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Return & Volatility Spillovers into the AEX

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Abstract

This paper examines the return and volatility spillover effects of the DAX 30, FTSE 100, Nikkei 225, Hang Seng Index (HSI) and S&P 500 into the AEX return and volatility using a daily return sample from January 1990 until December 2018. The return spillover effects are analysed using a 3-dimension VAR(1) and the volatility spillover effects are examined using a two step AR(1)-GARCH(1,1) procedure. Not enough evidence is found to support that the return spillover effects have increased with time, however, in accordance with past research, the volatility spillover effects are found to increase throughout the sample. In agreement with literature, the volatility spillover effects are found to be asymmetric; negative return periods lead to larger volatility spillovers. Additionally, it is found that the market opening closest to the AEX, namely the HSI, has significantly larger return spillover effects. Lastly, as concluded by previous literature, the one day lagged return and shocks from the S&P 500 are found to have large return and volatility spillover effects into the AEX.

Contents

1 Introduction

Globalization has brought about a rapidly changing and increasingly interdependent world economy; where distance between economies has become irrelevant (Freund & Weinhold, 2004; Bogan, 2008; Issing, 2000). Through various channels such as trade liberalization, significant advances in technology and increased mobility, financial markets have become less isolated (Economides et al., 2001; Issing, 2000). As a result, economies have become increasingly more interdependent and susceptible to foreign shocks (Coelho, Gilmore, Lucey, Richmond, & Hutzler, 2007).

Interdependence, defined as "the relationship that exists between asset classes on average over the sample period" (Beirne & Gieck, 2014), has real implications for practitioners who use international equity markets to diversify away country specific risk. The benefits of international portfolios are reduced as international markets become more correlated and co-move together. One of main issues of this co-movement, as highlighted by Solnik, Boucrelle, and Le Fur (1996), is when the domestic market is subject to a large negative shock. Consequently, the market correlations significantly increase and the benefits of international portfolio diversification virtually disappear. This implies that international portfolio diversification strategies may not work as effectively anymore due to the growing international interdependence.

This paper will focus on the interdependence of the Dutch financial market because it is becoming an increasingly relevant country in the financial industry. External forces such as the uncertainty surrounding the outcome of Brexit has forced financial trading institutions to relocate to Amsterdam (*Netherlands prepares to be EU financial trading hub after Brexit*, 2018; Goodman, 2019). As a result, the Netherlands is gaining attention as to whether it could be Europe's next financial hub (Espinoza, 2018). For this reason, it is necessary to investigate how the Dutch financial market is influenced and susceptible to international market shocks. Specifically, the Dutch financial market interdependence is measured in terms of foreign financial market spillovers into the Dutch financial market, leading to the research question:

To what extent does news from international financial markets spillover into the Dutch financial market?

The research aims to examine the interdependence of the Dutch financial market, represented by the Amsterdam Stock Exchange index (AEX), with the international world by examining the daily spillover effects from January 1990 until December 2018. The news analysed in the research refers to the general information which spills over and is transmitted across the financial markets. The spillover effects are investigated with respect to the returns and the volatility, because the transmission of information affects the mean but also the variance of market returns (Baele, 2005; Bekaert & Harvey, 1997).

The research is academically relevant as it builds on existing literature by examining a longer- and more recent sample[1]. This allows to draw conclusions about how international equity market interde-

[1] An additional intraday analysis was conducted focusing on the interactions between the three simultaneously open indices: the AEX, DAX 30 and FTSE 100. However, the results did not add any further explanations to the research

pendence have developed over time. Furthermore, this research focuses on the foreign spillovers into the Netherlands which has not been investigated in existing literature. The research is socially relevant as it elaborates on how the Netherlands is influenced by international markets allowing practitioners to make more informed investment and capital allocation decisions. Specifically, understanding how foreign shocks propagate through the Dutch financial market allows for practitioners to better anticipate market movements.

In the coming sections of this thesis, the existing literature about international financial market spillovers are addressed in section 2. This is then followed by the development of hypotheses in section 3. In section 4 and 5, the data and methodology of the research are addressed respectively. The results are presented and interpreted in section 6, allowing to answer the hypotheses. Lastly, the implications of the results, their limitations and recommendations for future research are discussed in section 7.

2 Literature Review

There are two main conclusions common in most literature investigating financial market spillovers using daily price data. The first conclusion is that U.S. indices highly influence foreign indices (Ehrmann & Fratzscher, 2002; Bessler & Yang, 2003; Singh, Kumar, & Pandey, 2010; Ehrmann, Fratzscher, & Rigobon, 2011). The second conclusion is that over the past 40 years, market interdependence across the globe has been increasing significantly. (Baele, 2005; Solnik et al., 1996; Ehrmann & Fratzscher, 2002).

Singh et al. (2010) investigate price and volatility spillovers present in financial markets across North America, Europe and Asia from January 2000 until February 2008. They focus on fifteen different markets and conclude that a particular index is most affected by the indices which open before it. Additionally, they conclude that there was greater regional interdependence present in Asian markets as opposed to European and U.S. markets. Specifically, the Japanese market is jointly driven by U.S. and European markets. For Asia, there was evidence that Japan was the transmitter of the spillover effects to the rest of the Asian markets.

Liu and Pan (1997) examine the return and volatility spillovers from the U.S. and Japan to four Asian markets: Hong Kong, Singapore, Taiwan and Thailand, using a sample from 1984 until 1991. Their results suggest that the U.S. has a larger impact than the Japanese market in transmitting return and volatility spillovers to the four Asian markets. This conclusion is different than that of Singh et al. (2010), as their conclusion indicates that the U.S. has the largest influence on Asian markets. Additionally, they conclude that the spillover effects are unstable over time and significantly increase during the 1987 market crash.

Similarly Hamao, Masulis, and Ng (1990) examine the short-run interdependence of price and volatility across three stock markets: Tokyo, London and New York. In line with Singh et al. (2010), they find significant evidence for volatility spillover effects from New York and London to Tokyo. Additionally, the reverse volatility spillover effect, from Tokyo to the U.S. and Europe, is found to be much weaker.

question and thus were omitted from the main research. The framework and results are presented in Appendix B for completeness.

When using exchange rate adjusted returns, their results remained unchanged. A similar conclusion was obtained by Dimpfl and Jung (2012), who find weaker and less persistent return spillovers from Japan to the U.S. as compared to the spillover effects from the U.S. to Japan. Generally, they found volatility spillovers to be significantly "more pronounced and persistent" (Dimpfl & Jung, 2012) as compared to return spillovers. This finding highlighted that the timing of the markets opening before the home market are less relevant for volatility spillovers as it is not always the market opening before the home market which influences the volatility the most.

Furthermore, Baele (2005) investigated the effects of integration and globalization on volatility spillover effects in European equity markets. Their results suggest that spillover effects increased considerably over the sample period from 1980 until 2001. A similar conclusion was made by Coelho et al. (2007) who found evidence that equity markets are becoming increasingly interrelated with time. Additionally, evidence was found in support of contagion from the U.S. to Europe, especially during high volatility periods. This is a similar observation as found by Liu and Pan (1997), who find significantly larger spillover effects during periods where the market experienced abnormally high volatility. Koutmos (1996) arrived to similar conclusions when examining return and volatility interactions between the four largest European stock markets: the UK, France, Germany and Italy. He concluded that the volatility transmission mechanism was found to be asymmetric; where negative innovations lead to larger volatility transmissions than positive innovations. When looking at intraday data, Bae and Karolyi (1994) and Tse (1999) arrived to similar conclusions. Bae and Karolyi (1994) however, further noted that when this asymmetric relationship is ignored, then the estimated spillover effects are significantly understated.

Lastly, Jawadi, Louhichi, and Idi Cheffou (2015) concluded that daily return and volatility spillover estimates do not accurately capture the effects because they concluded that the spillover effect was dependent on the time of the day. More precisely, the direction of the spillover and the magnitude differed at different times. Baillie and Bollerslev (1991) also emphasised that the spillover effect was related to the time of day and specifically to the opening and closing of the major world markets.

3 Hypothesis Development

Based on the past research outlined in the Literature Review, hypotheses are developed allowing to answer the research question more thoroughly. The first hypothesis aims to understand the dynamics of financial market spillovers by looking at how the spillovers have changed with time. Over the last half century, large technology advancements have taken place easing the flow of information around the world. One key technological development is the creation of the internet in 1989 (*A short history of the Web*, n.d.). The internet has impacted the flow of information in a multitude of ways (Economides et al., 2001). This includes information in forms such as analyst reports which aids foreign investors to make investing decisions in markets other than their domestic market. Additionally, the development of the internet has facilitated access to markets, meaning that markets which previously could not be invested in, are now available to everyone (Bogan, 2008; Economides et al., 2001). The internet has broken the barriers preventing investors from investing in foreign equities. Additionally, the rise in popularity of international portfolio strategies to benefit from international diversification has caused markets to become increasingly interrelated (Driessen & Laeven, 2007). Thus, over time, spillovers between markets should increase. As noted by past research by Baele (2005) and Coelho et al. (2007) there is evidence for the effect of time on the spillovers. Therefore, accordingly, the first hypothesis is formulated:

H1: Foreign market spillover effects into the AEX have increased over the sample period.

