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Financial Contagion during the 2008 Financial Crisis

Globalization or Contagion?

Author: B. Bennink
Student number: 303336bb
Thesis supervisor: Dr. A. Markiewicz
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PREFACE AND ACKNOWLEDGEMENTS

This thesis is a mandatory part of finishing a Master in Economics and Business, specializing in Financial Economics. The subject of my thesis is a hot item these days which made it very interesting to do more research regarding contagion.

My thank goes to Agnieszka Markiewicz, my thesis supervisor, for her guidance and judgement.

ABSTRACT

The 2008 financial crisis started in America but quickly expanded throughout the whole world. Is globalization to blame? Were economies already highly connected to each other? Or did country-linkages increase during the crisis, meaning contagion. With a basic GARCH model and a GARCH-M model indices returns have been tested whether the Standard and Poor's 500 had more effect on these indices as soon as the crisis started. Evidence pointed out that there was no significant increase noticeable for all models. This suggests that there is no presence of contagion and that indices were already highly linked with the Standard and Poor's 500 before the crisis.

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1 Introduction

After the recent financial crisis the word on the financial markets was that increasing correlation made it impossible to diversify ones portfolio efficiently. This process is assumed to happen during every major crisis. Low correlation between countries during stable periods reduces the total risk of a portfolio when he or she invests internationally. However, during a crisis these opportunities tend to disappear. People argue that this is caused due to increased country linkages.
But is this true? And if so, what causes this effect?

For two decades, academics have tried to find out how the process works. How is it possible that during a crisis international diversification isn't profitable anymore? The results from the past two decades still are inconclusive whether there is an increase in country linkages during a crisis. This differs very much between the type of crisis (currency crisis, financial crisis, house bubble collapse) and the different methods of testing.
The goal of this paper is to make an attempt to test whether there is a significant increase in country linkages between asset indices during the 2008 financial crisis.

After the summer of 2008 the financial markets really began to notice in what kind of trouble some financial institutions were. This happened mainly in the USA but also in Europe. These problems all started a year earlier during the subprime mortgage crisis. In this case the USA was to blame. Banks and other financial institutions had to write down billions of dollars. Bloomberg announced a press release where it stated that in August 2008 a little over 500 billion had been written down so far and they expected another 1000 billion in write downs yet to come. A few major financial players in the market fell and the financial market was at the beginning of a major crisis.

After the fall of Lehman Brothers in September 2008 the crisis really started off. During this period not only in the USA but also in Europe and Asia stock markets declined heavily. The expansion of the crisis from the USA to Europe and Asia leads to interesting topics for further investigation. How high is the level of interdependence between these continents during a crisis relative to a stable period?

The following section will provide information regarding the process of increasing country linkages during a crisis. After that, a data description will provide information how and which data will be used, and the reasons why certain countries were chosen and others not. After that the different models will be explained which will then be followed by the results and a comparison with other results. Finally, a short conclusion will describe the most important literature, models and results.

2 Literature

2.1 Modern Portfolio Theory

Every investor learns in his or her early years at school how to diversify an investment portfolio efficiently. Therefore practically every investor is familiar with the Modern Portfolio Theory (Markowitz, 1952). This is a theory which describes how investors can obtain the optimal return given a certain level of risk. If an investor has the option to invest in two different stocks and the expected return and standard deviation of these stocks are known, it is possible to calculate the total risk of a portfolio of these two stocks. The formula for the total risk of a portfolio depends on the standard deviation of the securities which is invested in. Also the weight of an individual security compared to the total value of the total portfolio is important, and last but maybe most important, the correlation between the two securities.

The expected return of an investment portfolio with two stocks is defined as the weight of a stock relative to the total value times its expected return:

$$E(R_p) = E(R_a)w_a + E(R_b)w_b \tag{1}$$

In formula (1) $E(R_p)$ is the expected return of the total portfolio. $E(R_a)$ and $E(R_b)$ are the expected returns for asset A and asset B. The variance of the portfolio can be calculated by using the following formula:

$$\sigma_p^2 = w_a^2\,\sigma_a^2 + w_b^2\,\sigma_b^2 + w_a w_b \sigma_a \sigma_b \rho \tag{2}$$

Where w_a the weight of security A as a ratio of the total is value of the portfolio and σ_a is the standard deviation of security A. This means that w_a + w_b is equal to 1. The correlation coefficient is given by ρ. The total variance of a portfolio (σ_p^2) depends on the correlation between these two securities. This is the key to an optimal portfolio. When the correlation coefficient is close to 0, the second part of formula (2) won't have that much effect anymore on the total variance. In case the correlation coefficient is negative, the total variance could become even lower than the lowest expected variance of the two assets independent. To do so, an investor should look at stocks from different industries and different countries. For example a technology company listed on the Nasdaq-100 will have a very low level of correlation with an oil company from Russia.

The world economy has become much more integrated. This effect is not only visible between national financial markets but also between regions within a country. Globalization does have many benefits. For instance, markets become much more efficient and transparent. And also import and export reaches to stable levels. However sometimes people tend to forget that when things go wrong market integration will cause a domino effect among other countries. Due to globalization a crisis can easily spread throughout the whole world since markets are highly connected.

Several authors have claimed that during highly volatile periods the correlation coefficient between countries increases. For instance Solnik, Boucrelle and Le Fur (1996) suggest a higher correlation coefficient during more volatile periods. They saw an increase in correlation during the October 1987 crash. Furthermore, they explain that every peak in correlation in the last few decades can be explained by some global event, such as a financial crisis, an asset bubble or an oil shock. King and Wadhwani (1990) also did some research regarding the level of correlation during and after the October 1987 crash. They find that in the weeks after a crash the correlation coefficient rises. They show similar results with Solnik, Boucrelle and Le Fur (1996). This means that during a crisis, in which stock prices move a lot, the benefits to diversify a portfolio internationally diminish.

Longin and Solnik (1995) came to the conclusion that international covariance and correlation matrices are unstable over time. They also found evidence of a positive trend in correlation during a period of 30 years. This is bad news for international investors because a lower correlation results in a lower variance of one's investment portfolio.

2.2 Contagion

In the last decades academics gained more interest about changes in the level of correlation during a crisis. Several academics began to use the term contagion for this situation. However, there isn't a general consensus of the definition of contagion. The result was that there were many different definitions of contagion. For instance, Dornbusch, Park and Claessens (2000) describe contagion as 'the spread of market disturbances—mostly on the downside—from one country to the other, a process observed through comovements in exchange rates, stock prices, sovereign spreads, and capital flows'.

The definition of Forbes and Rigobon (2002) sounds pretty much the same. They describe contagion as a significant increase in cross-market linkages. Hamao, Masulis and Ng (1990) do not refer specifically to contagion but they do investigate the spillover effect of the volatility of a stock market to another major stock market. They conclude that during a crisis this spillover effect is much bigger compared to a stable period, suggesting presence of contagion. They define contagion as an increase in spillover effects between markets.

Eichengreen, Rose and Wyplosz (1996) did some research about the presence of contagion during a currency crisis. They define contagion as 'a systematic effect on the probability of a speculative attack which stems from attacks on other currencies, and is therefore an additional effect above and beyond those of domestic fundamentals'.

And last, Bekeart (2005) describes contagion as excess correlation. Meaning that the correlation coefficient will be higher compared to the level of correlation based on economic fundamental values. Bekeart suggests with this definition that contagion is always caused by irrational behaviour of investors.

In this paper contagion will be defined as: an increase in cross-country linkages where a crisis in one country disturbs the financial markets of other countries. One could think of an increasing effect in the returns from one market to another. But also at the amount of volatility that spills over from one market to another.

2.3 How does a crisis spread?

According to Karolyi (2003) there are two types of contagion. The type of contagion is closely linked with the way the crisis spreads over to other countries.

2.3.1 Fundamental based contagion

First there is the 'fundamentals-based contagion'. This occurs when there is a normal linkage between two economies and one of these countries gets hit by a crisis. Countries are linked these days because of international trade. Consumers and companies import their products cheap from abroad and companies export their products. There are also many multinationals these days, these are companies that offer their services in multiple countries. But also companies that provide unique services, companies with a monopoly, offer their services abroad.

An example for fundamental-based contagion is a shift in the US interest rate policy to endorse lending and investing. A change like this can have an enormous effect on the capital flows and the exchange rate (Calvo and Reinhart 1996). More money will be available on the market and foreign investors will also try to lend their money in the US. Changes in capital flows and exchange rates can cause severe problems for other countries. The crisis expands through the fundamentals of a country. The fundamentals, such as money supply and government debt, can be more closely related between countries than for instance asset prices. Since chances in import, export or capital flows are always visible in at least two countries. Decreasing asset prices can be explained since the fundamentals of the country are changing. Dornbusch (2000) proved that policy changes and common shocks to an economy will have its greatest impact on asset prices and capital flows. Countries are linked through their balance of payments. The balance of payment consists of two major accounting posts, the current account and the financial account. Import and export of merchandise and raw materials are balanced on the current account. On the financial account of the US all foreign investments in stocks, bonds and real estate are balanced against all investments in the US from abroad.

These linkages are possibly even stronger between neighbour countries or between countries with a similar economy such as Belgium and the Netherlands or the USA and Canada. The chance that a crisis extends to a country nearby is high. This is not only because economies are highly linked but also the same type of culture and the same language have their effect.

Globalization and financial integration can be a way how a country can get involved with a crisis in another country. Import and export will chance rapidly and will not affect just the country where the crisis originated.

There any many other rational ways how a crisis can spread to other countries. Some countries with fixed exchange rates devaluate the exchange rate with other countries in order to stabilize their market. What happens when the government devaluates the national currency? The value of the national currency will become lower. For example, after a devaluation of the euro (assuming it has a fixed exchange regime) against the US dollar, an US investor can now buy more euros against the same amount of dollars. Therefore the euro region becomes cheaper for US investors and customers. The American citizens will now try to buy their products cheap in Europe, so the export of the euro zone will rise. This situation is favourable for Europe but not good for the US. Production of goods and sales will decrease since export rises. As a reaction, stock prices can decrease as well as company earnings and sales. This principle, where there is one country that benefits after a change of policy while there is another country which suffers from this decision, is called the beggar-thy-neighbour principle.
Corsetti, Pesenti, Roubini and Till (1999) found out that when a country is in a crisis and it therefore devaluates her currency, this devaluation is much bigger than what’s actually necessary based on the changes of fundamentals, causing an even heavier effect than expected.

Another very important and rational cause of contagion is the lack of liquidity. When stock prices decrease the liquidity of investors will decrease as well. This causes several problems. Investors still need to pay margin calls and have other payment requirements. Therefore they will be obliged to sell assets in other countries to provide themselves with some liquidity. This will give the crisis an opportunity to expand to other countries. This is a common process for hedge funds with highly leveraged positions. Hedge funds that have high leveraged positions will suffer more from an overall 1 percent decrease in the stock market due to their position. A hedge fund can gain more when prices rise, but they will also lose more when prices decrease. It is therefore very likely that hedge funds will have liquidity problems when prices drop rapidly. A crisis can also affect the credit rating of commercial and investment banks. This will also be a reason to sell assets in other countries to provide extra liquidity and raise the credit rating.

