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Volatility Spillover Effects in Scandinavian Equity Markets

Master thesis in Finance

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Abstract

The mean and volatility spillover effects from the US and the aggregate European stock markets into individual Scandinavian equity markets are investigated by applying an EGARCH volatility-spillover model. Both the mean and volatility spillover effects from the US market are found to be significant. The European mean-spillover effects are small, negligible, and insignificant whereas the EU volatility-spillover effects are essential for all Nordic countries. In these four countries, the European effects are least significant. In Denmark and Norway, the local effects are most essential, followed by the US effects whereas the world influences are most significant in Sweden and Finland. The significance level of the world, regional, and local effects in Sweden and Denmark are neither changed by the formation of the OMX group, the 2008 financial crisis, nor the overall trend from 1995 until 2012. Although the two big events that had happened have increased the significance level of the impact from the US to Norway, but the general trend of the significant effects from the three markets (the US, EU, and the local) remains unaltered. In Finland, there is no significant change in spillover effect stemming from the occurrence of these two events, but the influences from the local effects are increasing over the sample period.

Key words: stock markets; US; the aggregate European; OMX group formation; 2008 financial crisis impacts; mean; volatility; spillover

Contants

1. Introduction

The advances in trading technology and information transmission are enabling the liberalization of capital flows and financial markets more integrated than ever before. This is evident both in developed countries and in emerging markets. The world-wide news processing and international financial transactions may reduce the isolation of domestic markets. Further, these factors contribute to the prompt reaction ability of a single market to the news and shocks generated from the rest of the world (Singh, Kumar, and Pandey, 2010). As a result, the stock markets around the world are becoming closer. This international linkage plays a significant role in domestic securities pricing and international hedging strategies (Ng, 2000). The activities or news from the major foreign trading partners may have important impact on the stock returns and volatilities in a domestic market when the linkage is strong, whereas weak linkage contributes to the gain of hedging through international portfolio diversification.

Volatility spillover effect illustrates that the volatility of an equity market not only depends on its own historical fluctuations, but may also be affected by the volatility in other markets (Engle et al., 1990). For example, the recent financial crisis that started in the US market caused great volatility in stock markets' returns in the rest of the world. Therefore, understanding the sources of volatility in short-run interdependence in returns and volatility across different markets is critical.

Several previous literatures analyze the factors that influenced the local return and volatility. At the beginning, only the world force has been considered. Bekaert and Harvey (1997) examined to what extent the emerging country is influenced by the world market and the effects are not as large as expected. Ng (2000) firstly divides the factors that affect the return and volatility spillover into local, regional, and world to detect which one is more significant in Pacific—Basin market. The results showed that both regional and world shocks accounted insignificantly in return volatility but are important in volatility spillover. Thenceforward, the three factors model has been widely applied. Baele (2002) examined the time-varying nature of volatility transmission mechanism from the world market (the US) and the regional effects (the aggregate European) to individual European equity markets. He found that both global effects and regional effects are significant to single European market where shock from EU is more pronounced. Similarly, Fratzscher (2002) investigated the same world and regional influences on European markets and found the same results. Miyakoshi (2003) analyzed the relative importance of the world market of the US and the regional Japanese market impact on the return and volatility spillovers in Asian equity market. The outcome is that only the US influences the Asian market in return spillover while regional Japanese plays a more significant role in volatility spillover. Besides the impact from the world and regional markets, the spillover effect within Asian markets is also examined. All these mentioned studies are mainly focused on the major economies, i.e. the impact from the US, Japan, and European, or the interdependence among these leading markets. The focus on the Scandinavian market is limited.

In the Scandinavian market's context, there is only one paper focusing specifically on the spillover among the four Nordic countries (Booth et al., 1997). Booth et al. (1997) stated that there are three spillovers in price, which are from Norway to Sweden, from Norway to Denmark, and from Sweden to Finland, and three spillovers in volatility, which are from Sweden to Norway, and the bidirectional interaction between Sweden and Finland. Further, their results indicated that the asymmetry in volatility spillover is captured in three markets, where Denmark is the exception. The dataset they applied is from May 1988 to June 1994, with the daily data, which is not up-to-date and the interdependence between these markets may change. One recent paper (Zhang, 2012, forthcoming) that examined the degree of financial integration in the Nordic countries also conducted the spillover test with a more updated sample period from September 2001 to December 2011 based on weekly data. Although these two papers applied different frequency dataset for testing, the results are quite similar. Zhang (2012) find the asymmetry in volatility exists between Sweden and Finland but not others. Sweden tends to be the leading market in terms of return spillover effects as it impacts on other three markets. The most significant difference in finding is in the volatility spillover effects. In the latter paper, there is only one spillover effect that is not significant, which is from Norway to Sweden, the remaining estimated coefficients are all significantly different from zero.

The number of studies on the extent of Scandinavian markets being influenced by shocks generated from the external markets is relatively small. As the Nordic markets are becoming more integrated then before, to study the returns and volatility spillover transmission mechanism is significant for Scandinavian investors. Based on the Ng (2000), this paper is going to apply the three factors model to examine the extent of the world and the regional factors that influenced the Nordic region.

Employing ARCH family models to examine volatility spillover was initiated by Engle et al. (1990). Hamao et al. (1990) investigated the short run spillover among the US, UK and Japan by using a multivariate Generalized Autoregressive Conditionally Heteroskedastic (GARCH). Kanas (1998) tested the volatility spillover effects among three major European stock markets, London, Frankfurt and Paris by applying the Exponential GARCH (EGARCH) model. Ng (2000) examined the world, regional, and local factors that influence the stock market return and volatility spillover effects for individual Asian markets. Martins and Poon (2001) used the multivariate GARCH model to investigate the interdependence of the US, UK, and France. Christiansen (2007) ran an AR-GARCH to investigate the world, regional, and local factors that affect the European bond markets. Miyakoshi (2003) employed the world shock as an exogenous factor and applied a bivariate EGARCH model between local factors and regional effects to analyze the volatility spillover effects in Asian stock markets. Skintzi and Refenes (2006) following the methods implemented by Miyakoshi (2003), also treated the world market as an exogenous variable while shocks in the regional market as an endogenous factor in the bivariate EGARCH model to measure the volatility spillover between the aggregate Euro index and individual European bond market. One of the major advantages of the EGARCH over the GARCH model documented by Nelson (1991) is that it allows asymmetric response to idiosyncratic shocks, while the GARCH model imposes a non-negative constraint on parameters, which is not accurate enough in capturing the shock effects. Considering the asymmetric conditional volatility effects, which implies that negative returns generated larger volatilities in future when comparing with the shocks induced by the same magnitude but positive returns (Nelson, 1991), this paper is going to employ the AR-EGARCH model to examine the impact from the US and the aggregate European markets on the Scandinavian region.

The integration and international correlation among the global markets is changing over time, especially being influenced by the major events, i.e. the financial crises, the volatility spillover effects may also be time-varying. The integration of Asian markets has been increased during the financial crisis period, which is studied by Jang and Sul (2002). The integration has been further proven by Lee (2009), who examined the return and volatility among six Asian markets and found that the co-movement effects are significant across these economies. Christiansen (2007) studied the mean and volatility spillover effects in the bond markets as well. The introduction of Euro increases the financial integration among EMU countries, where it is more pronounced for the aggregate EU bond market, while the US market plays a more essential role in non-EMU markets. Savva et al. (2004) analyzed the volatility spillover effects across the US and three largest European equity markets, German, French and UK. They found that not all the European markets are influenced by the US but French is the exception. They concluded that the introduction of Euro increased the impact power of the European Market. This result is further evidenced by Bartram et al. (2007). They examined the volatility transmission mechanism among Euro and non-Euro markets and found that the market dependence within European has been increasing after the introduction of the Euro. Therefore, I am going to examine whether the most recent 2008 financial crises impacts the degree and the pattern of the volatility spillovers. In the model, the time-varying will be investigated by allowing the influences of the world forces (US) and the regional factors (aggregate European) to change before and after the financial crises.

The purpose of this study is to investigate the fundamental forces driving the return and volatility of stock markets in Scandinavian countries, namely Sweden, Denmark, Norway, and Finland. In precise, I measure how and to what extent the stock return and volatility in the Scandinavian market are influenced by local, regional, and world shocks. According to Ng (2000), there are three major shocks that contribute to the volatility spillover—local, regional, and the world. Following this concept, this paper aims to examine whether the Scandinavian markets are mostly influenced by the local (own country), the regional (the EU), or the global (the US) market volatility in the *basic spillover model*. As the Nordic markets are becoming more integrated with the remarkable process of the establishing of the OMX group in 2003, it is important to examine how much of the return and volatility of these four small markets is driven by a world shock or a regional factor after the big event happened. Under the *event spillover model*, both the impact from the US and the EU stock markets had been examined after the occurrences of OMX group formation and the 2008 global financial crisis. Previous studies (King et al. (1994), Longin and Solnik (1995), Karolyi and Stulz (1996)) state that as the correlation across different markets is changing over time, the return and volatility spillover effects may also be time-varying. Therefore, in order to examine the time-varying impact, I am going to allow the shocks from the US and the aggregate European markets to vary in the *trend spillover model*.

The negative or no-first order autocorrelation for four countries are found in all these three models. In the basic spillover model, the most significant and strong spillover effects come from the US-volatility for all countries. However, for Denmark and Norway, the local variance ratios accounted for the largest proportion compared with the volatility caused by the US and the European markets.

In the event spillover model, the changes in mean and volatility spillover effects brought by the establishment of the OMX group and the most recent financial crisis are accounted. For all countries, the EU mean-spillover effects are stronger before than after these two big events happened. The US-volatility spillover effects are found to be stronger after these two events occurred in all markets. The percentage of the variance of unexpected return for individual country caused by the US has increased, which indicates that all these four countries are becoming more closely integrated with the world market after the NASDAQ purchased the OMX group and the impacts on Scandinavian stock markets by the worldwide financial tsunami are significant.

In the trend spillover model, the impacts from both the EU mean-spillover and EU volatility-spillover to individual Nordic country are decreasing over the sample period whereas the US volatility-spillover effects are increasing except for Sweden. With Sweden being the exception as well, the local volatility effects are becoming stronger from 1995 to 2012. However, in the case of Sweden, the volatility impacts from the US are still account for the largest proportion. This might be due to the fact that Sweden is the largest stock exchange within the Scandinavian region (Booth et al., 1997), which means it is more exposed to the world market and responded quicker to the external information, therefore, have been more influenced by the US market.

The remaining part of this paper is organized as follows. Section 2 briefly explains the development of the Scandinavian stock market. Section 3 presents the selected dataset and the preliminary analysis. Section 4 describes the AR-EGARCH model used for modeling returns and volatility spillover. Section 5 presents and analyzes empirical results and Section 6 concludes the paper.

2. Scandinavian Stock Market Development

In this section, the historical background of the Scandinavian stock markets is described, which includes a particular focus on the cornerstone of the integration both among these markets, with the European market, and with the global market.

Bekaert and Harvey (1997) showed that the increasing correlation exists in the return between local and the world market but not in the volatility with the policy liberalization. If this statement holds, one should expect a stronger spillover effects in the Scandinavian markets from the US and the aggregate Europe as the increasing integration of the market has taken place.

On one hand, the Nordic countries are becoming more closely related to the continental European markets. Denmark is the earliest country in these four that has joined the European Union (EU), which was in 1973. In January 1995, Sweden and Finland became the members of the EU as well. However, Norway is the mere country that has not join the EU until now. Further, Finland is the only Scandinavian country that has joined the European Monetary Union (EMU) in January 1999.

On the other hand, the integration of the region has also taken place. Zhang (2012) stated that in September 2003, the Stockholm stock exchange (OM group) and Helsinki exchange (HEX group) were merged to form the new OMX group. This was the first crucial step that initiated the financial integration of the Scandinavian region. Further, in January 2005, the newly founded OMX group acquired the Copenhagen stock exchange (CSE). The last set was taken in October 2006, when the OMX group purchased 10 percent stake of the owner of the Norwegian stock exchange, Oslo Børs Holding ASA, and dominated the stock market operation within the Scandinavian region.

