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Equity Transmission Effects and Autocorrelations across the U.S., the Eurozone and Japan

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Abstract

This paper presents statistically significant and causal trends of increasing transmission effects across equity markets of the world's three largest economies during the period of 1988 till 2010. When studying daily returns of the S&P 500, EURO STOXX and Nikkei 225 in a round-the-clock setting, increasing transmission effects were detected by our Autoregressive (AR) models and Granger causality tests. We have also observed and confirmed a considerably increasing trend of the Eurozone's relative influence on its peer markets. The fact that these dominant markets have become more interrelated suggests that portfolio managers obtain lower diversification benefits across the studied markets. The paper does not only examine transmission effects from foreign markets, but also lag effects from the home market. The results obtained from our AR(12) models and Ljung-Box tests implies the presence of slightly negative autocorrelations, possibly suggesting the occurrence of mean reversion within daily stock returns.

Key words: Transmission effects; causality; autocorrelation; mean reversion; international portfolio diversification

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1. INTRODUCTION

Within modern portfolio theory the technique of combining different securities to decrease the risk of a portfolio for a given expected return is called diversification and the fact that less correlated securities offer better diversification has been widely proven and accepted (Markowitz, 1959).

Diversification effects and its benefits are covered by extensive amount of research and it constitutes an important field of study within modern finance. Both academicians and professional investors are in the forefront of the study and in the search for assets and markets with attributes that are suitable for risk optimisation.

Previous studies, for instance by Levy & Sarnat (1970), Bailey & Stulz (1990) and Bailey & Lim (1992), have highlighted the fact that portfolio managers are able to obtain a well diversified portfolio by investing across different international markets. This phenomenon is based on the assumption that co-movements across different countries or regions are lower than those present within a domestic market. Furthermore, such low international correlations among equity markets have previously been proved by for instance Ripley (1973), Lessard (1976) and Hillard (1979).

In face of globalisation, integration and technological development across international markets, the importance of the above mentioned international transmission effects has increased dramatically for portfolio managers looking to diversify their investments globally. Previous studies, for instance by Lee & Kim (1993) amongst others, have shown that global equity markets have become much more interrelated since the 1987 financial crisis. These studies suggest that the effects of globalisation are becoming ever more evident across international equity markets.

In the light of these previous findings, this study aims to highlight and discuss the development of transmission effects across major international equity markets since the end of the 1987 financial crisis. We have studied transmission effects in an round-the-clock setting, using daily equity index returns of the world's three largest economies (the U.S, the Eurozone and Japan) ranging from 1988 till 2010. In our study we observe the transmission effects in a dynamic manner using an Autoregressive model (henceforth AR), which takes into account both same-date and lag effects across markets.

Considering our setting, an important topic for us to assess is the integration of the Eurozone and its relationship to other major stock markets. Earlier studies have implied that the Eurozone's equity markets have become highly integrated, much due to the development of the Economic and Monetary Union of the European Union (henceforth EMU) as well as increased its importance within global financial markets relative to the U.S. (Fratzscher, 2002). Also, a study by Baele (2003) focused on the time-varying nature of EU and U.S. volatility spill-overs on local European equity markets during the 1980's and 1990's. In his paper Baele found that while both the EU and U.S. shock spill-overs intensity had increased over the period, the rise was more prominent for EU spill-overs.

A study by Eun & Shim (1989) indicates that innovations taking place in the U.S. were rapidly transmitted to other stock markets, whereas no significant spill-overs from foreign markets on the U.S. market were observed. The calculations in their study were on daily returns during 1978 till 1985 and in a VAR system.

Furthermore, we have also studied autocorrelations from the three indices by running AR(12) models. Autocorrelations are of interest for us, as we aim to study not only transmission effects across markets in the AR setting, but also to examine effects from previous movements in the home market in own AR(12) setting. Previous studies on autocorrelations have shown that there are reasons to question the random walk theory in respect to stock returns. For instance Lo & MacKinlay (1999) showed, by using 1216 weekly observations from September 1962 to December 1985, that the weekly first-order autocorrelation coefficient of equally-weighted CRSP (Center for Research in Security Prices) return index was as high as 30 percent – clearly indicating the faultiness of the random walk theory. These aspects are also briefly discussed in our study.

We believe that the results from this study can be of significant importance for participants of the investment community looking to better understand transmission effects across major international equity markets. Our hopes are that the findings presented in this study will highlight the important influence that globalisation and other economic developments cause on the linkages among world equity markets.

2. DATA

2.1 Selection and description of the datasets

The full dataset used in this study is composed by end-day daily equity index quotes ranging from January 5th 1988 till April 15th 2010. This range has been chosen because it represents the period following the 1987 financial crisis. To add additional depth to our study and to enable meaningful inference to be drawn from the results we have also chosen to divide the full dataset into three subsets ranging over the following time periods: January 5th 1988 till April 12th 1996, April 15th 1996 till April 14th 2003 and April 15th 2003 till April 15th 2010.

Our study aims to observe round-the-clock transmission effects between major international equity markets. To accomplish this we have chosen to employ equity indices based on mainly the following criteria: Size of underlying economy, maturity of equity market, representation of region and also the level of established recognisability of the indices.

We choose to measure the size of the underlying economies based on the nominal GDP according to World Bank figures for 2008 (World Bank, 2010). The 2008 figures presented in *Table 2.1* are the latest available from the World Bank and also represent our period from 1988 till 2010 very well.

Table 2.1: *Nominal GDP 2008 according to the World Bank*

Rank	Region/Country	GDP (millions of USD)
1	United States	14,093,310
2	Eurozone	13,581,627
3	Japan	4,910,840
4	China	4,326,996
5	*Germany (Eurozone)*	*3,649,494*
6	*France (Eurozone)*	*2,856,556*
7	United Kingdom	2,674,057
8	*Italy (Eurozone)*	*2,303,079*
9	Russian Federation	1,679,484
10	*Spain (Eurozone)*	*1,604,235*

As we do not restrict ourselves to specific countries our study will treat the Eurozone as one geographical region. Subsequently, it emerges as the second largest economy in our study with a GDP of USD 13,581,627m. The largest economy in terms of GDP is the United States with USD 14,093,310m. In Asia the two largest economies are Japan and China with GDPs of USD 4,910,840m and USD 4,326,996m respectively. As we aim to look at developed economies and mature equity markets over the period of 1988 till 2010, Japan emerges as more suitable for our study in contrast to China. This is due to its long-lasting prominence as a dominant economy with a developed equity market.

By using the U.S., the Eurozone and Japan as underlying economies for our study we are able to observe the world's three largest economies in a setting which offers vast recognisability and credibility. Furthermore the three regions offer developed equity markets and are geographically independent of one another.

Based on the level of representation of region and recognisability, we have selected the following three equity indices to represent the given regions.

2.2 S&P 500 – The U.S.

The S&P 500 has over USD 3.5 trillion benchmarked, with index assets comprising around USD 915bn of this total. The index consists of 500 leading U.S. companies and covers 75 percent of all equities in the U.S. The S&P 500 is a free-float capitalization-weighted index. This means that each constituent is weighted by market-capitalization. (Standard and Poor's, 2010)

2.3 EURO STOXX – The Eurozone

The EURO STOXX is a broad yet liquid subset of the STOXX Europe 600 Index. The index represents large, mid and small capitalization companies of the 12 Eurozone countries: Austria, Belgium, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal and Spain. EURO STOXX is narrower than the broader STOXX Europe 600 that consists of companies across 18 countries of the entire European region. The EURO STOXX is a free-float capitalization-weighted index that consists of approximately 300 entities. This makes it more attractive for our study than the EURO STOXX 50, which consists of the 50 most liquid companies in the Eurozone. (STOXX Limited, 2010)

2.4 Nikkei 225 – Japan

The Nikkei 225 is the equal-weighted average price of 225 stocks traded on the first section of the Tokyo Stock Exchange. It is different from a simple average in that the divisor is adjusted to maintain continuity and to reduce the effect of external factors not directly related to the market. (Nikkei, 2010)

We choose to employ the Nikkei 225 index due to its large number of components and broad usage, as it is by far the foremost benchmark for Japanese stocks. Worth mentioning is also that the Nikkei 225 is expected to be less sensitive to the behaviours of small stocks than CRSP (The Center for Research in Security Prices) Japanese equity indices (Iwaisako, 2003). However, the CRSP was employed by Lo and MacKinlay (1988) in the study previously referred to. Nevertheless, we chose to employ Nikkei 225 in our study due to its superior recognisability and lower sensitivity to the behaviour of small stocks.

2.5 Descriptive statistics of the data

All time series have been obtained from Thomson Datastream Advance 4.0. Descriptive statistics are summarised in *Tables 2.2 to 2.7* and *Figures 2.1 to 2.3* on the following pages.

Descriptive statistics: S&P 500

Table 2.2: *Descriptive statistics for S&P 500 levels*

S&P 500	*Jan 1988-April 2010*	*Jan 1988-April 1996*	*April 1996-Aril 2003*	*April 2003-April 2010*
Mean	867.2909	404.5867	1090.6631	1190.6503
Standard Error	5.2579	2.0480	5.6475	4.3679
Median	931.8000	408.3300	1106.6850	1190.7450
Mode	1092.5400	462.3600	1092.5400	1418.3000
Std. Deviation	400.8813	95.1607	241.3262	186.7498
Sample Variance	160705.8535	9055.5611	58238.3339	34875.4849
Kurtosis	-1.4546	-0.1027	-1.0474	-0.5477
Skewness	-0.0787	0.5028	-0.1186	-0.1308
Range	1322.5200	418.8000	900.8000	888.6200
Minimum	242.6300	242.6300	626.6500	676.5300
Maximum	1565.1500	661.4300	1527.4500	1565.1500
Sum	5041562.2900	873502.7200	1991550.7700	2176508.8000
Count	5813	2159	1826	1828
Conf. Level 95%	10.3075	4.0163	11.0762	8.5666

Table 2.3: *Descriptive statistics for S&P 500 first-differences*

S&P 500 (LN Returns)	*Jan 1988-April 2010*	*Jan 1988-April 1996*	*April 1996-Aril 2003*	*April 2003-April 2010*
Mean	0.0003	0.0004	0.0002	0.0002
Standard Error	0.0001	0.0002	0.0003	0.0003
Median	0.0003	0.0003	0.0000	0.0007
Mode	0.0000	0.0000	0.0000	0.0000
Std. Deviation	0.0113	0.0077	0.0127	0.0133
Sample Variance	0.0001	0.0001	0.0002	0.0002
Kurtosis	9.7711	7.1727	2.4749	12.6392
Skewness	-0.2733	-0.6950	-0.0686	-0.2920
Range	0.2043	0.1068	0.1269	0.2043
Minimum	-0.0947	-0.0701	-0.0711	-0.0947
Maximum	0.1096	0.0367	0.0557	0.1096
Sum	1.5548	0.9114	0.3295	0.3139
Count	5813	2159	1826	1828
Conf. Level 95%	0.0003	0.0003	0.0006	0.0006

Descriptive statistics: EURO STOXX

Table 2.4: *Descriptive statistics for EURO STOXX levels*

EURO STOXX	*Jan 1988-April 2010*	*Jan 1988-April 1996*	*April 1996-Aril 2003*	*April 2003-April 2010*
Mean	2465.0070	1104.9265	3313.0672	3224.2280
Standard Error	16.6533	4.9444	25.0183	15.5668
Median	2488.5900	1057.8900	3354.0610	3051.1180
Mode	2456.4960	772.1100	2456.4960	4384.5470
Std. Deviation	1269.7012	229.7410	1069.0763	665.5604
Sample Variance	1612141.0650	52780.9093	1142924.0482	442970.6461
Kurtosis	-1.0282	-0.7847	-0.9403	-1.0061
Skewness	0.3222	0.2265	0.2185	0.3192
Range	4830.9300	1011.3500	3901.1100	2747.5940
Minimum	633.5000	633.5000	1563.3200	1809.9760
Maximum	5464.4300	1644.8500	5464.4300	4557.5700
Sum	14329085.6130	2385536.2400	6049660.6260	5893888.7470
Count	5813	2159	1826	1828
Conf. Level 95%	32.6467	9.6963	49.0676	30.5306

Table 2.5: *Descriptive statistics for EURO STOXX first-differences*

EURO STOXX (LN Returns)	*Jan 1988-April 2010*	*Jan 1988-April 1996*	*April 1996-Aril 2003*	*April 2003-April 2010*
Mean	0.0003	0.0004	0.0002	0.0002
Standard Error	0.0002	0.0002	0.0004	0.0003
Median	0.0005	0.0007	0.0006	0.0002
Mode	0.0000	0.0000	0.0000	0.0000
Std. Deviation	0.0130	0.0085	0.0161	0.0138
Sample Variance	0.0002	0.0001	0.0003	0.0002
Kurtosis	6.2371	9.2771	2.1773	8.2485
Skewness	-0.1561	-0.6524	-0.0778	-0.0743
Range	0.1865	0.1321	0.1370	0.1865
Minimum	-0.0821	-0.0752	-0.0662	-0.0821
Maximum	0.1044	0.0569	0.0708	0.1044
Sum	1.5596	0.9471	0.3313	0.2813
Count	5813	2159	1826	1828
Conf. Level 95%	0.0003	0.0004	0.0007	0.0006

Descriptive statistics: Nikkei 225

Table 2.6: *Descriptive statistics for Nikkei 225 levels*

Nikkei 225	*Jan 1988- April 2010*	*Jan 1988- April 1996*	*April 1996- Aril 2003*	*April 2003- April 2010*
Mean	17538.0347	23569.7917	15359.3555	12590.3898
Standard Error	86.7175	130.1891	90.2667	69.1635
Median	16839.1200	21391.0200	15910.7400	11623.4150
Mode	17394.9200	30159.0000	19361.3500	17394.9200
Std. Deviation	6611.6041	6049.2430	3857.2511	2957.0914
Sample Variance	43713309.0085	36593341.4403	14878385.8010	8744389.6482
Kurtosis	0.6646	-0.5580	-0.9537	-1.1075
Skewness	0.9443	0.7204	-0.2006	0.3161
Range	31860.8900	24606.4600	14914.7000	11207.0000
Minimum	7054.9800	14309.4100	7752.1000	7054.9800
Maximum	38915.8700	38915.8700	22666.8000	18261.9800
Sum	101948595.930	50887180.2600	28046183.1000	23015232.5700
Count	5813	2159	1826	1828
Conf. Level 95%	169.9985	255.3092	177.0369	135.6477

Table 2.7: *Descriptive statistics for Nikkei 225 first-differences*

Nikkei 225 (LN Returns)	*Jan 1988- April 2010*	*Jan 1988- April 1996*	*April 1996- Aril 2003*	*April 2003- April 2010*
Mean	-0.0001	0.0000	-0.0006	0.0002
Standard Error	0.0002	0.0003	0.0004	0.0004
Median	0.0000	0.0000	0.0000	0.0000
Mode	0.0000	0.0000	0.0000	0.0000
Std. Deviation	0.0147	0.0134	0.0151	0.0158
Sample Variance	0.0002	0.0002	0.0002	0.0002
Kurtosis	6.3196	6.7229	1.9612	9.4138
Skewness	-0.0376	0.4423	0.0900	-0.4943
Range	0.2535	0.1926	0.1489	0.2535
Minimum	-0.1211	-0.0683	-0.0723	-0.1211
Maximum	0.1323	0.1243	0.0766	0.1323
Sum	-0.6323	0.0207	-1.0275	0.3745
Count	5813	2159	1826	1828
Conf. Level 95%	0.0004	0.0006	0.0007	0.0007

Index levels for S&P 500, EURO STOXX & Nikkei 225 (Jan 1988 – April 2010)

