.84
Milan	0.97
Amsterdam	0.69
Madrid	0.69
Log-Likelihood	58566.40