Moreover, the correlation between the OMX group and the global market has been increasing. On May 25, 2007, the NASDAQ purchase the OMX to announce a new NASDAQ OMX group is established.

3. Data Description and Preliminary Analysis

3.1 Data Description

The data employed in this paper are weekly equity indices from four Scandinavian countries, the aggregate European, and the US. All the prices are in terms of US dollars as compiled by DataStream International[1]. The indices used are the OMX Stockholm 30 (OMXS30) for Sweden, OMX Copenhagen 20 (OMXC20) for Denmark, OMX Helsinki 25 (OMXH 25) for Finland, Oslo SE (OBX) for Norway, the aggregate European (EU50)[2], and the Standard and Poor's 500 (S&P500) for the US[3]. Weekly data are commonly applied when examining the volatility spillover effects (Ng, 2000, Baele, 2002, Skintzi and Refenes, 2006, Christiansen, 2007, etc.). The advantage of applying this lower frequency data (compared to the daily one) is that it avoids the non-synchronous trading problem. The trading hours are almost the same within Scandinavian region but partially overlapping with the US market. Therefore, higher frequency data might generate the asymmetric information sharing issue. The time period in this paper begins from January 1995 to Dec 2012. The analysis is initiated in January 1995 as Sweden and Finland became European members at that time. In order to investigate the time-varying effect in volatility spillover, I am going to examine two sub-periods, one is going to test the effects before and after Sep 2003, which is examine whether the OMX group integration has impact on the volatility spillover. The other is going to investigate the magnitude of spillover effects before and after June 2008[4].

3.2 Preliminary Analysis

The summary statistics, which are weekly samples of the 4 countries and 2 benchmarks, are presented in Table 1. For each market, there are 939 observations. The average weekly returns are all positive and fall within a range from 0.07% in Europe to 0.18% in Denmark. Four individual markets outperform the regional and the world market, where Norway (0.120%) is almost as the same as the US (0.119%). The standard deviation ranges from 0.0255 to 0.0356. None of the Skeweness of these six indices is equal to zero and none of the Kurtosis follows normal distribution. The negative skewness and excess kurtosis illustrate that the negative/large shocks are more frequent than the positive/expected shocks in all equity markets (Skintzi and Refenes, 2006). The non-normal distribution of these six data sets is further confirmed

[1] Here all market returns are collected as USD dominated. The investors are therefore assumed to be unhedged against the different currencies exchange risk. In order to examine the impact of foreign exchange risk, the analysis should be run in local currency (Engle et al., 1990). However, this is not the objective of this paper.

[2] This is inspired by Baele (2002). He collected the EU-15 from DataStream as the index for the aggregate European market. Here, I employ the EU-50 from the DataStream as one of the benchmark indexes for the aggregate European equity market. Moreover, to ensure there is no spurious correlation between EU 50 and individual Scandinavian country, I checked the list of these 50 equities and none of them is from the four testing countries. Therefore, the result can be seen as robust.

[3] As the OMX group has been purchased by NASDAQ, in order to avoid the spurious correlation, here I use S&P500 to represent the index of the US.

[4] The time period chosen is based on the paper of Asharian et al. (2012). The test period in their paper was January 1991 to June 2008 in order to avoid the most recent financial crises influences when they apply a GARCH-MIDAS method to investigate the role of the macroeconomic variables in forecasting the return volatility of the US stock market.

by the Jarque-Bera test as the probability to accept the null hypothesis of normal distribution are all equal to zero, which means the rejection of normal distribution. The last four rows display the Ljung and Box (1978) tests for the autocorrelation of both returns and squared returns for each index from first order up to fifth order[5]. The statistics showed the non-linear dependency in both returns and squared returns series, which indicates that the autoregressive conditional heteroskedasticity (ARCH) might exist (Ng, 2000). The data sets follow non-normal distribution and the presence of non-linear dependency motivates ARCH specifications (Bera and Higgins, 1993). As EGARCH belongs to the ARCH family models, the AR-EGARCH model is going to be applied.

Table 1
Preliminary Analysis

The table illustrates the summary statistics of all weekly returns, which are calculated in US dollars. The stock indices for four individual countries and two benchmarks are gathered from DataStream. The mean return, standard deviation, skewness, kurtosis, autocorrelation of the time series (order 1 and order 5 are expressed as AC(1) and AC(5)), and the autocorrelation of the squared returns (order 1 and order 5 represented by AC ^{2}(1) and AC ^{2}(5)).

	US	Europe	Sweden	Denmark	Norway	Finland
Mean	0.119%	0.073%	0.145%	0.175%	0.120%	0.133%
Median	0.0024	0.0038	0.0035	0.0039	0.0047	0.0045
Maximum	0.1136	0.1359	0.1792	0.1172	0.1683	0.1610
Minimum	-0.2008	-0.2513	-0.2253	-0.2249	-0.2478	-0.2032
Std. Dev.	0.0255	0.0313	0.0321	0.0279	0.0336	0.0356
Skewness	-0.7550	-0.7638	-0.4699	-1.1711	-1.0348	-0.6482
Kurtosis	6.1285	5.7650	4.2234	7.7405	7.5601	3.0285
Jarque-Bera	1539.76	1374.65	722.82	2529.46	2375.76	419.07
JB Prob.	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
AC (1)	-0.0780	-0.0630	-0.0560	-0.0580	-0.0090	-0.0250
AC (5)	0.0280	0.0210	0.1040	-0.0070	0.0570	0.0930
AC ^{2}(1)	0.2740	0.1180	0.1050	0.2340	0.3030	0.1290
AC ^{2}(5)	0.1170	0.1290	0.1380	0.1550	0.2920	0.1370

[5] The null hypothesis of Ljung and Box test is that there is no auto-correlation up to order k. The null hypothesis for EU 50, S&P 500 and OMXH25 are rejected at 5% confidence level until order six, for OMXS30 and OMXC20 are rejected at order 4 and order 2, respectively. The mere exception is OBX25, which is not rejected the null hypothesis up to order 10. Overall, the fifth order is selected. The full results are illustrated in Appendix Table A1.

4. Spillover Model

The empirical volatility-spillover model applied in this paper is based on the models specified by Nelson (1991) and Christiansen (2007).

Nelson (1991) introduced a new model in the ARCH family, which is the Exponential GARCH (EGARCH) model. The mean equation identical to the previous ARCH family models, but the corresponding variance equation is in the logarithms term.

$$\log(\sigma_t^2) = \omega + \alpha_1 \varepsilon_{t-1} + \alpha_2 \left[|\varepsilon_{t-1}| - \sqrt{\frac{2}{\pi}} \right] + \beta log(\sigma_{t-1}^2) \quad (1)$$

By specifying the conditional variance in logarithm form, it allows the parameters to be negative, and thus, the positive and negative innovations can generate different magnitude impacts on the conditional variance.

Christiansen (2007) applies a three steps AR-GARCH model in estimating the volatility-spillover effects from the US and the Europe to individual European Bond Market. In the first step, the US return is obtained from a univariate AR-GARCH model. Next, in the second step, the univariate AR-GARCH model is applied to estimate the aggregate European return but in an extended version. The US return at time $t-1$ and the US residuals at time t are included into the mean equation of estimating the aggregate European return as endogenous variables. Lastly, in the third step, the extended univariate AR-GARCH model is applied in estimating the return for individual European market. Both the one-period lagged return and the contemporary idiosyncratic shocks form the US and the aggregate European are endogenous variables in the mean equation for the individual European bond market return. One merit of this three steps model is that it ensures the residuals from the US and the aggregate European are orthogonal. However, as the GARCH model constraints parameters to be positive, the same magnitude of volatility is generated irrespective of the sign of the unexpected returns (Nelson, 1991). Therefore, the GARCH model is not capable in distinguishing the asymmetric effects on volatility created by positive or negative returns. In order to capture this asymmetric effect, I used the EGARCH instead of the GARCH in this three steps model to investigate the impacts of the global and the regional markets on individual Scandinavian country.

4.1 Basic Spillover Model

The return of the US market is denoted as $R_{us,t}$

$$R_{us,t} = C_{0,us} + C_{1,us} R_{us,t-1} + e_{us,t} \quad (2)$$

where $e_{us,t} \sim \mathrm{N}(0, \sigma_{us,t}^2)$

$\sigma_{us,t}^2$, which indicates the conditional variance of the US market, follows an

EGARCH (1, 1) specification:

$$\ln \sigma_{us,t}^2 = \omega_{us} + \alpha_{1,us} \frac{e_{us,t-1}}{\sigma_{us,t-1}} + \alpha_{2,us} \left(\left| \frac{e_{us,t-1}}{\sigma_{us,t-1}} \right| - \sqrt{\frac{2}{\pi}} \right) + \beta_{us} \ln \sigma_{us,t-1}^2 \qquad (3)$$

In Eq. (2), $C_{1,us}$ measures the impact of lagged return from the US market itself, and $e_{us,t}$ is the innovation of the US market. In Eq. (3), the parameter β_{us} measures the persistence of volatility. In addition, the variance to the shocks is controlled by $\alpha_{1,us}$ in Eq. (3), which allows the asymmetric responses to positive or negative news. The asymmetric responses can be described as follow:

$$\begin{cases} \frac{e_{us,t-1}}{\sigma_{us,t-1}} > 0, & then\ the\ effect\ of\ the\ shock\ e_{us,t-1}\ is\ (\alpha_{1,us} + \alpha_{2,us}) \left(\frac{e_{us,t-1}}{\sigma_{us,t-1}} \right) \\ \frac{e_{us,t-1}}{\sigma_{us,t-1}} < 0, & then\ the\ effect\ of\ the\ shock\ e_{us,t-1}\ is\ (\alpha_{2,us} - \alpha_{1,us}) \left(\frac{e_{us,t-1}}{\sigma_{us,t-1}} \right) \\ \alpha_{1,us} = 0, & then\ the\ response\ of\ variance\ to\ shocks\ is\ symmetric \end{cases}$$

The return of the aggregate European market is denoted as $R_{E,t}$

$$R_{E,t} = C_{0,E} + C_{1,E} R_{E,t-1} + \gamma_E R_{us,t-1} + \varphi_E e_{us,t} + e_{E,t} \qquad (4)$$

The aggregate European market return depends on both its own lagged return and the lagged return of the US. Further, the shocks from US market and from its own market at time t are influences the mean return of the European market. The return and volatility spillover effects from the US market to European market is measured by γ_E and φ_E, respectively. The shock of the European market is a normal distribution with a mean 0 and the conditional variance follows an EGARCH (1, 1) specification:

$$\ln \sigma_{E,t}^2 = \omega_E + \alpha_{1,E} \frac{e_{E,t-1}}{\sigma_{E,t-1}} + \alpha_{2,E} \left(\left| \frac{e_{E,t-1}}{\sigma_{E,t-1}} \right| - \sqrt{\frac{2}{\pi}} \right) + \beta_E \ln \sigma_{E,t-1}^2 \qquad (5)$$

The asymmetric response of the variance to the different European shocks is controlled by $\alpha_{1,E}$.

The individual Scandinavian market return is denoted as follow, where $i = 1,2,3,4$ representing for the four countries:

$$R_{i,t} = C_{0,i} + C_{1,i} R_{i,t-1} + \gamma_i R_{us,t-1} + \delta_i R_{E,t-1} + \varphi_i e_{us,t} + \psi_i e_{E,t} + e_{i,t} \qquad (6)$$

Similar to the return for the regional market, return for each country is affected by the lagged return of the US $R_{us,t-1}$ as well as the lagged return of the aggregate

European market $R_{E,t-1}$. The joint effects of the shocks come from the world market, the regional market, and the local market are influencing the return. The return and volatility spillover effects from the world market are measured by γ_i and φ_i , while the regional return and volatility effects are estimated by δ_i and ψ_i, respectively. The idiosyncratic shock $e_{i,t} \sim \mathrm{N}\ (0, \sigma_{i,t}^2)$:

$$\ln \sigma_{i,t}^2 = \omega_i + \alpha_{1,i} \frac{e_{i,t-1}}{\sigma_{i,t-1}} + \alpha_{2,i} \left(\left| \frac{e_{i,t-1}}{\sigma_{i,t-1}} \right| - \sqrt{\frac{2}{\pi}} \right) + \beta_i \ln \sigma_{i,t-1}^2 \tag{7}$$

The $\alpha_{1,i}$ in Eq. (7) controls the asymmetric response of the sign of the shocks.