Figure 2.1: *S&P 500 levels (1988-2010)*

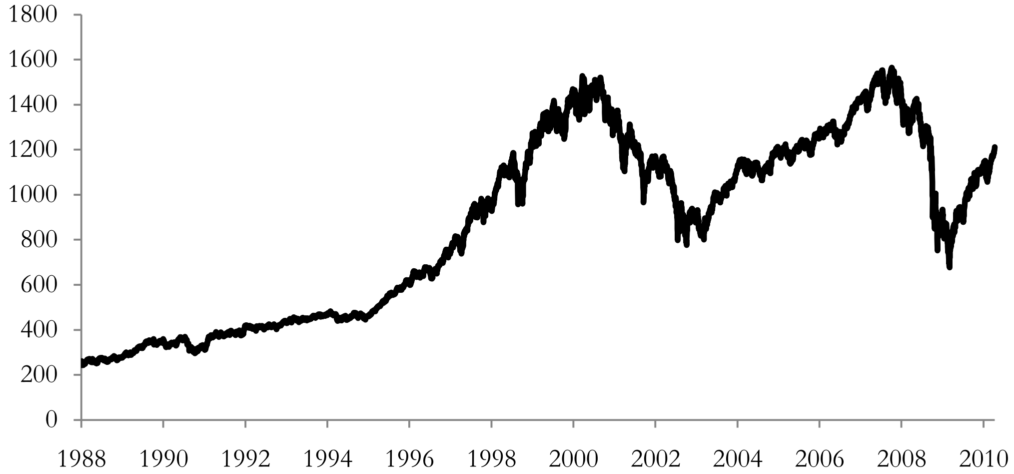


Figure 2.2: *EURO STOXX levels (1988-2010)*

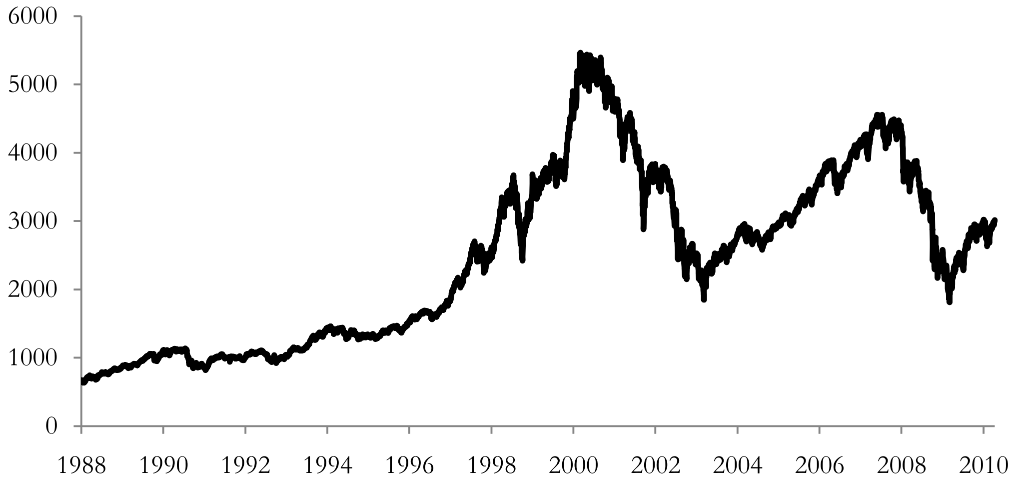
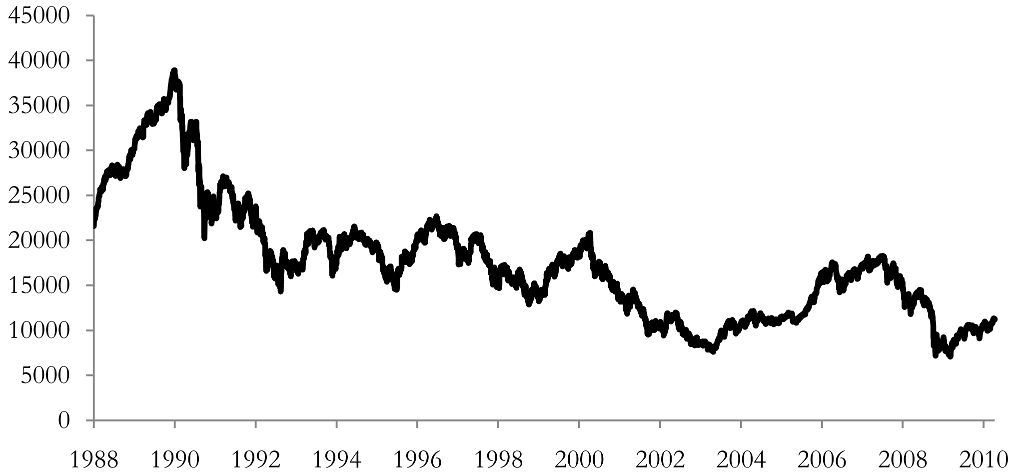


Figure 2.3: *Nikkei 225 levels (1988-2010)*



2.6 Discussing the descriptive statistics

As seen in *Table 2.2 to 2.7* each time series consists of 5831 daily index observations. We have also presented the descriptive statistics on subset levels, as most of the estimations will be made not only on the full dataset but also on the three respective subsets. The time periods each consists of 2159 (Jan 1988 – April 1996), 1826 (April 1996 – April 2003) and 1828 (April 2003 – April 2010) observations. This gives us large samples and thus should constitute a strong statistical base to implement our study upon.

The descriptive statistics were calculated on index levels as well as on logarithmic returns. Since the study uses the logarithmic returns, these results are of primary interest. However, the index level statistics are suitable to use as a point of reference.

From *Tables 2.3, 2.5 and 2.7* we observe that daily logarithmic returns have a close to zero mean for all indices. Both the S&P 500 and EURO STOXX display slightly positive daily returns in all time periods. The Nikkei 225 had slightly negative daily returns during the period spanning from 1996 to 2003. This can most certainly be attributed to the 1997-1998 Asian financial crisis.

The standard deviations during the entire period are highest in Japan (0.0147), followed by the Eurozone (0.0130) and the U.S. (0.0113) respectively. The standard deviation can also be interpreted as the volatility of the market. In *Tables 2.2, 2.4 and 2.6* one can see the equivalent standard deviation in index points for each index. From the standard deviation statistics we also see that the values have increased since the 1988-1996 period for all three indices. The S&P 500 and Nikkei 225 display their highest standard deviations during the 2003-2010 subset. This can certainly be attributed to the huge market swings during and since the 2007-2009 financial crisis. The EURO STOXX displays its highest standard deviation during the 1996-2003 period followed by the 2003-2010 period. This could be due to the growth of the EMU and later, the 2007-2009 financial crisis and its aftermath.

3. METHODOLOGY

All model estimations and tests in this study were executed in the software JMulTi (version 4.24), which is an interactive software that is specialized in univariate and multivariate time series analysis. (Krätzig & Lütkepohl, 2004)

3.1 The Augmented Dickey-Fuller test for stationarity

The Augmented Dickey-Fuller test (henceforth ADF) is used to test the variables for stationarity and is based on *Model 3.1* (Krätzig & Lütkepohl, 2004).

$$\Delta y_t = \phi y_{t-1} + \sum_{j=1}^{p-1} \alpha_j^* \Delta y_{t-j} + u_t \quad (3.1)$$

Testing the following hypothesis:

$$H_0: \phi = 0 \textit{ and } H_1: \phi < 0 \quad (3.2)$$

The hypothesis testing depicted in *Model 3.2* is based on the t-statistics of ϕ, which represents the coefficient from an OLS estimation of *Model 3.1* (Fuller, 1996).

If the reported t-statistics from the OLS are smaller than the critical values the null hypothesis can be rejected. Furthermore, under the null hypothesis the time series y_t is proven nonstationary and thus has a unit root. Subsequently, if the null hypothesis is in fact rejected the series is considered to be stationary and thus suitable for time series analysis.

Our ADF tests were executed with non-zero means, no seasonal dummies and lags as suggested by the Schwarz Criterion (see *Section 3.3* for the reasoning behind the usage of information criteria in our study).

3.2 Adapting the original data

Based on our results from the ADF we adapt our original data to be suitable for time series analysis. This is done by using the first difference of logarithm index levels, as depicted in *Model 3.3*.

$$Return_t = ln\left(\frac{index_t}{index_{t-1}}\right) \quad (3.3)$$

When using transformed variables, such as logarithm variables, one needs to be cautious when interpreting coefficients. However, in our case both the dependent variable and the independent variables will be logarithm variables. Thus coefficients can be interpreted as a fairly accurate approximation of the percentage influence by exogenous variables on the endogenous variable.

However, to obtain the precise proportional change in the dependent variable associated with an *x* percent increase in an independent variable *Model 3.4* should be applied.

$$\beta_a = e^{a\beta_r} \quad (3.4)$$

where

β_a is the actual and precise coefficient

a is the chosen percentage increase recalculated as follows ln((100+x)/100)

β_r is the reported coefficient obtained from the regression analysis

Since the difference between reported coefficients and calculated actual coefficients is of low magnitude, we have exclusively chosen to only refer to reported coefficients throughout this study.

3.3 Information criteria

Throughout the study we have decided to commit and remain consistent to the Schwarz Criterion (henceforth SC) as information criterion in our model selection. The reasoning behind this is that the SC is a more parsimonious model than for instance the Akaike Information Criterion (henceforth AIC), which is also commonly used. This is due to its characteristics of higher marginal cost when adding regressors and its higher suitability when dealing with large sample sizes (Enders, 2004). However, when determining the number of lags in our Granger causality tests we have decided to use the AIC (see *Section 3.4* for a detailed reasoning behind this decision).

To depict how the SC operates, we have chosen to introduce the case of model selection for AR models similar to the one in *Model 3.5*. However, the SC model differs slightly when used for ADF model selection. The optimum number of SC lags is obtained by minimising *Model 3.6* (Schwarz, 1978). The optimum number of AIC lags is obtained by minimising *Model 3.7* (Akaike, 1973).

$$y_t = A_1 y_{t-1} + \cdots + A_p y_{t-p} + B_0 B x_t + \cdots + B_q B x_{t-q} + C D_t + u_t \quad (3.5)$$

where

y_t	endogenous variables
x_t	exogenous or unmodelled variables
D_t	all the deterministic variables
q	the lag order of the exogenous variables
u_t	the error term
K	the number of observed endogenous variables*
M	the number of exogenous or unmodelled variables
A_p, B_j & C	the parameter matrices of suitable dimension

$$SC(n) = log\,det(\tilde{\sum_u}(n)) + \frac{logT}{T} nK^2 \quad (3.6)$$

$$AIC(n) = log\,det(\tilde{\sum_u}(n)) + \frac{2}{T} nK^2 \quad (3.7)$$

where

$\sum_{\tilde{u}}(n)$ is estimated by $T^{-1}\sum_{t=1}^{T}\hat{u}_t\hat{u}_t'$

n is the number of endogenous lags and the number of exogenous variables and deterministic terms.

3.4 The Granger causality test

To observe the causalities between the different indices we implement the Granger causality test. The intuition behind this test is described by Granger (1980) as *the general definition of causality*, which is depicted in *Model 3.8*.

General definition of causality:

Y_n is said to cause X_{n+1} if

$$Prob(X_{n+1} \in A \mid \Omega_n) \neq Prob(X_{n+1} \in A \mid \Omega_n - Y_n) \text{ for some A} \quad (3.8)$$

where

X & Y	two random variables in the universe
$X_{n+1} \in A$	probability statement for set A
Ω_n	all the knowledge available in the universe at time *n*
$\Omega_n - Y_n$	the above minus the value of Y_n

Model 3.9 show the reasoning used in JMulTi when estimating Granger causality.

$$\begin{bmatrix} y_{1t} \\ y_{2t} \end{bmatrix} = \sum_{i=1}^{p} \begin{bmatrix} \alpha_{11,i} & \alpha_{12,i} \\ \alpha_{21,i} & \alpha_{22,i} \end{bmatrix} \begin{bmatrix} y_{1,t-i} \\ y_{2,t-i} \end{bmatrix} + CD_t + \begin{bmatrix} u_{1t} \\ u_{2t} \end{bmatrix} \quad (3.9)$$

In *Model 3.9* y_{1t} and y_{2t} represents two sub-vectors that are compared. The aim of the model is to show whether or not y_{1t} is Granger causal by containing useful information for predicting y_{2t}. Y_{2t} is not Granger causal for y_{2t} if the conditions presented in *Model 3.10* are fulfilled.

$$a_{21,i} = 0 \qquad i = 1,2,\dots,p \quad (3.10)$$

Hence, the null hypothesis is tested alongside the alternative that at least one of the $a_{21,i}$ is zero. Consequently one could test the reversed relationship that the Granger causality y_{2t} has with respect to y_{1t}. (Krätzig & Benkwitz, 2009)

When estimating Granger causality, the number of lags used in the model is of great importance for the causality results obtained and is therefore a debated issue amongst researchers. This relationship was described in a working paper by Thornton & Batten (1984). The paper illustrates how causality outcomes can be quite opposite, simply by altering the lags used in the model. Similarly to several other studies on the topic, it suggests that an appropriate statistical criterion should be employed when determining the *right* number of lags. Within other parts of this study we use the SC exclusively. However, the studies on the implications when using the SC in model selection for causality tests clearly show its characteristic of diminishing the Granger causality due to its extremely short lag suggestions. When running the SC with regards to our lags, all suggestions were in the one to two lags range. Hence, in this case we chose to employ the AIC to relax the restrains on the model and obtain more realistic causality results.

Given the substantial importance of the lags used in the model, we considered the decision of not using the SC thoroughly before committing to the AIC for model selection in our Granger causality tests.

3.5 The Autoregressive model

The basic AR model in JMulTi is depicted in *Model 3.11*. The model has previously been fully described in *Section 3.3*.

$$y_t = A_1 y_{t-1} + \cdots + A_p y_{t-p} + B_0 B x_t + \cdots + B_q B x_{t-q} + C D_t + u_t \quad (3.11)$$

When estimating the model JMulTi uses feasible generalized least squares (GLS). To do this the program initially executes an OLS. The residuals are then used to calculate the GLS estimator. (Krätzig & Benkwitz, 2009)

In the AR model we will set the home market as the endogenous variable and the foreign markets as exogenous variables. We have chosen to include three exogenous lags, as we have identified a sharp drop of significance in further lags. We will also include the number of endogenous lags, as suggested by the SC, to fulfil a correct parameterisation of the model. However, these endogenous lags will not be considered with regards to the autocorrelation effects implied by them. Instead we employ an AR(12) model, with no exogenous variables other than the endogenous lags, to examine autocorrelation effects within home markets.

Due to the time-zone adjustments, later discussed in *Section 3.7*, we feel comfortable in using foreign indices as exogenous variables in the AR model, since our specific setting limits risks of endogeneity problems occurring.

3.6 Autocorrelations

As previously mentioned the AR setting above only includes endogenous lags as a means to obtain the correct parameterisation of the model. Per definition autocorrelations are simply the effect of endogenous lags on the endogenous variable, and should hence be studied in an isolated setting. Therefore we have chosen to employ an AR(12) model, that consists of only the endogenous lags, to examine the autocorrelations further.

The estimations of the autocorrelations are similar to those made in the previous model, with the crucial difference that there are no exogenous variables with the exception of the endogenous lags.

We first run the regression on twelve lags to illustrate potential trends over a longer time period. We thereby ignore the low significance and possible exclusion of certain lags, simply to extend the visible horizon of the autocorrelations. However, we also chose to employ a Portmanteau test, namely the Ljung-Box test. This analysis aims to test whether any of a group of autocorrelations of a time series is different from zero, hence indicating which lags in an autoregressive setting are of outmost importance. The Portmanteau test is executed as follows. (Krätzig & Lütkepohl, 2004)

The hypothesis depicted in *Model 3.12* is tested.

$$H_0: \rho_{u,1} = \cdots = \rho_{u,h} = 0 \text{ and } H_1: \rho_{u,1} \neq 0 \text{ for at least one } i = 1,\ldots,h \quad (3.12)$$

Where $\rho_{u,i}$ = Corr(u_t,u_{t-i}) indicates the autocorrelation coefficients of the residual series. *Model 3.13* depicts the test statistics LB_h, which we present together with its p-values.

$$LB_h = T^2 \sum_{j=1}^{h} \frac{1}{T-j} \hat{\rho}_{uj}^2 \quad (3.13)$$

where $\hat{\rho}_{uj} = T^{-1} \sum_{t=j+1}^{T} \hat{u}_t^s \hat{u}_{t-j}^s$

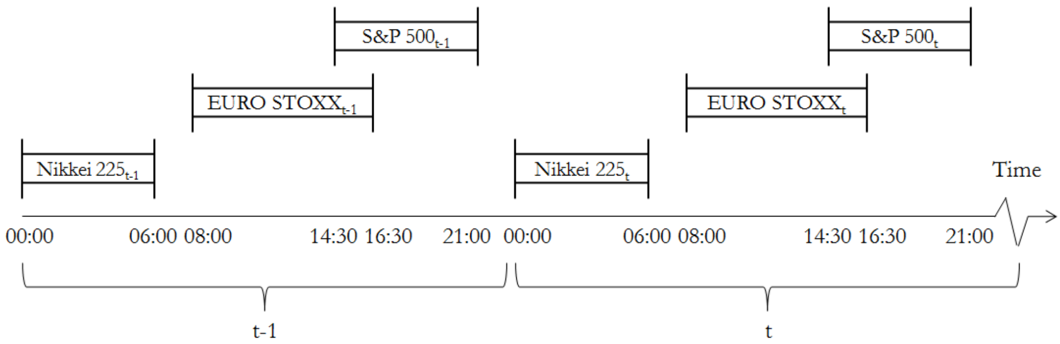
If the $\hat{u}_t$ are residuals from an estimated ARMA(*p, q*) model, the test statistics have an approximate asymptotic $\chi^2(h - p - q)$ distribution if the null hypothesis holds.

We have chosen the Ljung-Box over the Box-Pierce test since it is superior to the Box-Pierce test, across all sample sizes (Ljung & Box, 1978). The ARMA p's and q's were selected by using the SC and are displayed together with the test results in *Section 4.5*. No seasonal dummies were used when running the Ljung-Box test.

3.7 Time-zone adjustments

As this study aims to observe relationships between markets in three different time zones the datasets had to be adjusted somewhat before some of the tests were executed. This is to align the trading sessions in such a manner that the exogenous variables always occur prior to the endogenous variable in our AR and Granger causality settings. *Figure 3.1* demonstrates the different trading hours and their occurrence in relationship to each other:

Figure 3.1: *Around the clock trading hours for the selected markets (all times GMT)*



The Nikkei 225 opens at 00:00 and closes at 06:00 (Nikkei, 2010). The EURO STOXX trades from 08:00 until 16:30 (STOXX Limited, 2010). Before the close in the Eurozone, the S&P 500 opens at 14:30 and runs until 21:00 (NYSE Euronext, 2010 & NASDAQ OMX, 2010). All of the times above are Greenwich Mean Time (GMT). These times differ somewhat under shorter periods of daylight savings time gaps during spring and autumn.