2.3.2 Irrational contagion

The second type of contagion according to Karolyi is caused by irrational behaviour of investors. Academics often refer in this situation to 'irrational contagion'. Irrational contagion occurs when investors sell their assets and bonds because somewhere else the stock market decreases rapidly. A good example is when an American investor sells his stocks the day on Black Monday in 1987. The reason for this was not because changes in the underlying value of the stock, but only because of the panic on the markets. Asian and European markets already suffered major losses, Wall Street opened when these markets were already closed. Moser (2003) calls this 'mental contagion', sell stocks and bonds in other countries because one gets frightened by the situation in other countries. But there is also another possible explanation for this type of contagion. Goldstein (1998) came up with the 'wake-up call' hypotheses. It could be that the major decreases gave a reason to check whether stock prices were right. Investors will reassess their positions to check if there is something wrong with their stocks as well. Chances are that they overlooked some things in an earlier stage and then decide to sell the asset.

A possible way to expand this example is to think of the possibility that a European investor wants to sell all its assets in a certain sector. Assuming that many institutional investors also have American stocks, they will probably try to sell these stocks as well, setting the downward trend in motion.

2.4 Previous research

As mentioned earlier, for the last two decades many people have looked at different ways to contagion and whether it existed or not. Hamao, Masulis and Ng (1990) were one of the first who took a look at the presence of contagion. They build a GARCH model to look for evidence of volatility spillovers during the 1987 crisis in the US. They found evidence of an increasing level of volatility spillover effect between the US, the UK and Japan. A few years later Calvo and Reinhart (1996) tried to look for presence of contagion. They found evidence of increasing comovements between several countries in Latin America when looking at weekly returns. This evidence was found during the Mexican Peso crisis in 1994.

Calvo and Reinhart (1996) were not the only who were searching for evidence of contagion during the Mexican Peso crisis. Edwards (1998) used an augmented GARCH model to test for contagion in interest rates during this crisis. Evidence showed that there was contagion between Mexico and Argentina but not between Mexico and Chile. A few years later Forbes and Rigobon (2002) began to do some research regarding contagion. They tried to calculate the conditional correlation coefficient during a stable and an unstable period. They figured out that the conditional correlation coefficient contained some errors making its estimates inaccurate, mainly caused due to heteroskedasticity. Therefore some adjustments were made to calculate the unconditional correlation coefficient. The conditional correlation coefficient suggested presence of contagion in the US stock market crisis in 1987, the Mexican Peso crisis in 1994 and the Asian crisis in 1997. According to the unconditional correlation coefficient, there was no evidence of contagion. But a few years later by using an advanced GARCH model, a multivariate GARCH model, evidence was found by Arestis et al. (2005). They found evidence of contagion during the Asian crisis.

The point is, is that there is no clear answer according to the research papers whether contagion exists. Since every model is different from another model, but also every definition of contagion, it is hard to judge whether a certain outcome really is evidence in favour of contagion.

3 Methodology

There are many possibilities to test for presence of contagion. Forbes and Rigobon (2002) look at the unconditional correlation coefficient. Eun and Shim (1989) try to identify the main channels of interaction between national markets using a vector autoregression system (VAR). Hamao, Masulis and Ng (1990) try to locate volatility spillovers from one financial market to another using a modified GARCH model.

3.1 Dummy variable test

In the following sections four different methods will be explained. The first method does not give evidence of contagion but it looks at the behaviour of investors during a crisis and its recovery. By introducing two dummies, the effects of a positive and a negative return of the S&P 500 can be separated:

$$R_{i,t} = \alpha + \beta_1 D_p R_{s\&p\ 500} + \beta_2 D_n R_{s\&p\ 500} + \varepsilon \qquad (3)$$

D_p is equal to 1 when the S&P 500 generates a positive return. In this case D_n is equal to 0. When the S&P 500 closes the day lower compared to last days closing price the dummy works the other way around. In that case D_p is equal to 0 and D_n equal to 1.

Rationally thinking, one would suggest that β_1 is equal to β_2. A situation where $\beta_2$is significantly bigger than β_1 means that negative returns of the S&P 500 have a bigger effect on foreign stock markets that positive returns. In a stable market, with relatively more positive returns, the effect of the S&P 500 will be lower. Contagion would suggest that during a crisis, a period generally with more negative returns than positive, these negative returns will have a bigger effect on the stock market of a foreign country.

3.2 Ordinary least square regression and heteroskedasticity

A standard procedure to test for differences between two periods would be with an ordinary least square (OLS) regression and run it twice for two different time periods, a stable and a turmoil period. And afterwards compare the coefficients. However, in many cases there is presence of heteroscedasticity in asset prices. Heteroscedasticity means that the variance of the errors is not constant. An assumption of the classic linear regression model (CLRM) is that these errors are constant. A way to correct for this is to use a Generalized Autoregressive Conditional Heteroscedasticity (GARCH) model. Therefore instead of an ordinary least square regression a GARCH model will be used for the following methods.

The most commonly used method to test for presence of heteroskedasticity is to conduct the White's test (1980). This test is introduced by Halbert White in 1980. The White's test is performed for every country. This test start with a regression model with the return of a country index as dependent variable and the return of the S&P 500 as the independent market:

$$R_{i,t} = \alpha + \beta_1 R_{S\&P\ 500} + \varepsilon \quad (4)$$

Without confirmation of the White's test that there is heteroskedasticity in the stock prices, there is no clear reason to use the GARCH models instead of the ordinary least squares regression models. White's test gives three different statistics, each calculated on a slightly different method. It is possible that not all three statistics suggest presence of heteroskedasticity. However, if one of the three statistics is significant, there is a plausible reason to use the GARCH models. The first test statistic is an F-test, which uses the residuals of the sum of squares (RSS) of both an unrestricted and a restricted regression. The second test is better known as the Lagrange Multiplier test, which uses a χ^2 distribution. The third test is based on the normalised version of the explained sum of squares.

3.3 GARCH (1, 1) Model

The second test in this paper uses a GARCH (1, 1) model. This model is somewhat similar to formula (4) but there are important differences. The addition in this model lies with the error term. The error term is now also a dependent variable. The value of the error term, also known as the conditional variance, depends on the information about the volatility of a previous period; and on the fitted variance from the last period. When information of only one previous period is used, the model has one lag. However, the model can also gather information from the last two or three periods. In this case the model has two or three lags.

The number of lags to determine the GARCH model is based on two different thoughts. First the GARCH (1, 1) model is the most commonly used in practice. And second the statistical evidence shows the same results. The Akaike information criterion, the Schwarz criterion and the Hannan-Quinn criterion should all be minimized. By testing for different values for the number of lags, the GARCH (1, 1) model fit the best according to the data. For some countries a different number of lags fitted better, but for the majority of the indices the GARCH (1, 1) model fitted best (Appendix A).

Only one lag for each independent variable is used to determine the conditional variance, hence the term GARCH (1, 1) model:

$$R_{i,t} = \beta_1 + \beta_2 R_{s\&p\ 500} + u_t \quad \text{with} \quad u_t \sim N\ (0, \sigma_t^2)$$
$$\sigma_{i,t}^2 = \alpha_0 + \alpha_1 u_{t-1}^2 + \beta\sigma_{t-1}^2 \tag{5}$$

The term $\alpha_1 u_{t-1}^2$ represents the effect of the volatility of the last period on the current conditional variance. This term has been referred to as the ARCH coefficient. The term $\beta\sigma_{t-1}^2$ tells something about the variance from the last period and its weight to the current conditional variance. This term is also known as the GARCH term. The term R_i is usually called the conditional mean, whereas σ_t^2 is usually referred to as the conditional variance. In the following sections these terms will be used more often.

By running this model in two different time periods, a stable and a turmoil period, significant changes in the coefficient β_2 indicate an increase in linkages between R_i and $R_{s\&p\ 500}$. Differences will be tested for significance with a two sample t-test:

$$t = \frac{\beta_1 - \beta_2}{\sqrt{\frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}}} \tag{6}$$

Where β_1 is the coefficient from the stable period, $\beta_2$the coefficient from the turmoil period, σ_1^2 the variance from the stable period and n_1 the number of observations from the stable period. A significant increase of β_2 will suggest presence of contagion.

3.4 The GARCH (1, 1)-M Model

The third method looks at contagion at a slightly different way. Presence of contagion will be pointed out when the volatility spillover between the US and other countries increases during a crisis. The methods are very familiar with the one of Hamao et al. (1990). Hamao also adds a moving average in the conditional mean. The first step to calculate the model is to generate the squared residuals from a GARCH-M model with only a constant included in the conditional mean.

This GARCH (1, 1)-M model looks as follows:

$$R_{S\&P\ 500} = \alpha + \boldsymbol{\beta\sigma} + u_t$$
$$\sigma_{i,t}^2 = \alpha_0 + \alpha_1 u_{t-1}^2 + \beta\sigma_{t-1}^2 \quad (7)$$

This means that the dependent variable $R_{S\&P\ 500}$ now also depends on $\beta\sigma$. The reason to add this term in the conditional mean is because it stabilizes the volatility process. When $\alpha_1 + \beta > 1$ the volatility process is very unstable, this extra term in the conditional mean equation is trying to correct for this process. It furthermore tries to reflect a risk premium. The conditional variance can be seen as a risk factor, the variance of a portfolio is a common risk measurement. Therefore an increase of the conditional variance is assumed to be an increase of risk. When the conditional variance is added to the conditional mean, an extra risk factor is added. If beta is positive and significant the effect of taking additional risk can be seen in an increase in R_t. And the variable is also useful for the next models.

The reason to use the squared residuals of this model is because these can be interpreted as volatility shocks. When the residuals are large, the deviations from model (7) are big. This is generally the case when there are some market disturbances, extreme positive or negative returns for instance. Small returns will get captured by the model. So during a stable period, with a constant trend, the residuals will be small. The squared residuals are an indicator when the volatility of the market rises.

Model (7) will be done twice, one time only for the stable period and one time for the entire period. The entire period consists of the stable period and the turmoil period. More of this will be explained in the data section.

The extended GARCH (1, 1) – M model will only change the conditional variance of formula (7):

$$R_{i,t} = \alpha + \beta\sigma + u_t$$
$$\sigma_{i,t}^2 = \alpha_0 + \alpha_1 u_{t-1}^2 + \beta\sigma_{t-1}^2 + \boldsymbol{\delta X_{usa,t}} \quad (8)$$

The variable X_t is the squared residual on time t and δ gives the effect of the squared residuals on σ_t^2. These residuals will be from the United States, meaning that the squared residuals from the S & P 500 will be used. When the coefficient is significant and positive there is volatility spillover from the Standard & Poor’s 500 to a foreign index.

The residuals derived from model (7) will be used in model (8). Model (7) has been calculated twice, once for the stable period and once for the whole period. The residuals of these models differ, since the periods are not equal even though the stable period is also included in the whole period. These residuals will be matched with the model they belong to. So when model (8) is tested for the entire period, the residuals are derived from model (7) when using the entire period. The last step is to compare the coefficients derived from the stable and entire period. Significant differences between the two coefficients will mean that there is an increase in spillover effects during a crisis. This significant increase suggests presence of contagion.