The second hypothesis focuses on how strong negative shocks affect foreign market spillovers into the AEX. Practitioners especially need the benefits of international diversification during negative shocks because this is when they need to minimise their losses. However, during negative shocks, international market interdependence increases significantly meaning that the benefits of international diversification disappear (Solnik et al., 1996). Additionally, Koutmos (1996) notes that the volatility transmission mechanism between markets to be asymmetric. Specifically, when there is a negative shock, the volatility spillover was significantly higher than during positive shocks. An explanation for asymmetric volatility spillover effects is the leverage effect as outlined by Bekaert and Wu (2000). The negative correlation between returns and volatility exists because a drop in return increases financial leverage, thus making the equity riskier and increasing the volatility. Consequently the increase in volatility leads to increased volatility spillovers. Therefore, the second hypothesis states:

H2: Foreign market return and volatility spillover effects into the AEX are larger when the foreign market experiences a negative shock.

The third hypothesis aims to explain how information affects the AEX. Specifically, whether information from markets which open closer in time to the AEX have a larger influence on the AEX. According to the efficient market hypothesis (EMH), this should be the case because, the markets opening closer in time, should have all the past information incorporated into its prices. Thus, the market opening closest to the AEX, should therefore have the most information content priced in, resulting in a larger spillover into the AEX than markets which closed further back in time. Consistent with this, Singh et al. (2010) found significantly larger spillover effects from markets which open close in time. Therefore, this leads to the formulation of the third hypothesis:

H3: Foreign market spillovers which open closer in time to the AEX are larger.

4 Data

The analysis focuses on the differences between the market opening times. In Figure 1, the market open times and durations are displayed. The times have been standardised to the Coordinated Universal Time (UTC). Additional detailed information is displayed in Table 11 (Appendix A).

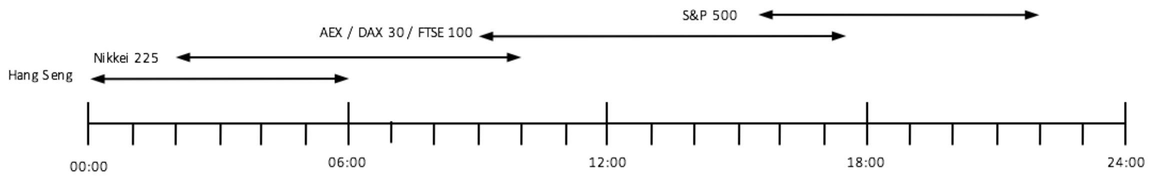

Figure 1: Timeline of the various indices. The times have been standardised to Coordinated Universal Time (UTC). The timeline indicates the periods during which the HSI, Nikkei 225, AEX, DAX 30, FTSE 100 and S&P 500 are open (Singh et al., 2010).

The sample of daily closing prices, retrieved from DataStream, include prices from five major indices around the world ranging from January 1st 1990 until December 31st 2018. The U.S. market is represented by the S&P 500. In Europe, the two main financial markets are Germany and the United Kingdom which are represented by the FTSE 100 and DAX 30 respectively. The Netherlands is represented using the Amsterdam Stock Exchange index (AEX). In Asia, Japan and Hong Kong are are represented by the NIKKEI 225 and the Hang Seng Index (HSI) respectively. The daily close-to-close returns are estimated using equation 1.

$$r_t = ln(p_t) - ln(p_{t-1}) \tag{1}$$

All indices chosen are market-capitalization-weighted allowing for a fairer representation of the countries' financial markets. In Table 1, the descriptive statistics of the daily returns for each respective index is presented. Additionally, the test statistics for the Augmented Dickey Fuller test are included to determine whether the returns are stationary, and the Shapiro-Wilk test statistics are included to determine whether the returns are normally distributed.

The sample consists of 7566 daily close to close returns spanning over 28 years. Noteworthy is that the returns of each index are stationary given by the Augmented Dickey Fuller test being rejected at the 1% level. Additionally, visible from the Shapiro-Wilk test of normality which is rejected at 1% for all indices, the returns do not follow a normal distribution. Given the high kurtosis, it means that the return distribution has heavy tails. This is normal for financial return data and given the large sample, this will not have a significant effect on the results (Bradley & Taqqu, 2003).

Visible from the descriptive statistics, the average daily returns from all the indices are positive except for the Nikkei 225 which has an average return of -0.9%. Additionally, looking at the standard deviation, which gives an indication of the average level of risk in the market, it is clear that all the indices have

Table 1: Descriptive statistics for the daily returns of the indices. Note that the mean is reported as a percentage. Additionally, the augmented Dickey Fuller test statistics, testing for stationarity, and the Shapiro-Wilk test for normality are included.

	AEX	DAX 30	FTSE 100	Nikkei 225	Hang Seng	S&P 500
Observations	7566	7566	7566	7566	7566	7566
Mean (%)	0.017	0.023	0.014	-0.009	0.029	0.026
St. Dev.	0.013	0.014	0.011	0.015	0.015	0.011
Max	0.100	0.108	0.094	0.132	0.172	0.110
Min	-0.096	-0.099	-0.093	-0.121	-0.147	-0.095
Skewness	-0.166	-0.161	-0.127	-0.152	-0.019	-0.260
Kurtosis	9.939	8.083	9.383	8.914	13.308	12.215
ADF(no constant)	-86.515***	-87.561***	-88.021***	-89.211***	-86.516***	-91.697***
Shapiro-Wilk	15.348***	14.390***	14.604***	14.249***	15.584***	15.611***

a similar level of risk. Overall the six indices are comparable in the average level of return and risk indicating that not one market is significantly less developed.

5 Methodology

The analysis focuses on the return and volatility spillovers between the indices. In the following sections of the Methodology, the general return and volatility models are presented, and the models for each hypothesis are formulated.

5.1 General Return & Volatility Spillover Model

5.1.1 Return Spillover Model

The return spillover is modeled using a VAR model with p lags allowing to estimate the partial effects of one market on another after having incorporated the partial effects of the remaining markets (Singh et al., 2010). This is because if a bi-variate VAR model analyzing the relation between the Nikkei and AEX is used, then the partial effect estimated could likely be biased. This bias could be induced by Hong Kong or the previous day S&P 500 movements, affecting the Nikkei which in turn drives the effect on the AEX. Therefore, Model 1 considers the return movements of all six indices controlling for exogenous effects of the other indices. Model 1 shown in equation 2 takes the following form:

$$r_t = \phi_0 + \sum_{i=1}^{p} \phi_i r_{t-1} + \varepsilon_t \tag{2}$$

where, $r_t = (r_{AEX,t}, r_{FTSE100,t}, r_{DAX30,t}, r_{HSI,t}, r_{Nikkei225,t}, r_{S\&P500,t})'$. The partial cross-correlations between each index is represented by ϕ_i.

Furthermore, to identify whether there is a flow of information between markets, a model is constructed which includes three additional return variables which specify whether the market has opened before, simultaneously, or after the market under examination (Singh et al., 2010). If the market has opened before the market under examination, then the same day returns are used. For simultaneously opening markets and markets opening after the market under examination, the one day lagged returns are used. Equation 3 incorporates the differing opening times of the financial markets taking the following form:

$$r_t = \phi_0 + \sum_{n=1}^{b} \phi_{b,t} r_{b,t} + \sum_{n=1}^{a} \phi_{a,t} r_{a,t-1} + \sum_{n=1}^{s} \phi_{s,t} r_{s,t-1} + \varepsilon_t \tag{3}$$

where $r_t = (r_{AEX,t}, r_{FTSE100,t}, r_{DAX30,t})'$, $(1, \ldots, s)$ are the indices which open simultaneously, $(1, \ldots, b)$ are indices which open before $(1, \ldots, s)$ and $(1, \ldots, a)$ are indices which open after $(1, \ldots, s)$. If, the market does not have any other simultaneously opening markets, then an AR model is used as described in equation 4.

$$r_t = \beta_i + \sum_{n=1}^{b} \phi_{b,t} r_{b,t} + \sum_{n=1}^{a} \phi_{a,t} r_{a,t-1} + \sum_{n=1}^{s} \phi_{s,t} r_{s,t-1} + \varepsilon_t \tag{4}$$

In order for the coefficient estimates to be consistent, the sample needs to be covariance stationary meaning that (i) $E(r_{i,t}) = \mu$, (ii) $Var(r_{i,t}) = \sigma^2 < \infty$ and (iii) $cov(r_{i,t}, r_{i,t-1})$ is finite for all t, and is only dependent on index i. To test whether the sample is covariance stationary, (i) an augmented dickey fuller test is conducted on returns to check for stationary, and for (ii) and (iii) Newey-West standard errors are used (Newey & West, 1986).