The unexpected returns for each market are defined as follow:

$$\varepsilon_{us,t} = e_{us,t} \tag{8}$$

$$\varepsilon_{E,t} = \varphi_E e_{us,t} + e_{E,t} \tag{9}$$

$$\varepsilon_{i,t} = \varphi_i e_{us,t} + \psi_i e_{E,t} + e_{i,t} \tag{10}$$

The idiosyncratic shocks $e_{us,t}$, $e_{E,t}$, and $e_{i,t}$ are assumed to be independent. Therefore, the conditional variance of the unexpected return of country i can be expressed as follow:

$$h_{i,t} = E\left(\varepsilon_{i,t}^2 \middle| I_{t-1}\right) = \varphi_i^2 \sigma_{us,t}^2 + \psi_i^2 \sigma_{E,t}^2 + \sigma_{i,t}^2 \tag{11}$$

As the formula illustrated above, the conditional variance of the unexpected return for country i at time t depends on the variance of the US, European and its own idiosyncratic shocks happening at the same time. The variance ratio used to examine whether the volatility is affected more by the world market or the regional market is defined as follow:

$$VR_{i,t}^{us} = \frac{\varphi_i^2 \sigma_{us,t}^2}{h_{i,t}} \tag{12}$$

$$VR_{i,t}^{E} = \frac{\psi_i^2 \sigma_{E,t}^2}{h_{i,t}} \tag{13}$$

After accounting the world and regional market effects, the rest of the volatility is caused by each individual market itself:

$$VR_{i,t}^{i} = 1 - VR_{i,t}^{us} - VR_{i,t}^{E} = \frac{\sigma_{i,t}^{2}}{h_{i,t}} \quad (14)$$

The variance ratios provide an intuitive illustration about to what extent the local variance is affected by the global, regional, and local impacts.

4.2 Event Spillover Model

The integration and international correlation among the global markets is changing over time, especially influenced by the big events, i.e. the financial crises or the introduction of Euro, the volatility spillover effects may also be time-varying. Therefore, this section is going to introduce to models to examine the time variation effects by introducing the dummy variables, which is based on Christiansen (2007).

In order to investigate whether the formation of the OMX group and the most recent financial crises impacts the volatility spillover effects, the dummy variable is introduced to capture the change. The *event spillover model* is as follow, where the spillover parameters are assumed to be constant before and after the events:

$$\gamma_{i,t} = \gamma_{0,i} + \gamma_{1,i}D_{1,t} + \gamma_{2,i}D_{2,t} \quad (15)$$
$$\delta_{i,t} = \delta_{0,i} + \delta_{1,i}D_{1,t} + \delta_{2,i}D_{2,t} \quad (16)$$
$$\varphi_{i,t} = \varphi_{0,i} + \varphi_{1,i}D_{1,t} + \varphi_{2,i}D_{2,t} \quad (17)$$
$$\psi_{i,t} = \psi_{0,i} + \psi_{1,i}D_{1,t} + \psi_{2,i}D_{2,t} \quad (18)$$

where $D_{1,t}$ and $D_{2,t}$ are dummy variables which represent the starting date of the OMX group combing and the starting date of the 2008 financial crises, respectively. These two dummy variables assume the value of 0 for days before the events and equates to 1 for days afterwards.

4.3 Trend Spillover Model

As the correlation across different markets is changing over time (King et al. (1994), Longin and Solnik (1995), Karolyi and Stulz (1996)), the return and volatility spillover effects may also be time-varying. Therefore, in order to examine the time-varying impact, I am going to allow the shocks from the US and the aggregate European markets vary in the *trend spillover model*, by allowing the spillover parameters to experience a gradual transition as they undertake a different value each year during the sample period:

$$\gamma_{i,t} = \gamma_{0,i} + \gamma_{1,i}DT_{t} \quad (19)$$
$$\delta_{i,t} = \delta_{0,i} + \delta_{1,i}DT_{t} \quad (20)$$
$$\varphi_{i,t} = \varphi_{0,i} + \varphi_{1,i}DT_{t} \quad (21)$$
$$\psi_{i,t} = \psi_{0,i} + \psi_{1,i}DT_{t} \quad (22)$$

The variable DT_t equals 1 for the observations collected in 1995, 2 for the observations gathered in 1996, etc.

5. Empirical Results

In this section, the *basic spillover model* is firstly established to test the return and volatility spillover effects over the full sample period (from Jan 1995 to Dec 2012). Subsequently, the impact from two big events (OMX group formation and financial crisis) has been investigated by applying the *event model*. Further, in order to estimate the time-varying effects, the *trend model* is formed. In addition, to test for the robustness of the results, the Wald tests for different joint hypotheses are applied to each model.

5.1 Basic Spillover Model Results

Table 2 is the summary statistics from the basic spillover model. The first column of Table 2 reports the results from the US. The coefficient of US lagged returns $c_{1,us}$ (AR (1)) is small and negative but significant at 5% significance level, which is consistent with the result presents in Table 1. The parameter ($c_{1,us}$) implies (no or weak) negative first-order autocorrelation. The existence of asymmetric volatility is tested by $\alpha_{1,i}$. The estimated $\alpha_{1,i}$ value of US is -0.2202 and is significant at 1% level, implying the existence of asymmetric conditional volatility. Further, the US returns display a high degree of volatility persistence as $\beta_{us} = 0.9149$.

The second column of Table 2 covers the summary statistics for the European stock market. The own lagged return has negative impact while US lagged return has relatively small impact on the European index: $c_{1,E}$ is negative and γ_E is positive, both parameters are significant at 1% level. The coefficient of contemporaneous US residual is large and significant in explaining the value of current European return. The result evidences the volatility spillover from the US to the aggregate European stock markets, which is consistent with the findings of Granger Causality tests. The robust Wald test result for no US-spillover effects: $H_0: \gamma_E = \varphi_E = 0$, is strongly rejected, which is reported in Table 3. The asymmetric volatility effect exists but it is negligible, which is evidenced by $\alpha_{1,i}$, where the estimated value of EU is -0.0752 and significant at 1% significance level. The persistence of volatility is high as well, i.e. $\beta_E = 0.9451$.

Lastly, the spillover effects for individual Scandinavian markets are estimated. For each country, the model includes one-period lagged returns from the US and the aggregate European markets and contemporary residuals from these two benchmarks. The model is advantageous as it allows both the mean and volatility from the world and the regional markets to impact the individual Nordic countries. The results are reported in the rest columns of Table 2. The returns exhibit negative or no first-order autocorrelation for all these four countries ($c_{1,i}$ almost equal to 0 for all markets), but the statistics are significant at 10% significance level for Sweden and Finland. The asymmetric volatility effects exist except in Denmark, even though all the parameters for asymmetric volatility are small and insignificant. Finland has the highest degree of the volatility persistency, i.e. $\beta_i = 0.9876$, while the other three countries are high in

Table 2

Basic Spillover Model

The table reports the estimating statistics from the basic spillover model. US return: $R_{us,t} = c_{0,us} + c_{1,us}R_{us,t-1} + e_{us,t}$ where $e_{us,t}$ has 0 mean and conditional variance follows an EGARCH: $\ln\sigma^2_{us,t} = \omega_{us} + \alpha_{1,us}\frac{e_{us,t-1}}{\sigma_{us,t-1}} + \alpha_{2,us}\left(\left|\frac{e_{us,t-1}}{\sigma_{us,t-1}}\right| - \sqrt{\frac{2}{\pi}}\right) + \beta_{us}\ln\sigma^2_{us,t-1}$. European return: $R_{E,t} = c_{0,E} + c_{1,E}R_{E,t-1} + \gamma_E R_{us,t-1} + \varphi_E e_{us,t} + e_{E,t}$ where $e_{E,t}$ has mean 0 and conditional variance: $\ln\sigma^2_{E,t} = \omega_E + \alpha_{1,E}\frac{e_{E,t-1}}{\sigma_{E,t-1}} + \alpha_{2,E}\left(\left|\frac{e_{E,t-1}}{\sigma_{E,t-1}}\right| - \sqrt{\frac{2}{\pi}}\right) + \beta_E\ln\sigma^2_{E,t-1}$. Individual country return is denoted as $R_{i,t}$, where i is the four Scandinavian markets: $R_{i,t} = c_{0,i} + c_{1,i}R_{i,t-1} + \gamma_i R_{us,t-1} + \delta_i R_{E,t-1} + \varphi_i e_{us,t} + \psi_i e_{E,t} + e_{i,t}$ where $e_{i,t}$ has mean 0 and conditional variance: $\ln\sigma^2_{i,t} = \omega_i + \alpha_{1,i}\frac{e_{i,t-1}}{\sigma_{i,t-1}} + \alpha_{2,i}\left(\left|\frac{e_{i,t-1}}{\sigma_{i,t-1}}\right| - \sqrt{\frac{2}{\pi}}\right) + \beta_i\ln\sigma^2_{i,t-1}$. The results in parentheses are Bollerslev and Wooldridge (1992) robust standard errors. * (§) [#], indicates that the value is significant at 1% (5%) [10%] level of significance.

	US	EU	Sw	De	No	Fi
$c_{0,i}$	0.0857 §	-0.1740*	-0.0972*	-0.1589*	-0.1251*	-0.1227*
	(0.0356)	(0.0406)	(0.0317)	(0.0357)	(0.041)	(0.0407)
$c_{1,i}$	-0.0840 §	-0.1596*	-0.0728#	-0.0516	-0.0507	-0.0575#
	(0.0354)	(0.0356)	(0.0383)	(0.0331)	(0.0322)	(0.0325)
γ_i		0.1747*	0.0987*	0.1611*	0.1276*	0.1252*
		(0.0408)	(0.0317)	(0.0357)	(0.0410)	(0.0406)
δ_i			-0.0033	-0.0234	-0.0194	-0.0418
			(0.0371)	(0.0330)	(0.0367)	(0.0411)
φ_i		0.9632*	0.9356*	0.6181*	0.7610*	0.9312*
		(0.0231)	(0.0193)	(0.0231)	(0.0250)	(0.0232)
ψ_i			0.6797*	0.5002*	0.4679*	0.7262*
			(0.0256)	(0.0301)	(0.0332)	(0.0310)
ω_i	-0.8078*	-0.6258*	-1.0077*	-0.4952*	-0.4763*	-0.2074*
	(0.1169)	(0.1840)	(0.2191)	(0.1615)	(0.1580)	(0.0638)
$\alpha_{1,i}$	-0.2202*	-0.0752*	-0.0426	0.0070	-0.0051	-0.0167
	(0.0221)	(0.0223)	(0.0333)	(0.0250)	(0.0296)	(0.0168)
$\alpha_{2,i}$	0.2012*	0.2466*	0.3536*	0.2190*	0.2226*	0.1418*
	(0.0393)	(0.0460)	(0.0574)	(0.0421)	(0.0483)	(0.0321)
β_i	0.9149*	0.9451*	0.9100*	0.9592*	0.9600*	0.9876*
	(0.0135)	(0.0203)	(0.0250)	(0.0187)	(0.0182)	(0.0069)

the persistence of volatility as well ($\beta_i > 0.90$).

For all countries, the US has positive impact while the European has negative influence on the mean spillover effects. In addition, the US mean spillover is greater than the aggregate European market for these four countries i.e. γ_i is positive and significant but δ_i is negative and insignificant. The robust Wald test for the hypothesis of no mean-spillover effects: $H_0: \gamma_i = \delta_i = 0$, is strongly rejected.