3.5 Extended GARCH (1, 1)-M Model

The last method is again an extension of the GARCH (1, 1) – M model. In the previous formula, (8), the squared residuals were only used in the conditional variance, σ_t^2, to find spillover effects. In the next situation the conditional mean, R_t, will also be adjusted. Now the return of the S&P 500 will be added to the conditional variance, as in model (5). Combining this with model (8) the model will not only identify spillover effects in the conditional variance but it will also identify the effect of the S&P 500 on the conditional mean.

This model is a combination of formula (4) and (8):

$$R_{i,t} = \alpha + \beta_1\sigma + \boldsymbol{\beta_2 R_{s\&p\,500}} + u_t$$

$$\sigma_{i,t}^2 = \alpha_0 + \alpha_1 u_{t-1}^2 + \beta\sigma_{t-1}^2 + \delta X_{usa,t} \qquad (9)$$

The squared residuals, $X_{usa,t}$, are from the same market as the return in the conditional mean, $R_{s\&p\,500}$.

3.6 Data

Each method described uses a different periods over time to find whether there was contagion during the 2008 financial crisis. The first method, with the dummy variable, uses a period between January 2008 and December 2009. This period does not only contain the large drop of stock prices but also a part of the recovery during the second part of 2009. The dummy also tries to calculate the effect of positive returns of the S&P500 on foreign countries; therefore the number of positive returns had to be balanced with the same amount of negative returns. These situation, crisis and recovery, would give the best view how foreign financial markets react on positive and negative returns of the Standard and Poor’s 500.

The start of the crisis is determined by three factors which are all connected, the fall of Lehman Brothers, the Standard & Poor's 500 and the CBOE Volatility Index (VIX). Lehman Brothers declared bankruptcy on the 15th of September 2008. From this day on, people finally understood that there was really something wrong. The fall of Lehman brothers was within seconds visible on the stock exchanges all over the world. The S&P 500 lost over 4,5% that day (Appendix C). The S&P 500 was not the only indicator that things went wrong. The VIX represents the implied volatility which is used to valuate options. However, this index also gives an expectation what the volatility of the markets will be in the following weeks (next 30 days). This index has a nickname, called the fear index. When the VIX is high, turmoil periods are up ahead. On the 15th of September the VIX rose above 30, where is has been below 30 almost the entire year. The months after that the VIX only increased more. The top was at the end of November, the VIX reached a value of 87. In May 2009 the index dropped below 30 again.

FIGURE 1: THE CBOE VOLATILITY INDEX

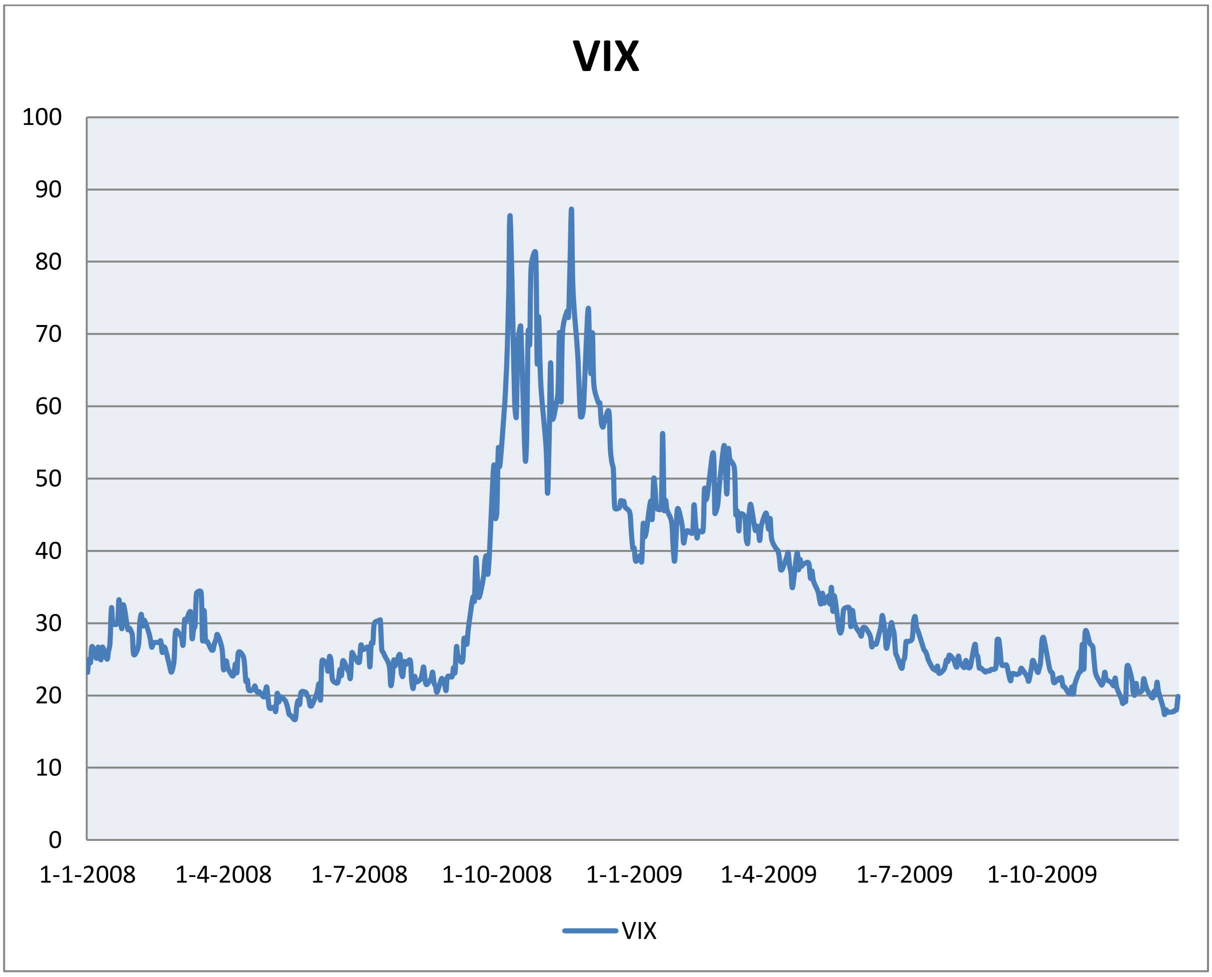

Figure 1: The VIX is an indicator of the expected volatility for the next 30 days. The graph shows a clear increase around September 2008, the time when the financial crisis started.

The GARCH (1, 1) model uses close-to-close returns. All returns are calculated in local currency. The stable period has been determined from the first of May 2008 until the end of August, 31-08-2008. After that the turmoil period starts, which is between the first of September 2008 and 30-11-2008. Both periods have a length of three months. Since the period is relatively short, also a test is conducted where both periods have a length of six months. The stable period is now between 01-02-2008 and 31-08-2008 and the turmoil period starts on 01-09-2008 and lasts until 28-02-2009.

The third and fourth method use a slightly different time period to test for volatility spillovers. Comparable to Hamao et al. (1990), the test includes two time periods. The first period contains a large stable period and a turmoil period. This period is defined as the whole period. The whole period is from 01-01-2007 until 28-02-2009. The second period only includes the stable period which is from 01-01-2007 until 31-08-2008.

Thirty three countries have been used to find evidence of contagion including the US as base country. Table 1 gives vital information regarding these countries and their indices. The dataset consists of fourteen European countries, three North American countries, three South American countries, nine Asian countries (including Australia), three countries from Africa and Kuwait from the Middle East.
Of course most European countries have a negative mean, given the severity of the crisis. It is also relatively easy to find which countries are emerging and which are not. Countries with a standard deviation above 2 percent are perfect candidates to be classified as emerging countries. However, there are a few exceptions. Chile and Tunisia for instance aren't the most developed countries but these two countries have the lowest standard deviation. It is also visible that some indices have made very high returns in the past. The index of Russia increased with more than 22% on one day. On the other side, it also lost the most value on one day and Russia also has the highest standard deviation.

Skewness and kurtosis say something about the normality of the returns of these indices. The Jarque-Bera statistic also gives evidence whether the indices returns are normally distributed. The Jarque-Bera statistic makes use of the level of skewness and kurtosis. If the level of skewness is close to zero, the returns are distributed rather normal. When the level of skewness is negative, the left tail is longer compared to the right tail. Malaysia is a good example of negative skewness (Appendix D). A high level of kurtosis means that there is a high peak around the mean and then a large decrease, such as Chile (Appendix E). When the level of kurtosis is around three, the returns are not peaked around the mean. A significant Jarque-Bera statistic means that the returns are not normally distributed. All JB-statistics in table 1 are significant. The Jarque-Bera statistic would be significant when both the skewness as the kurtosis is equal to three.

3.7 Sensitivity analyses

The results and coefficients from the previously mentioned methods will also be tested for their sensitivity to changes. Returns from the S&P 500 are not lagged for instance. Therefore the last three methods will be tested when returns and/or residuals are being lagged. Especially for the Asian and European indices this could cause large differences. The Asian markets are closed when the S&P 500 is open and the European markets are only two hours a day both open at the same time.

$$R_{i,t} = \beta_1 + \beta_2 R_{s\&p\ 500}(-1) + u_t$$
$$\sigma_{i,t}^2 = \alpha_0 + \alpha_1 u_{t-1}^2 + \beta\sigma_{t-1}^2 \qquad (10)$$

Also the extended GARCH (1, 1)-M model will have lagged returns in the conditional mean. Also the squared residuals will be lagged. It would make sense that this method should give very clear answers for the Asian and European indices.

$$R_{i,t} = \alpha + \beta_1\sigma + \beta_2 R_{s\&p\ 500}(-1) + u_t$$
$$\sigma_{i,t}^2 = \alpha_0 + \alpha_1 u_{t-1}^2 + \beta\sigma_{t-1}^2 + \delta X_{usa,t}(-1) \qquad (11)$$

Model (11) has lagged returns and lagged squared residuals.