5.1.2 Volatility Spillover Model

As concluded in past literature, volatility is a better proxy for measuring the flow of information compared to the returns (Clark, 1973; Tauchen & Pitts, 1983; Ross, 1989). For this reason, this section explains the framework to determine the volatility spillover effects. A two-stage AR-GARCH approach is used to investigate the transmission of stock volatility (Liu & Pan, 1997). For the first stage the return of each market index is modeled through an AR(1) and the residuals from the mean equation are obtained, as described in equation 5.

$$r_{i,t} = \alpha + \beta_{i,t-1} + \varepsilon_{i,t} \tag{5}$$

where, the residual is the residual of index "i" at time "t" and follows a normal distribution , and is the return of index "i" at time t. For the second stage, the residuals estimated in equation 5 are used in the GARCH(1,1) equation of the other indices as described in equation 6.

$$\sigma_{i,t}^2 = \phi_0 + \alpha_{i,1} \varepsilon_{i,t-1}^2 + \beta_{i,t} \sigma_{i,t-1}^2 + \sum_{b=1}^{B} \alpha_b \varepsilon_{b,t}^2 + \sum_{a=1}^{A} \alpha_a \varepsilon_{a,t}^2 + \sum_{s=1}^{S} \alpha_s \varepsilon_{s,t}^2 \tag{6}$$

where $\phi_0 > 0$, $\alpha_{i,1} + \beta_{i,1} < 1$, b represents the indices which open before index i, a represents the indices which open after index i, and s represents the indices which open at the same time as index i. The volatility spillovers of the foreign indices into index i are represented by a_b; which can be interpreted as the volatility spillover effects of indices which open prior to index i, a_a; which can be interpreted as the volatility spillover effects of indices which open after index i and a_i; which can be interpreted as the volatility spillover effects of indices which open at the same time as index i.

5.2 Hypotheses Models: Daily Return & Volatility Spillovers

In the following sections the models which allow to answer the hypotheses are discussed. Specifically, there is a distinction made between the Models using intraday and daily data.

5.2.1 Hypothesis 1

Hypothesis 1 states *foreign market spillover effects into the AEX have increased over the sample period*, and in order to capture the effect of time on foreign return and volatility spillovers, time interaction variables are included. More precisely, T represents the time trend as a fraction of the total sample (7566 observations): $T_i = \frac{t_i}{t_{max}}$. The time effect on the return spillovers for indices which open before, simultaneously and after are represented by $\phi_{b,2}$, $\phi_{s,2}$ and $\phi_{a,2}$ in equation 7 respectively. These coefficients can be interpreted as the change in the spillover effect for the respective index from one day to the next.

$$r_t = \phi_0 + \sum_{b=1}^{B}(\phi_{b,1} + \phi_{b,2}T_t)r_{b,t} + \sum_{a=1}^{A}(\phi_{a,1} + \phi_{a,2}T_{t-1})r_{a,t-1} + \sum_{s=1}^{S}(\phi_{s,1} + \phi_{s,2}T_{t-1})r_{s,t-1} + \varepsilon_t \quad (7)$$

where $r_t = (r_{AEX,t}, r_{FTSE100,t}, r_{DAX30,t})'$.

Similarly, the time effect on the volatility spillovers for indices which open before, simultaneously and after are represented by $\alpha_{b,2}$, $\alpha_{s,2}$ and $\alpha_{a,2}$ in equation 8 respectively. These coefficients represent the change in the volatility spillover effects from one day to the next.

$$\sigma^2_{i,t} = \phi_0 + (\alpha_{i,1} + \alpha_{i,2}T_{i,t-1})\varepsilon^2_{i,t-1} + \beta_{i,t}\sigma^2_{i,t-1} + \sum_{b=1}^{B}(\alpha_{b,1} + \alpha_{b,2}T_t)\varepsilon^2_{b,t} + \sum_{a=1}^{A}(\alpha_{a,1} + \alpha_{a,2}T_{t-1})\varepsilon^2_{a,t-1} + \sum_{s=1}^{S}(\alpha_{s,1} + \alpha_{s,2}T_{t-1})\varepsilon^2_{s,t-1} \quad (8)$$

5.2.2 Hypothesis 2

Hypothesis 2 states *foreign market return and volatility spillover effects into the AEX are larger when the foreign market experiences a negative shock.* In order to capture the effect of a negative shock on return spillovers, negative return interaction coefficients represented by ω_b, ω_s and ω_a for indices which open before, simultaneously and after respectively. The coefficient can be interpreted as the change in the return spillover effect of the index if the corresponding return is negative. The coefficient is estimated only for instances where the corresponding index returns is negative resulting in $I_{r_{i/a/b/s}}$ equalling to 1, otherwise when the return is positive, it is equal to zero.

$$r_{t,i} = \phi_0 + \sum_{n=1}^{b}(\phi_{b,1} + \omega_b I_{(r_{t-1}<0)})r_{b,t} + \sum_{n=1}^{a}(\phi_{a,1} + \omega_a I_{(r_{t-2}<0)})r_{a,t-1} + \sum_{n=1}^{s}(\phi_{s,1} + \omega_s I_{(r_{t-2}<0)})r_{s,t-1} + \varepsilon_t \quad (9)$$

where $r_t = (r_{AEX,t}, r_{FTSE100,t}, r_{DAX30,t})'$.

Similarly equation 10 captures the difference in the volatility spillover effects for positive and negative return periods. To do so, a TARCH(1,1,1) with negative return interaction variables are included into equation 6. The negative return effect on the foreign market volatility spillover is captured by the $\gamma_{i/b/a/s}$.

$$\sigma_{i,t}^2 = \phi_0 + (\alpha_{i,1} + \gamma_i I_{(r_{i,t-1}<0)})\varepsilon_{i,t-1}^2 + \beta_{i,t}\sigma_{i,t-1}^2 + \sum_{n=1}^{b}(\alpha_b + \gamma_b I_{(r_{b,t-1}<0)})\varepsilon_{b,t}^2 + \sum_{n=1}^{a}(\alpha_a + \gamma_a I_{(r_{a,t-2}<0)})\varepsilon_{a,t}^2 + \sum_{n=1}^{s}(\alpha_s + \gamma_s I_{(r_{s,t-2}<0)})\varepsilon_{s,t}^2 \quad (10)$$

In equation 10, $\gamma_{i/a/b/s}$ represent the difference in the volatility spillover effects on the AEX when the corresponding index exhibits positive and negative returns. Specifically, it can be interpreted as the difference in the volatility spillover effect during a negative return period for the corresponding index.

5.2.3 Hypothesis 3

Hypothesis 3 states *foreign market spillovers which open closer in time to the AEX are larger.* To test this hypothesis with respect to return spillovers, a Wald test is used to see whether the coefficients of the return spillover effects of indices opening before, simultaneously and after for $r_{AEX,t}$ in equation 3 are significantly different from each other. The null hypothesis for the Wald test is shown below.

$$H_0 : \phi_{DAX30,t-1} = \phi_{FTSE100,t-1} = \phi_{Nikkei225,t} = \phi_{HSI,t} = \phi_{S\&P500,t-1}$$

A similar Wald test will be conducted to test whether the volatility spillover effects differ between indices which open before, simultaneously and after the AEX in equation 6. The Wald test will determine whether the volatility spillover effects for each of index significantly differ from each other. The null hypothesis is shown below.

$$H_0 : \alpha_{DAX30,t-1} = \alpha_{FTSE100,t-1} = \alpha_{Nikkei225,t} = \alpha_{HSI,t} = \alpha_{S\&P500,t-1}$$

6 Results

6.1 Daily Return & Volatility Spillovers

To obtain a general overview of the interactions between the six indices, a 6 dimensional VAR(1) is conducted. This preliminary auto-regression does not specify any differences between the opening times of the indices. The results for this regression are presented in table 2.

Table 2: Results for the 6 dimension VAR(1) on the daily returns of the six indices.