As the AR and Granger causality tests are dependent on the order in which each observation occur, as well as its occurrence in relationship to other observations, we had to adjust the order of some of the indices. When looking at the impact of foreign market returns on a domestic market's return, we have decided to include returns that have occurred, rather than exclusively those from the same date, t. For instance, when looking at the influence S&P 500 returns has on Nikkei 225 returns we use the previous date's S&P 500 returns and the current date's Nikkei 225 returns. Subsequently, when looking at the opposite relationship, values from the same date are used. *Table 3.1* depicts these relationships.

Table 3.1: *Principles used to adjust for time-zone differences across markets*

Dependent index (in period t)	Causing index	Period used for causing index
Nikkei 225_t	EURO STOXX	Previous date, t-1
Nikkei 225_t	S&P 500	Previous date, t-1
EURO $STOXX_t$	Nikkei 225	Same date, t
EURO $STOXX_t$	S&P 500	Time-Weighted*
S&P 500_t	Nikkei 225	Same date, t
S&P 500_t	EURO STOXX	Same date, t

**See second paragraph below for further explanation.*

The reason for using previous date values when assessing the influence which the Eurozone and the U.S. imposes on the Japanese market is quite clear-cut since we cannot use future values to estimate current values. Since the S&P 500 is the last index to close and only has a few hours overlap with the EURO STOXX we use same date values for the exogenous variables of the Eurozone and Japan.

From the perspective of EURO STOXX the Nikkei 225 is clearly suitable to employ with the same date, given that it closes a few hours before the markets in the Eurozone open. However, since the markets in the US overlap with the Eurozone markets by two hours, we have decided to construct an approximation of the actual influence of the S&P 500 on the EURO STOXX. Our approximation is constructed by weighting the S&P 500's effect on the EURO STOXX. The weighted measure of the S&P 500's effect on the EURO STOXX takes into account both the previous date returns and the same date returns in relation to the overlapping time period. The European trading session is 8 hours and 30 minutes, of which 2 hours (*4/17*) will be overlapped by the S&P 500 (since this is an approximation we do not consider the two periods of daylight savings time differences that annually occur). Therefore, the proportion of the trading session which overlaps is assigned to same-date S&P 500 returns. Further, the proportion of the remaining 6 hours and 30 minutes (*13/17*) is assigned to previous-date S&P 500 returns. *Model 3.14* is used to weight the S&P 500's influence on EURO STOXX.

$$x_{weighted} = \frac{4}{17}x_t + \frac{13}{17}x_{t-1} \quad (3.14)$$

Where x_t constitutes the coefficients obtained from using same-date S&P 500 returns and x_{t-1} constitutes the coefficient using previous-date S&P 500 returns. This weight-adjustment is only applicable to coefficients, not to t-values or p-values. Hence we chose not to display weighted t-values in our model estimations for S&P 500's effect on the EURO STOXX. Instead refer to the underlying t-values presented in the *Appendix (Tables 8.5-8.7, 8.19-8.21 and 8.33-8.35).*

It is our belief that this weighted time-zone approximation will enable us to obtain a more realistic read on the S&P 500's effect on the EURO STOXX. Even though it is not the optimal way to calculate the effects, we consider it to be superior to ascribing all of the significance to either previous-date or same-date returns. The ideal way, and also a suggestion for further studies to measure the relationship would be to use intraday S&P 500 values, from 14:30 to 16:30 GMT, in order to capture the same-date effects. We have included all estimations (using same-date, previous-date and weighted values) in the *Appendix* to help the reader better grasp the relationships and we will also return to discuss the implications of this setting further in *Section 5.2*.

In our analysis we will use the term *first-cycle* and *second-cycle* coefficients. This is based on the methodology presented in *Table 3.1*. Coefficients in the first-cycle refer to the specific index's exogenous variables in the most recent trading session. Coefficients in the second-cycle refer to the specific index's exogenous variables in the next to last trading session.

Furthermore, due to the fact that our study is set up in a round-the-clock perspective and the studied markets are not traded simultaneously (except for the previously discussed overlap) one could assume that a sort of time bias occurs, where the closest previously traded market has the largest influence on the currently trading market. Obviously this relationship should also hold for future events, as the currently trading market will, given ceteris paribus, have the most significant influence on the next traded market, rather than the succeeding traded market.

In our AR setting we always have two indices as exogenous variables. All else equal, due to the time bias we expect the coefficients of the closer, from a time perspective, to be relatively higher than the coefficients of the distant index. This, in combination with the overlap previously discussed, makes it hard for us to draw precise inference from our results when observing coefficients in absolute terms.

However, our setting of three subsets offer us the possibility to draw inference from changes between time periods and thus makes it possible to observe and also with great certainty draw conclusions about the overall trends. Our setting thus overcomes the problematic inference disturbance caused by the time bias.

In the case of the autocorrelations, executed with only the specific endogenous index in the model, we do not need to take into consideration any of the above mentioned time-zone adjustments.

4. RESULTS

In this *Section* we present the most valuable results. Complete results are available in the *Appendix Sections 8.1 (1988-2010), 8.2 (1988-1996), 8.3 (1996-2003) and 8.4 (2003-2010).*

4.1 Augmented Dickey-Fuller test results

Table 4.1 depicts the critical values employed by JMulTi (Davidson & MacKinnon, 1993).

Table 4.1: *ADF critical values*

Significance level	1%	5%	10%
Critical value	-3.43	-2.86	-2.57

Table 4.2 depicts the ADF test statistics on index levels.

Table 4.2: *ADF results on index levels*

Equity index (Variable)	S&P 500	EURO STOXX	Nikkei 225
Value of test statistics	-1.3592	-1.5000	-1.2611
Optimal no. lags (SC)	2	4	2

The results in *Tables 4.1 and 4.2* suggest that the null hypothesis of present unit roots cannot be rejected when using index levels. That is to say, all variables have unit roots and are nonstationary.

Table 4.3 depicts the ADF test statistics on the first difference.

Table 4.3: *ADF results on the first difference*

Equity index (Variable)	S&P 500	EURO STOXX	Nikkei 225
Value of test statistics	-58.9381	-47.9181	-57.1961
Optimal no. lags (SC)	1	2	1

The results in *Table 4.3* suggest that the null hypothesis of unit roots can be rejected when using the first difference of index levels. That is to say, all variables lack unit roots and are stationary. Thus, to enable consistent time series analysis we have performed our tests on the first difference of index levels, which provides us with a stationary time series.

4.2 Granger causality results

Granger causality p-values are displayed in the *Tables 4.4 to 4.7* (lags as suggested by the AIC). Parameters significant at the 5 % level are marked with asterisks.

Affected variable: S&P 500

Table 4.4: *Granger causality p-values (S&P 500 as affected variable)*

Causing variable	EURO STOXX	Nikkei 225
1988-2010	0.0001*	0.0008*
1988-1996	0.0026*	0.0206*
1996-2003	0.3007	0.1002
2003-2010	0.0000*	0.0001*

Affected variable: EURO STOXX

Table 4.5: *Granger causality p-values (EURO STOXX as affected variable)*

Causing variable	S&P 500 (Previous-date)	S&P (Same-date)	Nikkei 225
1988-2010	0.0188*	0.0000*	0.0002*
1988-1996	0.0657	0.0000*	0.0172*
1996-2003	0.2004	0.0000*	0.0011*
2003-2010	0.0000*	0.0000*	0.5200

Affected variable: Nikkei 225

Table 4.6: *Granger causality p-values (Nikkei 225 as affected variable)*

Causing variable	S&P 500	EURO STOXX
1988-2010	0.0333*	0.0095*
1988-1996	0.6032	0.0448*
1996-2003	0.2362	0.6205
2003-2010	0.2438	0.0012*

Model lags as suggested by the AIC

Table 4.7: *Model lags used in Granger causality test, as suggested by the AIC*

Causing variable	Affected variable	AIC lags 1988-2010	AIC lags 1988-1996	AIC lags 1996-2003	AIC lags 2003-2010
EURO STOXX (t)	S&P 500	7	1	3	8
Nikkei (t)	S&P 500	8	2	2	8
S&P 500 (t-1)	EURO STOXX	8	1	5	10
S&P 500 (t)	EURO STOXX	7	1	3	8
Nikkei (t)	EURO STOXX	5	1	1	6
S&P 500 (t-1)	Nikkei	4	2	1	9
EURO STOXX (t-1)	Nikkei	5	3	3	5

4.3 Transmission Effect results

Throughout the estimations we have chosen to use three exogenous lags for all regressions. Furthermore, the SC is used for model selection in terms of the number of endogenous lags. *Tables 4.8 to 4.16* depicts the coefficients and t-values included in the model. Only variables suggested by the SC were included. *Models 4.1 to 4.3* depicts the obtained estimated models.

Endogenous Variable: S&P 500

Coefficients

Table 4.8: *AR coefficients (S&P 500 as endogenous variable)*

Exogenous variables Lags	S&P 500 t-1	S&P 500 t-2	EURO STOXX t	Nikkei 225 t	EURO STOXX t-1	Nikkei 225 t-1	EURO STOXX t-2	Nikkei 225 t-2	EURO STOXX t-3	Nikkei 225 t-3
1988-2010	-0.308	-0.084	0.492		0.140					
1988-1996	-0.100		0.228	0.044						
1996-2003	-0.259	-0.088	0.435		0.124		0.041			
2003-2010	-0.521	-0.166	0.689		0.311					

T-Values

Table 4.9: *AR t-values (S&P 500 as endogenous variable)*

Exogenous variables Lags	S&P 500 t-1	S&P 500 t-2	EURO STOXX t	Nikkei 225 t	EURO STOXX t-1	Nikkei 225 t-1	EURO STOXX t-2	Nikkei 225 t-2	EURO STOXX t-3	Nikkei 225 t-3
1988-2010	-22.227	-6.997	47.561		11.625					
1988-1996	-4.384		10.779	3.496						
1996-2003	-10.388	-3.515	25.799		6.247		2.25			
2003-2010	-21.827	-8.846	39.153		13.648					

Giving us the following model for the entire period:

Model 4.1: *Estimated AR model for S&P 500, 1988-2010*

$$S\&P_t = -0.308\ S\&P_{t-1} - 0.084\ S\&P_{t-2} + 0.492\ EUROSTOXX_t + 0.140\ EUROSTOXX_{t-1}$$

Endogenous Variable: EURO STOXX (With previous-date S&P 500)

Coefficients

Table 4.10: *AR coefficients (EURO STOXX as endogenous variable, previous-date S&P 500 values)*

Exogenous variables	EURO STOXX	EURO STOXX	EURO STOXX	EURO STOXX	EURO STOXX	S&P 500	Nikkei 225	S&P 500	Nikkei 225	S&P 500	Nikkei 225	S&P 500	Nikkei 225
Lag	t-1	t-2	t-3	t-4	t-5	t	t	t-1	t-1	t-2	t-2	t-3	t-3
1988-2010	-0.27	-0.077	-0.071	0.036	-0.055	0.399	0.198	0.095		0.062			
1988-1996	-0.114					0.407	0.139						
1996-2003	-0.206		-0.068			0.464	0.172	0.098	-0.083				
2003-2010	-0.512	-0.2	-0.136			0.348	0.333	0.15	0.083	0.152		0.088	

T-Values

Table 4.11: *AR t-values (EURO STOXX as endogenous variable, previous-date S&P 500 values)*

Exogenous variables	EURO STOXX	EURO STOXX	EURO STOXX	EURO STOXX	EURO STOXX	S&P 500	Nikkei 225	S&P 500	Nikkei 225	S&P 500	Nikkei 225	S&P 500	Nikkei 225
Lag	t-1	t-2	t-3	t-4	t-5	t	t	t-1	t-1	t-2	t-2	t-3	t-3
1988-2010	-17.77	-4.985	-5.086	3.056	-4.575	23.63	17.213	5.294		3.602			
1988-1996	-5.785					18.48	11.1						
1996-2003	-7.748		-3.146			14.232	6.977	3.22	-3.367				
2003-2010	-16.488	-6.055	-4.567			11.003	15.047	4.146	3.557	4.49		3.702	

Endogenous Variable: EURO STOXX (With same-date S&P 500)

Coefficients

Table 4.12: *AR coefficients (EURO STOXX as endogenous variable, same-date S&P 500 values)*

Exogenous variables	EURO STOXX	EURO STOXX	EURO STOXX	EURO STOXX	EURO STOXX	S&P 500	Nikkei 225	S&P 500	Nikkei 225	S&P 500	Nikkei 225	S&P 500	Nikkei 225
Lag	t-1	t-2	t-3	t-4	t-5	t	t	t-1	t-1	t-2	t-2	t-3	t-3
1988-2010	-0.276	-0.067	-0.061		-0.034	0.548	0.132	0.466		0.121		0.052	
1988-1996	-0.113					0.223	0.122	0.409					
1996-2003	-0.253	-0.115	-0.090			0.600	0.121	0.512		0.168		0.105	
2003-2010	-0.462	-0.073	-0.049			0.618	0.182	0.521		0.177		0.036	

T-Values

Table 4.13: *AR t-values (EURO STOXX as endogenous variable, same-date S&P 500 values)*

Exogenous variables	EURO STOXX	EURO STOXX	EURO STOXX	EURO STOXX	EURO STOXX	S&P 500	Nikkei 225	S&P 500	Nikkei 225	S&P 500	Nikkei 225	S&P 500	Nikkei 225
Lag	t-1	t-2	t-3	t-4	t-5	t	t	t-1	t-1	t-2	t-2	t-3	t-3
1988-2010	-21.227	-5.064	-5.085		-3.360	45.993	13.281	32.019		7.898		3.519	
1988-1996	-5.847					10.814	9.942	19.091					
1996-2003	-10.853	-4.892	-4.172			25.351	5.708	18.156		5.584		3.573	
2003-2010	-20.541	-3.612	-2.971			36.87	10.787	21.628		7.562		2.465	

Endogenous Variable: EURO STOXX (With weighted S&P 500)

Coefficients

Table 4.14: *AR coefficients (EURO STOXX as endogenous variable, weighted S&P 500 values)*

Exogenous variables	EURO STOXX	EURO STOXX	EURO STOXX	EURO STOXX	EURO STOXX	S&P 500	S&P 500	S&P 500	S&P 500
Lag	t-1	t-2	t-3	t-4	t-5	t	t-1	t-2	t-3
1988-2010	-0.271	-0.075	-0.069	0.036	-0.050	0.434	0.182	0.076	0.052
1988-1996	-0.114					0.364	0.409		
1996-2003	-0.217	-0.115	-0.073			0.496	0.195	0.168	0.105
3003-2010	-0.500	-0.170	-0.116			0.412	0.237	0.158	0.076

The weighted model for the entire period (using weighted S&P coefficients):

Model 4.2: *Estimated AR model for EURO STOXX with weighted S&P 500 values, 1988-2010*

$$\text{EUROSTOXX}_t = -0.271\ \text{EUROSTOXX}_{t-1} - 0.075\ \text{EUROSTOXX}_{t-2} - 0.069\ \text{EUROSTOXX}_{t-3} + 0.036\ \text{EUROSTOXX}_{t-4} - 0.050\ \text{EUROSTOXX}_{t-5} + 0.434\ \text{S\&P}_t + 0.198\ \text{Nikkei}_t + 0.182\ \text{S\&P}_{t-1} + 0.076\ \text{S\&P}_{t-2} + 0.052\ \text{S\&P}_{t-3}$$

Endogenous Variable: Nikkei 225

Coefficients

Table 4.15: *AR coefficients (Nikkei 225 as endogenous variable)*

Exogenous variables	Nikkei 225	Nikkei 225	S&P 500	EURO STOXX	S&P 500	EURO STOXX	S&P 500	EURO STOXX	S&P 500	EURO STOXX
Lags	t-1	t-2	t	t	t-1	t-1	t-2	t-2	t-3	t-3
1988-2010	-0.1	-0.035	0.409	0.193						
1988-1996			0.343	0.121						0.117
1996-2003	-0.132		0.309	0.162						
2003-2010	-0.232	-0.111	0.579	0.233	0.213		0.127			

T-Values

Table 4.16: *AR t-values (Nikkei 225 as endogenous variable)*

Exogenous variables	Nikkei 225	Nikkei 225	S&P 500	EURO STOXX	S&P 500	EURO STOXX	S&P 500	EURO STOXX	S&P 500	EURO STOXX
Lags	t-1	t-2	t	t	t-1	t-1	t-2	t-2	t-3	t-3
1988-2010	-8.013	-2.955	23.259	12.137						
1988-1996			9.263	3.571						3.571
1996-2003	-5.903		10.468	6.814						
2003-2010	-9.756	-4.753	19.728	8.033	7.067		4.528			

Giving us the following model for the entire period:

Model 4.3: *Estimated AR model for Nikkei 225, 1988-2010*

$$\text{Nikkei}_t = -0.1\ \text{Nikkei}_{t-1} - 0.035\ \text{Nikkei}_{t-2} + 0.409\ \text{S\&P}_t + 0.193\ \text{EUROSTOXX}_t$$

4.4 Autocorrelation results, AR(12)

The autocorrelations were calculated separately for each index and with 12 lags. The SC was employed to exclude non-significant lags. Variables selected in the model with regards to the SC are marked with asterisks. The autocorrelation results are presented in *Tables 4.17 to 4.22, Models 4.4 to 4.6* and *Figures 4.1 to 4.3*.