Table 3

Joint Wald Tests

The table reports the joint Wald tests results for four different hypotheses, where the null hypothesis for each test is as follow: $H_0^1: \gamma_i = \delta_i = 0$ (no mean spillover effects); $H_0^2: \varphi_i = \psi_i = 0$ (no volatility spillover effects); $H_0^3: \gamma_i = \varphi_i = 0$ (no US-spillover effects); $H_0^4: \delta_i = \psi_i = 0$ (no European-spillover effects). * (§) [#], indicates that the value is significant at 1% (5%) [10%] level of significance.

		EU	Sw	De	No	Fi
Wald 1	F-statistic		5.51*	12.73*	5.93*	5.00*
	Prob.		0.0042	0.0000	0.0028	0.0069
	Chi-square		11.02*	25.46*	11.85*	9.99*
	Prob.		0.0041	0.0000	0.0027	0.0068
Wald 2	F-statistic		1417.78*	474.52*	547.67*	1080.00*
	Prob.		0.0000	0.0000	0.0000	0.0000
	Chi-square		2835.56*	949.05*	1095.35*	2160.00*
	Prob.		0.0000	0.0000	0.0000	0.0000
Wald 3	F-statistic	905.40*	1178.34*	371.63*	466.77*	814.11*
	Prob.	0.0000	0.0000	0.0000	0.0000	0.0000
	Chi-square	1810.80*	2356.68*	743.26*	933.54*	1628.21*
	Prob.	0.0000	0.0000	0.0000	0.0000	0.0000
Wald 4	F-statistic		355.07*	138.24*	99.82*	274.25*
	Prob.		0.0000	0.0000	0.0000	0.0000
	Chi-square		710.14*	276.48*	199.64*	548.50*
	Prob.		0.0000	0.0000	0.0000	0.0000

The parameters for both the US and the aggregate European volatility-spillover are significant for all countries. Although the coefficients are all positive, the US volatility has much larger impact to individual market than the European volatility: φ_i and ψ_i are positive and significance at 1% level. The robust Wald test for the hypothesis of no volatility-spillover effects: $H_0: \varphi_i = \psi_i = 0$, leaves the results unaltered. The joint Wald tests results of no US-spillover effects: $H_0: \gamma_i = \varphi_i = 0$ and no European-spillover effects: $H_0: \delta_i = \psi_i = 0$ are also rejected for all countries.

To summarize, volatility-spillover effects from both the world and the regional markets are strong, while there is weak indications of the mean-spillover effects from the US market, and negative or no indications of the mean-spillover effects from the aggregate European market.

Table 4
Variance Ratios

The mean and standard deviation of the US, the aggregate European, and own variance ratios are contained in this table for the basic spillover model: $VR_{i,t}^{us} = \frac{\varphi_i^2 \sigma_{us,t}^2}{h_{i,t}}$, $VR_{i,t}^{E} = \frac{\psi_i^2 \sigma_{E,t}^2}{h_{i,t}}$, and $VR_{i,t}^{i} = 1 - VR_{i,t}^{us} - VR_{i,t}^{E}$. $h_{i,t}$ is the conditional variance of the unexpected return for individual country i and σ_{us} and σ_E are the conditional variance of the US and European idiosyncratic shocks.

		Sw	De	No	Fi
VR^{US}	Mean	0.554	0.349	0.376	0.465
	St. Dev.	0.643	0.440	0.442	0.527
VR^{E}	Mean	0.156	0.122	0.076	0.151
	St. Dev.	0.146	0.124	0.072	0.138
VR^{i}	Mean	0.290	0.529	0.549	0.384
	St. Dev.	0.211	0.436	0.486	0.335

However, the above conclusions only illustrate the sign and significance of the spillover parameters of the US and the European markets. The relative proportion or the quantitative extents of the influence from these two markets have not been assessed. To examine the quantified significance of the volatility-spillover effects on the individual Nordic country from the world and the regional markets, the mean and standard deviation of the variance ratios $VR_{i,t}^{us}$, $VR_{i,t}^{E}$, and $VR_{i,t}^{i}$ from Eq. (12) to (14) are calculated and reported in Table 4.

On average, most of the conditional variance of the unexpected return for individual country i is made up by the US volatility-spillover effects, which accounts from 34.9% up to 55.4%. The US volatility-spillover effects are remarkable in Sweden (55.4%) and Finland (46.5%) but less significant in Norway (37.6%) and Denmark (34.9%). The average European volatility-spillover effects are relatively small compared to the US effects, which is tightly ranged from 7.6% to 15.6%. Norway and Denmark are mostly influenced by the local volatility (means 54.9% and 52.9%, respectively).

5.2 Event Spillover Model Results

In the financial market, major occurrences might change the direction or the extent of the spillover effects (Ng, 2000). Therefore, the *event model* is carried out to capture two big events that had occurred in the Scandinavian markets in recent years to detect whether the spillover effects from the US and the aggregated European have been

Table 5

Event Spillover Model

The table reports the summary statistics from the event spillover model. The US return is the same as the basic spillover model. European return: $R_{E,t} = c_{0,E} + c_{1,E}R_{E,t-1} + (\gamma_{0,E} + \gamma_{1,E}D_{1,t} + \gamma_{2,E}D_{2,t})R_{us,t-1} + (\varphi_{0,E} + \varphi_{1,E}D_{1,t} + \varphi_{2,E}D_{2,t})e_{us,t} + e_{E,t}$ where $e_{E,t}$ has mean 0 and conditional variance: $\ln \sigma^2_{E,t} = \omega_E + \alpha_{1,E}\frac{e_{E,t-1}}{\sigma_{E,t-1}} + \alpha_{2,E}\left(\left|\frac{e_{E,t-1}}{\sigma_{E,t-1}}\right| - \sqrt{\frac{2}{\pi}}\right) + \beta_E \ln \sigma^2_{E,t-1}$. Individual country return is denoted as $R_{i,t}$, where i is the four Scandinavian markets: $R_{i,t} = c_{0,i} + c_{1,i}R_{i,t-1} + (\gamma_{0,i} + \gamma_{1,i}D_{1,t} + \gamma_{2,i}D_{2,t})R_{us,t-1} + (\delta_{0,i} + \delta_{1,i}D_{1,t} + \delta_{2,i}D_{2,t})R_{E,t-1} + (\varphi_{0,i} + \varphi_{1,i}D_{1,t} + \varphi_{2,i}D_{2,t})e_{us,t} + (\psi_{0,i} + \psi_{1,i}D_{1,t} + \psi_{2,i}D_{2,t})e_{E,t} + e_{i,t}$ where $e_{i,t}$ has mean 0 and conditional variance: $\ln \sigma^2_{i,t} = \omega_i + \alpha_{1,i}\frac{e_{i,t-1}}{\sigma_{i,t-1}} + \alpha_{2,i}\left(\left|\frac{e_{i,t-1}}{\sigma_{i,t-1}}\right| - \sqrt{\frac{2}{\pi}}\right) + \beta_i \ln \sigma^2_{i,t-1}$. $D_{1,t}$ equals 0 before September 5, 2003 and 1 afterwards. $D_{2,t}$ equals to 0 before July 4, 2008 and 1 hereafter. ω_i, $\alpha_{1,i}$, $\alpha_{2,i}$, and β_i are not reported here but can be found in Appendix (Table A2). The results in parentheses are Bollerslev and Wooldridge (1992) robust standard errors. * (§) [#], indicates that the value is significant at 1% (5%) [10%] level of significance.

		US	EU	Sw	De	No	Fi
	$c_{0,i}$	0.0035 §	0.0079	-0.1554*	-0.1238*	-0.0812 §	-0.0952#
		(0.0010)	(0.0421)	(0.0321)	(0.0367)	(0.0407)	(0.0491)
	$c_{1,i}$	-0.1309 §	-0.0409	-0.1004*	-0.0516	-0.0457	0.0068
			(0.0361)	(0.0370)	(0.0321)	(0.0317)	(0.0444)
mean spillover from US	γ_0		-0.0067	0.1562*	0.1261*	0.0830 §	0.0943#
			(0.0424)	(0.0320)	(0.0367)	(0.0406)	(0.0491)
	γ_1		-0.0023#	0.0003	-2.43E-05	0.0029 §	0.0031#
			(0.0012)	(0.0011)	(0.0012)	(0.0013)	(0.0017)
	γ_2		0.0010	0.0006	-0.0005	-0.0037 §	-0.0020
			(0.0015)	(0.0013)	(0.0015)	(0.0015)	(0.0019)
mean spillover from EU	δ_0			0.0196	0.0273	0.0704#	0.0336
				(0.0404)	(0.0370)	(0.0414)	(0.0560)
	δ_1			-0.0110	0.0026	-0.0536	-0.0815
				(0.0467)	(0.0607)	(0.0635)	(0.0694)
	δ_2			-0.0984 §	-0.0878	-0.0857	-0.0421
				(0.0469)	(0.0639)	(0.0640)	(0.0700)
volatility spillover from US	φ_0		0.8519*	0.9416*	0.5213*	0.5371*	0.8100*
			(0.0336)	(0.0299)	(0.0332)	(0.0331)	(0.0415)
	φ_1		-0.0073	0.0297	0.1865*	0.3774*	0.1096
			(0.0602)	(0.0577)	(0.0681)	(0.0718)	(0.0927)
	φ_2		0.2232*	-0.0835	0.0370	0.1156	0.1030
			(0.0607)	(0.0572)	(0.0690)	(0.0760)	(0.0935)
volatility spillover from EU	ψ_0			0.7105*	0.5109*	0.4445*	0.7653*
				(0.0340)	(0.0363)	(0.0403)	(0.0514)
	ψ_1			0.1445 §	0.0265	0.2954*	0.0328
				(0.0725)	(0.0858)	(0.0986)	(0.1137)
	ψ_2			-0.3246*	-0.1361	-0.4915*	-0.1254
				(0.0814)	(0.1000)	(0.1116)	(0.1281)

changed. The model allows the mean and volatility spillover parameters to have different values in order to examine the changes on the effects introduced by two big events—the establishment of OMX group and the most recent financial crisis in 2008. The summary statistics of the results from the *event spillover model* are presented in Table 5. The estimates of the EGARCH parameters are not reported here in Table 5 as the results are similar to the basic spillover model, but they can be found in Appendix (Table A2). Table 6 lists the 12 joint Wald tests null hypotheses and the corresponding results are illustrated in Table 7.

The first column of Table 5 reports the results for the US return, which is identical to that of the basic spillover model as the regression processes are the same. The second column in Table 5, which is also the second step of the model, reports the return of the aggregate European index. All statistics of mean spillover from US to European $\gamma_{0,\mathrm{E}}$, $\gamma_{1,\mathrm{E}}$, and $\gamma_{2,\mathrm{E}}$ are really small and insignificant. The nearly negligible changes can be further proven by the non-rejection of the joint hypothesis of no mean-spillover effects changes after the OMX group establishment and the 2008 financial crisis, which is in a p-value of 30.43%. The first event is insignificant and contributes a little to the change of volatility-spillover effects ($\varphi_{1,\mathrm{E}} < 0$), whereas the second event is significant and has a large statistical increase on the impact of the US volatility-spillover effects, i.e. $\varphi_{2,\mathrm{E}}$ is significant at 1% level, which makes sense as the impact from the US subprime crisis was felt internationally. The robust joint Wald tests of no changes in volatility-spillover effects $H_0^6: \varphi_{0,E} = \varphi_{1,E} = \varphi_{2,E} = \psi_{0,E} = \psi_{1,E} = \psi_{2,E} = 0$ have been strongly rejected. The test of no US-spillover changes caused by the first event is not rejected but is strongly rejected for the second event and the joint tests of the changes caused by these two events together, which are in the p-value of 17.96%, 0.12%, and 0.00%, respectively.

In the third step of the event model, the changes in mean and volatility spillover from the US and the aggregate Europe to individual Scandinavian market caused by the two biggest events have been investigated.