TABLE 1: DESCRIPTIVE STATISTICS

	Mean	Median	Maximum	Minimum	Std. Dev.	Skewness	Kurtosis	Jarque-Bera
ARGENTINA	0.04%	0.03%	11.00%	-12.15%	2.19%	-0.46	8.09	873.51
AUSTRALIA	-0.01%	0.00%	5.79%	-8.34%	1.56%	-0.27	5.85	275.29
BELGIUM	-0.06%	0.00%	9.66%	-7.98%	1.70%	0.00	7.52	666.83
BRAZIL	0.08%	0.10%	14.66%	-11.39%	2.38%	0.25	8.34	939.51
CANADA	0.01%	0.09%	10.32%	-9.81%	1.85%	-0.35	8.50	1005.66
CHILE	0.03%	0.07%	9.48%	-4.89%	1.03%	0.22	15.14	4824.79
CHINA	0.08%	0.13%	9.45%	-8.84%	2.17%	-0.25	5.36	190.41
FRANCE	-0.03%	0.00%	11.18%	-9.04%	1.85%	0.37	9.38	1347.78
GERMANY	0.00%	0.03%	11.40%	-7.16%	1.79%	0.49	10.22	1739.00
GREECE	-0.07%	0.00%	9.54%	-9.71%	1.92%	-0.13	6.52	406.63
HONG KONG	0.04%	0.00%	14.35%	-12.70%	2.35%	0.37	8.33	945.54
INDIA	0.06%	0.03%	16.75%	-11.03%	2.19%	0.25	8.87	1134.77
ITALY	-0.06%	0.00%	11.49%	-8.24%	1.84%	0.27	8.77	1097.75
JAPAN	-0.04%	0.00%	14.15%	-11.41%	2.01%	-0.10	10.41	1798.90
KUWAIT	-0.05%	0.00%	5.29%	-7.24%	1.30%	-0.43	6.98	542.15
MALAYSIA	0.03%	0.01%	4.35%	-9.50%	1.07%	-1.08	12.36	3015.20
MEXICO	0.04%	0.07%	11.01%	-7.01%	1.80%	0.39	7.68	736.51
MORROCCO	0.10%	0.08%	4.56%	-4.89%	1.12%	-0.35	5.81	275.41
NETHERLANDS	-0.03%	0.00%	10.55%	-9.14%	1.91%	0.12	9.29	1294.96
POLAND	-0.02%	0.00%	6.27%	-7.95%	1.69%	-0.18	5.00	134.87
PORTUGAL	-0.02%	0.01%	10.20%	-9.86%	1.45%	0.01	11.62	2432.97
RUSSIA	0.01%	0.06%	22.39%	-19.10%	2.97%	0.20	12.84	3171.76
SOUTH AFRICA	0.03%	0.02%	7.07%	-7.30%	1.70%	0.03	5.17	154.26
SOUTH KOREA	0.04%	0.07%	12.23%	-10.33%	1.86%	-0.20	8.68	1059.99
SINGAPORE	0.02%	0.00%	7.82%	-8.33%	1.74%	0.03	5.74	245.42
SPAIN	-0.01%	0.02%	10.65%	-9.14%	1.79%	0.19	8.71	1072.45
SWEDEN	-0.01%	0.00%	10.37%	-7.24%	1.92%	0.38	6.39	395.74
SWISS	-0.03%	0.00%	11.39%	-7.79%	1.55%	0.37	9.72	1497.02
THAILAND	0.02%	0.00%	7.84%	-10.50%	1.63%	-0.55	8.52	1035.22
TUNISIA	0.08%	0.04%	3.24%	-4.88%	0.61%	-0.54	12.99	3303.85
TURKEY	-0.03%	0.00%	12.89%	-8.62%	2.12%	0.10	6.36	370.57
UK	0.00%	0.00%	9.84%	-8.85%	1.70%	0.14	8.80	1102.23
USA	-0.01%	0.04%	11.58%	-9.03%	1.85%	0.06	9.66	1451.77

Table 1: The descriptive statistics of daily returns of the most important indices of the world are shown. The second and third column gives the value of the mean and median of the daily returns. The two following columns give the value of the maximum and minimum increase on a trading day. Std. Dev. gives the standard deviation of the daily returns. The skewness, kurtosis and Jarque-Bera statistic can say something about the distribution of the returns.

4 Results

In the following sections the results of the different methods will be described. But for starters the results of the White's test will be discussed. The White's test gave values which indicate presence of heteroskedasticity. Unfortunately some country indices did not give a significant p-value. The p-values of China, Morocco and Tunisia were higher than the 5% confidence level required to define them significant (Appendix F). Nonetheless, these results gave a plausible reason to use the GARCH (1, 1) models in the following sections.

4.1 Dummy variable test

The first method used a dummy variable in the regression. The effects of positive and negative returns are hereby separated. This could give a more general look, whether countries are more dependent on negative or on positive returns of the Standard and Poor's 500. It could also tell something about the behaviour of investors.

Table 2 contains the results of the first method. There were in two years' time 266 positive daily returns on the S&P 500 between January 2008 and December 2009. There were 238 negative daily returns and on 19 days there was no return. This was due to several national holidays like Christmas and 4th of July. To get an image of the situation as correct as possible the number of positive returns should be balanced with the number of negative returns.

From the thirty two country indices that were compared with the S&P 500, 22 of them react heavier on a negative return of the S&P 500 than on a positive return. This is very hard evidence that investors do not react identical to a one percent positive and a one percent negative return of the S&P 500. During a crisis this does have serious consequences. The period between January 2008 and December 2009 contains a stable part, in the beginning of 2008, a part where stocks decrease rapidly, between September 2008 and March 2009 and the recovery from March 2009 until the end of the year. Low standard deviations and a high number of observations caused all the differences between the coefficients to be significant at a 5% confidence interval except for Greece.

TABLE 2: DUMMY VARIABLE TEST

$$R_{i,t} = \alpha + \beta_p D_p R_{s\&p\ 500} + \beta_n D_n R_{s\&p\ 500} + \varepsilon$$

Country	β_p	β_n	$\beta_p < \beta_n$?	t-value	p-value
Argentina	0.71	0.87	Yes	34.93	0.000
Australia	0.05	0.18	Yes	22.11	0.000
Belgium	0.46	0.56	Yes	18.98	0.000
Brazil	0.96	0.87	No	-22.03	0.000
Canada	0.65	0.88	Yes	55.92	0.000
Chile	-0.01	-0.03	Yes	-7.11	0.000
China	-0.05	0.02	Yes	9.15	0.000
France	0.65	0.77	Yes	24.57	0.000
Germany	0.67	0.74	Yes	17.00	0.000
Greece	0.34	0.34	No	-0.95	0.170
Hong Kong	0.38	0.13	No	-34.98	0.000
India	0.43	0.34	No	-11.96	0.000
Italy	0.57	0.70	Yes	25.82	0.000
Japan	0.00	0.14	Yes	23.10	0.000
Kuwait	-0.01	0.02	Yes	5.44	0.000
Malaysia	0.04	0.13	Yes	32.90	0.000
Mexico	0.71	0.76	Yes	17.46	0.000
Morocco	0.00	-0.04	No	-14.77	0.000
Netherlands	0.61	0.73	Yes	23.34	0.000
Poland	0.43	0.35	No	-14.78	0.000
Portugal	0.30	0.32	Yes	4.36	0.000
Russia	0.59	0.27	No	-34.27	0.000
Singapore	0.27	0.20	No	-13.11	0.000
South Africa	0.38	0.40	Yes	2.47	0.007
South Korea	0.17	0.22	Yes	8.40	0.000
Spain	0.62	0.66	Yes	9.55	0.000
Sweden	0.65	0.56	No	-16.41	0.000
Swiss	0.44	0.48	Yes	7.45	0.000
Thailand	0.19	0.22	Yes	5.56	0.000
Tunisia	0.02	0.01	No	-1.79	0.037
Turkey	0.00	0.03	Yes	4.34	0.000
UK	0.54	0.64	Yes	22.54	0.000
Number	266	238			

Table 2:The Dummy variable test. Beta P is the coefficient which shows what the effect of a positive return of the S&P 500 on the index of a certain country is. Beta N shows what the effect of a negative return of the S&P 500 is to another index. Rationally thinking beta p should be equal to beta n. The fourth column shows whether beta n is bigger than beta p or not. The fifth column shows the t-value of the difference with in the last column the corresponding p-value.

The developed West-European countries typically show coefficients above 0.5. Greece, Poland and Portugal are an exception of this rule. A reason for this could be that these countries are not as developed as for instance the United Kingdom or Holland. Also the countries nearby America, Canada and Mexico, have high coefficients compared to the rest. Argentina and Brazil give the highest coefficients, even though these countries do not lie directly next to America. The high coefficients are not expected, since these two countries have a completely different kind of economy compared to America. Argentina and Brazil are very dependent on commodities; both countries produce huge amounts of steel and have a big agriculture sector. A possible reason for this could be that American investors see these two countries as two very stable developing countries with high future potentials. It could be the case that American investors have large influences on the stock markets in these countries since they might own large amounts of shares. Also another possibility could be that the large hedge funds had to withdraw money from these areas in order to meet margin calls and other payment requirements when stocks dropped on Wall Street.

According to the coefficient of table 2, Brazil and Argentina are very vulnerable when a crisis occurs in the United States. Strange then are the low coefficients of Chile, which lies next to Argentina. The economy of Chile is very dependent on international trade; therefore high coefficients would be expected.

The Asian indices gave low coefficients. The most likely reason for this is the fact that the returns from the S&P 500 are generated when the stock exchanges are closed in Asia for at least eight hours. Since Asia is in a completely different time zone, the stock exchanges in these regions are open before the US stock exchanges for that same day are opening (See Appendix G). There is no overlap in trading hours. Lagged returns could possibly adjust the coefficient in such way that the effect of the S&P 500 on these countries is better visible. But what is important is that six of the nine Asian indices showed a significant difference between β_p and β_n.

The point of this test is to see that investors react different when negative returns are generated, and especially that the influence of America to other stock markets becomes larger with negative returns in the US. During a crisis this is very important. Human interference could be the main reason why this happened. Negative returns in America, the leading economy of the world, will cause doubts and fear among international investors. Investors then withdraw their accounts all over the world.

4.2 The GARCH (1, 1) Model

For the second method a GARCH (1, 1) model was used to test for contagion. The coefficients of the turmoil period were compared with the period just before the crisis hit the markets, from June 2008 until the end of August 2008. Table 3 gives the results from the GARCH (1, 1) model.

The effect of returns of the S&P 500 is very different between regions. Twenty-one of thirty-two country indices show an increase in dependence on the S&P 500. Many county indices gave significant coefficients from the models. Therefore almost every indices (except for the UK) the difference between the stable and turmoil period was significant at a 5% confidence level.

The indices from Argentina and Brazil become significantly more dependent of the United States according to this model. Brazil even has a beta which is bigger than 1. The effect of the returns of the S&P 500 on the Argentinian stock exchange is doubled compared to the stable period. But again, just like with the dummy variable, America does not have that much effect on the Chilean stock exchange. A possible reason for Argentina and Brazil could be related to the subprime mortgage crisis. During this period the financial sectors of South America and North America got disconnected. The subprime mortgage crisis was much less active in these regions. A year later, when the worldwide financial crisis started, Argentina and Brazil also got affected by this crisis. The markets reconnected during this period again. This could be a reason why the coefficients increased during the time of crisis. But again the future potential and the liquidity problems at hedge funds could also be an explanation.

Unfortunately it does not explain why America does not have any effect on the Chilean stock exchange. There is a lot of international trade between Chile and America, which would most likely increase the coefficients, Chile is much dependent on this export. Argentina and Brazil have convincing coefficients but Chile has a coefficient of 0.08 in the stable period and -0.02 during the crisis. This effect can be minimized. When graphing the returns of Chile and then compare them with the returns of the S&P 500 it becomes clear that the Chilean stock exchange is immune to the state of the economy in the US (Appendix H).

There is also evidence of contagion between Asia and North America. From the nine Asian indices, eight of them show a significantly increasing beta coefficient, pointing out that contagion occurred during the latest crisis. China is the only Asian country where there is no evidence of contagion. There is also evidence that the effect of America on Japan has increased, however, this effects is not significant. All coefficients are very low relative to the coefficients of for instance Argentina or Brazil.