S&P 500

Table 4.17: *S&P 500 autoregressive coefficients (12 lags)*

Lag	t-1	t-2	t-3	t-4	t-5	t-6	t-7	t-8	t-9	t-10	t-11	t-12
1988-2010	-0.058*	-0.056*	0.001	-0.017	-0.018	-0.024	-0.040*	0.02	-0.010	0.027	-0.009	0.004
1988-1996	0.022	-0.015	-0.036	-0.03	0.009	-0.055	-0.045	-0.016	0.012	0.001	-0.023	0.049
1996-2003	-0.012	-0.024	-0.042	-0.015	-0.023	-0.023	-0.038	0.003	0.000	0.030	-0.039	0.024
2003-2010	-0.133*	-0.103*	0.042	-0.002	-0.016	-0.014	-0.039	0.051	-0.015	0.035	0.013	-0.025

Table 4.18: *S&P 500 autoregressive t-values (12 lags)*

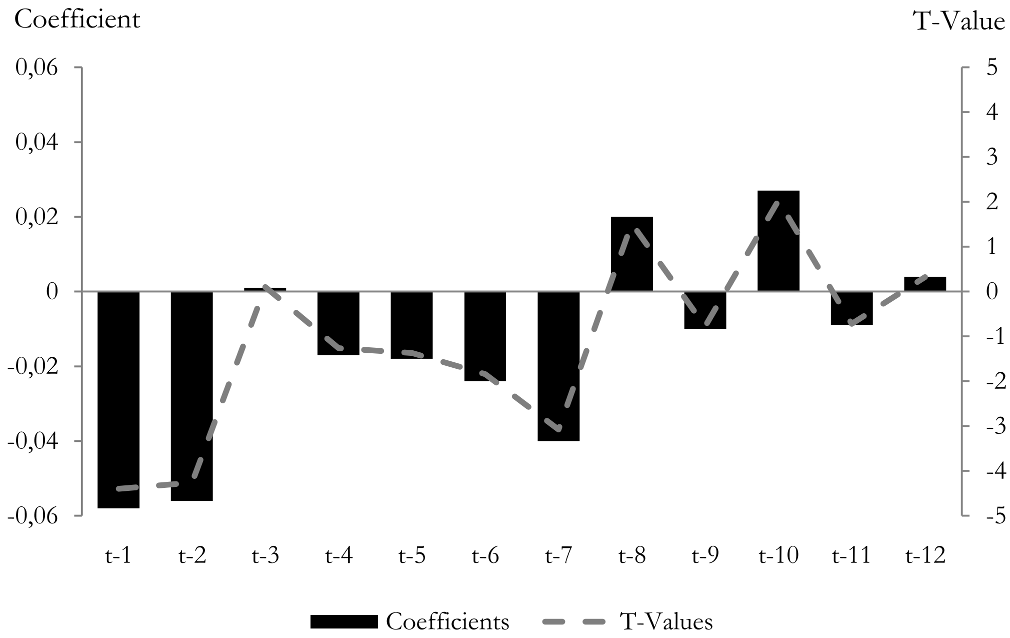
Lag	t-1	t-2	t-3	t-4	t-5	t-6	t-7	t-8	t-9	t-10	t-11	t-12
1988-2010	-4.398	-4.260	0.104	-1.264	-1.370	-1.838	-3.075	1.518	-0.775	2.032	-0.722	0.322
1988-1996	1.039	-0.698	-1.657	-1.414	0.433	-2.550	-2.069	-0.732	0.580	0.044	-1.096	2.331
1996-2003	-0.504	-1.026	-1.793	-0.640	-0.993	-0.967	-1.592	0.106	0.002	1.273	-1.622	1.010
2003-2010	-5.643	-4.341	1.771	-0.087	-0.666	-0.592	-1.645	2.133	-0.650	1.476	0.568	-1.071

Giving the following estimated model with regards to autocorrelations:

Model 4.4: *S&P 500 autoregressive coefficients (12 lags employed), 1988-2010*

$$S\&P_t = -0.058\ S\&P_{t-1} - 0.056\ S\&P_{t-2} - 0.040\ S\&P_{t-7}$$

Figure 4.1: *Autoregressive coefficients and t-values for S&P 500 (12 lags), 1988-2010*



EURO STOXX

Table 4.19: *EURO STOXX autoregressive coefficients (12 lags)*

Lag	t-1	t-2	t-3	t-4	t-5	t-6	t-7	t-8	t-9	t-10	t-11	t-12
1988-2010	-0.017	-0.028	-0.058*	0.044*	-0.045*	-0.024	-0.010	0.033	-0.011	0.014	0.009	0.000
1988-1996	-0.001	0.017	-0.015	0.033	-0.022	-0.015	0.011	-0.008	-0.004	0.032	0.003	0.035
1996-2003	0.014	-0.030	-0.060	0.012	-0.044	-0.052	-0.020	0.059	0.010	0.003	0.004	-0.020
2003-2010	-0.068*	-0.048	-0.070*	0.089*	-0.043	0.007	-0.004	0.010	-0.049	0.008	0.014	0.009

Table 4.20: *EURO STOXX autoregressive t-values (12 lags)*

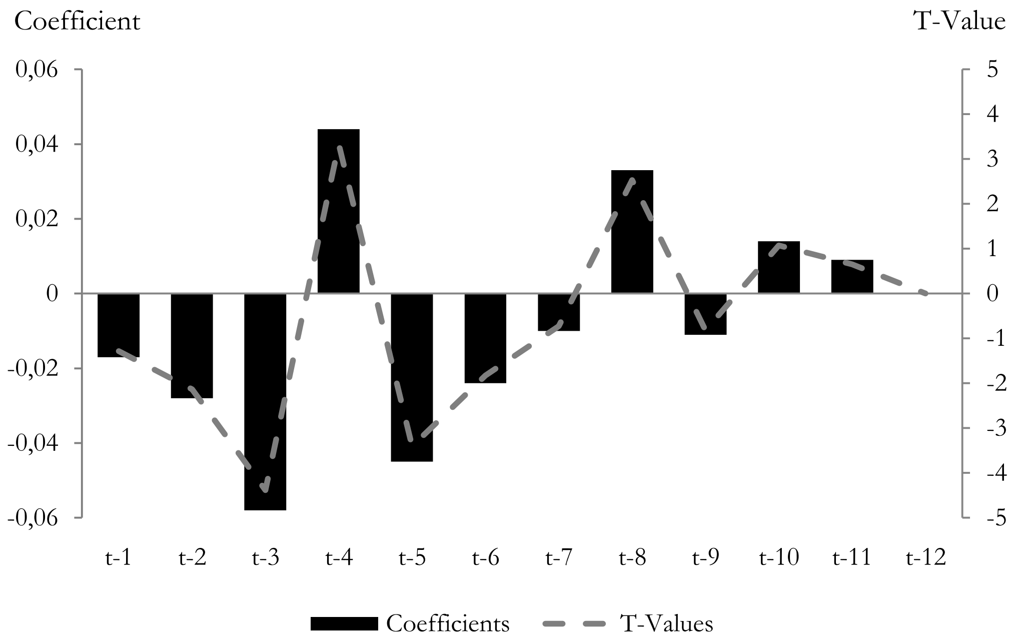
Lag	t-1	t-2	t-3	t-4	t-5	t-6	t-7	t-8	t-9	t-10	t-11	t-12
1988-2010	-1.286	-2.136	-4.38	3.331	-3.403	-1.825	-0.729	2.529	-0.816	1.072	0.651	0.005
1988-1996	-0.028	0.776	-0.690	1.519	-1.038	-0.704	0.521	-0.390	-0.203	1.486	0.151	1.654
1996-2003	0.603	-1.268	-2.527	0.514	-1.859	-2.216	-0.853	2.499	0.401	0.128	0.189	-0.858
2003-2010	-2.876	-2.042	-2.987	3.781	-1.799	0.284	-0.149	0.432	-2.076	0.333	0.608	0.396

Giving the following estimated model with regards to autocorrelations:

Model 4.5: *EURO STOXX autoregressive coefficients (12 lags employed), 1988-2010*

$$EUROSTOXX_t = -0.058\ EUROSTOXX_{t-3} + 0.044\ EUROSTOXX_{t-4} - 0.045\ EUROSTOXX_{t-5}$$

Figure 4.2: *Autoregressive coefficients and t-values for EURO STOXX (12 lags), 1988-2010*



Nikkei 225

Table 4.21: *Nikkei 225 autoregressive coefficients (12 lags)*

Lag	t-1	t-2	t-3	t-4	t-5	t-6	t-7	t-8	t-9	t-10	t-11	t-12
1988-2010	-0.019	-0.057*	-0.018	0.016	0.000	-0.023	-0.006	0.002	0.012	0.015	0.025	0.021
1988-1996	0.023	-0.061*	0.004	0.023	-0.029	-0.010	-0.013	0.025	0.067	0.044	0.010	-0.006
1996-2003	-0.068*	-0.044	-0.008	-0.017	0.002	-0.042	0.002	0.006	0.010	-0.025	0.014	0.008
2003-2010	-0.011	-0.064	-0.042	0.041	0.018	-0.018	-0.014	0.021	-0.038	0.016	0.04	0.052

Table 4.22: *Nikkei 225 autoregressive t-values (12 lags)*

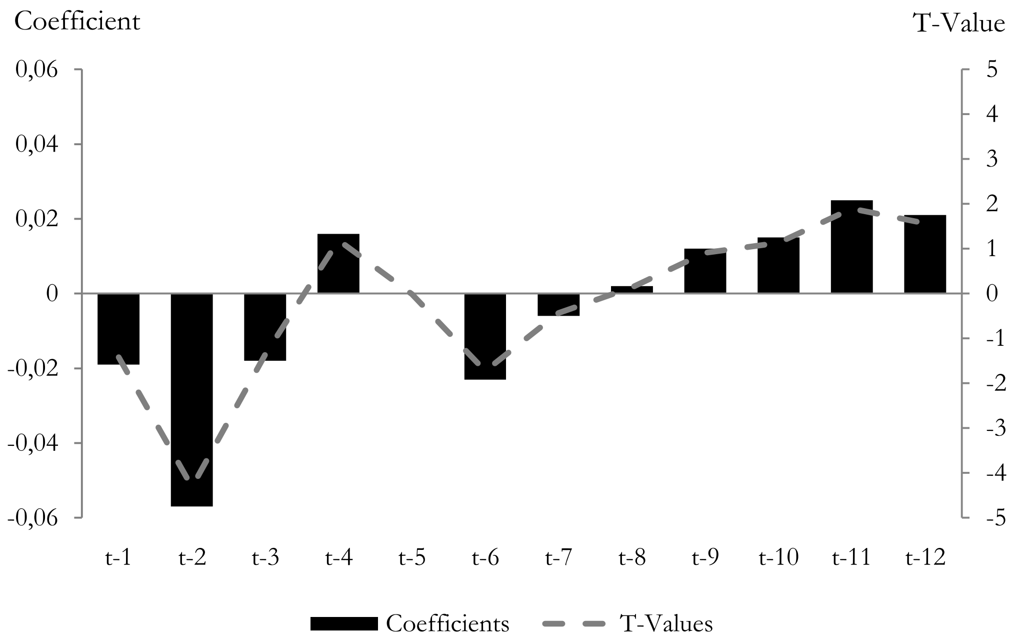
Lag	t-1	t-2	t-3	t-4	t-5	t-6	t-7	t-8	t-9	t-10	t-11	t-12
1988-2010	-1.416	-4.31	-1.354	1.187	-0.012	-1.727	-0.43	0.139	0.913	1.129	1.893	1.566
1988-1996	1.063	-2.837	0.199	1.086	-1.328	-0.479	-0.607	1.164	3.115	2.028	0.454	-0.297
1996-2003	-2.892	-1.868	-0.342	-0.707	0.074	-1.763	0.074	0.243	0.439	-1.036	0.585	0.338
2003-2010	-0.486	-2.741	-1.778	1.732	0.777	-0.747	-0.575	-0.911	-1.61	0.679	1.687	2.219

Giving the following estimated model with regards to autocorrelations:

Model 4.6: *Nikkei autoregressive coefficients (12 lags employed), 1988-2010*

$$\text{Nikkei}_t = -0.057\ \text{Nikkei}_{t-2}$$

Figure 4.3: *Autoregressive coefficients and t-values for Nikkei 225 (12 lags), 1988-2010*



4.5 Ljung-Box results

The Ljung-Box findings are presented in *Tables 4.23 to 4.28*.

S&P 500

An estimated p-value<0.05 implies serial correlation and is marked with an asterisks.

Table 4.23: *Ljung-Box test results for S&P*

Lags	1	2	3	4	5	6	7
1988-2010	0.0001	0.0028	0.0964	1.1706	3.4076	6.2086	14.3398
1988-1996	0.2859	0.4419	5.0059	6.0625	6.1386	11.7218	15.3700
1996-2003	0.2152	0.9813	4.0366	4.2369	5.0211	5.7272	8.1358
2003-2010	0.0386	0.0846	3.0722	3.3020	3.7727	3.9606	6.0608

Table 4.24: *Ljung-Box test p-values (Chi^2) for S&P*

Lags	1	2	3	4	5	6	7
1988-2010	-1.0000*	-1.0000*	1.0000	0.2793	0.1820	0.1019	0.0063*
1988-1996	-1.0000*	0.5062	0.0818	0.1086	0.1890	0.0388*	0.0176*
1996-2003	-1.0000*	0.3219	0.1329	0.2370	0.2851	0.3337	0.2283
2003-2010	-1.0000*	-1.0000*	-1.0000*	0.0692	0.1516	0.2657	0.1947

EURO STOXX

An estimated p-value<0.05 implies serial correlation and is marked with an asterisks.

Table 4.25: *Ljung-Box test results for EURO STOXX*

Lags	1	2	3	4	5	6	7
1988-2010	0.0081	0.0108	0.0138	0.0725	0.1062	3.3287	3.7379
1988-1996	0.0015	0.7407	1.6024	2.6514	4.2996	4.5230	4.8866
1996-2003	0.5431	2.3497	8.8094	9.0803	12.4888	17.5966	18.2673
2003-2010	0.0137	0.0407	0.4346	2.0846	2.1667	3.2138	3.8201

Table 4.26: *Ljung-Box test p-values (Chi^2) for EURO STOXX*

Lags	1	2	3	4	5	6	7
1988-2010	-1.0000*	-1.0000*	-1.0000*	-1.0000*	-1.0000*	-1.0000*	0.0532
1988-1996	-1.0000*	0.3894	0.4488	0.4485	0.3670	0.4768	0.5584
1996-2003	-1.0000*	0.1253	0.0122*	0.0282*	0.0141*	0.0035*	0.0056
2003-2010	-1.0000*	-1.0000*	-1.0000*	-1.0000*	-1.0000*	0.0730	0.1481

Nikkei 225

An estimated p-value<0.05 implies serial correlation and is marked with an asterisks.

Table 4.27: *Ljung-Box test results for Nikkei 225*

Lags	1	2	3	4	5	6	7
1988-2010	0.0059	0.0096	1.9407	3.3584	3.3591	6.5067	6.6782
1988-1996	1.5997	9.3447	9.3523	10.6720	12.4586	12.8969	13.2373
1996-2003	0.0139	2.7187	2.7708	3.0296	3.0409	6.1177	6.1509
2003-2010	0.0718	9.2116	12.7477	16.4043	17.2371	17.9002	18.2485

Table 4.28: *Ljung-Box test p-values (Chi^2) for Nikkei* 225

Lags	1	2	3	4	5	6	7
1988-2010	-1.0000*	-1.0000*	-1.0000*	0.0669	0.1865	0.0894	0.1539
1988-1996	-1.0000*	0.0022*	0.0093*	0.0136*	0.0142*	0.0244*	0.0394*
1996-2003	-1.0000*	-1.0000*	0.0960	0.2199	0.3854	0.1905	0.2918
2003-2010	-1.0000*	0.0024*	0.0017*	0.0009*	0.0017*	0.0030*	0.0056*

5. DISCUSSING THE RESULTS

5.1 Discussing the Granger causality results

The Granger causality results presented in *Tables 4.4 to 4.6* indicates whether or not causalities have been established, by using the 0.05 threshold for p-values. The results are summarized in *Table 5.1*. √ denotes that causality has been established with significance at the 5 % level and the column labelling X ► Y indicates the causality X has on Y.

Table 5.1: *Summarised Granger causality test results*

Causality matrix	JPN ► EU	JPN ► U.S.	EU ► U.S.	EU ► JPN	U.S. ► JPN	U.S. ► EU
1988-2010	√	√	√	√	√	√
1988-1996	√	√	√	√		
1996-2003	√					
2003-2010		√	√	√		√

These results clearly indicate that causality runs across all three equity markets and in all direction for the full dataset ranging from 1988 till 2010. These findings press the relevance of studying these relationships further, as causality has been established.