Firstly, the mean spillover effects from both the world market and the regional index are small to Sweden where the two big events have not altered too much of the results from the basic spillover model. The joint test of no mean-spillover change from the US market induced by the first event cannot be rejected (H_0^1 with a p-value of 93.66%) but the test of event 2 leads to no changes has been rejected at 10% significance level. The joint test of no changes on the mean-spillover effects after the two events occurred: $H_0^3: \gamma_{o,i} = \gamma_{1,i} = \gamma_{2,i} = \delta_{0,i} = \delta_{1,i} = \delta_{2,i} = 0$ has been strongly rejected. The merger among the Nordic markets has a positive impact on the volatility-spillover effects from the aggregate European market to some extent but not on the effects from the US. Surprisingly, the recent financial crisis exhibits a negative influence on the volatility-spillover both from the US and the aggregate European market to Sweden. More surprisingly the joint test of no volatility-spillover changes caused by the establishment of OMX group cannot be rejected, which means the integration among the Nordic region has no effects on the magnitude or the direction of the volatility-spillover, whereas the rejection has taken the place on no effects caused by the subprime crisis. The joint Wald test of no US and no EU spillover changes: $H_0^9: \gamma_{0,i} = \gamma_{1,i} = \gamma_{2,i} = \varphi_{0,i} = \varphi_{1,i} = \varphi_{2,i} = 0$ and $H_0^{12}: \delta_{0,i} = \delta_{1,i} = \delta_{2,i} = \psi_{0,i} = \psi_{1,i} = \psi_{2,i} = 0$ have been strongly rejected.

Table 6
Null Hypotheses for joint Wald tests

The table illustrates all the null hypotheses for the joint Wald tests for the Event Model.

$H_0^1: \gamma_{1,i} = \delta_{1,i} = 0$ (no mean spillover changes by event 1)	$H_0^7: \gamma_{1,i} = \varphi_{1,i} = 0$ (no US-spillover changes by event 1)
$H_0^2: \gamma_{2,i} = \delta_{2,i} = 0$ (no mean spillover changes by event 2)	$H_0^8: \gamma_{2,i} = \varphi_{2,i} = 0$ (no US-spillover changes by event 2)
$H_0^3: \gamma_{o,i} = \gamma_{1,i} = \gamma_{2,i} = \delta_{0,i} = \delta_{1,i} = \delta_{2,i} = 0$ (no mean spillover changes overall)	$H_0^9: \gamma_{0,i} = \gamma_{1,i} = \gamma_{2,i} = \varphi_{0,i} = \varphi_{1,i} = \varphi_{2,i} = 0$ (no US-spillover changes overall)
$H_0^4: \varphi_{1,i} = \psi_{1,i} = 0$ (no volatility spillover changes by event 1)	$H_0^{10}: \delta_{1,i} = \psi_{1,i} = 0$ (no EU-spillover changes by event 1)
$H_0^5: \varphi_{2,i} = \psi_{2,i} = 0$ (no volatility spillover changes by event 2)	$H_0^{11}: \delta_{2,i} = \psi_{2,i} = 0$ (no EU-spillover changes by event 2)
$H_0^6: \varphi_{0,i} = \varphi_{1,i} = \varphi_{2,i} = \psi_{0,i} = \psi_{1,i} = \psi_{2,i} = 0$ (no volatility spillover changes overall)	$H_0^{12}: \delta_{0,i} = \delta_{1,i} = \delta_{2,i} = \psi_{0,i} = \psi_{1,i} = \psi_{2,i} = 0$ (no EU-spillover changes overall)

Furthermore, in Denmark, both the first and the second event has a negative impact on the mean-spillover effects from the world market but the OMX group formation has a positive influence on the mean-spillover from the regional index, even though all these impacts are small and insignificant. The results are evidenced by the Wald test where the non-rejection of the no changes in mean-spillover after these two events happened. The first event has more significant impact then the second one on the volatility-spillover from the US whereas the 2008 financial crisis has larger impact on the European-volatility spillover effects, which are quite controversial. The robust Wald tests cannot reject there are no changes in mean-spillover effects after the two events, i.e. $H_0^1: \gamma_{1,i} = \delta_{1,i} = 0$ and $H_0^2: \gamma_{2,i} = \delta_{2,i} = 0$ are not rejected. Similar to the results of Sweden, the joint tests of no US and no European spillover effects changes have been strongly rejected.

Next, focusing on Norway, the first and the second event are at 5% significance level in the mean-spillover effects from the US return and have negative and insignificant impact from the European return. All the Wald tests of no changes in mean-spillover: $H_0^1: \gamma_{1,i} = \delta_{1,i} = 0$ (no mean spillover changes by event 1); $H_0^2: \gamma_{2,i} = \delta_{2,i} = 0$ (no mean spillover changes by event 2); and $H_0^3: \gamma_{o,i} = \gamma_{1,i} = \gamma_{2,i} = \delta_{0,i} = \delta_{1,i} = \delta_{2,i} = 0$ (no mean spillover changes overall) are rejected in which p-values are 7.57%, 1.81%, and 0.04%, respectively. Similar to the results in Sweden, the OMX group formation has a larger impact on the volatility-spillover both from the US and the aggregate European market then the 2008 financial crisis. Surprisingly, the financial crisis is insignificant in the volatility-spillover from the country where it took place and has a negative impacts on the volatility transferred from the European market. There are changes in the volatility-spillover, US-spillover, and European-spillover in Norway after the two events happened, as H_0^6: $\varphi_{0,i} = \varphi_{1,i} = \varphi_{2,i} = \psi_{0,i} = \psi_{1,i} = \psi_{2,i} = 0$ (no volatility spillover changes overall), H_0^9: $\gamma_{0,i} = \gamma_{1,i} = \gamma_{2,i} = \varphi_{0,i} = \varphi_{1,i} = \varphi_{2,i} = 0$ (no US-spillover changes overall), and H_0^{12}: $\delta_{0,i} = \delta_{1,i} = \delta_{2,i} = \psi_{0,i} = \psi_{1,i} = \psi_{2,i} = 0$ (no EU-spillover changes overall) are strongly rejected.

Table 7
Joint Wald tests—Event Model

The table reports the joint Wald tests results for the twelve null hypotheses listed in Table 6. * (§) [#], indicates that the value is significant at 1% (5%) [10%] level of significance.

		EU	Sw	De	No	Fi
Wald 1	Chi-square		0.1310	0.0022	5.1619#	4.4978
	Prob.		0.9366	0.9989	0.0757	0.1055
Wald 2	Chi-square		4.6714#	1.9983	8.0238 §	1.5577
	Prob.		0.0967	0.3682	0.0181	0.4589
Wald 3	Chi-square	3.6298	35.4458*	22.9731*	24.4109*	13.53 §
	Prob.	0.3043	0.0000	0.0008	0.0004	0.0354
Wald 4	Chi-square		4.0097	7.5097 §	32.2855*	1.4758
	Prob.		0.1347	0.0234	0.0000	0.4781
Wald 5	Chi-square		17.2896*	2.1713	21.7632*	1.9760
	Prob.		0.0002	0.3377	0.0000	0.3723
Wald 6	Chi-square	1715.50*	2878.016*	1078.83*	1265.65*	1494.70*
	Prob.	0.0000	0.0000	0.0000	0.0000	0.0000
Wald 7	Chi-square	3.4336	0.3263	7.5207 §	30.4520*	4.3224
	Prob.	0.1796	0.8495	0.0233	0.0000	0.1152
Wald 8	Chi-square	13.522*	2.4912	0.4097	8.7474 §	2.6950
	Prob.	0.0012	0.2878	0.8148	0.0126	0.2599
Wald 9	Chi-square	1738.77*	2450.04*	855.45*	1093.74*	1108.30*
	Prob.	0.0000	0.0000	0.0000	0.0000	0.0000
Wald 10	Chi-square		3.9718	0.1053	9.4158*	1.3892
	Prob.		0.1373	0.9487	0.0090	0.4993
Wald 11	Chi-square		21.3217*	4.2808	21.6953*	1.4272
	Prob.		0.0000	0.1176	0.0000	0.4899
Wald 12	Chi-square		780.606*	300.526*	225.254*	366.44*
	Prob.		0.0000	0.0000	0.0000	0.0000

Finally, the mean-spillover effect on Finland from the US caused by the formation of the OMX group is significant at 10% significance level while the impact from the financial crisis is negligible. These two events exhibit negative influences on the mean-spillover from the aggregate European market to Finland but are really small and insignificant. The robust joint Wald tests evidenced the insignificant impacts as well, i.e. $H_0^1: \gamma_{1,i} = \delta_{1,i} = 0$ (no mean spillover changes by event 1), $H_0^2: \gamma_{2,i} = \delta_{2,i} = 0$ (no mean spillover changes by event 2), $H_0^4: \varphi_{1,i} = \psi_{1,i} = 0$ (no volatility spillover changes by event 1), and $H_0^5: \varphi_{2,i} = \psi_{2,i} = 0$ (no volatility spillover changes by event 2) cannot be rejected as p-values are in 10.55%, 45.89%, 47.81%, and 37.23%, respectively. Both events have some influences on the volatility-spillover from the US market as φ_1 and φ_2 are 0.1096 and 0.1030, but the impacts are not significant. The insignificant effects occurred on the volatility transferred from the European market as well. However, the joint Wald tests of no changes carried out by the two events in US-spillover and EU-spillover have been strongly rejected, which indicate the OMX group formation and the financial crisis changed the volatility-spillover effects from the world and the regional markets, i.e. $H_0^9: \gamma_{0,i} = \gamma_{1,i} = \gamma_{2,i} = \varphi_{0,i} = \varphi_{1,i} = \varphi_{2,i} = 0$ (no US-spillover changes overall) and $H_0^{12}: \delta_{0,i} = \delta_{1,i} = \delta_{2,i} = \psi_{0,i} = \psi_{1,i} = \psi_{2,i} = 0$ (no EU-spillover changes overall) are in the same p-value of 0.00%.

The mean-spillover from the world market is significant to each single Nordic index in both basic and event spillover models. Excluding Sweden, the other three countries showed the weaker US mean-spillover effects before the formation of the OMX group and the occurrence of the financial crisis are observed than the effects estimated by the basic spillover model, i.e. $\gamma_i > \gamma_{0,i}$. In the case of Sweden, the stronger US mean-spillover effects before these two events are found. The establishment of the OMX group strengthened the mean-spillover from the world market to individual countries i.e. $\gamma_{1,i} > 0$. The only exception is Denmark. But the return impact is dampened by recent financial crisis, i.e. $\gamma_{2,i} < 0$, where Sweden is being the exception here. In contrast, the mean-spillover effects from the regional index, which experienced a big change after these two events happened ($\delta_{0,i} > 0$ and $\delta_i < 0$), are insignificant and are found to be stronger before the occurrence of these two events, i.e. $\delta_{0,i} > \delta_i$. The determinant factor of the negative EU mean-spillover effects to the three Scandinavian countries (except Finland) is the 2008 subprime crisis, i.e. $\delta_{0,i} + \delta_{1,i} > 0 \; and \; \delta_{2,i} < 0$.

Compared to the mean-spillover effects, the volatility-spillover effects from the US and the aggregate European market are significant at 1% level. The US volatility-spillover effects follow the same trend as the US mean-spillover effects, which are found to be weaker for three out of four Nordic countries (with the exception of Sweden) before the two events took place, i.e. $\varphi_i > \varphi_{0,i}$. The volatility-spillover effects are strengthened by the formation of the OMX group, i.e. $\varphi_{1,i} > 0$, and are stronger than the effects estimated by the basic spillover model, i.e. $\varphi_{0,i} + \varphi_{1,i} > \varphi_i$, with Finland as the exception. Other than Sweden, the US volatility-spillover effects are magnified by the financial crisis in three countries, i.e. $\varphi_{2,i} > 0$ and $\varphi_{0,i} + \varphi_{1,i} + \varphi_{2,i} > \varphi_i$. In the case of Sweden, the volatility-spillover effect caused by the subprime crisis dampened the overall volatility transferred from the world market, i.e. $\varphi_{0,i} + \varphi_{1,i} + \varphi_{2,i} < \varphi_i$. In terms of the EU volatility-spillover, except Norway, the effects are found to be stronger before the occurrences of these two events, i.e. $\psi_{0,i} > \psi_i$, which is contrary to the US volatility-spillover effects. The following commonalities in the effects generated by the two events are found in all these four countries. The formation of the OMX group strengthened the EU volatility-spillover effects, i.e. $\psi_{1,i} > 0$ and the effects are stronger then the estimation by the basic spillover model, i.e. $\psi_{0,i} + \psi_{1,i} > \psi_i$. However, the big impact from the financial tsunami dampened the EU spillover effects to a large extent, i.e. $\psi_{2,i} < 0$ and $\psi_{0,i} + \psi_{1,i} + \psi_{2,i} < \psi_i$.