TABLE 3: GARCH (1, 1) MODEL WITH A 3 MONTH CRISIS PERIOD

$$R_{i,t} = \beta_1 + \beta_2 R_{s\&p\,500} + u_t \quad \text{with} \quad u_t \sim N\,(0, \sigma_t^2)$$

$$\sigma_{i,t}^2 = \alpha_0 + \alpha_1 u_{t-1}^2 + \beta \sigma_{t-1}^2 \tag{5}$$

	Stable Period 3 Months		Turmoil Period 3 Months				
Country	Coefficient	Std. Dev.	Coefficient	Std. Dev	T>S	t-value	p-value
Argentina	0.40	0.18	0.85	0.06	TRUE	19.05	0.000
Australia	-0.13	0.15	0.11	0.04	TRUE	12.24	0.000
Belgium	0.68	0.13	0.52	0.01	FALSE	-9.88	0.000
Brazil	0.59	0.13	1.07	0.07	TRUE	25.84	0.000
Canada	0.38	0.00	0.87	0.07	TRUE	53.36	0.000
Chile	0.08	0.09	-0.02	0.03	FALSE	-8.65	0.000
China	0.34	0.14	-0.03	0.05	FALSE	-19.35	0.000
France	0.60	0.13	0.57	0.06	FALSE	-2.09	0.018
Germany	0.55	0.11	0.59	0.01	TRUE	3.45	0.000
Greece	0.02	0.16	0.41	0.08	TRUE	17.52	0.000
Hong Kong	-0.18	0.00	0.39	0.13	TRUE	35.27	0.000
India	0.08	0.26	0.46	0.11	TRUE	10.78	0.000
Italy	0.51	0.12	0.44	0.02	FALSE	-4.81	0.000
Japan	-0.02	0.14	0.08	0.14	TRUE	3.82	0.000
Kuwait	0.02	0.05	-0.03	0.00	FALSE	-7.36	0.000
Malaysia	-0.12	0.00	0.04	0.04	TRUE	28.70	0.000
Mexico	0.60	0.00	0.77	0.01	TRUE	93.17	0.000
Morocco	0.07	0.08	-0.03	0.02	FALSE	-9.30	0.000
Netherlands	0.66	0.10	0.60	0.02	FALSE	-4.57	0.000
Poland	0.21	0.14	0.31	0.06	TRUE	5.09	0.000
Portugal	0.25	0.16	0.42	0.07	TRUE	7.95	0.000
Russia	-0.21	0.15	0.45	0.00	TRUE	34.83	0.000
Singapore	-0.05	0.15	0.29	0.10	TRUE	15.20	0.000
South Africa	0.30	0.11	0.36	0.08	TRUE	3.61	0.000
South Korea	-0.05	0.17	0.21	0.13	TRUE	9.70	0.000
Spain	0.64	0.17	0.54	0.09	FALSE	-4.21	0.000
Sweden	0.39	0.01	0.55	0.04	TRUE	31.24	0.000
Swiss	0.47	0.10	0.45	0.10	FALSE	-1.68	0.046
Thailand	-0.10	0.16	0.23	0.09	TRUE	14.36	0.000
Tunisia	0.00	0.03	0.01	0.01	TRUE	2.38	0.009
Turkey	-0.08	0.05	-0.02	0.04	TRUE	7.46	0.000
UK	0.50	0.11	0.49	0.04	FALSE	-1.26	0.103
Observations	65		65				

Table 3: Coefficients represent the value of β_2 generated from the GARCH (1, 1) model. High standard deviations make the results less reliable. If T>S then the turmoil period is bigger than the coefficient of the stable period. T-values are calculated with the use of formula (6).

Of course there is a possibility that the sensitivity analysis does not give very conclusive results regarding the coefficients of the Asian countries. In that case there has to be another reason why the coefficients of the Nikkei and the other Asian stock exchanges are that small. A possible reason could be that the financial crisis did not hit the Asian continent as hard as it did in Europe and America.

Half of the European country indices show signs of an increased linkage between the stock returns of their domestic market and the S&P 500 when looking at the three month period. This seems a little bit low; one would expect higher coefficients during the crisis. The crisis was very severe in Europe. Many banks needed extra money from governments to survive, unemployment rose, many companies had to declare bankruptcy and sales and profits decreased. Two years after the beginning of the crisis European countries still have trouble recovering from the crisis. It is difficult to find a pattern in Europe. Which stock exchanges do have evidence of contagion and which do not?

The S&P 500 only had more influence on the DAX when looking at the developed and large European countries. The length of the period could be a possible explanation. The following test, with the 6 month crisis period, will point out whether this influences the results or not.

Again a possible reason for the lack of evidence of contagion is the trading hours. The AEX, DAX and CAC-40 have an overlap of approximately two hours. Of course, some news available on the American markets will already be visible on these European stock exchanges. But in the other six trading hours in America a tiny news report can set the whole markets upside down.

Some other remarks regarding table three. The effect of America on the Russian stock exchange has increased most. In the stable period the coefficient was -0.21, so an increase of the S&P 500 had a negative effect on the Russian index, but in the turmoil period the coefficient was almost 0.5, an increase over 300 percent. The 0.5 is also extremely high given the relationship between America and Russia.
Another remarkable result is the level of the coefficient of Canada. Since it is the neighbour country of America, the coefficient of the stable period would be expected higher. The coefficient generated from the turmoil period gives a far more realistic value compared to the coefficient from the stable period.
And the effect of the S&P 500 on the African markets is very low. This was also the case with the dummy variable. Several emerging countries such as Turkey, Morocco, Tunisia, Malaysia and Chile had very low coefficients. This could be explained by the fact that these countries are emerging markets and this will probably stay so for a while.

TABLE 4: GARCH (1, 1) MODEL WITH A 6 SIX MONTH CRISIS PERIOD

$$R_{i,t} = \beta_1 + \beta_2 R_{s\&p\ 500} + u_t$$

$$\sigma_{i,t}^2 = \alpha_0 + \alpha_1 u_{t-1}^2 + \beta \sigma_{t-1}^2 \qquad (5)$$

	Stable Period 6M		Turmoil Period 6M				
Country	Coefficient	Std. Dev.	Coefficient	Std. Dev.	T>S	t-value	p-value
Argentina	0.48	0.11	0.77	0.06	TRUE	27.48	0.000
Australia	-0.06	0.11	0.10	0.06	TRUE	14.35	0.000
Belgium	0.60	0.08	0.37	0.06	FALSE	-27.34	0.000
Brazil	0.85	0.11	0.96	0.05	TRUE	9.96	0.000
Canada	0.58	0.06	0.84	0.05	TRUE	38.04	0.000
Chile	0.03	0.07	-0.03	0.02	FALSE	-8.04	0.000
China	-0.02	0.16	-0.06	0.04	FALSE	-2.83	0.002
France	0.64	0.08	0.54	0.04	FALSE	-13.72	0.000
Germany	0.62	0.07	0.59	0.05	FALSE	-3.94	0.000
Greece	0.15	0.11	0.33	0.06	TRUE	16.84	0.000
Hong Kong	-0.05	0.04	0.27	0.08	TRUE	42.47	0.000
India	0.12	0.18	0.35	0.08	TRUE	13.30	0.000
Italy	0.52	0.08	0.45	0.07	FALSE	-8.13	0.000
Japan	0.05	0.12	0.00	0.08	FALSE	-4.33	0.000
Kuwait	0.02	0.05	0.01	0.05	FALSE	-0.61	0.269
Malaysia	-0.02	0.00	0.05	0.03	TRUE	29.53	0.000
Mexico	0.63	0.03	0.69	0.03	TRUE	14.37	0.000
Morocco	0.02	0.07	-0.02	0.02	FALSE	-7.67	0.000
Netherlands	0.61	0.07	0.58	0.07	FALSE	-3.57	0.000
Poland	0.28	0.09	0.30	0.06	TRUE	1.57	0.058
Portugal	0.25	0.09	0.27	0.04	TRUE	2.47	0.007
Russia	0.05	0.11	0.40	0.15	TRUE	21.28	0.000
Singapore	0.08	0.10	0.22	0.07	TRUE	13.52	0.000
South Africa	0.22	0.09	0.33	0.07	TRUE	11.02	0.000
South Korea	0.08	0.11	0.20	0.09	TRUE	9.95	0.000
Spain	0.66	0.10	0.52	0.06	FALSE	-13.77	0.000
Sweden	0.57	0.11	0.56	0.06	FALSE	-1.09	0.137
Swiss	0.49	0.09	0.35	0.03	FALSE	-16.48	0.000
Thailand	-0.02	0.08	0.23	0.06	TRUE	27.32	0.000
Tunisia	0.02	0.02	0.01	0.01	FALSE	-4.82	0.000
Turkey	-0.01	0.11	0.00	0.05	TRUE	1.70	0.045
UK	0.54	0.07	0.49	0.06	FALSE	-7.02	0.000
Observations	130		130				

Table 4: Coefficients represent the value of β_2 generated from the GARCH (1, 1) model. High standard deviations make the results less reliable. If T>S then the turmoil period is bigger than the coefficient of the stable period. T-values are calculated with the use of formula (6).

The GARCH (1, 1) model was also tested with a stable and a turmoil period of six months each. The result of this test is somewhat different from the result of the shorter period. Table 4 provides the numbers. From the thirty two indices seventeen showed a significant increase of β_2. The Nikkei now shows a decline in dependency on the S&P 500. Nothing else dramatically changed for the other Asian indices.

For the European indices results show even fewer evidence of contagion. The beta of the DAX increased for the stable period while it did not change in value for the turmoil period. And also the presence of contagion in Sweden disappeared after the initial and turmoil period were extended. The differences between these periods became insignificant in the case of Sweden. Also for Kuwait and Poland differences became insignificant at a 5% confidence level.

The North American countries show clear significant increases in their beta, which is to be expected. Contagion is also visible in Latin America, in Argentina and Brazil. In Europe, some indices reacted quite differently to changes of the S&P 500. The Bel-20 for instance showed a decrease of more than 40%. The reason for this to happen is probably country specific. The effect of the extended period is for each country different compared to the test with a 3 month period. In Belgium the beta dropped dramatically in the turmoil period, while in Germany the beta of the stable period increased and in France the coefficient of the stable period increased and the coefficient of the turmoil period decreased. There is no logical reason why the coefficients went up or down for certain countries. The result of the extended period test does not give extraordinary results.

4.3 The GARCH (1, 1)-M Model

This method tries to identify increases of the volatility spillover effect. The volatility of the S&P 500 is defined as the squared residuals of the GARCH-M model (7). The effects of the squared residuals are visible in the conditional variance where the squared residuals have the function to act as a volatility surprise. During a crisis squared residuals are assumed to be higher, and therefore the coefficients should increase during the crisis period unless there is no strong connection between the S&P 500 and the other indices.

The results of the GARCH (1, 1)-M model are visible in table 5. With this method not only the significant differences between two periods are important, but it is also important whether the coefficients itself are significant. Chile for instance has two low coefficients, both insignificant, but the difference between these coefficients is significant. Can we now speak of a significant increase in volatility spillover effects while the coefficients itself are not significant? There are seven cases where this happens, Chile is one of them but also China, Kuwait, Morocco, Thailand, Tunisia and Turkey have insignificant coefficients. Overall in 17 out of 32 countries there was evidence of an increase in volatility spillovers. This is not enough to conclude that there was clear evidence of contagion.