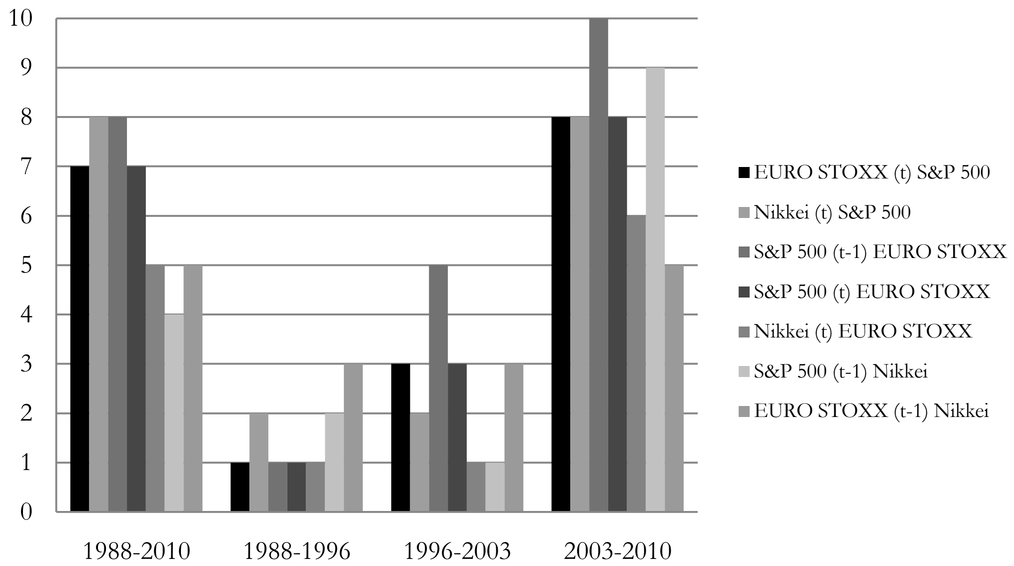
However, the results from the three subsets are more inconsistent and seem to suggest more decoupled scenarios, as causality gaps emerge. The 1988-1996 subset results suggest that causality runs to all markets from both the Eurozone and Japan. The 1996-2003 subset results show a period of low levels of causality across the markets, where the only statistically significant causality runs from Japan to the Eurozone. The results from the last period, being the 2003-2010 subset, suggest stronger feedbacks and again recognizes the Eurozone as a causing region, but also the U.S. on the Eurozone and Japan on the U.S.

We find it economically sound and reasonable that the Eurozone and Japan are causing regions in our setting. However, we do find that the subset results are somewhat baffling in the sense that they suggest that the U.S. is not to be seen as a causing region in most of the subsets.

The discrepancies from what seems economically reasonable can be ascribed to several factors. Perhaps most importantly the lag selection methods and criteria, previously discussed in *Section 3.4,* are sensitive issues when using the Granger causality test since they affect the outcome gravely. In our study we chose to implement the AIC for lag selection.

When implementing the AIC we found that the lag specifications vary immensely across our subsets. The two first subsets (1988-1996 and 1996-2003) seem to suggest very few lags in comparison to the last subset (2003-2010) and the full dataset. Especially the first subset suggests very few lags. *Figure 5.1* depicts the lag selection results when using the AIC.

Figure 5.1: *AIC lags for the Granger causality test*



Potentially the models have been under parameterised in the earlier subsets and over parameterized in the last subset, where AIC suggests more lags than in the full dataset. We attribute this possible misspecification and the evident inconsistent results from the Granger causality test to two major factors, namely that there is a good chance that the subsets are to gravely affected by the specific economic climates of the respective period and the simple fact that the full dataset enjoys the benefits of the law of large numbers, and thus offer better opportunities to find significant results. The fact that the test finds U.S. causality on Japan in the entire period, but not in any of the underlying, further highlights that the result divergences could be attributed to sample sizes and not to a de facto lack of causality. According to the law of large numbers, the average of the results obtained from a larger number of observations should be closer to the expected value, and will tend to move closer as the number of observations increase (Grimmett & Stirzaker, 1992).

During the period of the 1988-1996 subset the aftermath of the 1987 financial crisis played out and there was a period of relative calm and gradual recovery in the world economy, possibly causing the short lag lengths selected. This period was also largely impacted by the creation of the European Union in 1993. This rise of a unified major economy may well explain why the Eurozone is suggested to be the causing region of this time period – driven by the optimism of future opportunities in this economy.

When evaluating the causality relationships between Japan and the U.S. we also evaluated earlier studies made on the topic. In 1991 Shiller et al. studied the investor behaviour during the October 1987 stock market crash from a Japanese perspective. However, they used a more qualitative approach to the study than ours, by surveying Japanese institutional investors to recall what they thought and did during the worldwide stock market crash in October 1987. They confirm that the drop in U.S. stock prices was the primary factor on their minds, and news stories in the U.S. dominated domestic ones. We believe that the U.S. contagion would still be present in the period post-1987 as news from the U.S. would still have a significant impact on the mindset of Japanese investors. This leads us to suspect that the missing causality from the U.S. on the Japanese market in the 1988-1996 subset could be attributed to statistical effects rather than actual lack of causality. Other studies have also confirmed the contagion present during the October 1987 crash, for instance a study by King & Wadhwasi (1990).

During the period of the 1996-2003 subset several interesting and by all means major events took place in the world economy. From 1995 to 2002 the prelude, rise and fall of the dot-com bubble took place. Also, the sudden, but shocking Asian financial crisis unfolded between 1997 and 1998, possibly directly causing the biased results that suggest only one established causality, namely the one running from Japan to the Eurozone.

A paper by Yang et al. (2003) studies the long-run relationships and short-run dynamic causal linkages among the U.S., Japanese, and other Asian emerging stock markets, focusing on the 1997 till 1998 Asian financial crisis. Their results show that the causal linkages and integration between the markets increase during periods marked by financial crises, such as that of 1997 till 1998.

According to Nobel & Ravenhill (2000) the World Trade Organization blamed the Asian crisis for the substantial slowing of trade growth in 1998 - down from 10 percent in 1997 to 3.5 percent in 1998. This demonstrates the severity of the period.

The final subset representing the period between 2003 and 2010 has of course also been a period of major events. Since 2007 up until when this thesis is written, in May 2010, the world has gone through an unprecedented financial turmoil, which has sent its shockwaves throughout the global markets causing periods of sheer panic. During this period global transmission effects has become strikingly evident, even for average Joe. The shocks of the period has in themselves proven that causality in practice runs right across the globe with the 2008 Lehman Brothers bankruptcy in the U.S. and the 2010 severe default concerns of sovereign debt in Greece and the troublesome financials of the peripheral countries in Europe, sending lightning jolts across the globe. Longin & Solnik (2002) highlighted the fact that the correlations between international equity markets increase in bear markets and decreases in bull markets. This could, in combination with the increased globalisation, be the primary factors to the stronger causalities seen during the period. *Comment: As of May 2010 the sovereign debt concerns in Europe are still far from resolved and the story still unfolds.*

In light of the preceding discussion we feel confident in moving on by discussing transmission effect and autocorrelation results for all periods, with the notion that the Granger causality results for the full dataset proved that significant causalities run across all markets and in all directions.

5.2 Discussing the transmission effect results

The AR results presented in *Tables 4.8 to 4.16* and *Models 4.1 to 4.3* indicates how markets affect each other. We have adjusted the time-zone setting according to the methodology previously described in *Section 3.7* and performed the tests with the three different settings for the S&P 500's influence on the EURO STOXX. That is, data for the previous, the same day and our weighted coefficients. All of these are presented to illustrate the S&P 500's influence on the EURO STOXX. However, all other coefficients are based on the previous trading sessions of the respective indices.

The transmission effect results for the full period dataset are summarized in *Tables 5.2 and 5.3*. The rows contain the specific endogenous variables and the columns contain the corresponding exogenous variables. We have excluded the endogenous lags, since these are instead based on the AR(12) discussed further in *Section 5.3*.

Table 5.2: *First cycle time-zone adjusted significant coefficients, 1988-2010 (cross-coefficients lag 1)*

↓ Endogenous variables	S&P 500 (Previous)	S&P 500 (Same)	S&P 500 (Weighted)	EURO STOXX	Nikkei 225
S&P500	-	-	-	0.49	Insignificant
EURO STOXX	0.40	0.55	0.43	-	0.20
Nikkei 225	0.41	-	-	0.19	-

Table 5.3: *Second cycle time-zone adjusted significant coefficients, 1988-2010 (cross-coefficients lag 2)*

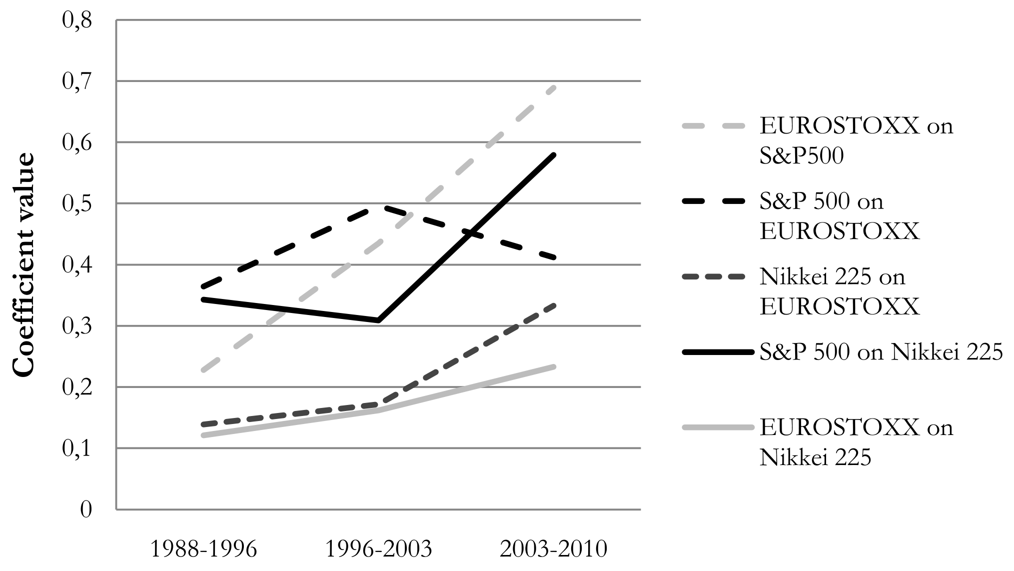
↓ Endogenous variables	S&P 500 (Previous)	S&P 500 (Same)	S&P 500 (Weighted)	EURO STOXX	Nikkei 225
S&P500	-	-	-	0.14	Insignificant
EURO STOXX	0.10	0.47	0.18	-	0.06
Nikkei 225	Insignificant	-	-	Insignificant	-

For the full dataset a couple of major relationships appear from the AR model results. It is evident that the U.S. and the Eurozone are the most influential in the setting, presenting significant coefficients across all markets in the first cycle and obvious effects on each other in the second cycle. However, it is not entirely clear which of the U.S. and the Eurozone is the most prominent with regards to its transmission effects. The coefficient for EURO STOXX influence on S&P 500 in the first cycle is 0.49, while the S&P 500 influence on EURO STOXX ranges from 0.40 to 0.55 in our three different settings and our weighted coefficient, which we previously described the reasoning behind in *Section 3.7*, is 0.43.

Furthermore, it is evident that the Japanese market is the weakest in the crowd. It does not show any significant influence on the U.S. market in either of the cycles and relatively weak coefficients of 0.20 and 0.06 of influence on the Eurozone. The weakness of the Japanese market is further amplified by the fact that both the U.S. and the Eurozone seem to inflict greater influence on the Japanese market. The coefficient of S&P 500 on Nikkei 225 is 0.41 in the first cycle, compared to 0.19 for EURO STOXX. However, none of the U.S. and the Eurozone shows any significant second cycle lag effects on the Japanese market.

The most significant transmission effect results from our three subsets are summarized in *Figure 5.2*. Please note that in this summary we have chosen to exclusively present the weighted S&P 500 coefficients for the EURO STOXX setting. Also note that the influence of Nikkei 225 on S&P 500 was deemed insignificant by the SC during the 1996-2003 and 2003-2010 periods, and has hence been excluded from the figure.

Figure 5.2: *First cycle coefficient trends (cross-coefficient lag 1 – trends)*



From the subset transmission effect results we can draw some new interesting inference, of which the most significant are:

- The trend is clearly upward sloping – indicating increasing coefficients and thus increasing transmission effects.
- The influence of the Eurozone increase over time.
- The influence of the U.S. on the Eurozone increase from 1988-1996 to 1996-2003, but decrease in the 2003-2010 subset. The inverted results occur for its influence on Japan.
- The influence Japan has on the Eurozone increases over time, but its influence on the U.S. remains weak in all periods.

In light of the facts that we consider that causalities are proven among the studied markets, our AR results are of great economic interest since they open up for some rather interesting discussions regarding the economics behind these relationships. However, it would be unwise not to first consider the inevitable overlap of trading hours and expected time bias previously discussed in *Section 3.7*.

Regarding the weighted coefficients we feel more confident about our weighted measure than looking exclusively at results from previous trading session data, since it should enable a better approximation of the actual coefficients. *Figure 5.3* depicts a comparison between using the weighted and the previous trading session data for the U.S. influence on the Eurozone.

Figure 5.3: *First cycle coefficient trends (cross-coefficients lag 1 – trends)*

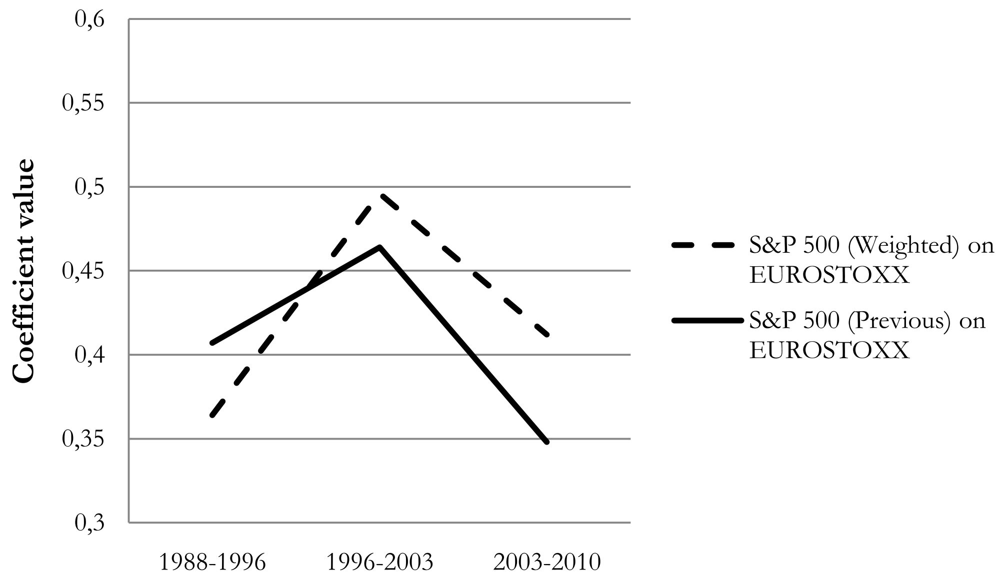


Figure 5.2 also implies that it's not a clear cut case which of these datasets offers the best approximation. However, it is clear that the trends are similar and that the differences are not of any sizable magnitude. A possible solution and suggestion for further studies is to use a dataset compiled by 14:30 GMT quotes or similar to adjust for the overlap. This could also be studied closely by looking at an intraday setting, similarly to the one applied by Harju & Mujahid (2006).

Furthermore, given the previously mentioned time bias, the results regarding the Japanese market does not to surprisingly suggest that Japan does not influence the U.S. market, even though it does influence the Eurozone. Similarly the U.S. influence on Japan is strong, but the Eurozone's influence on Japan is limited. This also match the observations presented earlier showing that the Eurozone's influence on the U.S. is reported to be higher than the inverted relationship. These specific observations enlighten and imply the potential presence of the time bias influence.

However, since our subset results enable us to study the relative changes in coefficients rather than the coefficients in absolute terms, we are able to draw significant inference from them and compare the trends of the influence across regions.

Our AR results have in effect statistically proven that there are major transmission effects among world markets and that they are constantly changing and currently in an increasing trend. The fact that we have established proof for increasing transmissions between the studied economies indicates that the international diversification benefits within major economies are declining. The economics and reasoning behind these results can of course be attributed to several factors. However, it is pretty clear that the ever more globalised world economy is the biggest contributor to the increasing interdependence distinctly evident in *Figure 5.2*.

Our results also imply an increasing importance of the Eurozone in the world economy, with increasing coefficients in all possible cases, ranging as high as 0.69 on the U.S. market and 0.23 on the Japanese market for the 2003-2010 subset. The corresponding figures in *Table 5.1*, showing the coefficients for the full dataset, are 0.50 and 0.19 respectively.

The increase of the Eurozone's influence should be put in contrast to the seemingly relatively decreasing or stagnated importance of the U.S., which coefficients of influence on the Eurozone is 0.36 in the 1988-1996 subset, increases to 0.50 in the second subset, only to decrease to 0.41 in the last subset. However, the U.S. does show a sharp increase of influence on Japan in the last subset ending up with 0.58, which is substantially higher than the corresponding Eurozone figure. The figures for the U.S. influence on the Eurozone and Japan in *Table 5.1,* showing the coefficients for the full dataset, are 0.43 and 0.41 respectively.