Table 8

Variance Ratios—Event Spillover Model

The mean and standard deviation of the US, the EU, and own variance ratios are contained in this table for the three sub periods of event spillover model: $VR_{i,t}^{us} = \frac{(\varphi_{0,i}+\varphi_{1,i}D_{1,t}+\varphi_{2,i}D_{2,t})^2\sigma_{us,t}^2}{h_{i,t}}$, $VR_{i,t}^{E} = \frac{(\psi_{0,i}+\psi_{1,i}D_{1,t}+\psi_{2,i}D_{2,t})^2\sigma_{E,t}^2}{h_{i,t}}$, and $VR_{i,t}^{i} = 1 - VR_{i,t}^{us} - VR_{i,t}^{E}$. $h_{i,t}$ is the conditional variance of the unexpected return for individual country i and σ_{us} and σ_E are the conditional variance of the US and European idiosyncratic shocks. $D_{1,t}$ equals 0 before September 5, 2003 and 1 afterwards. $D_{2,t}$ equals to 0 before July 4, 2008 and 1 hereafter.

			Sw	De	No	Fi
Before OMX Group Establishment	VR^{US}	mean	0.4920	0.4346	0.5365	0.4221
		St. Dev.	0.5214	0.4655	0.5327	0.4210
	VR^{E}	mean	0.1260	0.0905	0.0224	0.1310
		St. Dev.	0.1453	0.1055	0.0242	0.1423
	VR^{i}	mean	0.3820	0.4749	0.4412	0.4469
		St. Dev.	0.3332	0.4290	0.4431	0.4367
Between OMX and Financial Crisis	VR^{US}	mean	0.5289	0.3701	0.4029	0.5431
		St. Dev.	0.4679	0.3661	0.3938	0.4490
	VR^{E}	mean	0.0953	0.0542	0.0118	0.1186
		St. Dev.	0.1069	0.0680	0.0147	0.1243
	VR^{i}	mean	0.3758	0.5756	0.5853	0.3383
		St. Dev.	0.4252	0.5659	0.5915	0.4267
After Financial Crisis	VR^{US}	mean	0.6880	0.5157	0.6250	0.6930
		St. Dev.	0.7780	0.6111	0.6686	0.7800
	VR^{E}	mean	0.0837	0.0511	0.0124	0.1023
		St. Dev.	0.0684	0.0437	0.0096	0.0832
	VR^{i}	mean	0.2283	0.4332	0.3626	0.2047
		St. Dev.	0.1536	0.3452	0.3219	0.1368

Table 8 presents the mean and standard deviation of the variance ratios from the three sub periods of the event spillover model. Compared to the basic spillover model, the percentage of the US volatility-spillover effects in the conditional variance of the unexpected return for individual country i is increasing and the range of the US effects is becoming more tightened, i.e. from 45.5% to 56.5%. For all countries, the average US variance ratios are largest in the third sub period, followed by the time between OMX group establishment and the financial crisis in Sweden and Finland, whereas in Denmark and Norway are followed by the first sub period. Surprisingly, the EU variance ratios are largest for all four countries in the period before the formation of the OMX group and are smallest in the third sub period for three markets with the exception of Norway. The impact from the US on Scandinavian stock markets has increased while the influencing power from the EU is reduced. This might due to the Nordic region becoming more closely related to the world market as NASDAQ has purchased the OMX group. The purely localized volatility effects declined as well. For Sweden and Finland, their own markets have the largest influences in the first sub period whereas this is only the case in the second sub period for Denmark and Norway. Thus, the merger of the OMX group and the 2008 financial crisis increased the volatility spillover impacts from the US market to individual Nordic country while it decreased the influences from the aggregate European market.

5.3 Trend Spillover Model Results

The spillover parameters (both in mean and volatility) are allowed to increase with a constant value each year during the entire sample period from January 1995 to December 2012 in the trend spillover model by adding the dummy variable, c.f. Eq. (19) to (22). The intensive beforehand is to see how do the mean and volatility spillover effects from the US and the aggregate European market change (increase or decrease) over the testing period. The estimated results from this model are presented in Table 9.

Similar to both the basic and event spillover model, the US mean-spillover effects are significant here as well while the European mean-spillover effects are insignificant in all three models. For the impacts of the US return, although the increase (in Sweden and in Norway) or the decrease (in Denmark and in Finland) are really small, i.e. $\gamma_{1,i} < 0.01\%$, the robust Wald test, as reported in Table 10, indicates that the non-rejection of the constant return spillover parameter from the world market (the null hypothesis: $H_0^1: \gamma_{1,i} = 0$, is not rejected. The mean-spillover effects from the European market experienced a downward trend during the sample period ($\delta_{1,i} < 0$). Except the acceptance of the mean-spillover parameter is constant in Denmark, the hypothesis that influences from the EU mean-spillover have changed from 1995 until now in the rest three countries, i.e. $H_0^2: \delta_{1,i} = 0$ are rejected with p-values in 0.1%, 0.67%, and 0.02%, respectively.

According to the results from previous two models, the strong volatility-spillover effects from the world and regional markets exist. In order to be consistent with the preceding findings, either $\varphi_{0,i}$, $\varphi_{1,i}$ or both from the US stock market and either $\psi_{0,i}$, $\psi_{1,i}$, or both from the European stock market should be significant. The estimated results from the trend spillover model are identical with previous findings as $\varphi_{0,i}$ is significant for all countries and $\varphi_{1,i}$ is significant for three markets where

Table 9
Trend Spillover Model

The table reports the summary statistics from the trend spillover model. The US return is the same as the basic spillover model. European return: $R_{E,t} = c_{0,E} + c_{1,E}R_{E,t\text{-}1} + (\gamma_{0,E} + \gamma_{1,E}D_{1,t})R_{us,t\text{-}1} + (\varphi_{0,E} + \varphi_{1,E}D_{1,t})e_{us,t} + e_{E,t}$ where $e_{E,t}$ has mean 0 and conditional variance: $\ln\sigma^2_{E,t} = \omega_E + \alpha_{1,E}\frac{e_{E,t\text{-}1}}{\sigma_{E,t\text{-}1}} + \alpha_{2,E}\left(\left|\frac{e_{E,t\text{-}1}}{\sigma_{E,t\text{-}1}}\right| - \sqrt{\frac{2}{\pi}}\right) + \beta_E \ln\sigma^2_{E,t\text{-}1}$. Individual country return is denoted as $R_{i,t}$, where i is the four Scandinavian markets: $R_{i,t} = c_{0,i} + c_{1,i}R_{i,t\text{-}1} + (\gamma_{0,i} + \gamma_{1,i}D_{1,t})R_{us,t\text{-}1} + (\delta_{0,i} + \delta_{1,i}D_{1,t})R_{E,t\text{-}1} + (\varphi_{0,i} + \varphi_{1,i}D_{1,t})e_{us,t} + (\psi_{0,i} + \psi_{1,i}D_{1,t})e_{E,t} + e_{i,t}$ where $e_{i,t}$ has mean 0 and conditional variance: $\ln\sigma^2_{i,t} = \omega_i + \alpha_{1,i}\frac{e_{i,t\text{-}1}}{\sigma_{i,t\text{-}1}} + \alpha_{2,i}\left(\left|\frac{e_{i,t\text{-}1}}{\sigma_{i,t\text{-}1}}\right| - \sqrt{\frac{2}{\pi}}\right) + \beta_i \ln\sigma^2_{i,t\text{-}1}$. $D_{1,t}$ equals to 1 for the 1995 observations, 2 for the 1996 observations, and so on. ω_i, $\alpha_{1,i}$, $\alpha_{2,i}$, and β_i are not reported here but can be found in Appendix (Table A3). The results in parentheses are Bollerslev and Wooldridge (1992) robust standard errors. * (§) [#], indicates that the value is significant at 1% (5%) [10%] level of significance.

	US	EU	Sw	De	No	Fi
$c_{0,i}$	0.0035 (0.0010)	-0.1128* (0.0340)	-0.1543* (0.0318)	-0.1606* (0.0360)	-0.1081* (0.0406)	-0.1287* (0.0402)
$c_{1,i}$	-0.1309	-0.1037* (0.0350)	-0.0832 § (0.0404)	-0.0566# (0.0322)	-0.0372 (0.0331)	-0.0563# (0.0320)
γ_0		0.1136* (0.0344)	0.1540* (0.0317)	0.1629* (0.0359)	0.1102* (0.0407)	0.1314* (0.0401)
γ_1		-0.0003 § (0.0001)	0.0001 (0.0000)	-3.30E-06 (0.0001)	2.51E-05 (0.0001)	-3.83E-05 (0.0001)
δ_0			0.0854 (0.0541)	0.0418 (0.0510)	0.1168 § (0.0542)	0.1337 § (0.0580)
δ_1			-0.0111* (0.0034)	-0.0065 (0.0041)	-0.0113* (0.0042)	-0.0150* (0.0040)
φ_0		0.6968* (0.0515)	0.9712* (0.0492)	0.4819* (0.0527)	0.3981* (0.0558)	0.7433* (0.0603)
φ_1		0.0268* (0.0046)	-0.0043 (0.0043)	0.0149* (0.0046)	0.0375* (0.0049)	0.0155* (0.0051)
ψ_0			0.7996* (0.0576)	0.5985* (0.0560)	0.5375* (0.5375)	0.7888* (0.0702)
ψ_1			-0.0117 § (0.0055)	-0.0131 § (0.0056)	-0.0126# (0.0065)	-0.0080 (0.0064)

Sweden is the exception. From the robust Wald tests, the constancy of US volatility-spillover parameters are rejected (the rejection of the null hypothesis that $\varphi_{1,i} = 0$) in three countries with the Sweden being the exception as well. In the case of Sweden, the volatility-spillover effects from the world market are not changing too much during the entire sample period, i.e. $\varphi_{1,i} = 0$ is not rejected.

Table 10

Wald Tests—Trend Spillover Model

The table reports the joint Wald tests results for four different hypotheses, where the null hypothesis for each test is as follow: $H_0^1: \gamma_{1,i} = 0$ (US mean-spillover parameter is constant); $H_0^2: \delta_{1,i} = 0$ (EU mean-spillover parameter is constant); $H_0^3: \varphi_{1,i} = 0$ (US volatility-spillover parameter is constant); $H_0^4: \psi_{1,i} = 0$ (EU volatility-spillover parameter is constant). * (§) [#], indicates that the value is significant at 1% (5%) [10%] level of significance.

		EU	Sw	De	No	Fi
Wald 1	Chi-square	4.1782 §	1.9809	0.0011	0.0585	0.1213
	Prob.	0.0409	0.1593	0.9738	0.8088	0.7277
Wald 2	Chi-square		10.8104*	2.5795	7.3646*	14.1776*
	Prob.		0.0010	0.1083	0.0067	0.0002
Wald 3	Chi-square	34.3901*	1.0039	10.3727*	57.6623*	9.3736*
	Prob.	0.0000	0.3164	0.0013	0.0000	0.0022
Wald 4	Chi-square		4.4523 §	5.5586 §	3.7456#	1.5783
	Prob.		0.0349	0.0184	0.0529	0.2090

The volatility-spillover effects from the European market are found to be significant for all these four countries as well, i.e. $\psi_{0,i}$ are significant at 1% significance level for all markets. This result is consistent with those findings from the basic and event spillover models. Unlike the tendency of the increasing impacts from the US volatility-spillover to individual Scandinavian stock market, the European volatility spillover effects are decreasing over the sample period. Besides Finland, all the negative EU volatility-spillover parameters are significant and are not constant at up to 10% significance level (the null hypotheses of $\psi_{1,i} = 0$ are rejected).