Parameters	AEX	DAX 30	FTSE 100	Nikkei 225	HSI	S&P 500
AEX(t-1)	-0.135***	-0.041	-0.102***	0.048	-0.051	-0.020
	(0.040)	(0.040)	(0.032)	(0.036)	(0.045)	(0.034)
DAX 30(t-1)	0.005	-0.128***	-0.016	0.067**	-0.037	0.030
	(0.030)	(0.032)	(0.025)	(0.033)	(0.045)	(0.024)
FTSE 100(t-1)	-0.054	-0.002	-0.074**	0.134***	0.260***	0.015
	(0.035)	(0.036)	(0.029)	(0.033)	(0.040)	(0.032)
Nikkei 225(t-1)	-0.029*	-0.027*	-0.029**	-0.122***	-0.096***	-0.022
	(0.015)	(0.016)	(0.013)	(0.016)	(0.019)	(0.016)
HSI(t-1)	0.000	-0.000	-0.000	0.000	-0.000**	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
S&P 500(t-1)	0.433***	0.396***	0.381***	0.433***	0.485***	-0.065***
	(0.027)	(0.027)	(0.023)	(0.026)	(0.036)	(0.025)
Constant	0.000	0.000	0.000*	-0.001*	0.001**	0.001**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)

Newey-West standard errors in parentheses

$^{***}p < 0.01, ^{**}p < 0.05, ^{*}p < 0.1$

As found by previous research (Ehrmann & Fratzscher, 2002; Bessler & Yang, 2003; Singh et al., 2010; Ehrmann et al., 2011), the one day lagged return of the S&P 500 significantly spills over into the five other markets at the 1% level. More precisely, the one day lagged partial spillover effects of the S&P 500 are positive implying that the other indices generally co-move with the S&P 500. Additionally, the Nikkei 225 has significant spillovers into the AEX, DAX 30, FTSE 100 and HSI. At 1% significance, the Nikkei 225 spills over into the HSI, at a 5% significance level it spills over into the FTSE 100 and at a 10% level it spillovers into the AEX and DAX 30. Notably, all the significant partial return spillover effects are negative indicating that if the Nikkei 225 daily return is positive, the associated spillover effect is negative. Lastly, the one day lagged return of the FTSE 100 significantly spills over into the Nikkei 225 and HSI, at a 1% level. However, it does not have a significant return spillover effects on the AEX: the one day lag return of the AEX has significant negative spillover effects into the FTSE 100, at a 1% significant level.

The preliminary 6-dimensional VAR(1) does not take into account the differing opening and closing times of the indices therefore the more representative 3-dimensional VAR(1) is conducted. The AEX, DAX 30 and FTSE 100 which open simultaneously, are included as dependent variables, Nikkei 225 and HSI, which open before the dependent variables are included with the same day return (t), and the S&P

500 which opens after the dependent variables is included in the model with the one day lagged returns (t-1). In Table 3 the results for the 3-dimensional VAR(1) are presented.

Table 3: Results for the 3 dimension VAR(1) on the daily returns of the AEX, DAX 30 and FTSE 100 after taking into account the different opening times of the different indices.

Parameters	AEX	DAX 30	FTSE 100
AEX(t-1)	-0.129***	-0.033	-0.098***
	(0.041)	(0.038)	(0.030)
DAX 30(t-1)	0.005	-0.126***	-0.017
	(0.029)	(0.028)	(0.023)
FTSE 100(t-1)	-0.125***	-0.081**	-0.134***
	(0.035)	(0.037)	(0.028)
Nikkei 225(t)	0.125***	0.124***	0.107***
	(0.013)	(0.014)	(0.012)
HSI(t)	0.218***	0.248***	0.179***
	(0.019)	(0.017)	(0.015)
S&P 500(t-1)	0.273***	0.221***	0.248***
	(0.031)	(0.030)	(0.026)
Constant	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)

Newey-West standard errors in parentheses

$^{***}p < 0.01,^{**}p < 0.05,^{*}p < 0.1$

When comparing the results from Table 3 to Table 2 the most notable difference is that both the partial spillover effects from the Nikkei 225 and the HSI are larger and significant at the 1% level. This finding indicates that they play a significant role in transferring previous day and overnight shocks, and spilling them over into the European markets as found by Singh et al. (2010). Additionally, the spillover effect from the S&P 500 remains largely positive and significant at the 1% level. Again this finding is in line with past research which concludes that the U.S. is the primary *exporter* of world significantly spilling over into all the financial markets around the world (Ehrmann & Fratzscher, 2002; Bessler & Yang, 2003; Singh et al., 2010; Ehrmann et al., 2011). Within Europe, the FTSE 100 significantly spills over into the AEX and DAX 30. The effect, significant at 1%, is negative indicating that when the FTSE 100 exhibits positive returns, the associated spillover effect into the AEX and DAX 30 is negative. There are also negative own-return spillover effects for the AEX, DAX 30 and FTSE 100, significant at 1%, indicative of remaining autocorrelation in the model. However, given that Newey-West standard errors are used, the estimates remain consistent.

To obtain estimates on the volatility spillovers into the AEX, the two step AR(1)-GARCH(1,1) procedure outlined by Liu and Pan (1997) is conducted. The results are presented in Table 4.

The results indicate the the volatility spillover effects from the DAX 30, Nikkei 225, HSI and S&P 500 into the AEX are significant at the 1% level. The spillover effect from the S&P 500 is positive and the largest out which is inline with the conclusions found in literature. Similarly to the return spillover effects of the Nikkei 225 and HSI into the AEX, they also significantly positively spillover into the AEX volatility. Surprisingly, however, is that the FTSE 100, similarly to the return spillover, does

Table 4: General AR(1)-GARCH(1,1).

Parameters	AEX
ARCH(1)	0.088***
	(0.007)
GARCH(1)	0.853***
	(0.007)
$\varepsilon^2{}_{DAX30}(t-1)$	0.012***
	(0.003)
$\varepsilon^2{}_{FTSE100}(t-1)$	-0.007
	(0.004)
$\varepsilon^2{}_{Nikkei225}(t)$	0.005***
	(0.001)
$\varepsilon^2{}_{HSI}(t)$	0.007***
	(0.001)
$\varepsilon^2{}_{S\&P500}(t-1)$	0.033***
	(0.005)
Constant	0.000***
	(0.000)

Standard errors in parentheses

$^{***}p < 0.01, ^{**}p < 0.05, ^{*}p < 0.1$

not significantly spillover into the AEX volatility. This finding is surprising as the FTSE 100 is generally found to significantly spillover into the rest of Europe (Harrison & Moore, 2009). The AEX own-volatility spillover effect represented by the GARCH(1) coefficient, significant to 1%, is the largest effect on the AEX volatility. It indicates that the most of the AEX volatility is driven by its one day lagged volatility.

The following sections will address the hypotheses of this research, analysing the nature of the return and volatility spillover effects into the AEX.

6.1.1 Hypothesis 1

Hypothesis 1 states: *H1: Foreign market spillover effects into the AEX have increased over the sample period* and aims to determine whether the spillover effects into the AEX are increasing with time. Specifically, this is done by looking at whether the spillovers are increasing throughout the sample by including time return variables into the 3-dimensional VAR(1). The results for the regression are presented in Table 5.

The results in Table 5 indicate that there is a significant change in the spillover effect with time for the S&P 500 and the HSI. The S&P 500 time interaction variable is negative and significant with 95% confidence indicating that over the sample the S&P 500 return spillover effect into the AEX return has decreased. This is also reflected in the S&P 500 coefficient significantly increasing from 0.273 in the simple 3 dimension VAR(1) (Table 3) to 0.373. On average, the S&P 500 return spillover effect into the AEX return on the 31st of December 2018 is 19% lower than the spillover effect on the 1st of January 1990. Additionally, the HSI time interaction variable is significantly positive with 99% confidence. As a result, the spillover effect of the HSI has increased significantly over the sample which is reflected in the

Table 5: Three dimensional VAR(1) with time interaction variables included.