The fact that the Eurozone regardless of time bias effects, has strengthened its effects on the world economy, alongside with the indication that the U.S.'s relative position has weakened in favour of the Eurozone is perhaps one of our most interesting findings. One of the most plausible reasons behind the increasing importance of the Eurozone is the fast and seemingly effective development of the European Union during the 1990's and the gradual implementation of the EMU starting in 1995.

The integration process of European equity markets and the effect the EMU has had on its processes was presented in a study by the European Central Banker Marcel Fratzscher (2002). The study concludes three key results: First, European equity markets have become highly integrated only since 1996. Second, the Eurozone market has gained considerably in importance in world financial markets and has passed the U.S. as the most dominant force for markets of individual countries in the Eurozone. Third, the integration of European equity markets is in large part explained by the drive towards EMU, and in particular the elimination of exchange rate volatility and uncertainty in the process of monetary unification. These findings certainly support the ones in our study further.

Similar findings were made by Baele (2003) who studied the time-varying nature of EU and U.S. volatility spill-overs on local European equity markets during the 1980's and 1990's. He concluded that while both the EU and U.S. shock spill-over intensity has increased over the period, the rise was more prominent for EU spill-overs. Increased trade integration, equity market development, and low inflation where shown to have contributed to the increase in EU shock spill-over intensity during the period. The study also highlights the increased contagion effects during periods of high world market volatility.

The development of the European Union is a very firm sign of the increasing globalisation of the world, which inevitably also leads to more co-integrated equity markets. Further proof of the ever more increasing transmission effects can be related to the macroeconomic events presented in *Section 5.1*, which definitely and in an easy to grasp setting suggest that markets are increasingly linked together in more complex multilateral connections, where for instance U.S. subprime mortgages ran European banks close to bankruptcy during the financial crisis in 2008-2009.

5.3 Discussing the Autocorrelation results

The most significant autoregressive results from the AR(12) presented in *Tables 4.17 to 4.22* and *Figures 4.1 to 4.3* can be summarized as in *Figures 5.3 to 5.5*. The number of lags chosen in the summary of the autoregressive results is based on the Ljung-Box findings presented in *Tables 4.23 to 4.28*. The Ljung-Box results for the full dataset indicate that the Eurozone has a lag memory of six periods. This memory effect is the longest one observed among the three markets and will henceforth constitute the limit for the number of lag periods which we discuss.

Please note that we do not take any notice of the autocorrelation results provided by the AR focusing on transmission effects, since the autocorrelation coefficients included merely fulfil the parameterisation suggested by the SC to provide an intact estimation, rather than capturing the true autoregressive effects of the endogenous variables. Also note that all lags, regardless of significance are included in *Figures 5.4 to 5.6*.

Figure 5.4: *Autoregressive coefficients – S&P 500*

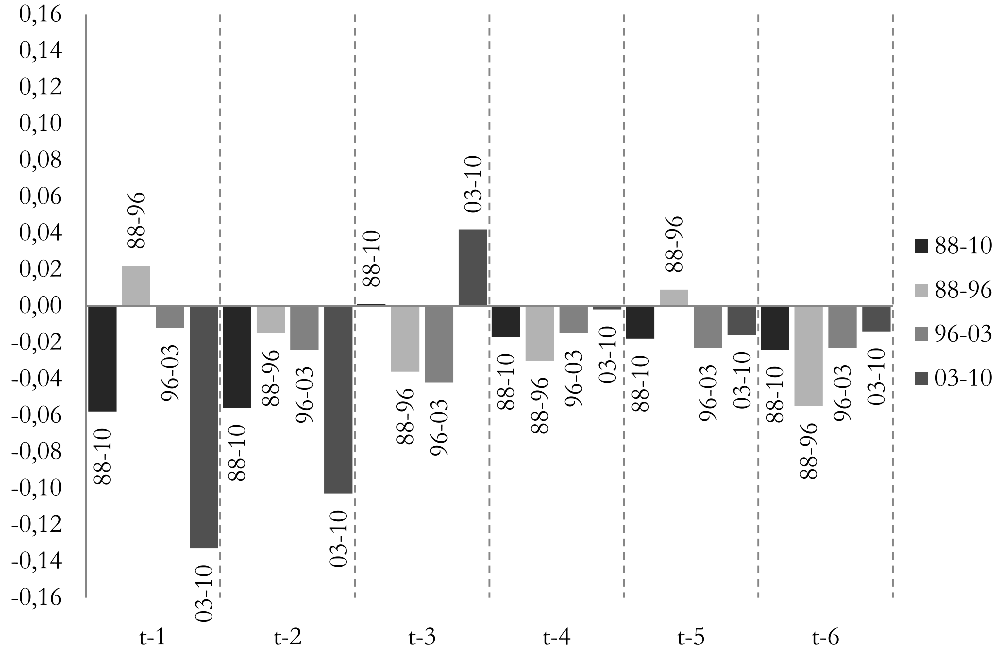


Figure 5.5: *Autoregressive coefficients – EURO STOXX*

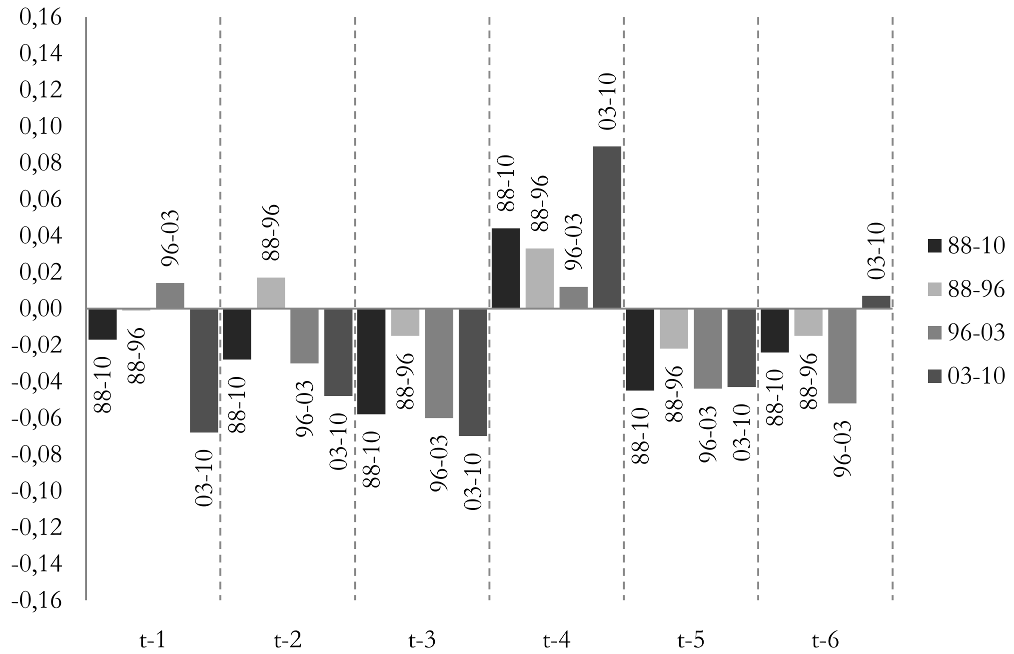
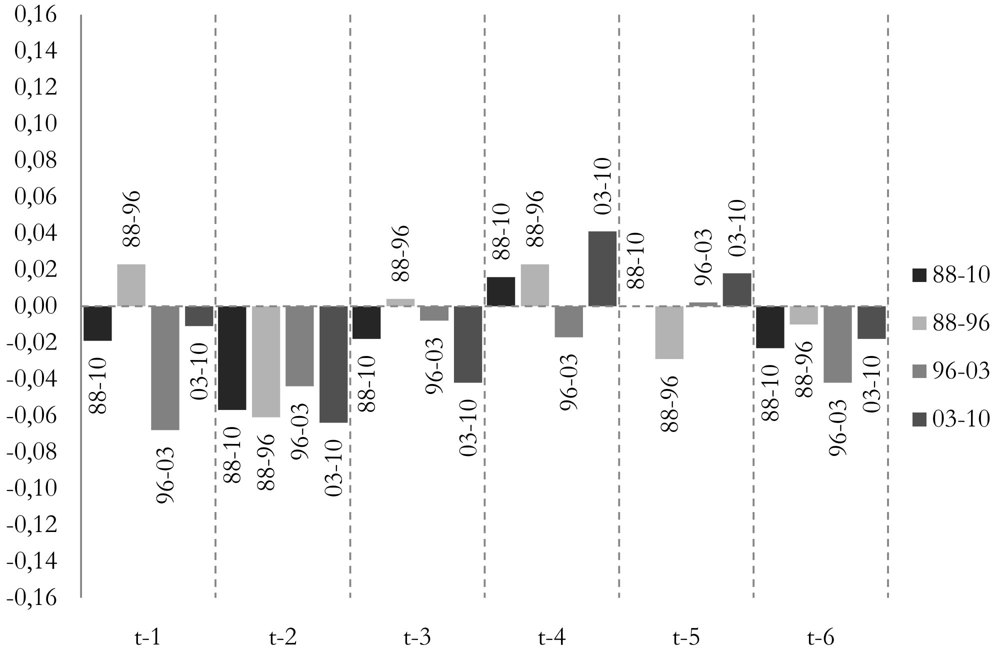


Figure 5.6: *Autoregressive coefficients – Nikkei 225*



To enhance the significance of this overview, we also present the corresponding graphics when including only significant lags. The significant autocorrelation lags are depicted in *Figures 5.7 to 5.9*.

Figure 5.7: *Significant autoregressive coefficients – S&P 500*

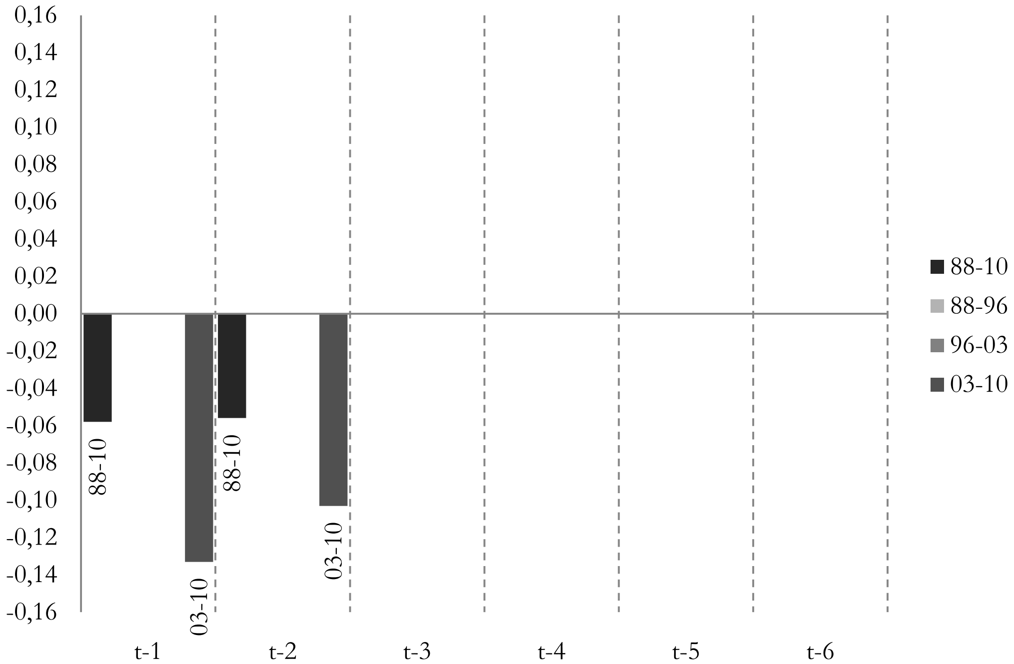


Figure 5.8: *Significant autoregressive coefficients – EURO STOXX*

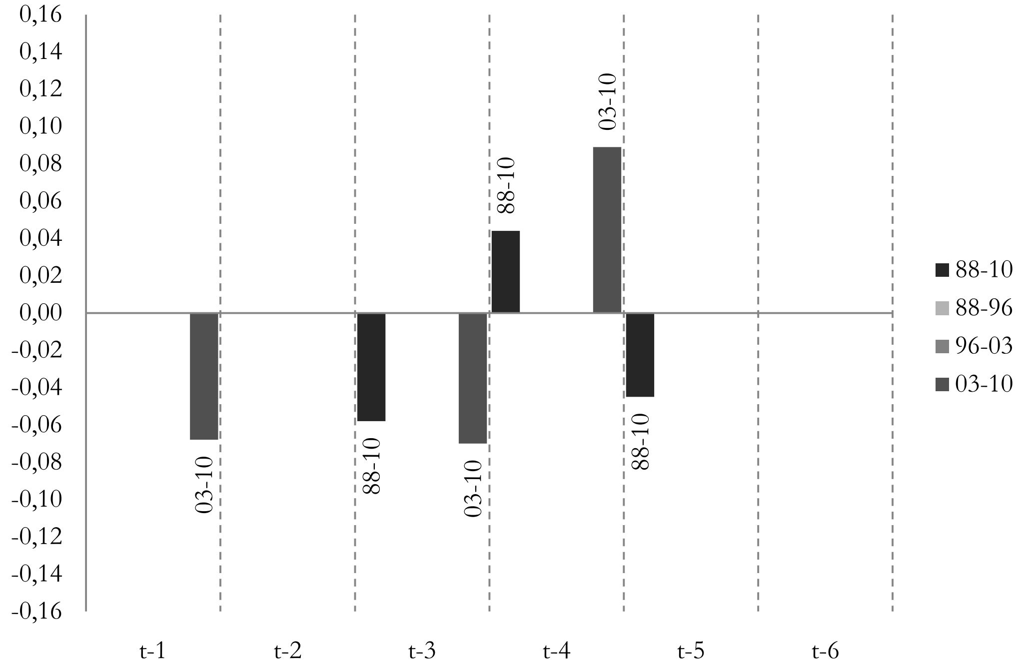
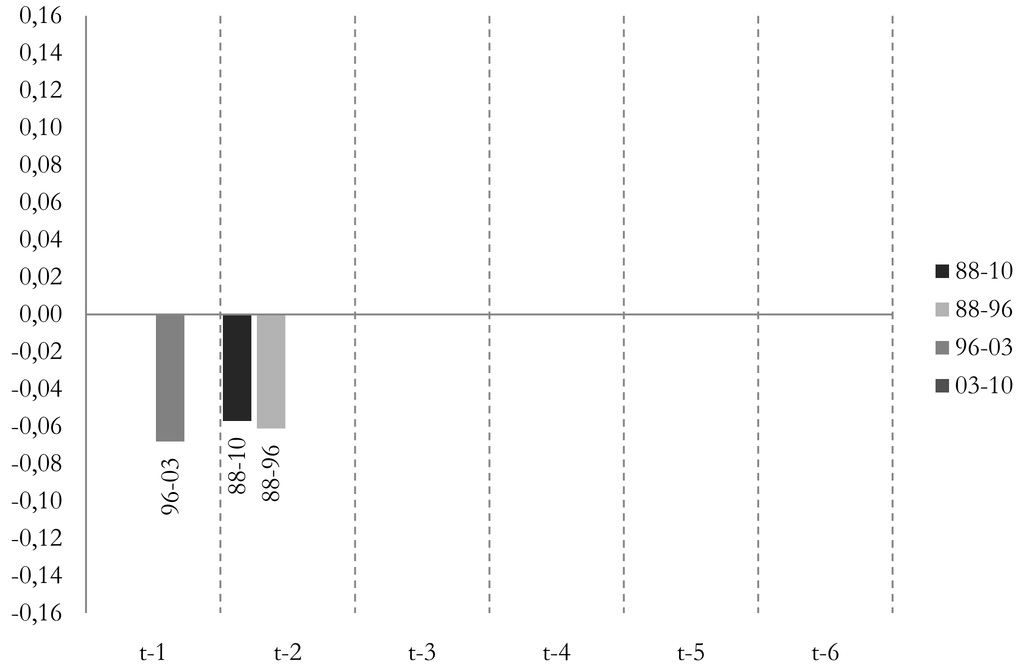


Figure 5.9: *Significant autoregressive coefficients – Nikkei 225*



From *Figures 5.4 to 5.9* it is clear that autocorrelations are of a small magnitude across the datasets. No autocorrelation results exceed -0.133, which is the first lag of the S&P 500 in the 2003-2010 subset. Furthermore, it is also obvious that few of the results are deemed significant by the SC and that the 2003-2010 subset seem to be the dominant time period in terms of coefficient magnitudes. However, the significant results for Nikkei 225 do not support this and are inconsistent.

When observing the visual patterns displayed in our graphics one especially interesting piece of information becomes evident, namely that most of the lag effects are negative. Out of the 13 significant lags across the three markets, 11 provide us with negative coefficients. And out of the total of 72 lags, as many as 54 display negative coefficients.

The above mentioned observations should be considered in light of the small coefficients presented. The average significant coefficient is only roughly -0.05 and would correspond to the 2.4^{th} lag, when weighted. This is not an entirely correct way to draw inference, but still provides some valuable insight. Furthermore, the average first lag coefficient, regardless of significance, is roughly -0.03.