Table 11 presents the average and standard variance ratios from the trend spillover model[6]. Compared to the basic spillover model, the local volatility increased dramatically in Norway during the sample period whereas it is almost constant for the other three countries. Figure A1 (see Appendix) illustrates the overall trend for the four countries during the sample period. Sweden and Finland almost follow the same trend, where the US variance ratios are increasing from 1996 and reached the peak point around 2009 before experiencing a decreasing trend. In these two countries, the EU impacts are almost constant from 1995 to 2012 but the local influences see a sharp drop from 1995 to 1998 followed by a 10 year relative level off and begin to increase at the end of 2008. In Denmark and Norway, the purely local variances are the largest

[6] The full variance ratios for individual countries for different years can be found in Appendix Table A4.

influencing factors for the entire sample period. The US and the EU markets are nearly having the same degree of impacts on these two countries (between 10% and 20% over the testing period).

Table 11

Variance Ratios—Trend Spillover Model

The mean and standard deviation of the US, the EU, and own variance ratios are contained in this table for the trend spillover model: $VR_{i,t}^{us} = \frac{(\varphi_{0,i}+\varphi_{1,i}D_{1,t})^2 \sigma_{us,t}^2}{h_{i,t}}$, $VR_{i,t}^{E} = \frac{(\psi_{0,i}+\psi_{1,i}D_{1,t})^2 \sigma_{E,t}^2}{h_{i,t}}$, and $VR_{i,t}^{i} = 1 - VR_{i,t}^{us} - VR_{i,t}^{E}$. $h_{i,t}$ is the conditional variance of the unexpected return for individual country i and σ_{us} and σ_E are the conditional variance of the US and European idiosyncratic shocks. $D_{1,t}$ equals 1 for the observations in 1995, 2 in 1996, and so on.

		Sw	De	No	Fi
VR^{US}	Mean	0.542	0.245	0.160	0.356
	St. Dev.	0.628	0.319	0.201	0.415
VR^{E}	Mean	0.192	0.181	0.124	0.201
	St. Dev.	0.001	0.001	0.001	0.001
VR^{i}	Mean	0.266	0.574	0.716	0.443
	St. Dev.	0.372	0.680	0.798	0.584

6. Concluding Remarks

In this paper, the mean and volatility spillover effects from the US and the aggregate European stock markets transmitted to the four Scandinavian countries were investigated. In order to figure out the spillover effects form the world, regional, and local markets, the AR-EGARCH model was applied, which allows the mean and volatility from both the US and the EU markets to be added into the return regression equation for single Nordic country. Mean-spillover effects from the US are significant for all countries whereas the effects from the European market are negligible. The volatility-spillover effects are essential from both the world and the regional markets. For all these four countries, the European effects are least significant, the local effects are larger than the US effects in Denmark and Norway whereas the world effects are most significant in Sweden and Finland.

The significance of the world, regional, and local effects in Sweden and Denmark is neither changed by the formation of the OMX group, nor by the most recent financial crisis, nor the overall trend during the entire sample period. Although the occurrence of these two major events have increased the significance level of impact from the US to Norway, the general trend of the significant effects from the three markets (the US, EU, and the local) has remained unaltered. In Finland, there is no significant change in spillover due to the two events but the influences from the local effects are increasing over the sample period.

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Appendix

Table A1: Autocorrelation and Ljung Box statistics for six indexes

EU50

Sample: 1/06/1995 12/28/2012

Included observations: 939

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
| |	| |	1	-0.063	-0.063	3.7888	0.052
| |	| |	2	0.057	0.054	6.8954	0.032
| |	| |	3	-0.047	-0.041	9.0231	0.029
| |	| |	4	-0.005	-0.013	9.0428	0.060
| |	| |	5	0.021	0.025	9.4665	0.092
|* |	|* |	6	0.102	0.105	19.414	**0.004**
*| |	| |	7	-0.073	-0.065	24.443	0.001
| |	| |	8	0.041	0.024	26.006	0.001
| |	| |	9	-0.043	-0.023	27.743	0.001
| |	| |	10	0.017	0.006	28.021	0.002

S&P500

Sample: 1/06/1995 12/28/2012

Included observations: 939

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
*| |	*| |	1	-0.078	-0.078	5.7755	0.016
| |	| |	2	0.065	0.059	9.7404	0.008
| |	| |	3	-0.045	-0.036	11.685	0.009
| |	| |	4	-0.051	-0.061	14.114	0.007
| |	| |	5	0.028	0.026	14.878	0.011
| |	|* |	6	0.073	0.084	19.974	**0.003**
*| |	*| |	7	-0.076	-0.075	25.462	0.001
| |	| |	8	0.025	0.003	26.032	0.001
| |	| |	9	-0.054	-0.032	28.780	0.001
| |	| |	10	0.010	0.004	28.875	0.001

OMXS30

Sample: 1/06/1995 12/28/2012

Included observations: 939

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
| |	| |	1	-0.056	-0.056	2.9092	0.088
| |	| |	2	0.055	0.052	5.7816	0.056
| |	| |	3	0.016	0.022	6.0152	0.111
*| |	*| |	4	-0.066	-0.067	10.112	0.039
|* |	|* |	5	0.104	0.096	20.403	**0.001**
|* |	|* |	6	0.080	0.099	26.505	0.000
*| |	*| |	7	-0.102	-0.105	36.344	0.000
|* |	|* |	8	0.102	0.077	46.259	0.000
| |	| |	9	-0.063	-0.032	49.997	0.000
| |	| |	10	0.020	0.007	50.377	0.000

OMXH25

Sample: 1/06/1995 12/28/2012

Included observations: 939

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
| |	| |	1	-0.025	-0.025	0.5716	0.450
| |	| |	2	0.044	0.043	2.3858	0.303
| |	| |	3	0.056	0.058	5.3470	0.148
| |	| |	4	0.011	0.012	5.4585	0.243
|* |	|* |	5	0.093	0.089	13.554	0.019
| |	|* |	6	0.073	0.075	18.594	**0.005**
| |	| |	7	-0.056	-0.061	21.523	0.003
| |	| |	8	0.059	0.040	24.832	0.002
| |	| |	9	-0.049	-0.053	27.116	0.001
| |	| |	10	0.017	0.006	27.401	0.002

OMXC20

Sample: 1/06/1995 12/28/2012

Included observations: 939

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
| |	| |	1	-0.058	-0.058	3.2014	0.074
|* |	|* |	2	0.131	0.128	19.420	**0.000**
| |	| |	3	0.006	0.021	19.457	0.000
| |	| |	4	-0.013	-0.029	19.616	0.001
| |	| |	5	-0.007	-0.013	19.665	0.001
| |	| |	6	0.060	0.066	23.104	0.001
*| |	| |	7	-0.071	-0.063	27.889	0.000
| |	| |	8	0.017	-0.007	28.170	0.000
| |	| |	9	0.002	0.020	28.176	0.001
| |	| |	10	0.017	0.022	28.451	0.002

OBX25

Sample: 1/06/1995 12/28/2012

Included observations: 939

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
| |	| |	1	-0.009	-0.009	0.0809	0.776
|* |	|* |	2	0.078	0.078	5.7762	0.056
| |	| |	3	0.032	0.033	6.7214	0.081
| |	| |	4	-0.027	-0.032	7.3936	0.116
| |	| |	5	0.057	0.052	10.462	0.063
| |	| |	6	0.036	0.041	11.681	0.069
| |	| |	7	-0.020	-0.027	12.076	0.098
| |	| |	8	0.050	0.040	14.480	0.070
| |	| |	9	-0.043	-0.038	16.230	0.062
| |	| |	10	0.034	0.027	17.337	**0.067**

Table A2: EGARCH parameters for the event spillover model

	US	EU	Sw	De	No	Fi
ω_i	-0.8078*	-0.9314*	-0.6977*	-0.4266*	-0.5433*	-0.6491*
	(0.1169)	(0.2178)	(0.1753)	(0.1580)	(0.1633)	(0.1480)
$\alpha_{1,i}$	-0.2202*	-0.1216*	-0.0521*	0.0028	-0.0017	-0.0795*
	(0.0221)	(0.0235)	(0.0267)	(0.0252)	(0.0329)	(0.0201)
$\alpha_{2,i}$	0.2012*	0.2624*	0.2693*	0.1967*	0.2612*	0.2350*
	(0.0393)	(0.0414)	(0.0500)	(0.0434)	(0.0522)	(0.0366)
β_i	0.9149*	0.9086*	0.9405*	0.9658*	0.9557*	0.9357*
	(0.0135)	(0.0247)	(0.0189)	(0.0180)	(0.0185)	(0.0186)

Table A3: EGARCH parameters for trend spillover model

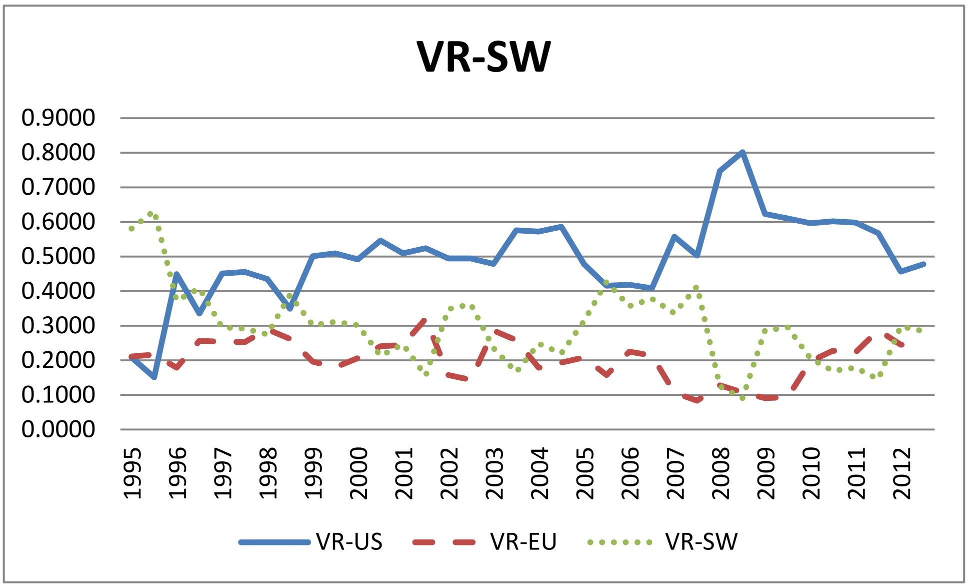
	US	EU	Sw	De	No	Fi
ω_i	-0.8078*	-2.0216*	-1.0740*	-0.4910*	-0.5735*	-0.2269*
	(0.1169)	(0.3071)	(0.2585)	(0.1670)	(0.1777)	(0.0696)
$\alpha_{1,i}$	-0.2202*	-0.1488*	-0.1022*	0.0054	-0.0011	-0.0151
	(0.0221)	(0.0294)	(0.0282)	(0.0255)	(0.0271)	(0.0178)
$\alpha_{2,i}$	0.2012*	0.3653*	0.2552*	0.2149*	0.2648*	0.1514*
	(0.0393)	(0.0478)	(0.0430)	(0.0438)	(0.0508)	(0.0349)
β_i	0.9149*	0.7755*	0.8922*	0.9595*	0.9523*	0.9861*
	(0.0135)	(0.0377)	(0.0295)	(0.0195)	(0.0212)	(0.0074)