Again the American countries (Argentina, Canada, Mexico and Brazil) show that they become more affected by the state of the S&P 500 during the crisis. The coefficient of Brazil is in both test results above 1, Mexico also has very high coefficients. During the previous tests Argentina also had a solid connection with the S&P 500 but when it comes to volatility spillover, the effect is rather low. Again the Chilean index is not very affected by any movements of the S&P 500.

The effect on the Asian indices is pretty different compared to previous results. The GARCH (1, 1) model gave clear evidence of contagion during the crisis. With this method this is not the case. Now only three of the nine Asian indices used show an increase between the two periods. China, South Korea and Thailand have a significant increase of their delta coefficient when comparing the stable period with the whole period. These results are more logical, since the residuals are not lagged; the changes of the volatility in the S&P 500 are too late for the Nikkei and the other Asian indices to have an effect. In case of lagged residuals high coefficients and significant increases are to be expected. Also China and Thailand both had highly insignificant coefficients. How can those coefficients be interpreted? These results should be discussed carefully and should not have much influence on the primary conclusion.

Even though it does sound logical, that the coefficients of the Asian indices should not have that much effect of returns of the S&P 500 which are generated after the Asian markets close. The coefficients of the Asian indices are is some cases pretty high and significant. The mean is around 0.2 but there are some indices such as the Hang Seng which reports coefficients of 0.34.

TABLE 5: GARCH (1, 1)-M MODEL

$$R_{i,t} = \alpha + \beta\sigma + u_t$$

$$\sigma_{i,t}^2 = \alpha_0 + \alpha_1 u_{t-1}^2 + \beta\sigma_{t-1}^2 + \delta X_{usa,t} \quad (8)$$

	Stable Period		Whole Period				
	δ	p-value	δ	p-value	W>S	t-value	p-value
Argentina	0.341	0.000	0.397	0.000	TRUE	16.163	0.000
Australia	0.202	0.003	0.158	0.001	FALSE	-11.856	0.000
Belgium	0.262	0.000	0.240	0.000	FALSE	-5.915	0.000
Brazil	1.061	0.000	1.264	0.000	TRUE	12.496	0.000
Canada	0.300	0.000	0.254	0.000	FALSE	-11.379	0.000
Chile	-0.003	0.426	0.000	0.698	TRUE	18.251	0.000
China	-0.015	0.153	0.003	0.280	TRUE	34.782	0.000
France	0.293	0.001	0.326	0.000	TRUE	6.299	0.000
Germany	0.250	0.001	0.286	0.000	TRUE	8.204	0.000
Greece	0.120	0.001	0.140	0.000	TRUE	9.378	0.000
Hong Kong	0.344	0.002	0.288	0.001	FALSE	-8.679	0.000
India	0.179	0.001	0.084	0.002	FALSE	-34.603	0.000
Italy	0.236	0.001	0.271	0.000	TRUE	7.935	0.000
Japan	0.199	0.000	0.195	0.000	FALSE	-1.258	0.104
Kuwait	-0.016	0.330	0.022	0.001	TRUE	44.548	0.000
Malaysia	0.134	0.001	0.020	0.019	FALSE	-58.713	0.000
Mexico	0.706	0.000	0.719	0.000	TRUE	1.385	0.083
Morocco	-0.010	0.323	-0.004	0.001	TRUE	12.262	0.000
Netherlands	0.246	0.000	0.298	0.000	TRUE	12.275	0.000
Poland	0.260	0.000	0.177	0.000	FALSE	-29.253	0.000
Portugal	0.109	0.006	0.108	0.000	FALSE	-0.629	0.265
Russia	0.099	0.011	0.124	0.001	TRUE	10.588	0.000
Singapore	0.250	0.006	0.161	0.001	FALSE	-18.582	0.000
South Africa	0.177	0.002	0.158	0.001	FALSE	-5.639	0.000
South Korea	0.260	0.001	0.269	0.000	TRUE	1.823	0.034
Spain	0.228	0.001	0.255	0.000	TRUE	6.472	0.000
Sweden	0.373	0.000	0.436	0.000	TRUE	10.352	0.000
Swiss	0.221	0.000	0.208	0.000	FALSE	-3.961	0.000
Thailand	0.028	0.234	0.034	0.018	TRUE	5.085	0.000
Tunisia	0.003	0.433	0.000	0.130	FALSE	-18.789	0.000
Turkey	-0.086	0.011	0.002	0.693	TRUE	54.033	0.000
UK	0.258	0.000	0.244	0.000	FALSE	-3.436	0.000
Observations	435		565				

Table 5: Coefficients generated from the GARCH (1, 1)-M model with corresponding p-values. The sixth column tells whether the coefficient of the whole period is larger than the coefficient of the stable period. T-values are calculated with the use of model (6).

So the Asian markets do not give clear evidence of contagion. The leading indices in Europe do show an increase in the delta coefficient. More than 60% of the indices have a higher delta over the whole period compared to the stable period. The crisis did hit Europe as hard as it did in America, especially compared to the Asian region. That could be a solid explanation why the effect is visible in Europe and not in Asia. But still, the residuals are not lagged and therefore it should make the most sense if the coefficients had small effects, with high standard deviations. However for this model, the size does not necessarily have to matter. It matters whether a coefficient is significant or not. When that is the case, there is an indirect effect on the return of the AEX caused by high volatility of the S&P 500. And when the delta of model (8) is significantly higher for the whole period compared to the stable period there is an increase in volatility spillover. This effect is according to table 5 visible in Europe and in America but not in Asia and Africa.

4.4 Extended GARCH (1, 1)-M Model

The extended GARCH (1, 1)-M model does not only use the squared residuals mentioned in the previous sector but also the return of the S&P 500 to see what happened with international connections between the leading indices of the world. Table 6 and table 7 give the results of the extended GARCH (1, 1)-M model. Table 6 discusses the value of the β_2 coefficient of model (9), the effect of the return of the Standard & Poor's 500 on the return of an index. In table 7 the effect of the squared residuals on the conditional variance is described.

The results of table can be compared with table 4, but the testing periods do not match for the two different models. The height of β_2 is now not the only independent variable in the conditional mean. The conditional mean is now also affected by the GARCH term. And this GARCH term is affected by the value of the squared residuals. High volatility of the S&P 500 gets translated from the conditional variance to the condition mean through the GARCH term in the conditional mean. Table 7 can be compared with table 5, but again since model (9) is slightly different there is not much to conclude about any comparisons or differences between the two tables.

In table 6 only 15 of the 32 comparisons show an increased $\beta_2$coefficient. In the regular GARCH (1, 1) model there were more than twenty indices which had an increased β_2. Table 7 also does not give evidence in favour of contagion. For only thirteen indices the conditional variance got more affected by the squared residuals. There are a few 'exceptions' which had both an increasing β_2 as an increase in the δ coefficient.

TABLE 6: EXTENDED GARCH (1, 1)-M MODEL; CONDITIONAL MEAN

$$R_{i,t} = \alpha + \beta_1\sigma + \boldsymbol{\beta_2 R_{s\&p\ 500}} + u_t$$

$$\sigma_{i,t}^2 = \alpha_0 + \alpha_1 u_{t-1}^2 + \beta\sigma_{t-1}^2 + \delta X_{usa,t} \qquad (9)$$

	Stable Period		Whole Period				
	β_2	p-value	β_2	p-value	W>S	t-value	p-value
Argentina	0.677	0.000	0.702	0.000	TRUE	7.027	0.000
Australia	0.090	0.213	0.103	0.065	TRUE	3.054	0.001
Belgium	0.561	0.000	0.514	0.000	FALSE	-14.540	0.000
Brazil	1.168	0.000	1.083	0.000	FALSE	-23.772	0.000
Canada	0.694	0.000	0.725	0.000	TRUE	14.208	0.000
Chile	0.005	0.830	-0.012	0.455	FALSE	-13.302	0.000
China	0.030	0.650	-0.027	0.490	FALSE	-15.854	0.000
France	0.614	0.000	0.607	0.000	FALSE	-2.301	0.011
Germany	0.553	0.000	0.561	0.000	TRUE	2.410	0.008
Greece	0.340	0.000	0.336	0.000	FALSE	-1.359	0.087
Hong Kong	0.104	0.285	0.168	0.020	TRUE	11.576	0.000
India	0.177	0.063	0.267	0.000	TRUE	17.060	0.000
Italy	0.526	0.000	0.510	0.000	FALSE	-4.945	0.000
Japan	0.092	0.180	0.089	0.136	FALSE	-0.687	0.246
Kuwait	0.021	0.484	0.003	0.929	FALSE	-9.150	0.000
Malaysia	0.080	0.113	0.058	0.028	FALSE	-8.170	0.000
Mexico	0.874	0.000	0.790	0.000	FALSE	-31.939	0.000
Morocco	0.008	0.845	-0.008	0.630	FALSE	-7.570	0.000
Netherlands	0.560	0.000	0.579	0.000	TRUE	6.298	0.000
Poland	0.404	0.000	0.357	0.000	FALSE	-12.594	0.000
Portugal	0.284	0.000	0.280	0.000	FALSE	-1.344	0.089
Russia	0.231	0.003	0.265	0.000	TRUE	7.341	0.000
Singapore	0.175	0.027	0.195	0.001	TRUE	4.386	0.000
South Africa	0.327	0.000	0.331	0.000	TRUE	1.063	0.144
South Korea	0.163	0.038	0.182	0.004	TRUE	3.924	0.000
Spain	0.538	0.000	0.538	0.000	TRUE	0.216	0.414
Sweden	0.600	0.000	0.603	0.000	TRUE	0.773	0.220
Swiss	0.476	0.000	0.442	0.000	FALSE	-10.923	0.000
Thailand	0.091	0.093	0.147	0.001	TRUE	17.460	0.000
Tunisia	0.025	0.191	0.011	0.128	FALSE	-14.126	0.000
Turkey	-0.029	0.660	-0.009	0.832	TRUE	5.646	0.000
UK	0.555	0.000	0.541	0.000	FALSE	-4.440	0.000
Observations	435		565				

Table 6: The second column gives the value of the β_2 coefficient of model (9). The p-values match with the coefficient. The sixth column tells whether the coefficient of the whole period is larger than the coefficient of the stable period. T-values are calculated with the use of model (6).