Parameters	AEX	DAX 30	FTSE 100
AEX(t-1)	-0.041	0.087	-0.102**
	(0.052)	(0.060)	(0.044)
DAX 30(t-1)	-0.033	-0.208***	-0.002
	(0.036)	(0.040)	(0.030)
FTSE 100(t-1)	-0.073*	0.056	-0.011
	(0.042)	(0.053)	(0.040)
Nikkei 225(t)	0.123***	0.121***	0.108***
	(0.019)	(0.024)	(0.017)
HSI(t)	0.105***	0.152***	0.049***
	(0.022)	(0.030)	(0.019)
S&P 500(t-1)	0.373***	0.353***	0.285***
	(0.036)	(0.048)	(0.032)
Time Interaction Variables			
$\phi_{AEX(t-1)}$	-0.197*	-0.263**	0.024
	(0.116)	(0.120)	(0.101)
$\phi_{DAX30(t-1)}$	0.090	-0.206**	-0.036
	(0.085)	(0.080)	(0.072)
$\phi_{FTSE100(t-1)}$	-0.089	-0.276**	-0.251***
	(0.093)	(0.109)	(0.086)
$\phi_{Nikkei225(t)}$	-0.003	0.009	-0.018
	(0.040)	(0.046)	(0.036)
$\phi_{HSI(t)}$	0.249***	0.204***	0.291***
	(0.061)	(0.062)	(0.047)
$\phi_{S\&P500(t-1)}$	-0.190**	-0.249***	-0.066
	(0.087)	(0.096)	(0.078)
Constant	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)

Newey-West standard errors in parentheses

$^{***}p < 0.01, ^{**}p < 0.05, ^{*}p < 0.1$

coefficient changing from 0.218 in the simple 3 dimension VAR(1) (Table 3) to 0.105. More precisely, the HSI return spillover effect into the AEX return increased by 24.9% over the entire sample. Literature, however, concluded that return spillover effects significantly increased with time (Baele, 2005; Coelho et al., 2007). Baele (2005), however, concluded that the significant effect of time on the spillover effects were due to significant increases in the global market integration. Therefore, a possible explanation for the inconclusive time effect on return spillovers could be that, throughout the sample period, no significant increases in market integration have occurred. Given that all the financial markets used in this research are, and have been since the beginning of the sample, highly developed, this could be the case. As concluded by Bekaert and Harvey (1995), analysing the time effect using emerging markets could yield more meaningful and insightful conclusions. Overall the effect of time on the return spillovers into the AEX is inconclusive and therefore it is not possible to adequately answer Hypothesis 2 with respect to return spillover effects.

Next, the effect of time on the volatility spillovers is analysed and the results are presented in Table 6.

The results indicate that the volatility spillover effects into the AEX have significantly changed only for the HSI and FTSE 100. The HSI and FTSE 100 effects have increased by 3.9% and 8% throughout the entire sample respectively, both significant at the 1% level. Additionally, the spillover effect of the AEX into the AEX itself has significantly decreased throughout the sample. The results are in accordance with past literature (Baele, 2005; Coelho et al., 2007).

Table 6: AR(1)-GARCH(1,1) with time interaction variables.

Parameters	AEX
ARCH(1)	0.125***
	(0.013)
GARCH(1)	0.833***
	(0.008)
${\varepsilon^2}_{DAX}(t-1)$	0.011*
	(0.007)
${\varepsilon^2}_{FTSE}(t-1)$	-0.033***
	(0.007)
${\varepsilon^2}_{Nikkei}(t)$	0.009***
	(0.002)
${\varepsilon^2}_{HSI}(t)$	0.000
	(0.001)
${\varepsilon^2}_{S\&P500}(t-1)$	0.040***
	(0.012)
Time Interaction Variables	
$\alpha_{AEX(t-1)}$	-0.097***
	(0.028)
$\alpha_{DAX30(t-1)}$	0.012
	(0.016)
$\alpha_{FTSE100(t-1)}$	0.080***
	(0.019)
$\alpha_{Nikkei225(t)}$	-0.003
	(0.005)
$\alpha_{HSI(t)}$	0.039***
	(0.007)
$\alpha_{S\&P500(t-1)}$	-0.016
	(0.020)
Constant	0.000***
	(0.000)

Standard errors in parentheses

$***p < 0.01, **p < 0.05, *p < 0.1$

6.1.2 Hypothesis 2

Hypothesis 2 aims to determine whether the return and volatility spillover effects into the AEX are asymmetric and dependent on whether the return of the respective index is positive or negative. The asymmetric nature of the return spillovers are analysed by including negative return interaction variables capturing the difference in the return spillover of the respective index during a period where the return is less than zero. In Table 7, the output of a 3-dimension VAR(1) with the negative return interaction variables is presented.

Table 7: Three dimensional VAR(1) with negative return dummies included.

Parameters	AEX	DAX 30	FTSE 100
AEX(t-1)	-0.148***	-0.041	-0.108***
	(0.047)	(0.044)	(0.035)
DAX 30(t-1)	0.009	-0.135***	-0.010
	(0.035)	(0.034)	(0.027)
FTSE 100(t-1)	-0.126***	-0.103**	-0.154***
	(0.043)	(0.045)	(0.034)
Nikkei 225(t)	0.120***	0.114***	0.108***
	(0.018)	(0.020)	(0.017)
HSI(t)	0.214***	0.246***	0.170***
	(0.025)	(0.002)	(0.019)
S&P 500(t-1)	0.284***	0.224***	0.273***
	(0.041)	(0.040)	(0.035)
Negative Return Interaction Variables			
$\omega_{AEX(t-1)}$	-0.000	-0.000	0.000
	(0.000)	(0.000)	(0.000)
$\omega_{DAX30(t-1)}$	0.000	-0.000	0.000
	(0.000)	(0.000)	(0.000)
$\omega_{FTSE100(t-1)}$	-0.001	-0.001	-0.001*
	(0.000)	(0.000)	(0.000)
$\omega_{Nikkei25(t)}$	-0.000	-0.000	0.000
	(0.000)	(0.000)	(0.000)
$\omega_{HSI(t)}$	-0.000	-0.001	-0.000
	(0.000)	(0.000)	(0.000)
$\omega_{S\&P500(t-1)}$	0.000	0.000	0.001*
	(0.000)	(0.000)	(0.000)
Constant	0.000	0.001**	0.000
	(0.000)	(0.000)	(0.000)

Newey-West standard errors in parentheses

$***p < 0.01, **p < 0.05, *p < 0.1$

The results presented in table 7 indicate that return spillovers into the AEX return are not significantly different during periods of positive- and negative returns. This indicates that return spillovers into the AEX return do not exhibit asymmetric effects. Therefore, Hypothesis 2 with respect to return spillovers into the AEX returns is rejected. A possible explanation for this result is that the degree of optimism and pessimism which leads to returns being asymmetric is transferred between markets in the longer run

(Chen, Chen, & Lee, 2013).

However, the uncertainty related to the degree of optimism and pessimism is represented by the volatility and is a short term effect (Chen et al., 2013). To determine whether volatility spillovers are asymmetric, negative return interaction variables are included in the conditional variance of the AR(1)-TARCH(1,1,1) presented in Table 8.

Table 8: AR(1)-TARCH(1,1,1) with conditional variance negative return interaction variables included for the respective indices.

Parameters	AEX
ARCH(1)	0.046***
	(0.009)
GARCH(1)	0.859***
	(0.006)
TARCH(1)	0.057***
	(0.015)
$\varepsilon^2_{DAX}(t-1)$	-0.002
	(0.006)
$\varepsilon^2_{FTSE}(t-1)$	-0.010
	(0.006)
$\varepsilon^2_{Nikkei}(t)$	0.001
	(0.001)
$\varepsilon^2_{HSI}(t)$	0.001
	(0.002)
$\varepsilon^2_{S\&P500}(t-1)$	-0.009
	(0.007)
Negative Return Interaction Variables	
$\gamma_{DAX30(t-1)}$	0.038***
	(0.009)
$\gamma_{FTSE100(t-1)}$	0.002
	(0.011)
$\gamma_{Nikkei225(t)}$	0.008***
	(0.003)
$\gamma_{HSI(t)}$	0.013***
	(0.003)
$\gamma_{S\&P500(t-1)}$	0.068**
	(0.013)
Constant	0.000***
	(0.000)

Standard errors in parentheses

$^{***}p < 0.01, ^{**}p < 0.05, ^{*}p < 0.1$

The results of the regression in Table 8 indicate that the variance of the AEX returns are significantly larger when the AEX return is less than zero, represented by the TARCH(1) coefficient. More precisely, it is 5.7% larger, significant to 1%, indicating that the AEX returns experience the leverage effect (Koutmos, 1996). Unlike for the return spillovers, the volatility spillovers into the AEX return differ significantly during periods where the foreign index experiences positive and negative returns. Specifically, the DAX

30 volatility spillovers into the AEX return are 3.8% larger when the DAX 30 experiences a period of negative returns. This effect is significant with 99% confidence. Similarly, the volatility spillovers from Asia represented by the Nikkei 225 and HSI are 0.8% and 1.3% larger during period of negative returns respectively. Both asymmetric spillover effects are significant to 1% . Lastly, the spillover effect from the S&P 500 is 6.8% larger during periods where it experiences negative returns, significant to 1%. Therefore, Hypothesis 2 is not rejected with respect to volatility spillovers. This result is in line with the findings of Koutmos (1996) who concluded that if there is negative news, then the volatility spillover effect is much more pronounced.

Additionally, when the negative return interaction variables are added to the general volatility spillover model, the regular spillover effects for all indices are insignificant. This there means that the spillover effects into the AEX are only significant when the foreign index experiences negative returns. Otherwise, the spillover effects are found to be insignificant. This finding is partially with existing literature and sheds light into the volatility spillover mechanism (Baele, 2005).