Thus, in effect these small reported coefficients suggest too small effects to draw solid conclusions. The -0.05 reported coefficient implies that if the return yesterday was +1 %, the lagged effect would correspond to a 0.05 negative percentage point move today and could thus easily be dismissed as statistical noise. In contrast our significant first cycle reported coefficients from the full dataset VAR ranged from 0.19 to 0.55, thus providing a explanatory power corresponding to a 0.19 to 0.55 positive percentage point move on a +1 % return of the exogenous variable.

However, the most interesting piece of information still remains, namely that a clear majority of the autocorrelations are negative. This implies the possibility of a deviation from the random walk theory. The random walk theory states that stock price changes have the same distribution and are independent of each other, so the past movement or trend of a stock price or market cannot be used to predict its future movement (Samuelson, 1965). Our results clearly depicts that we have an uneven distribution of the lag effects. As stated previously, there seems to be a clear overweight of negative lags, indicating a pattern of mean reversions in the observed markets during the studied periods. However, facts remain, the small coefficients and inconsistent significance of the results does make it hard to directly question the random walk theory.

When observing the subsets some other weak but interesting trends emerge. From *Figure 5.4* it is evident that the S&P 500 first and second lag autocorrelations for the 2003-2010 subset are of distinct magnitude compared to the earlier subsets. This is also the case for the EURO STOXX. However, in the Nikkei 225 case the same distinct magnitude of the first lag appears for the 1996-2003 subset. Possibly these deviations could be attributed to the major economic events during the specific time periods, namely the financial crisis during the 2003-2010 subset and the Asian financial crisis during the 1996-2003 subset.

6. CONCLUSIONS

The aim of this study has been to highlight and discuss the development of transmission effects across international equity markets since the end of the 1987 financial crisis. To accomplish this we began by investigating Granger causalities among the U.S., the Eurozone and Japan. The results from our Granger causality tests discussed in *Section 5.1* provide it feasible that feedbacks run across all three markets and in all possible directions. Based on these findings we moved on to investigate the strength of the present transmission effects by implementing a AR model with forign markets as exogenous variables as well as an AR(12) model with only home lag effects, using the latter to obtain relevant autocorrelation results. To enhance the reliability of the AR(12) results, we also implemented the Ljung-Box test to determine how many lags to draw inference from.

The most significant findings from the transmission effect results discussed in *Section 5.2* were the upward sloping trends of the coefficients, strongly implying increasing transmission effects. The increasing transmission effects are in line with previous research by for instance Lee & Kim (1993), stating that global equity markets has been increasingly interrelated since the 1987 financial crisis. In addition to this general trend we have also concluded that the influence of the Eurozone has increased over time, while the U.S. influence rather has shown tendencies of relative decline or stagnation. These trends are nicely depicted in *Figure 5.2* under *Section 5.2*.

In *Section 5.1 and 5.2* many interesting transmission effect and Granger causality results are discussed which may be explained by or linked to the major economic events during the different time periods studied. The most significant of these is the trend of the increasing strength of the Eurozone coefficients. We found that the Eurozone's influence is increasing both on the U.S. and Japan, and the Granger causality results implying that the Eurozone is a causing region in the setting further underlines the importance of these findings. The findings are fully in line with the study previously mentioned on the European integration process by Marcel Fratzscher (2002).

Our autocorrelation results discussed in *Section 5.3* was of a lower magnitude (average first lag coefficient of -0.03), but still offered some interesting insights. The most significant being a clear overweight of negative lags emerging when studying *Figures*

5.4 to 5.9, possibly implying mean reversion in the studied markets and thus also questioning the random walk theory. However, the bottom line is that we have not found any major significant autocorrelation effects in the studied datasets.

In this study we have highlighted and discussed the development of transmission effects across international equity markets by identifying statistically significant and causal trends showing increasing coefficients of influence among the studied markets. These increasing transmission effects are proof of an ever more globalised world with increasingly linked equity markets. The increasing linkages can be ascribed to many different factors like peace, prosperity, new international institutions (such as the EU), technological development and financial innovation. Especially the effects of financial innovation has lately emerged as a forceful fear factor in financial markets, with the financial crisis of 2007-2009 culminating into one of the worst bear markets in a century.

Increasing transmissions does not only reflect an ever more globalised world. They also imply the decreasing benefits of international diversification. Investors who have previously sought to manage risk by investing across international markets are running out of luck and it is reasonable to believe that transmission effects across equity markets are only likely to continue to increase if no major events alter the course of development present in the world today. An example of an event which could possibly change this development is the possibility of the EMU failing and the reversal back to local currencies in the Eurozone. As of when this thesis is written, in May 2010, this topic is widely debated in the light of the sovereign debt crisis facing several EMU members and the effects that this has on the Euro as a currency (Bloomberg, 2010).

Our hope is that the findings in this paper invites to further studies on the subject. We wish to suggest some possible amendments for future studies. Firstly, we suggest using another method when correcting for the overlap period of the Eurozone and the U.S., for instance by using intraday data. Secondly, another possibility could be to use narrower sub-periods, or to impose dummies in the datasets to study crisis periods versus periods of relative calm. Finally, it could be interesting to widen the scope of markets and to include emerging markets in the study. As our study confirms that transmission effects have increased across equity markets of the major economies, investors within these regions will probably be looking to allocate their capital to markets with lower correlations, possibly the emerging markets.

In light of the importance of diversification effects and its central role within portfolio theory, we believe that the results obtained from this paper are of interest to the investment community. The fact that we have proven the presence of increasing transmission effects across major international markets should be of vital importance for investors looking to improve their asset allocation.

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8. APPENDIX

8.1 Results for entire period, January 1988 – April 2010

8.1a Granger causality results

Tables 8.1 and 8.2 depict the Granger Causality results (lags as suggested by AIC). Parameters significant at the 5 % level are marked with asterisks.

P-Values

Table 8.1: *P-Values from Granger causality test, 1988-2010*

	S&P500	S&P500 (previous)	S&P500 (same)	EURO STOXX	Nikkei 225
S&P500				0.0001*	0.0008*
EURO STOXX		0.0188*	0.0000*		0.0002*
Nikkei 225	0.0333*			0.0095*	

T-Values

Table 8.2: *T-Values from Granger causality test, 1988-2010*

	S&P500	S&P500 (previous)	S&P500 (same)	EURO STOXX	Nikkei 225
S&P500				4.271	3.351
EURO STOXX		2.294	122.223		4.868
Nikkei 225	2.617			3.042	

Table 8.3 depicts the number of lags used in the model when the causality test were carried out.

Table 8.3: *Model lags used in the Granger causality test, 1988-2010*

Causing variable	Affected variable	AIC lags
EURO STOXX (t)	S&P 500	7
Nikkei (t)	S&P 500	8
S&P 500 (t-1)	EURO STOXX	8
S&P 500 (t)	EURO STOXX	7
Nikkei (t)	EURO STOXX	5
S&P 500 (t-1)	Nikkei	4
EURO STOXX (t-1)	Nikkei	5

8.1b Transmission effect results

Endogenous variable: S&P 500

Table 8.4: *Results from AR with S&P 500 as the endogenous variable, 1988-2010*

Exogenous variables	S&P 500	S&P 500	EURO STOXX	Nikkei 225	EURO STOXX	Nikkei 225	EURO STOXX	Nikkei 225	EURO STOXX	Nikkei 225
Lags	t-1	t-2	t	t	t-1	t-1	t-2	t-2	t-3	t-3
Coefficients	-0.308	-0.084	0.492		0.140					
T-Values	-22.227	-6.997	47.561		11.625					

Enogenous variable: EURO STOXX

Table 8.5: *AR results for "previous-date U.S values", EURO STOXX as endogenous variable, 1988-2010*

Exogenous variables	EURO STOXX	EURO STOXX	EURO STOXX	EURO STOXX	EURO STOXX	S&P 500	Nikkei 225	S&P 500	Nikkei 225	S&P 500	Nikkei 225	S&P 500	Nikkei 225
Lag	t-1	t-2	t-3	t-4	t-5	t	t	t-1	t-1	t-2	t-2	t-3	t-3
Coefficients	-0.270	-0.077	-0.071	0.036	-0.055	0.399	0.198	0.095		0.062			
T-Values	-17.772	-4.985	-5.086	3.056	-4.575	23.631	17.213	5.294		3.602			

Table 8.6: *AR results for "same-date U.S values", EURO STOXX as endogenous variable, 1988-2010*

Exogenous variables	EURO STOXX	EURO STOXX	EURO STOXX	EURO STOXX	EURO STOXX	S&P 500	Nikkei 225	S&P 500	Nikkei 225	S&P 500	Nikkei 225	S&P 500	Nikkei 225
Lag	t-1	t-2	t-3	t-4	t-5	t	t	t-1	t-1	t-2	t-2	t-3	t-3
Coefficients	-0.276	-0.067	-0.061		-0.034	0.548	0.132	0.466		0.121		0.052	
T-Values	-21.227	-5.064	-5.085		-3.360	45.993	13.281	32.019		7.898		3.519	

Table 8.7: *AR results for "weighted U.S values", EURO STOXX as endogenous variable, 1988-2010*

Exogenous variables	EURO STOXX	EURO STOXX	EURO STOXX	EURO STOXX	EURO STOXX	S&P 500	S&P 500	S&P 500	S&P 500
Lag	t-1	t-2	t-3	t-4	t-5	t	t-1	t-2	t-3
Coefficients	-0.271	-0.075	-0.069	0.036	-0.050	0.434	0.182	0.076	0.052
T-Values*									

** T-values are not weighted, see table 8.5 and 8.6 for underlying t-statistics.*

Endogenous variable: Nikkei 225

Table 8.8: *Results from AR with Nikkei 225 as the endogenous variable, 1988-2010*

Exogenous variables	Nikkei 225	Nikkei 225	S&P 500	EURO STOXX	S&P 500	EURO STOXX	S&P 500	EURO STOXX	S&P 500	EURO STOXX
Lag	t-1	t-2	t	t	t-1	t-1	t-2	t-2	t-3	t-3
Coefficients	-0.1	-0.035	0.409	0.193						
T-Values	-8.013	-2.955	23.259	12.137						

8.1c Autocorrelation results, AR(12)

The SC suggests two periods of lags for S&P 500 and Nikkei 225 autocorrelations. For EURO STOXX it suggests five periods of lags. However, we have chosen to display twelve periods of lags in *Tables 4.12 to 4.13* to extend the visibility with regards to autocorrelations. All of the 12 periods are also depicted in *Figures 4.1 to 4.3*. However, only by SC suggested lags are included in *Models 4.4 to 4.6*.

Coefficients

Table 8.9: *Autocorrelation coefficients for all indices, 1988-2010*

Lag	t-1	t-2	t-3	t-4	t-5	t-6	t-7	t-8	t-9	t-10	t-11	t-12
$S\&P500_t$	-0.058*	-0.056*	0.001	-0.017	-0.018	-0.024	-0.040*	0.020	-0.010	0.027	-0.009	0.004
Euro $Stoxx_t$	-0.017	-0.028	-0.058*	0.044*	-0.045*	-0.024	-0.010	0.033	-0.011	0.014	0.009	0.000
Nikkei 225_t	-0.019	-0.057*	-0.018	0.016	-0.000	-0.023	-0.006	0.002	0.012	0.015	0.025	0.021

T-Values

Table 8.10: *Autocorrelation t-values for all indices, 1988-2010*

Lag	t-1	t-2	t-3	t-4	t-5	t-6	t-7	t-8	t-9	t-10	t-11	t-12
$S\&P500_t$	-4.398	-4.260	0.104	-1.264	-1.370	-1.838	-3.075	1.518	-0.775	2.032	-0.722	0.322
Euro $Stoxx_t$	-1.286	-2.136	-4.380	3.331	-3.403	-1.825	-0.729	2.529	-0.816	1.072	0.651	0.005
Nikkei 225_t	-1.416	-4.310	-1.354	1.187	-0.012	-1.727	-0.430	0.139	0.913	1.129	1.893	1.566

Giving the following estimated models with regards to autocorrelations:

$S\&P_t = -0.058\ S\&P_{t-1} - 0.056\ S\&P_{t-2} - 0.040\ S\&P_{t-7}$ (4.4)

$EUROSTOXX_t = -0.058\ EUROSTOXX_{t-3} + 0.044\ EUROSTOXX_{t-4} - 0.045\ EUROSTOXX_{t-5}$ (4.5)

$Nikkei_t = -0.057\ Nikkei_{t-2}$ (4.6)

8.1d Ljung-Box test results

An estimated p-value<0.05 implies serial correlation and is marked with an asterisks.

Table 8.11: *ARMA lags used in Ljung-Box test for S&P 500, 1988-2010*

	p	q
S&P 500	0	2
EUROSTOXX	5	0
Nikkei 225	2	0

Table 8.12: *S&P 500 Ljung-Box test results, 1988-2010*

Lags	1	2	3	4	5	6	7
Ljung-Box	0.0001	0.0028	0.0964	1.1706	3.4076	6.2086	14.3398
Ljung-Box P-Value (Chi^2)	-1.0000*	-1.0000*	1.0000	0.2793	0.1820	0.1019	0.0063*

Table 8.13: *EURO STOXX Ljung-Box test results, 1988-2010*

Lags	1	2	3	4	5	6	7
Ljung-Box	0.0081	0.0108	0.0138	0.0725	0.1062	3.3287	3.7379
Ljung-Box P-Value (Chi^2)	-1.0000*	-1.0000*	-1.0000*	-1.0000*	-1.0000*	-1.0000*	0.0532

Table 8.14: *Nikkei 225 Ljung-Box test results, 1988-2010*

Lags	1	2	3	4	5	6	7
Ljung-Box	0.0059	0.0096	1.9407	3.3584	3.3591	6.5067	6.6782
Ljung-Box P-Value (Chi^2)	-1.0000*	-1.0000*	-1.0000*	0.0669	0.1865	0.0894	0.1539

8.2 Results for period January 1988 – April 1996

8.2a Granger causality results

The following tables depict the Granger Causality results (lags as suggested by AIC). Parameters significant at the 5% level are marked with asterisk.

P-Values

Table 8.15: *P-Values from Granger causality test, 1988-1996*

	S&P500	S&P500 (previous)	S&P500 (same)	EURO STOXX	Nikkei 225
S&P500				0.0026*	0.0206*
EURO STOXX		0.0657	0.0000*		0.0172*
Nikkei 225	0.6032			0.0448*	

T-Values

Table 8.16: *T-Values from Granger causality test, 1988-1996*

	S&P500	S&P500 (previous)	S&P500 (same)	EURO STOXX	Nikkei 225
S&P500				0.9593	3.8874
EURO STOXX		3.3878	416.7363		4.0643
Nikkei 225	0.5055			2.6887	

The following lags were used in the model when the causality test was carried out:

Table 8.17: *Model lags used in the Granger causality test, 1988-1996*

Causing variable	Affected variable	AIC lags
EURO STOXX (t)	S&P 500	1
Nikkei (t)	S&P 500	2
S&P 500 (t-1)	EURO STOXX	1
S&P 500 (t)	EURO STOXX	1
Nikkei (t)	EURO STOXX	1
S&P 500 (t-1)	Nikkei	2
EURO STOXX (t-1)	Nikkei	3

8.2b Transmission effect results

Endogenous variable: S&P 500

Table 8.18: *Results from AR with S&P 500 as the endogenous variable, 1988-1996*

Exogenous variables	S&P 500	EURO STOXX	Nikkei 225	EURO STOXX	Nikkei 225	EURO STOXX	Nikkei 225	EURO STOXX	Nikkei 225
Lags	t-1	t	t	t-1	t-1	t-2	t-2	t-3	t-3
Coefficients	-0.100	0.228	0.044						
T-Values	-4.384	10.779	3.496						

Endogenous variable: EURO STOXX

Table 8.19: *AR results for "previous-date US values", EURO STOXX as endogenous variable, 1988-1996*

Exogenous variables	EURO STOXX	S&P 500	Nikkei 225	S&P 500	Nikkei 225	S&P 500	Nikkei 225	S&P 500	Nikkei 225
Lag	t-1	t	t	t-1	t-1	t-2	t-2	t-3	t-3
Coefficients	-0.114	0.407	0.139						
T-Values	-5.785	18.480	11.100						

Table 8.20: *AR results for "same-date US values", EURO STOXX as endogenous variable, 1988-1996*

Exogenous variables	EURO STOXX	S&P 500	Nikkei 225	S&P 500	Nikkei 225	S&P 500	Nikkei 225	S&P 500	Nikkei 225
Lag	t-1	t	t	t-1	t-1	t-2	t-2	t-3	t-3
Coefficients	-0.113	0.223	0.122	0.409					
T-Values	-5.847	10.814	9.942	19.091					

Table 8.21: *AR results for "weighted US values", EURO STOXX as endogenous variable, 1988-1996*

Exogenous variables	EURO STOXX	S&P 500	S&P 500	S&P 500	S&P 500
Lag	t-1	t	t-1	t-2	t-3
Coefficients	-0.1138	0.3637	0.4090		
T-Values*					

** T-values are not weighted, see table 8.19 and 8.20 for underlying t-statistics.*

Endogenous variable: Nikkei 225

Table 8.22: *Results from AR with Nikkei 225 as the endogenous variable, 1988-1996*

Exogenous variables	S&P 500	EURO STOXX	S&P 500	EURO STOXX	S&P 500	EURO STOXX	S&P 500	EURO STOXX
Lags	t	t	t-1	t-1	t-2	t-2	t-3	t-3
Coefficients	0.343	0.121						0.117
T-Values	9.263	3.571						3.571

8.2c Autocorrelation results, AR(12)

Coefficients

Table 8.23: *Autocorrelation coefficients for all indices, 1988-1996*

Lag	t-1	t-2	t-3	t-4	t-5	t-6	t-7	t-8	t-9	t-10	t-11	t-12
$S\&P500_t$	0.022	-0.015	-0.036	-0.030	0.009	-0.055	-0.045	-0.016	0.012	0.001	-0.023	0.049
Euro $Stoxx_t$	-0.001	0.017	-0.015	0.033	-0.022	-0.015	0.011	-0.008	-0.004	0.032	0.003	0.035
Nikkei 225_t	0.023	-0.061*	0.004	0.023	-0.029	-0.010	-0.013	0.025	0.067	0.044	0.010	-0.006

T-Values

Table 8.24: *Autocorrelation t-values for all indices, 1988-1996*

Lag	t-1	t-2	t-3	t-4	t-5	t-6	t-7	t-8	t-9	t-10	t-11	t-12
$S\&P500_t$	1.039	-0.698	-1.657	-1.414	0.433	-2.550	-2.069	-0.732	0.580	0.044	-1.096	2.331
Euro $Stoxx_t$	-0.028	0.776	-0.690	1.519	-1.038	-0.704	0.521	-0.390	-0.203	1.486	0.151	1.654
Nikkei 225_t	1.063	-2.837	0.199	1.086	-1.328	-0.479	-0.607	1.164	3.115	2.028	0.454	-0.297

8.2d Ljung-Box test results

An estimated p-value<0.05 implies serial correlation and is marked with an asterisks.