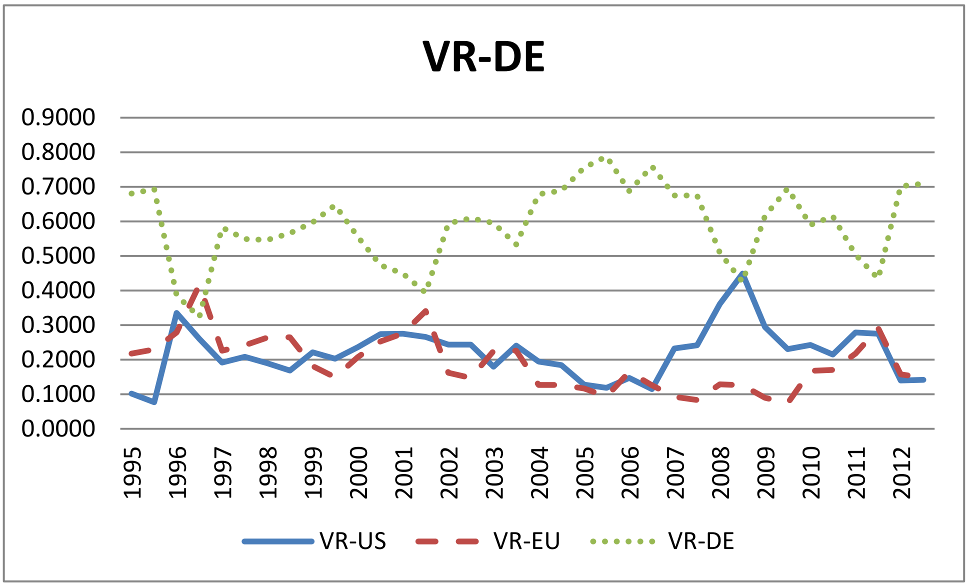
Table A4: Variance Ratios in the trend spillover model (from 1995 to 2012)

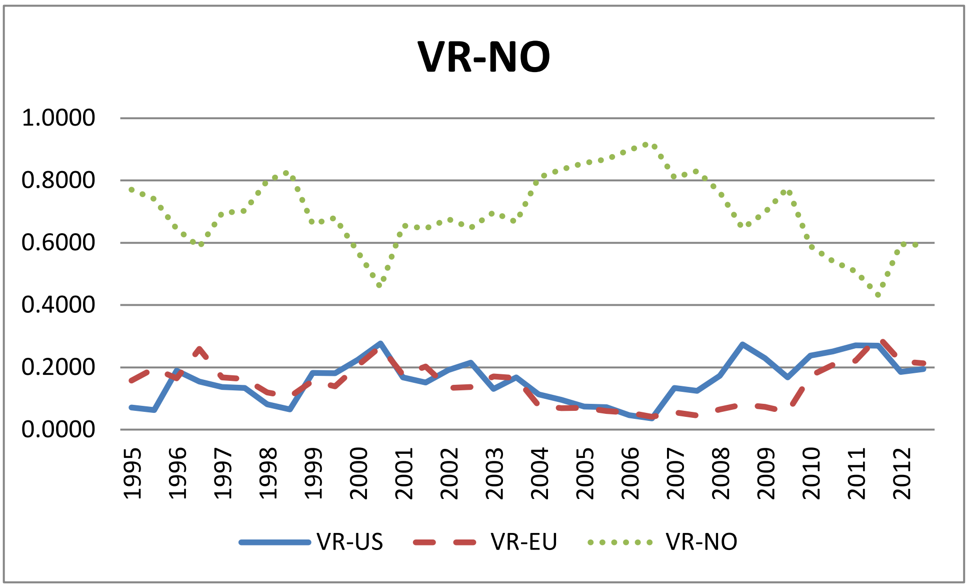
		SW			DE		
		VR^{US}	VR^{E}	VR^{i}	VR^{US}	VR^{E}	VR^{i}
1995	Mean	0.2081	0.2113	0.5805	0.1024	0.2174	0.6802
	St. Dev.	0.1514	0.2163	0.6322	0.0768	0.2295	0.6936
1996	Mean	0.4488	0.1788	0.3724	0.3349	0.2790	0.3862
	St. Dev.	0.3353	0.2566	0.4080	0.2603	0.4167	0.3230
1997	Mean	0.4509	0.2537	0.2955	0.1920	0.2259	0.5821
	St. Dev.	0.4558	0.2527	0.2916	0.2087	0.2419	0.5494
1998	Mean	0.4355	0.2899	0.2746	0.1896	0.2639	0.5465
	St. Dev.	0.3487	0.2621	0.3892	0.1688	0.2653	0.5659
1999	Mean	0.5012	0.1968	0.3020	0.2212	0.1816	0.5971
	St. Dev.	0.5096	0.1794	0.3110	0.2032	0.1496	0.6472
2000	Mean	0.4917	0.2064	0.3019	0.2366	0.2078	0.5556
	St. Dev.	0.5459	0.2407	0.2134	0.2739	0.2525	0.4735
2001	Mean	0.5088	0.2446	0.2466	0.2749	0.2764	0.4487
	St. Dev.	0.5235	0.3205	0.1560	0.2662	0.3407	0.3932
2002	Mean	0.4942	0.1578	0.3480	0.2432	0.1623	0.5945
	St. Dev.	0.4941	0.1436	0.3623	0.2432	0.1478	0.6089
2003	Mean	0.4787	0.2863	0.2350	0.1800	0.2251	0.5949
	St. Dev.	0.5756	0.2586	0.1659	0.2408	0.2262	0.5330
2004	Mean	0.5726	0.1788	0.2487	0.1945	0.1270	0.6786
	St. Dev.	0.5858	0.1936	0.2206	0.1843	0.1274	0.6884
2005	Mean	0.4774	0.2082	0.3143	0.1281	0.1168	0.7551
	St. Dev.	0.4160	0.1576	0.4264	0.1185	0.0938	0.7877
2006	Mean	0.4187	0.2249	0.3564	0.1471	0.1652	0.6877
	St. Dev.	0.4087	0.2137	0.3776	0.1153	0.1260	0.7587
2007	Mean	0.5576	0.1065	0.3358	0.2326	0.0929	0.6745
	St. Dev.	0.5028	0.0836	0.4136	0.2413	0.0839	0.6748
2008	Mean	0.7466	0.1279	0.1255	0.3611	0.1293	0.5096
	St. Dev.	0.8017	0.1073	0.0910	0.4491	0.1257	0.4252
2009	Mean	0.6231	0.0910	0.2859	0.2948	0.0901	0.6151
	St. Dev.	0.6104	0.0940	0.2956	0.2305	0.0742	0.6953
2010	Mean	0.5966	0.1977	0.2057	0.2423	0.1679	0.5898
	St. Dev.	0.6019	0.2281	0.1700	0.2148	0.1702	0.6149
2011	Mean	0.5984	0.2232	0.1784	0.2789	0.2176	0.5035
	St. Dev.	0.5678	0.2870	0.1451	0.2750	0.2907	0.4344
2012	Mean	0.4565	0.2458	0.2978	0.1403	0.1579	0.7018
	St. Dev.	0.4776	0.2384	0.2840	0.1422	0.1484	0.7094

		NO			FI		
		VR^{US}	VR^{E}	VR^{i}	VR^{US}	VR^{E}	VR^{i}
1995	Mean	0.0712	0.1580	0.7708	0.0449	0.0728	0.8823
	St. Dev.	0.0630	0.1969	0.7400	0.0271	0.0617	0.9112
1996	Mean	0.1896	0.1652	0.6452	0.2629	0.1671	0.5700
	St. Dev.	0.1547	0.2589	0.5865	0.2049	0.2501	0.5449
1997	Mean	0.1366	0.1680	0.6954	0.3192	0.2864	0.3944
	St. Dev.	0.1344	0.1629	0.7026	0.2663	0.2354	0.4983
1998	Mean	0.0819	0.1192	0.7989	0.2941	0.3122	0.3938
	St. Dev.	0.0646	0.1063	0.8291	0.2572	0.3084	0.4344
1999	Mean	0.1827	0.1569	0.6604	0.2895	0.1813	0.5292
	St. Dev.	0.1808	0.1392	0.6800	0.3008	0.1689	0.5303
2000	Mean	0.2239	0.2056	0.5705	0.2697	0.1806	0.5498
	St. Dev.	0.2765	0.2665	0.4570	0.2873	0.2020	0.5107
2001	Mean	0.1679	0.1765	0.6556	0.2922	0.2241	0.4837
	St. Dev.	0.1515	0.2028	0.6457	0.2753	0.2687	0.4560
2002	Mean	0.1912	0.1335	0.6753	0.4042	0.2058	0.3899
	St. Dev.	0.2155	0.1370	0.6475	0.4189	0.1942	0.3869
2003	Mean	0.1310	0.1713	0.6977	0.2812	0.2682	0.4506
	St. Dev.	0.1683	0.1653	0.6664	0.2922	0.2093	0.4985
2004	Mean	0.1135	0.0775	0.8091	0.4278	0.2130	0.3592
	St. Dev.	0.0956	0.0691	0.8352	0.4391	0.2315	0.3294
2005	Mean	0.0738	0.0704	0.8558	0.3617	0.2516	0.3868
	St. Dev.	0.0723	0.0599	0.8678	0.3887	0.2348	0.3764
2006	Mean	0.0469	0.0551	0.8980	0.2732	0.2339	0.4929
	St. Dev.	0.0364	0.0416	0.9220	0.2461	0.2052	0.5487
2007	Mean	0.1344	0.0562	0.8094	0.4391	0.1338	0.4271
	St. Dev.	0.1248	0.0454	0.8298	0.4538	0.1203	0.4259
2008	Mean	0.1734	0.0650	0.7616	0.6138	0.1677	0.2185
	St. Dev.	0.2739	0.0802	0.6459	0.6751	0.1442	0.1808
2009	Mean	0.2291	0.0732	0.6977	0.5851	0.1363	0.2786
	St. Dev.	0.1675	0.0564	0.7761	0.5649	0.1387	0.2964
2010	Mean	0.2382	0.1727	0.5891	0.4381	0.2316	0.3303
	St. Dev.	0.2507	0.2078	0.5415	0.4634	0.2801	0.2566
2011	Mean	0.2707	0.2209	0.5084	0.4084	0.2430	0.3486
	St. Dev.	0.2697	0.2982	0.4321	0.3285	0.2648	0.4066
2012	Mean	0.1858	0.2188	0.5954	0.2759	0.2370	0.4871
	St. Dev.	0.1950	0.2129	0.5921	0.2926	0.2329	0.4746

Figure A1: Variance Ratios in the trend spillover model (from Jan 1995 to Dec 2012)



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0.0000
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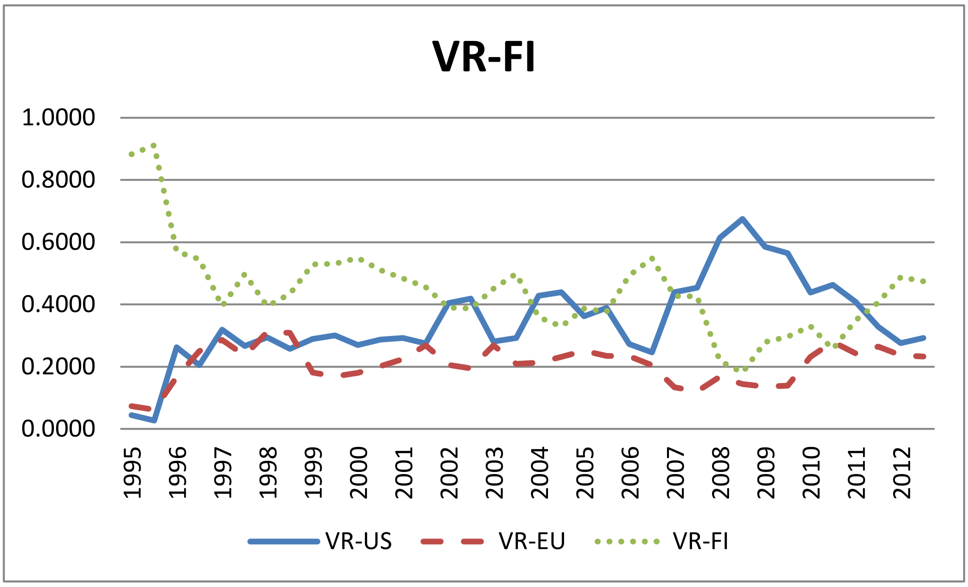
2012
VR-US
VR-EU
VR-NO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2011
2012
VR-US
VR-EU
VR-FI