6.1.3 Hypothesis 3

Hypothesis 3 states *Foreign market spillovers which open closer in time to the AEX are larger* and aims to determine whether markets opening closer in time to the AEX have larger spillover effects. This is because indices which open closer to the AEX have more information priced in which has not yet been incorporated into the AEX (Singh et al., 2010). For example, the Nikkei 225 opens prior to the AEX, however, it does not incorporate the information from markets which open between 6:00 and 8:00 UTC. Therefore, based on this reasoning, the HSI should have *all* the past information incorporated in its prices given that it opens at 2:00 and closes at 10:00 UTC. To test whether this is true, a Wald test of equality of coefficients is conducted on whether the return and volatility spillover coefficients are equal to each other or whether one or more significantly differs. The results for the Wald tests are presented in Table 9.

Table 9: Wald test for the equality of (1) return and (2) volatility spillover effects into the AEX return. For the test of the equality of the return spillover coefficients an F statistic reported. For the test of the equality of the volatility spillover coefficients a χ^2 statistic is reported.

Spillover	Null Hypothesis	Statistic
Return		
	$H_0 : \phi_{DAX30,t-1} = \phi_{FTSE100,t-1} = \phi_{Nikkei225,t} = \phi_{HSI,t} = \phi_{S\&P500,t-1}$	32.160***
Volatility		
	$H_0 : \alpha_{DAX30,t-1} = \alpha_{FTSE100,t-1} = \alpha_{Nikkei225,t} = \alpha_{HSI,t} = \alpha_{S\&P500,t-1}$	34.293***

$^{***}p < 0.01, ^{**}p < 0.05, ^{*}p < 0.1$

The results indicate that at least one of the coefficients for both the return and volatility spillover effects are not equal, significant to 1%, indicating that there are significant differences between the spillover effects. Focusing on the return spillover effects, the two largest effects are that of the HSI and S&P 500 which are not significantly different from each other (Appendix A.3). Additionally, the HSI return spillover effect is significantly different than that of the DAX 30, FTSE 100 and Nikkei 225 indicating that the return spillover effects into the AEX are the largest for the market which opens the closest to the AEX (Appendix A.3). Therefore Hypothesis 3 is not rejected with respect to return spillovers.

The volatility spillover effects, however, do not depend on whether the index opens closer to the AEX. Specifically when looking at the output from the general AR(1)-GARCH(1,1) in Table 4, the spillover effects of the HSI and Nikkei 225 are not significantly larger than that of the other indices, other than the S&P 500. Therefore Hypothesis 3 with respect to volatility spillovers is rejected.

These findings are partially in line with Singh et al. (2010) as they found that the largest return *and* volatility spillover effects came from indices which opened just before the index in question. A possible explanation for this conclusion is that volatility spillovers are not transferred through the global financial system but are transferred directly from one market to another (Theodossiou & Lee, 1993). In accordance with literature, the S&P 500 is the main volatility exporter spilling over directly into foreign markets which import the effect directly from the U.S. (Theodossiou & Lee, 1993).

Table 10: Summary of results - Daily Return & Volatility Spillovers

Hypothesis	Return Spillovers	Volatility Spillovers
1	Inconclusive	Not Rejected
2	Rejected	Not Rejected
3	Not Rejected	Rejected

7 Conclusion & Discussion

In conclusion, the results obtained indicate that there are significant return and volatility spillovers into the AEX from foreign markets. In line with literature (Ehrmann & Fratzscher, 2002; Bessler & Yang, 2003; Singh et al., 2010; Ehrmann et al., 2011), the U.S. is found to have lag return and volatility spillover effects into the AEX. Additionally, markets opening before the AEX, namely the Nikkei 225 and HSI, were also found to have significant positive return and volatility spillover effects. The research was complimented with an intraday sample analysis (See Appendix 2), however no significant spillover effects were found.

Additionally, three hypotheses were formulated to gain a better understanding about the spillover effects into the AEX. Hypothesis 1 states *foreign market spillover effects into the AEX have increased over the sample period* and the results indicate the effect of time on the return spillover effects is inconclusive. Concerning the time effect on the volatility spillovers, the results conclude there is a significant positive effect of time. Therefore, hypothesis 1 cannot be conclusively answered for return spillovers, and it is not rejected for volatility spillovers.

Hypothesis 2 states *foreign market return and volatility spillover effects into the AEX are larger when the foreign market experiences a negative shock.* The results indicate that return spillovers are not asymmetric meaning the spillover effect is unchanged even during a negative return period. With respect to volatility spillovers, the results indicate that the volatility spillover effects into the AEX are significantly larger during periods where the foreign market experiences negative daily returns. This finding is in accordance with past literature which conclude that the volatility transmission mechanism results in higher volatility transmission during negative return periods than in positive return periods (Koutmos, 1996). Therefore, hypothesis 1 is rejected for return spillovers but not rejected for volatility spillovers.

Lastly, Hypothesis 3 states *foreign market return and volatility spillover effects into the AEX are larger when the foreign market experiences a negative shock.* The return spillover effect from the HSI, the index which opens closest to the AEX, was found to be significantly larger than the other foreign markets return spillover effects, other than the S&P 500 spillover effect. Therefore, between the smaller indices, return spillover effects were larger for the market which opened closest in time. When looking at the volatility spillover effects, there was no significant difference between the spillover effect and when the index opened. As a result, hypothesis 3 is not rejected for return spillovers, but it is rejected for volatility spillovers. This finding is partially in line with that of Singh et al. (2010), who concluded that both the return and volatility spillovers into a particular index are largest for indices which open just before it.

Therefore, the research question: *To what extent does news from international financial markets spillover into the Dutch financial market?*, can be answered. More precisely, time does not have a clear effect on the spillover effects, only volatility spillovers are larger during negative return periods and markets which open closer in time have larger return spillover effects into the AEX.

The implications of the results are twofold. Firstly, for practitioners, this research indicates that the

AEX is subject to return and volatility spillovers from foreign markets. Generally, the effects are positive meaning that the AEX follows the global market. Secondly, this research confirms the existing findings that during negative return periods, the volatility spillover effects are significantly larger. Therefore, financial market participants need to be especially prudent during these periods as the spillovers effects can amplify the effect of the negative news.

There are, however, several limitations with respect to the research design which must be addressed. Firstly, the results are affected by simultaneity bias because the spillover effects estimated using the spillover coefficients capture both the fundamental effect from the index as well as a transferring effect. This transferring effect is the impact of a market which is propagated throughout the entire financial system, therefore, part of each coefficient captures the same effect. To partially remedy this, the Cholesky Orthogonalization procedure can be applied to the returns disentangling the fundamental spillover effect an index has on the AEX, and the transferring effect (Boudt, Laurent, Lunde, Quaedvlieg, & Sauri, 2017). Secondly, the methodology used only differentiates between markets with respect to their opening time. As a result, the models do not capture the intricate interactions and spillover effects between the markets. A possible solution for this is to use intraday data and capture the spillover effects when the markets are open, overlap and close. This will allow for more accurate conclusions concerning the nature of the spillover effects. Thirdly, the models only focus on the five larger indices around the world. Therefore, there are interactions and effects which are omitted leading to biased coefficients. To partially alleviate this problem, the intricate network of financial markets can be analysed by including 'hub markets' into the models. These 'hub markets' act as gateway markets, which transfer global spillover effects to regional markets and vice versa (Singh et al., 2010). Thus, the main spillover effects between international markets can be more accurately modeled.

Baring the limitations in mind, the recommendations for future research would be to focus on analysing the spillover effects by disentangling the fundamental effect from each market and the transferring effect. Additionally, analysing the effect of certain releases of information on the spillover effects would more accurately allow to determine the spillover effects between financial markets.

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Appendices

A Additional Information

A.1 Market opening and closing times

Table 11: Description of markets and their respective local and UTC opening times. The times are obtained from Singh et al. (2010).