TABLE 7: EXTENDED GARCH (1, 1)-M MODEL; CONDITIONAL VARIANCE

$$R_{i,t} = \alpha + \beta_1 \sigma + \beta_2 R_{s\&p\ 500} + u_t$$

$$\sigma^2_{i,t} = \alpha_0 + \alpha_1 u^2_{t-1} + \beta \sigma^2_{t-1} + \boldsymbol{\delta X_{usa,t}} \quad (9)$$

	Stable Period		Whole Period				
	δ	p-value	δ	p-value	W>S	t-value	p-value
Argentina	0.168	0.000	0.154	0.000	FALSE	-7.480	0.000
Australia	0.205	0.002	0.158	0.001	FALSE	-12.537	0.000
Belgium	0.122	0.000	0.110	0.000	FALSE	-6.161	0.000
Brazil	0.153	0.000	0.157	0.000	TRUE	1.518	0.064
Canada	0.016	0.034	0.022	0.000	TRUE	15.787	0.000
Chile	-0.004	0.421	0.000	0.741	TRUE	18.131	0.000
China	-0.015	0.171	0.003	0.288	TRUE	33.223	0.000
France	0.134	0.001	0.137	0.000	TRUE	1.018	0.154
Germany	0.099	0.002	0.094	0.000	FALSE	-3.150	0.001
Greece	0.072	0.010	0.072	0.002	FALSE	-0.278	0.391
Hong Kong	0.344	0.002	0.276	0.001	FALSE	-10.747	0.000
India	0.171	0.001	0.055	0.008	FALSE	-46.295	0.000
Italy	0.097	0.001	0.119	0.000	TRUE	11.847	0.000
Japan	0.200	0.000	0.195	0.000	FALSE	-1.563	0.059
Kuwait	-0.015	0.368	0.022	0.001	TRUE	42.716	0.000
Malaysia	0.138	0.001	0.019	0.026	FALSE	-61.567	0.000
Mexico	0.076	0.019	0.053	0.003	FALSE	-13.501	0.000
Morocco	-0.010	0.405	-0.004	0.002	TRUE	10.019	0.000
Netherlands	0.116	0.000	0.133	0.000	TRUE	8.531	0.000
Poland	0.104	0.036	0.093	0.006	FALSE	-3.790	0.000
Portugal	0.088	0.004	0.081	0.000	FALSE	-4.044	0.000
Russia	0.089	0.008	0.113	0.000	TRUE	11.644	0.000
Singapore	0.245	0.004	0.137	0.001	FALSE	-24.483	0.000
South Africa	0.139	0.006	0.112	0.003	FALSE	-9.566	0.000
South Korea	0.248	0.001	0.249	0.000	TRUE	0.287	0.387
Spain	0.110	0.001	0.106	0.001	FALSE	-2.160	0.015
Sweden	0.195	0.007	0.166	0.002	FALSE	-7.041	0.000
Swiss	0.106	0.001	0.103	0.000	FALSE	-1.940	0.026
Thailand	0.026	0.266	0.028	0.024	TRUE	2.046	0.020
Tunisia	0.002	0.603	0.000	0.201	FALSE	-13.225	0.000
Turkey	-0.085	0.011	0.002	0.690	TRUE	53.717	0.000
UK	0.130	0.001	0.114	0.000	FALSE	-7.440	0.000
Observations	435		565				

Table 7: The second column gives the value of the δ coefficient of model (9). The p-values match with the coefficient. The sixth column tells whether the coefficient of the whole period is larger than the coefficient of the stable period. T-values are calculated with the use of model (6).

With the previous models it was the case that both Argentina and Brazil always showed evidence of an increase in the coefficient discussed. Table 6 however does not show these results. Even though the coefficients of both indices are still significant and high, there is no evidence of contagion for Brazil. Also Mexico does not have a higher coefficient for the whole period compared to the stable period. With millions of Mexicans living in America this does not seem logical. The squared residuals do have an increased effect on the conditional variance for all these countries. One would expect that if the squared residuals have an increased effect on the conditional variance, the returns of the S&P 500 would most definitely have an increase as well.
There is no general consensus of the results of the American indices. Canada is the only country where the effect of the S&P 500 has increased since the start of the crisis but also the effect of the squared residuals increased. The other countries do not show these increases.

The African countries do not show very significant results. The coefficients of the indices of Morocco and Tunisia are not significant while the difference between the two periods for South Africa is not significant as well.

The stock exchanges of Thailand and South Korea are the only indices in Asia that have an increase in both the β_2 coefficient as the δ coefficient. Unfortunately the difference of the delta coefficient of South Korea is not significant. Six out of the nine Asian indices react heavier on the returns of the S&P 500. Even though returns are lagged they still have a significant effect on the Asian stock markets. The three betas that did not increased in value each showed high insignificant coefficients. There were only three indices that had an increased effect of the squared residuals. Two of these three also had insignificant coefficients. There can be concluded that the returns of the S&P 500 do have an increasing effect on the Asian stock exchanges during a crisis while the volatility of the S&P 500 does not.

Six European indices, such as the FTSE-100, did not show any signs of contagion. Rather, they became more independent, the effect of the S&P 500 decreased. Even though there were still three indices which did confirm presence of contagion, the general consensus of table 6 and 7 is that Europe did not suffer from contagion during the crisis, at least according to the extended GARCH (1, 1)-M method.

The conclusion of the extended GARCH (1, 1)-M model is that there is no contagion between the S&P 500 and Asia, Latin America and Europe.

4.5 Sensitivity Analysis

In the previous sections the idea to lag returns of the S&P 500 already came to mind. The Asian stock exchanges are already closed when the S&P 500 opens for trade, and most European countries have a trading overlap with the United States of two hours. The first GARCH (1, 1) model tries to find whether the returns of the S&P 500 on a certain Tuesday have an effect on the Nikkei-225 while the Nikkei-225 already closed several hours ago. Therefore the returns are lagged. Now the model describes what the effect is of the return of the S&P 500 on a Tuesday to the return of the Nikkei-225 on a Wednesday. Table 8 gives the results when the returns of the S&P 500 are being lagged with a three month crisis period. The results when using a six month crisis period look very similar (Appendix I).

Results of this test still do not show clear evidence of contagion. Seventeen indices showed a significant increase in their beta coefficient. The American indices, Brazil, Argentina, Canada, Chile and Mexico each showed a significant increase. But there is something interesting about these results. All beta coefficients of the stable period were negative of these countries. This suggests some sort of momentum, where a positive return of the S&P 500 will most likely be followed by a negative return of the Bovespa in Brazil on the next day. During the crisis, all coefficients become positive. A negative return of the S&P 500 will then most likely be followed by a negative return of the Bovespa.

The results for the Asian indices changed dramatically. Without the lagged returns of the S&P 500 eight of the nine indices showed a significant increase in their beta. Now it is the other way around. South Korea is the only country with an increasing beta. A possible explanation could be that the financial crisis was not as active in Asia compared to Europe and America. During the stable period there was a healthy connected between the economies but during the crisis the economies got disconnected.

In Europe many indices showed an increase. Especially all large countries such as Spain, France, Germany and the United Kingdom now showed signs of contagion. A few smaller countries such as Belgium, Greece and Poland became less dependent of the American economy during the financial crisis.

The conclusion of the lagged results is very clear. There is no sign of contagion in the Asian region while there is in Europe. This method should give the most robust results since the lagged returns now correct for the problem with the trading hours and time differences.

TABLE 8: GARCH (1, 1) MODEL WITH A 3 MONTH CRISIS PERIOD AND LAGGED RETURNS

$$R_{i,t} = \beta_1 + \beta_2 R_{s\&p\,500}(-1) + u_t$$

$$\sigma_{i,t}^2 = \alpha_0 + \alpha_1 u_{t-1}^2 + \beta \sigma_{t-1}^2 \quad (10)$$

	Stable Period 3M		Turmoil Period 3M				
Country	Coefficient	Std. Dev.	Coefficient	Std. Dev.	T>S	t-value	p-value
Argentina	-0.07	0.15	0.33	0.14	TRUE	16.16	0.000
Australia	0.69	0.11	0.49	0.06	FALSE	-13.27	0.000
Belgium	0.32	0.01	0.27	0.11	FALSE	-4.14	0.000
Brazil	-0.16	0.20	0.13	0.00	TRUE	11.60	0.000
Canada	-0.16	0.12	0.10	0.00	TRUE	18.70	0.000
Chile	-0.05	0.04	0.03	0.03	TRUE	13.95	0.000
China	0.03	0.00	-0.04	0.00	FALSE	-401.04	0.000
France	0.19	0.14	0.41	0.00	TRUE	12.90	0.000
Germany	0.18	0.13	0.23	0.08	TRUE	2.64	0.004
Greece	0.47	0.18	0.37	0.02	FALSE	-4.48	0.000
Hong Kong	0.56	0.00	0.33	0.11	FALSE	-16.73	0.000
India	0.83	0.15	0.13	0.12	FALSE	-29.43	0.000
Italy	0.28	0.07	0.43	0.01	TRUE	16.68	0.000
Japan	0.70	0.11	0.61	0.09	FALSE	-4.70	0.000
Kuwait	0.14	0.06	0.06	0.01	FALSE	-10.31	0.000
Malaysia	0.30	0.01	0.14	0.04	FALSE	-31.81	0.000
Mexico	-0.12	0.01	0.10	0.03	TRUE	67.00	0.000
Morocco	0.01	0.06	-0.01	0.02	FALSE	-1.85	0.032
Netherlands	0.22	0.15	0.41	0.13	TRUE	7.24	0.000
Poland	0.40	0.10	0.30	0.06	FALSE	-7.00	0.000
Portugal	0.25	0.12	0.38	0.04	TRUE	8.41	0.000
Russia	0.57	0.15	0.74	0.00	TRUE	9.02	0.000
Singapore	-0.05	0.15	0.29	0.10	TRUE	15.20	0.000
South Africa	0.27	0.14	0.34	0.02	TRUE	4.25	0.000
South Korea	0.51	0.13	0.33	0.09	FALSE	-9.07	0.000
Spain	0.21	0.13	0.38	0.01	TRUE	10.15	0.000
Sweden	0.41	0.11	0.29	0.13	FALSE	-5.82	0.000
Swiss	0.23	0.00	0.36	0.10	TRUE	10.78	0.000
Thailand	0.37	0.07	0.16	0.12	FALSE	-12.40	0.000
Tunisia	-0.06	0.03	-0.01	0.01	TRUE	11.00	0.000
Turkey	0.17	0.00	0.03	0.04	FALSE	-28.47	0.000
UK	0.20	0.14	0.40	0.12	TRUE	8.41	0.000
Observations	65		65				

Table 8: Coefficients represent the value of β_2 generated from the GARCH (1, 1) model with lagged returns. High standard deviations make the results less reliable. If T>S then the turmoil period is bigger than the coefficient of the stable period. T-values are calculated with the use of formula (6).

The extended GARCH (1, 1)-M model uses both lagged returns and lagged squared residuals in model (9). Appendix J gives the results of this test. When the independent variables are lagged, the results are more favourable for contagion. Eighteen of the thirty two indices became more dependent on the returns of the Standard and Poor's 500. Also the effect of the squared residuals on the conditional variance increased for seventeen indices. It is also the case that for twelve indices, including the CAC40, the DAX and the AEX, the coefficients are higher for both variables. So the effect of both the return and the squared residuals has increased for the whole period. Given the previous results of the extended GARCH (1, 1)-M model these results are very high. Unfortunately there is no clear connected between these twelve countries, four are from America, one from Asia, two from Africa and five from Europe. If all twelve countries were from Europe one could conclude that there is evidence of contagion between America and Europe. But there are still a few coefficients that are not significant at a 5% confidence level. Significant coefficients would give more strength to the results.

4.6 Comparison between methods

Is it plausible to speak of contagion when all these methods give different conclusions for each method? The returns of the Standard and Poor's 500 should have an increasing effect on the return of the AEX for instance. Could the conditional mean also be affected by the squared residuals directly?
The squared residuals now cause an increase in the conditional variance when there are large fluctuations in the S&P 500. The height of the conditional variance will then be translated into the conditional mean using the GARCH (1, 1)-**M** model.