Table 8.25: *ARMA lags used in Ljung-Box test for S&P 500, 1988-1996*

	p	q
S&P 500	0	0
EUROSTOXX	0	0
Nikkei 225	0	0

Table 4.26: *S&P 500 Ljung-Box test results, 1988-1996*

Lags	1	2	3	4	5	6	7
Ljung-Box	0.2859	0.4419	5.0059	6.0625	6.1386	11.7218	15.3700
Ljung-Box P-Value (Chi^2)	-1.0000*	0.5062	0.0818	0.1086	0.1890	0.0388*	0.0176*

Table 4.27: *EURO STOXX Ljung-Box test results, 1988-1996*

Lags	1	2	3	4	5	6	7
Ljung-Box	0.0015	0.7407	1.6024	2.6514	4.2996	4.5230	4.8866
Ljung-Box P-Value (Chi^2)	-1.0000*	0.3894	0.4488	0.4485	0.3670	0.4768	0.5584

Table 4.28: *Nikkei 225 Ljung-Box test results, 1988-1996*

Lags	1	2	3	4	5	6	7
Ljung-Box	1.5997	9.3447	9.3523	10.6720	12.4586	12.8969	13.2373
Ljung-Box P-Value (Chi^2)	-1.0000*	0.0022*	0.0093*	0.0136*	0.0142*	0.0244*	0.0394*

8.3 Results for period April 1996 – April 2003

8.3a Granger causality results

The following tables depict the Granger Causality results (lags as suggested by AIC). Parameters significant at the 5% level are marked with asterisk.

P-Values

Table 8.29: *P-Values from Granger causality test, 1996-2003*

	S&P500	S&P500 (previous)	S&P500 (same)	EURO STOXX	Nikkei 225
S&P500				0.3007	0.1002
EURO STOXX		0.2004	0.0000*		0.0011*
Nikkei 225	0.2362			0.6205	

T-Values

Table 8.30: *T-Values from Granger causality test, 1996-2003*

	S&P500	S&P500 (previous)	S&P500 (same)	EURO STOXX	Nikkei 225
S&P500				1.2203	2.3016
EURO STOXX		1.4575	88.2178		10.6755
Nikkei 225	1.4035			0.5915	

The following lags were used in the model when the causality test was carried out:

Table 8.31: *Model lags used in the Granger causality test, 1996-2003*

Causing variable	Affected variable	AIC lags
EURO STOXX (t)	S&P 500	3
Nikkei (t)	S&P 500	2
S&P 500 (t-1)	EURO STOXX	5
S&P 500 (t)	EURO STOXX	3
Nikkei (t)	EURO STOXX	1
S&P 500 (t-1)	Nikkei	1
EURO STOXX (t-1)	Nikkei	3

8.3b Transmission effect results

Endogenous variable: S&P 500

Table 8.32: *Results from AR with S&P 500 as the endogenous variable, 1996-2003*

Exogenous variables	S&P 500	S&P 500	S&P 500	EURO STOXX	Nikkei 225	EURO STOXX	Nikkei 225	EURO STOXX	Nikkei 225	EURO STOXX	Nikkei 225
Lags	t-1	t-2	t-3	t	t	t-1	t-1	t-2	t-2	t-3	t-3
Coefficients	-0.259	-0.088		0.435		0.124		0.041			
T-Values	-10.388	-3.515		25.799		6.247		2.250			

Endogenous variable: EURO STOXX

Table 8.33: *AR results for "previous-date US values", EURO STOXX as endogenous variable, 1996-2003*

Exogenous variables	EURO STOXX	EURO STOXX	EURO STOXX	S&P 500	Nikkei 225	S&P 500	Nikkei 225	S&P 500	Nikkei 225	S&P 500	Nikkei 225
Lag	t-1	t-2	t-3	t	t	t-1	t-1	t-2	t-2	t-3	t-3
Coefficients	-0.206		-0.068	0.464	0.172	0.098	-0.083				
T-Values	-7.748		-3.146	14.232	6.977	3.220	-3.367				

Table 8.34: *AR results for "same-date US values", EURO STOXX as endogenous variable, 1996-2003*

Exogenous variables	EURO STOXX	EURO STOXX	EURO STOXX	S&P 500	Nikkei 225	S&P 500	Nikkei 225	S&P 500	Nikkei 225	S&P 500	Nikkei 225
Lag	t-1	t-2	t-3	t	t	t-1	t-1	t-2	t-2	t-3	t-3
Coefficients	-0.253	-0.115	-0.090	0.600	0.121	0.512		0.168		0.105	
T-Values	-10.853	-4.892	-4.172	25.351	5.708	18.156		5.584		3.573	

Table 8.35: *AR results for "weighted US values", EURO STOXX as endogenous variable, 1996-2003*

Exogenous variables	EURO STOXX	EURO STOXX	EURO STOXX	S&P 500	S&P 500	S&P 500	S&P 500
Lag	t-1	t-2	t-3	t	t-1	t-2	t-3
Coefficients	-0.2171	-0.1150	-0.0732	0.4960	0.1954	0.1680	0.1050
T-Values*							

** T-values are not weighted, see table 8.33 and 8.34 for underlying t-statistics.*

Endogenous variable: Nikkei 225

Table 8.36: *Results from AR with Nikkei 225 as the endogenous variable, 1996-2003*

Exogenous variables	Nikkei 225	S&P 500	EURO STOXX	S&P 500	EURO STOXX	S&P 500	EURO STOXX	S&P 500	EURO STOXX
Lags	t-1	t	t	t-1	t-1	t-2	t-2	t-3	t-3
Coefficients	-0.132	0.309	0.162						
T-Values	-5.903	10.468	6.814						

8.3c Autocorrelation results, AR(12)

Coefficients

Table 8.37: *Autocorrelation coefficients for all indices, 1996-2003*

Lag	t-1	t-2	t-3	t-4	t-5	t-6	t-7	t-8	t-9	t-10	t-11	t-12
$S\&P500_t$	-0.012	-0.024	-0.042	-0.015	-0.023	-0.023	-0.038	0.003	0.000	0.030	-0.039	0.024
Euro $Stoxx_t$	0.014	-0.030	-0.060	0.012	-0.044	-0.052	-0.020	0.059	0.010	0.003	0.004	-0.020
Nikkei 225_t	-0.068*	-0.044	-0.008	-0.017	0.002	-0.042	0.002	0.006	0.010	-0.025	0.014	0.008

T-Values

Table 8.38: *Autocorrelation t-values for all indices, 1996-2003*

Lag	t-1	t-2	t-3	t-4	t-5	t-6	t-7	t-8	t-9	t-10	t-11	t-12
$S\&P500_t$	-0.504	-1.026	-1.793	-0.640	-0.993	-0.967	-1.592	0.106	0.002	1.273	-1.622	1.010
Euro $Stoxx_t$	0.603	-1.268	-2.527	0.514	-1.859	-2.216	-0.853	2.499	0.401	0.128	0.189	-0.858
Nikkei 225_t	-2.892	-1.868	-0.342	-0.707	0.074	-1.763	0.074	0.243	0.439	-1.036	0.585	0.338

8.3d Ljung-Box test results

An estimated p-value<0.05 implies serial correlation and is marked with an asterisks.

Table 8.39: *ARMA lags used in Ljung-Box test for S&P 500, 1996-2003*

	p	q
S&P 500	0	0
EUROSTOXX	0	0
Nikkei 225	0	1

Table 8.40: *S&P 500 Ljung-Box test results, 1996-2003*

Lags	1	2	3	4	5	6	7
Ljung-Box	0.2152	0.9813	4.0366	4.2369	5.0211	5.7272	8.1358
Ljung-Box P-Value (Chi^2)	-1.0000*	0.3219	0.1329	0.2370	0.2851	0.3337	0.2283

Table 8.41: *EURO STOXX Ljung-Box test results, 1996-2003*

Lags	1	2	3	4	5	6	7
Ljung-Box	0.5431	2.3497	8.8094	9.0803	12.4888	17.5966	18.2673
Ljung-Box P-Value (Chi^2)	-1.0000*	0.1253	0.0122*	0.0282*	0.0141*	0.0035*	0.0056

Table 8.42: *Nikkei 225 Ljung-Box test results, 1996-2003*

Lags	1	2	3	4	5	6	7
Ljung-Box	0.0139	2.7187	2.7708	3.0296	3.0409	6.1177	6.1509
Ljung-Box P-Value (Chi^2)	-1.0000*	-1.0000*	0.0960	0.2199	0.3854	0.1905	0.2918

8.4 Results for period April 2003 – April 2010

8.4a Granger causality results

The following tables depict the Granger Causality results (lags as suggested by AIC). Parameters significant at the 5% level are marked with asterisk.

P-Values

Table 8.43: *P-Values from Granger causality test, 2003-2010*

	S&P500	S&P500 (previous)	S&P500 (same)	EURO STOXX	Nikkei 225
S&P500				0.0000*	0.0001*
EURO STOXX		0.0000*	0.0000*		0.5200
Nikkei 225	0.2438			0.0012*	

T-Values

Table 8.44: *T-Values from Granger causality test, 2003-2010*

	S&P500	S&P500 (previous)	S&P500 (same)	EURO STOXX	Nikkei 225
S&P500				4.5601	4.0893
EURO STOXX		3.8723	43.2495		0.8647
Nikkei 225	1.2771			4.0336	

The following lags were used in the model when the causality test was carried out:

Table 8.43: *Model lags used in the Granger causality test, 2003-2010*

Causing variable	Affected variable	AIC lags
EURO STOXX (t)	S&P 500	8
Nikkei (t)	S&P 500	8
S&P 500 (t-1)	EURO STOXX	10
S&P 500 (t)	EURO STOXX	8
Nikkei (t)	EURO STOXX	6
S&P 500 (t-1)	Nikkei	9
EURO STOXX (t-1)	Nikkei	5

8.4b Transmission effect results

Endogenous variable: S&P 500

Table 8.44: *Results from AR with S&P 500 as the endogenous variable, 2003-2010*

Exogenous variables	S&P 500	S&P 500	EURO STOXX	Nikkei 225	EURO STOXX	Nikkei 225	EURO STOXX	Nikkei 225	EURO STOXX	Nikkei 225
Lags	t-1	t-2	t	t	t-1	t-1	t-2	t-2	t-3	t-3
Coefficients	-0.521	-0.166	0.689		0.311					
T-Values	-21.827	-8.846	39.153		13.648					

Endogenous variable: EURO STOXX

Table 8.45: *AR results for "previous-date US values", EURO STOXX as endogenous variable, 2003-2010*

Exogenous variables	EURO STOXX	EURO STOXX	EURO STOXX	S&P 500	Nikkei 225	S&P 500	Nikkei 225	S&P 500	Nikkei 225	S&P 500	Nikkei 225
Lag	t-1	t-2	t-3	t	t	t-1	t-1	t-2	t-2	t-3	t-3
Coefficients	-0.512	-0.200	-0.136	0.348	0.333	0.150	0.083	0.152		0.088	
T-Values	-16.488	-6.055	-4.567	11.003	15.047	4.146	3.557	4.490		3.702	

Table 8.46: *AR results for "same-date US values", EURO STOXX as endogenous variable, 2003-2010*

Exogenous variables	EURO STOXX	EURO STOXX	EURO STOXX	S&P 500	Nikkei 225	S&P 500	Nikkei 225	S&P 500	Nikkei 225	S&P 500	Nikkei 225
Lag	t-1	t-2	t-3	t	t	t-1	t-1	t-2	t-2	t-3	t-3
Coefficients	-0.462	-0.073	-0.049	0.618	0.182	0.521		0.177		0.036	
T-Values	-20.541	-3.612	-2.971	36.870	10.787	21.628		7.562		2.465	

Table 8.47: *AR results for "weighted US values", EURO STOXX as endogenous variable, 2003-2010*

Exogenous variables	EURO STOXX	EURO STOXX	EURO STOXX	S&P 500	S&P 500	S&P 500	S&P 500
Lag	t-1	t-2	t-3	t	t-1	t-2	t-3
Coefficients	-0.5002	-0.1701	-0.1155	0.4115	0.2373	0.1579	0.0758
T-Values*							

** T-values are not weighted, see table 8.45 and 8.46 for underlying t-statistics.*

Endogenous variable: Nikkei 225

Table 8.48: *Results from AR with Nikkei 225 as the endogenous variable, 2003-2010*

Exogenous variables	Nikkei 225	Nikkei 225	S&P 500	EURO STOXX	S&P 500	EURO STOXX	S&P 500	EURO STOXX	S&P 500	EURO STOXX
Lag	t-1	t-2	t	t	t-1	t-1	t-2	t-2	t-3	t-3
Coefficients	-0.232	-0.111	0.579	0.233	0.213		0.127			
T-Values	-9.756	-4.753	19.728	8.033	7.067		4.528			

8.4c Autocorrelation results, AR(12)

Coefficients

Table 8.49: *Autocorrelation coefficients for all indices, 2003-2010*

Lag	t-1	t-2	t-3	t-4	t-5	t-6	t-7	t-8	t-9	t-10	t-11	t-12
$S\&P500_t$	-0.133*	-0.103*	0.042	-0.002	-0.016	-0.014	-0.039	0.051	-0.015	0.035	0.013	-0.025
Euro $Stoxx_t$	-0.068*	-0.048	-0.070*	0.089*	-0.043	0.007	-0.004	0.010	-0.049	0.008	0.014	0.009
Nikkei 225_t	-0.011	-0.064	-0.042	0.041	0.018	-0.018	-0.014	0.021	-0.038	0.016	0.040	0.052

T-Values

Table 8.50: *Autocorrelation t-values for all indices, 2003-2010*

Lag	t-1	t-2	t-3	t-4	t-5	t-6	t-7	t-8	t-9	t-10	t-11	t-12
$S\&P500_t$	-5.643	-4.341	1.771	-0.087	-0.666	-0.592	-1.645	2.133	-0.650	1.476	0.568	-1.071
Euro $Stoxx_t$	-2.876	-2.042	-2.987	3.781	-1.799	0.284	-0.149	0.432	-2.076	0.333	0.608	0.396
Nikkei 225_t	-0.486	-2.741	-1.778	1.732	0.777	-0.747	-0.575	-0.911	-1.610	0.679	1.687	2.219

8.4d Ljung-Box test results

An estimated p-value<0.05 implies serial correlation and is marked with an asterisks.

Table 8.51: *ARMA lags used in Ljung-Box test for S&P 500, 2003-2010*

	p	q
S&P 500	2	0
EUROSTOXX	3	1
Nikkei 225	0	0

Table 8.52: *S&P 500 Ljung-Box test results, 2003-2010*

Lags	1	2	3	4	5	6	7
Ljung-Box	0.0386	0.0846	3.0722	3.3020	3.7727	3.9606	6.0608
Ljung-Box P-Value (Chi^2)	-1.0000*	-1.0000*	-1.0000*	0.0692	0.1516	0.2657	0.1947

Table 8.53: *EURO STOXX Ljung-Box test results, 2003-2010*

Lags	1	2	3	4	5	6	7
Ljung-Box	0.0137	0.0407	0.4346	2.0846	2.1667	3.2138	3.8201
Ljung-Box P-Value (Chi^2)	-1.0000*	-1.0000*	-1.0000*	-1.0000*	-1.0000*	0.0730	0.1481

Table 8.54: *Nikkei 225 Ljung-Box test results, 2003-2010*

Lags	1	2	3	4	5	6	7
Ljung-Box	0.0718	9.2116	12.7477	16.4043	17.2371	17.9002	18.2485
Ljung-Box P-Value (Chi^2)	-1.0000*	0.0024*	0.0017*	0.0009*	0.0017*	0.0031*	0.0056