Index	Country	Local Time		UTC Time		Market Duration
		Opening	Closing	Opening	Closing	
Nikkei 225	Japan	9:00	15:00	00:00	06:00	06:30
HSI	Hong Kong	10:00	16:00	02:00	08:00	06:00
FTSE 100	United Kingdom	07:50	16:20	07:50	16:20	08:30
DAX 30	Germany	09:00	17:35	08:00	16:35	08:35
AEX	Netherlands	09:00	17:35	08:00	16:35	08:35
S&P 500	United States	09:30	16:00	15:30	22:00	06:30

A.2 Market Return Plots

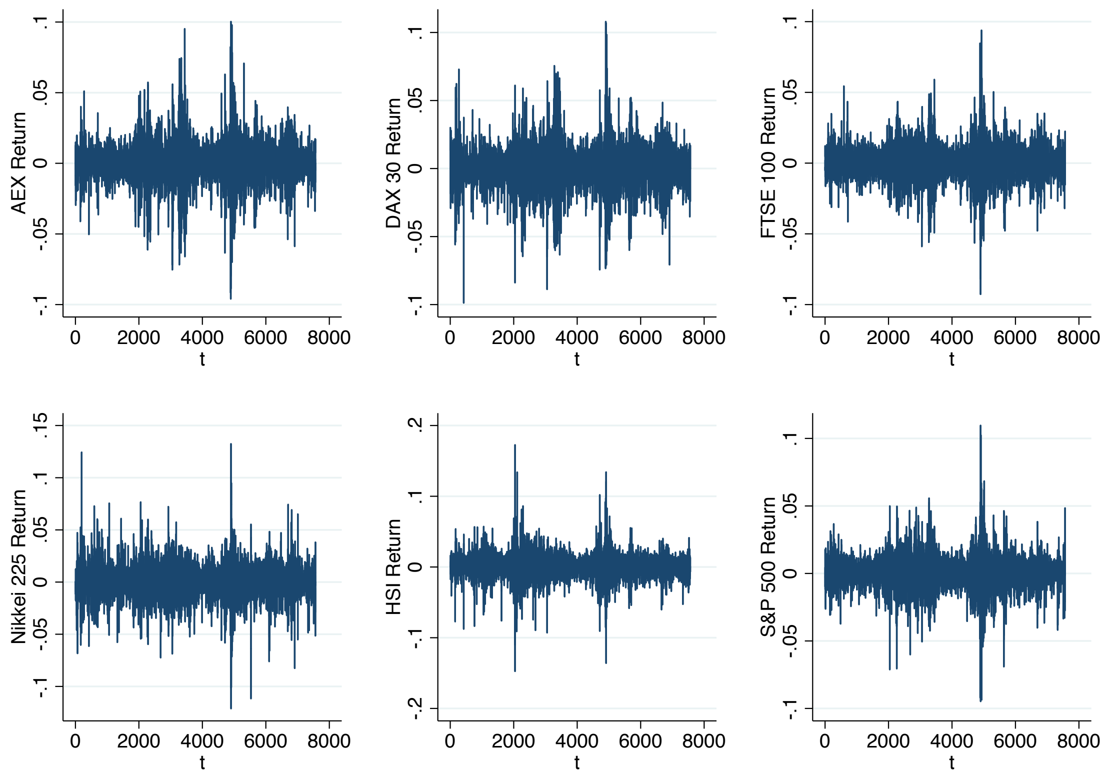

Figure 2: Daily returns for the 6 indices ranging from January 1st 1990 until December 12th 2018.

A.3 Additional Wald Test

Table 12: Wald test for the equality of return spillover effects into the AEX return. For the test of the equality of the return spillover coefficients an F statistic reported.

Spillover	Null Hypothesis	Statistic
Return		
	$H_0 : \phi_{HSI,t} = \phi_{S\&P500,t-1}$	2.47
	$H_0 : \phi_{HSI,t} = \phi_{Nikkei,t}$	16.92***

$^{***}p < 0.01, ^{**}p < 0.05, ^{*}p < 0.1$

B Intraday Return & Volatility Spillover Analysis

B.1 Data

The sample of 15-minute interval closing prices is retrieved from Bloomberg and focuses on the three main indices in Europe, namely, AEX, DAX 30 and FTSE 100. The data from the January 2nd 2018 until December 31st 2018, however, only trading days were kept in the sample where all three indices were simultaneously open. The limitations of doing so are addressed in Section 6: Conclusion & Discussion. Additionally, a distinction was made during the regular trading day returns and the after-market returns: where the regular trading returns were calculated as in equation (1) and the after-market returns were calculated using equation (2).

$$r_{t,night} = ln(OpeningPrice_t) - ln(ClosingPrice_{t-1}) \tag{11}$$

The 15-minute price interval is used to avoid the additional noise in the data due to bid-ask bounce as outlined by Jegadeesh and Titman (1995). Table 13 presents the descriptive statistics of the returns of the intraday sample for each respective index.

Table 13: Descriptive statistics for the 15-minute intraday returns of the indices. Additionally, the augmented Dickey Fuller test statistics, testing for stationarity, and the Shapiro-Wilk test for normality are included.

	AEX	DAX 30	FTSE 100
Observations	8470	8470	8470
Mean(%)	-0.011	-0.002	-0.002
Standard Deviation	0.001	0.002	0.001
Maximum	0.020	0.025	0.020
Minimum	-0.037	-0.037	-0.0
Skewness	-1.652	-0.403	-0.343
Kurtosis	77.781	46.949	44.072
ADF (no constant)	-94.855***	-92.935***	-89.338***
Shapiro-Wilk	18.417***	17.848***	17.927***

Observable from table 2, the 15-minute, all three return indices are stationary given that the Augmented Dickey Fuller test is rejected at the 1% significance. Additionally, as noted with the daily return data, the intra-day returns reject the Shapiro-Wilk test at 1% indicating that the series is not normally distributed. This again is not a surprise given that the financial returns are generally fat tailed. Given the large sample size, this does not significantly affect the results.

B.2 Methodology

To better understand the interactions between markets which are open simultaneously, the 15-minute interval intraday sample focuses on the AEX, DAX 30 and FTSE 100. Therefore, only Hypothesis 1 and

2 apply to this section of the analysis. Both the models for hypothesis 1 and 2 for the intraday sample are identical to the models for the daily sample except for the addition of an after market return interaction variable. This variable serves to capture the atypical price movements during after hours trading due to decreased trading volume and increased spreads (Barclay & Hendershott, 2004). Therefore the estimated spillover effects are not influenced by these irregularities. The general return and volatility models for the intraday sample are presented in equation 12 and 13 respectively, and where β represents the after hours trading effect.

$$r_{t,i} = \phi_0 + \sum_{n=1}^{b}(\phi_{b,t} + \beta_b)r_{b,t} + \sum_{n=1}^{a}(\phi_{a,t} + \beta_a)r_{a,t-1} + \sum_{n=1}^{s}(\phi_{s,t} + \beta_s)r_{s,t-1} + \varepsilon_t \tag{12}$$

$$\sigma_{i,t}^2 = \phi_0 + (\alpha_{i,1} + \omega_i)\varepsilon_{i,t-1}^2 + \beta_{i,t}\sigma_{i,t-1}^2 + \sum_{n=1}^{b}(\alpha_b + \beta_b)\varepsilon_{b,t}^2 + \sum_{n=1}^{a}(\alpha_a + \beta_a)\varepsilon_{a,t}^2 + \sum_{n=1}^{s}(\alpha_s + \beta_s)\varepsilon_{s,t}^2 \tag{13}$$

B.3 Results

To better understand the interactions between the indices which are open simultaneously with the AEX, a 3 dimensional VAR(1) is conducted using the DAX 30 and FTSE 100 as additional dependent variables. The results are presented in Table 14. The results indicate that there are no significant return spillovers into the AEX and DAX 30. The only significant return spillover effects are into the FTSE 100 from the AEX night interaction variable and DAX 30 night interaction variable. Both effects are positive significant to 1% and 5% respectively. The interpretation of these effects, although absent of any economic reasoning, is that the after market trading in both the AEX and DAX 30 lead proportionate return effects into the FTSE 100 return. This means that if the AEX exhibits positive returns during after market trading, then there is a positive effect on the FTSE 100 return. The similar interpretation holds for the DAX 30 night dummy.

A possible reasoning for the absence of any significant return spillover effect is that the data is noisy in combination with the spillover effects, at a 15-minute interval level, being very small. As a result the underlying spillovers are difficult to distinguish and appear to be insignificant. A possible solution for this issue is using noise reduction procedures such as sub-sampling.

When looking at the volatility spillovers from the general AR(1)-GARCH(1,1) presented in Table 19, both the DAX 30 and FTSE 100 spillover effects are significant at 1%. The DAX 30 spillover effect is positive, whereas that of the FTSE 100 is negative. This finding is consistent with the results found with the daily spillover effects. Additionally, all three night interaction variables are significant at 1% indicating that the after market trading significantly affects the volatility of AEX returns.

Table 14: Results for the 3-dimension VAR(1) on the 15-minute intraday returns of the AEX, DAX 30 and FTSE 100. Night interaction variables are included to capture the irregularities of after market trading.

Parameters	AEX	DAX 30	FTSE 100
AEX(t-1)	0.001	-0.003	-0.006
	(0.032)	(0.040)	(0.027)
DAX 30(t-1)	-0.007	-0.001	0.023
	(0.021)	(0.027)	(0.016)
FTSE 100(t-1)	-0.003	0.008	0.007
	(0.022)	(0.028)	(0.018)
Night Interaction Variables			
$\beta_{AEX(t-1)}$	-0.080	0.008	0.557***
	(0.077)	(0.087)	(0.088)
$\beta_{DAX30(t-1)}$	0.032	-0.022	0.189**
	(0.056)	(0.054)	(0.077)
$\beta_{FTSE100(t-1)}$	-0.048	-0.083	-0.481***
	(0.057)	(0.076)	(0.084)
Constant	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)

Newey-West standard errors in parentheses

$^{***}p < 0.01, ^{**}p < 0.05, ^{*}p < 0.$

Table 15: AR(1)-GARCH(1,1) with conditional variance night return interaction variables included for the respective indices.

Parameters	AEX
ARCH(1)	0.394***
	(0.008)
GARCH(1)	0.741***
	(0.005)
$\varepsilon^2_{DAX}(t-1)$	0.017***
	(0.002)
$\varepsilon^2_{FTSE}(t-1)$	-0.007***
	(0.002)
Night Interaction Variables	
$\beta_{AEX(t-1)}$	-0.394***
	(0.008)
$\beta_{DAX30(t-1)}$	-0.010***
	(0.003)
$\beta_{FTSE100(t-1)}$	0.007
	(0.007)
Constant	0.000***
	(0.000)

Standard errors in parentheses

$^{***}p < 0.01, ^{**}p < 0.05, ^{*}p < 0.1$

B.3.1 Hypothesis 1

Determing whether there is an effect of time on the return spillover effects, the 3-dimension VAR(1) is conducted with additonal time interaction variables. The results are presented in Table 18. The results are similar to the findings found for the daily return spillover effects, as no significant effect of time on the spillover is found. Intuitively this finding is not surprising as literature concluded that the effect of time on spillover effects is dependent on the degree of integration of the markets, and given no significant was found using the daily sample, this result therefore is in line with the conclusion.

Table 16: Results for the 3-dimension VAR(1) on the 15-minute intraday returns of the AEX, DAX 30 and FTSE 100, and Night Interaction variables. Additionally, negative return interaction variables are added to determine whether there is a significant difference between the spillover effects during postive and negative return periods.

Parameters	AEX	DAX 30	FTSE 100
AEX(t-1)	-0.017	0.059	0.025
	(0.059)	(0.071)	(0.053)
DAX 30(t-1)	0.018	-0.059	-0.051
	(0.043)	(0.054)	(0.041)
FTSE 100(t-1)	0.001	0.011	-0.024
	(0.049)	(0.061)	(0.036)
Night Interaction Variables			
$\beta_{AEX(t-1)}$	-0.075	0.006	0.570***
	(0.073)	(0.085)	(0.085)
$\beta_{DAX30(t-1)}$	0.028	-0.023	0.177**
	(0.056)	(0.055)	(0.075)
$\beta_{FTSE100(t-1)}$ -0.056	-0.088	-0.502***	
	(0.056)	(0.077)	(0.090)
Time Interaction Variables			
$\phi_{AEX(t-1)}$	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)
$\phi_{DAX30(t-1)}$	0.000	0.000	0.000**
	(0.000)	(0.000)	(0.000)
$\phi_{FTSE100(t-1)}$	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)
Constant	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)

Newey-West standard errors in parentheses

$^{***}p < 0.01, ^{**}p < 0.05, ^{*}p < 0.$

Furthermore, looking at whether there are effects of time on the volatility spillover effects, an AR(1)-GARCH(1,1) is estimated with additional time interaction variables. The same conclusion is reached as for the return spillover effects: there is no significant effect of time on the intraday volatility spillover effects. Again intuitively this makes sense. As a result, Hypothesis 1 with respect to both return and volatility spillovers is rejected using the intraday sample.

Table 17: AR(1)-GARCH(1,1) with conditional variance time interaction and night interaction variables included for the respective indices.

Parameters	AEX
ARCH(1)	0.15***
	(0.009)
GARCH(1)	0.600***
	(0.006)
$\varepsilon^2_{DAX}(t-1)$	-0.002
	(0.006)
$\varepsilon^2_{FTSE}(t-1)$	-0.010
	(0.006)
Night Interaction Variables	
$\beta_{AEX(t-1)}$	0.000
	(0.000)
$\beta_{DAX30(t-1)}$	0.038***
	(0.009)
$\beta_{FTSE100(t-1)}$	0.002
	(0.011)
Time Interaction Variables	
$\alpha_{AEX(t-1)}$	0.000
	(0.000)
$\alpha_{DAX30(t-1)}$	0.000
	(0.000)
$\alpha_{FTSE100(t-1)}$	0.000
	(0.000)
Constant	0.000***
	(0.000)

Standard errors in parentheses

$^{***}p < 0.01, ^{**}p < 0.05, ^{*}p < 0.1$

B.3.2 Hypothesis 2

The second hypothesis with respect to return spillovers is considered using a similar 3-dimension VAR(3) with additional negative return interaction variables. The results are displayed in Table 18. The results indicate that return spillovers are not asymmetric. More precisely, the effect is the same whether the foreign index is experiencing positive or negative returns. This finding is in agreement with the results found using daily returns.

Table 18: Results for the 3-dimension VAR(1) on the 15-minute intraday returns of the AEX, DAX 30 and FTSE 100, and Night Interaction variables. Additionally, 15-minute time interaction variables are added to determine whether there is a significant change in the spillover effects over the sample.

Parameters	AEX	DAX 30	FTSE 100
AEX(t-1)	0.017	-0.009	0.014
	(0.050)	(0.058)	(0.043)
DAX 30(t-1)	0.016	0.032	0.015
	(0.033)	(0.036)	(0.028)
FTSE 100(t-1)	0.010	-0.008	0.010
	(0.025)	(0.031)	(0.021)
Night Interaction Variables			
$\beta_{AEX(t-1)}$	-0.072	0.038	0.559***
	(0.076)	(0.080)	(0.089)
$\beta_{DAX30(t-1)}$	0.032	-0.037	0.187**
	(0.059) (0.055)	(0.078)	
$\beta_{FTSE100(t-1)}$	0.048	-0.092	-0.483***
	(0.056)	(0.076)	(0.085)
Negative Return Interaction Variables			
$\omega_{AEX(t-1)}$	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)
$\omega_{DAX30(t-1)}$	0.000	0.000	0.000**
	(0.000)	(0.000)	(0.000)
$\omega_{FTSE100(t-1)}$	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)
Constant	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)

Newey-West standard errors in parentheses

$^{***}p < 0.01, ^{**}p < 0.05, ^{*}p < 0.$

Next, looking at whether the volatility spillover effects are asymmetric as stated by literature, an AR(1)-TARCH(1,1,1) is estimated with additional negative return interaction variables in the conditional variance equation. The results are presented in Table 19. The results indicate that only the DAX 30 only spills over into the AEX return volatility when it exhibits negative returns because the spillover coefficient is found to be insignificant and the negative return interaction variable is found to be significant at 1%. This find is in agreement with the results found using the daily returns. Surprisingly, however, the FTSE 100 is found to have no significant spillover effect nor exhibit any asymmetries. This finding is not in accordance with the results found using the daily returns. Therefore, Hypothesis 2 is not rejects because the volatility spillover effects into the AEX are larger with the foreign index exhibits negative returns.

Table 19: AR(1)-TARCH(1,1,1) with conditional variance negative return interaction and night interaction variables included for the respective indices.

Parameters	AEX
ARCH(1)	0.394***
	(0.009)
GARCH(1)	0.740***
	(0.005)
TARCH(1)	-0.019***
	(0.007)
$\varepsilon^2_{DAX}(t-1)$	0.011
	(0.003)
$\varepsilon^2_{FTSE}(t-1)$	-0.014
	(0.003)
Night Interaction Variables	
$\beta_{AEX(t-1)}$	-0.388***
	(0.009)
$\beta_{DAX30(t-1)}$	-0.006*
	(0.003)
$\beta_{FTSE100(t-1)}$	0.002
	(0.006)
Negative Return Interaction Variables	
$\gamma_{DAX30(t-1)}$	0.015***
	(0.005)
$\gamma_{FTSE100(t-1)}$	0.027
	(0.006)
Constant	0.000***
	(0.000)

Standard errors in parentheses

$^{***}p < 0.01, ^{**}p < 0.05, ^{*}p < 0.1$

Table 20: Summary of results - Intraday Return & Volatility Spillovers

Hypothesis	Return Spillovers	Volatility Spillovers
1	Rejected	Rejected
2	Rejected	Not Rejected