The results from the conducted tests are not easy to compare. Not only do the methods differ but also the time intervals which are used for the models do not match. Still it can be concluded that there was contagion from the S&P 500 to the stock exchanges nearby, such as the stock exchange of Canada, Mexico and Argentina. These countries each showed in almost every model significant increases in the coefficients, even when returns were lagged.

The Asian indices became more dependent of the S&P 500 when using the GARCH (1, 1) models but when returns were lagged or the model gain variables, the effect vanished. For the European indices the situation is sort of the same, some models gave very convincing numbers but most models did not show any signs of contagion.
It seems to be the case that countries that got hit by the crisis were already linked to the United States and that there is no sign of contagion except for the North and South American region.

5 Conclusion

People assume these days that contagion is the reason why the 2008 financial crisis spread from the United States to Europe and other places all over the world. Contagion is a phenomenon which suggests that a crisis spreads from one country to one or several other companies. During this process, country linkages increase. In this paper contagion is defined as an increase in cross-country linkages where a crisis in one country disturbs the financial markets of other countries.

There are two types of contagion; fundamental and irrational contagion. Fundamental contagion describes the process where a crisis spreads through fundamental values of an economy. A devaluation of a currency in a fixed exchange rate for instance can have huge consequences for the level of import and export but also on the other capital flows of the country. The other type of contagion, irrational contagion, spreads through fear of foreign investors. When they see major losses on Wall Street they expect that there is something wrong. Their first reaction is to close all positions as quickly as possible. Investors do this without giving attention to the underlying value of an asset. Without any changes in sales, earnings or debt, an investor decides to close his position.

Several methods have been used to test whether this effect was visible in the indices of 32 leading industries in the world. The first test used two dummies to see how indices around the world react on a positive and a negative return of the S&P 500. It appeared that indices around the globe reacted heavier on a negative return compared to a positive return.
The second model was a GARCH (1, 1) model which gave proof that there was contagion from the S&P 500 to the Asian indices. These results seem rather strange since the Asian markets are already closed when the American market still has to open. There was also clear evidence of contagion in Latin America and North America (Canada and Mexico). Unfortunately there was insufficient evidence to conclude that there was also contagion in Europe.

The last two models use a GARCH (1, 1)-M model which tries to identify whether volatility shocks causes by the S&P 500 have their effect on foreign indices. These shocks are translated to an independent variable in the conditional variance of the model. The next step was to test the model for multiple periods and see whether there was an increase during after the 2008 financial crisis started. This model concluded that there was a significant increase in volatility spillover from the S&P 500 to large parts of Europe and America. For the Asian region no evidence could be found.
The last model was a combination of the last two models where it contained both the returns of the S&P 500 in the conditional mean as well as the squared residuals (which is assumed to be the volatility of the S&P 500) in the conditional variance. Again the results were not convincing enough to conclude that there was contagion.

Therefore the conclusion can be drawn that there was no presence of contagion during the 2008 financial crisis. If there was a region where one would suggest it, it would be Europe, where the crisis struck just as hard as it did in America. South and North America performed the 'best' is the tests. These continents showed in multiple models significant differences in coefficient, which suggests presence of contagion. But these results were not attained by every model. The largest economies were already highly linked before the crisis started, which caused the crisis to expand from the United States.

Some suggestions for further research could go in the direction of fundamental-based contagion. There is a lot still unknown how the fundamental values change during a crisis and what their effect is. When it is clear how these mechanisms work it is possible to make or adjust models in order to combine more variables.

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Appendix A

Akaike Information Criterion

Lag combination	0,1	1,0	1,1	1,2	2,2
Country					
Argentina	-5.55	-5.53	-5.55	***<u>-5.69</u>***	-5.68
Australia	-5.60	-5.69	***<u>-5.71</u>***	-5.62	-5.60
Belgium	-5.51	-5.54	-5.54	-5.54	***<u>-5.57</u>***
Brazil	-5.34	***<u>-5.44</u>***	-5.39	-5.33	-5.35
Canada	-5.93	-5.92	***<u>-5.97</u>***	-5.95	NA
Chile	***<u>-6.69</u>***	-6.43	-6.59	-6.43	-6.62
China	-4.53	-4.59	***<u>-4.83</u>***	-4.59	-4.77
France	-5.82	***<u>-5.91</u>***	-5.88	-5.85	-5.87
Germany	-6.21	-6.24	-6.22	-6.20	***<u>-6.25</u>***
Greece	-5.10	-5.04	-5.15	***<u>-5.28</u>***	-5.22
Hong Kong	-5.22	-5.37	-5.35	-5.33	***<u>-5.41</u>***
India	-4.49	-4.48	-4.50	***<u>-4.50</u>***	NA
Italy	-5.99	-5.99	-6.00	-5.97	***<u>-6.01</u>***
Japan	-5.68	-5.73	-5.70	-5.68	***<u>-5.75</u>***
Kuwait	-6.96	-6.94	-6.97	-7.06	***<u>-7.17</u>***
Malaysia	-6.24	-6.31	***<u>-6.51</u>***	-6.25	-6.35
Mexico	-7.13	-6.99	***<u>-7.20</u>***	-7.18	NA
Morocco	-7.12	-6.98	-7.11	***<u>-7.19</u>***	-7.13
Netherlands	-5.89	-6.02	***<u>-6.05</u>***	-6.02	-6.00
Poland	-5.83	-5.88	***<u>-5.94</u>***	-5.82	-5.94
Portugal	-5.44	-5.39	***<u>-5.53</u>***	-5.52	-5.50
Russia	-5.17	-4.90	***<u>-5.19</u>***	-5.11	-5.04
Singapore	-6.11	***<u>-6.20</u>***	-6.08	-6.12	-6.17
South Africa	-5.62	-5.49	***<u>-5.70</u>***	-5.63	-5.62
South Korea	-5.65	-5.71	-5.63	-5.66	***<u>-5.75</u>***
Spain	-5.53	***<u>-5.57</u>***	-5.55	-5.52	-5.52
Sweden	-5.40	-5.37	***<u>-5.48</u>***	-5.34	-5.44
Swiss	-6.29	-6.43	-6.41	-6.38	***<u>-6.46</u>***
Thailand	-5.51	***<u>-5.55</u>***	-5.52	-5.51	-5.49
Tunisia	-7.63	-7.84	-7.81	-7.81	***<u>-7.95</u>***
Turkey	-4.84	-4.73	***<u>-4.94</u>***	NA	NA
UK	-5.88	***<u>-5.96</u>***	-5.93	-5.91	-5.91

Appendix A: The Akaike Information Criterion should be as low as possible. The most negative value for each index is bold, underlined and in italics.

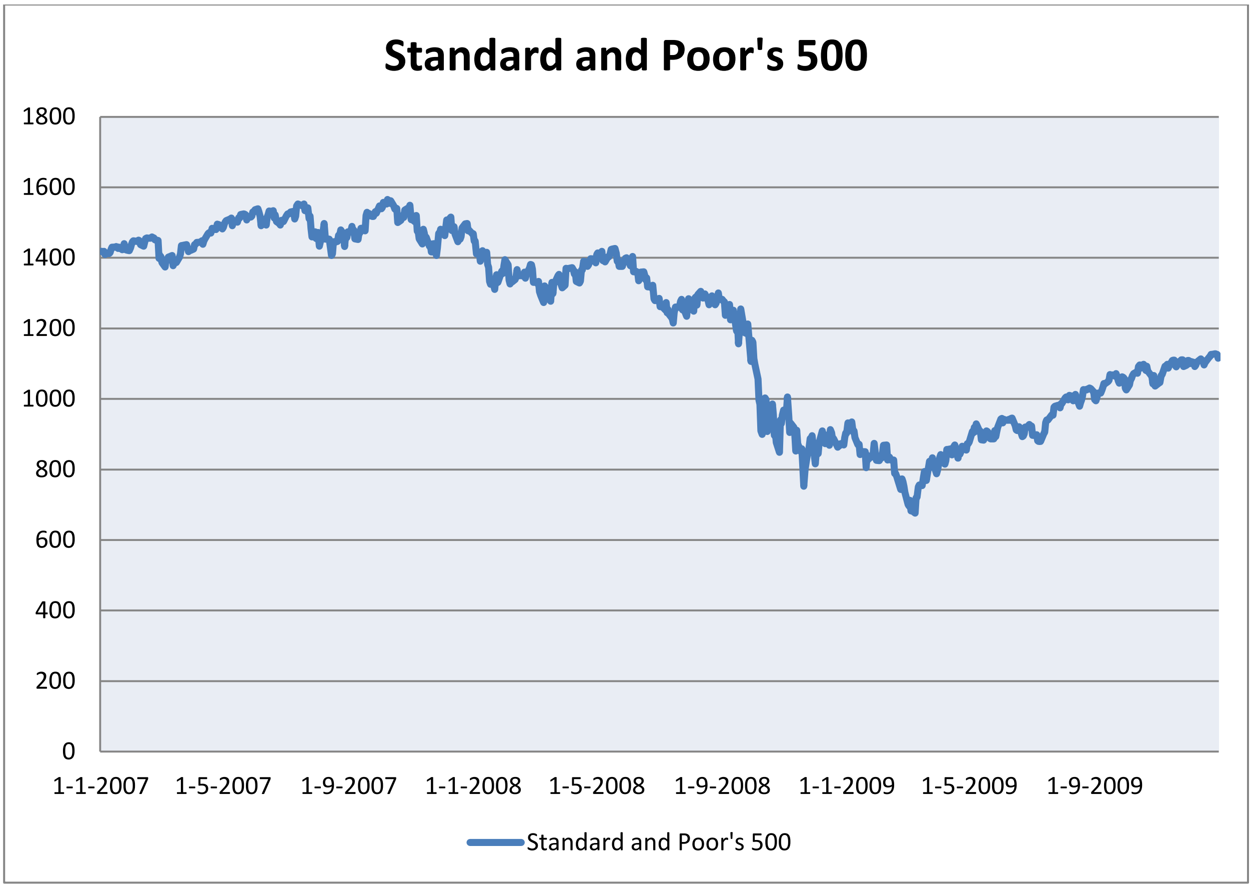
Appendix B

Country	Stock Exchange
Argentina	Mercado de Valores
Australia	S&P / ASX 200
Belgium	BEL-20
Brazil	BOVESPA
Canada	S&P/TSX 60 INDEX
Chile	CHILE GENERAL (IGPA)
China	SHANGHAI SE A SHARE
France	CAC 40
Germany	DAX 30 PERFORMANCE
Greece	ATHEX Composite
Hong Kong	HANG SENG
India	BSE National
Italy	FTSE MIB INDEX
Japan	NIKKEI 225 STOCK AVERAGE
Kuwait	KUWAIT KIC GENERAL
Malaysia	FTSE BURSA MALAYSIA KLCI
Mexico	MEXICO IPC (BOLSA)
Morocco	MOROCCO ALL SHARE INDEX
Netherlands	AEX INDEX (AEX)
Poland	WARSAW GENERAL INDEX
Portugal	PSI-20
Russia	RUSSIA RTS INDEX
Singapore	STRAITS TIMES INDEX L
South Africa	FTSE/JSE ALL SHARE
South Korea	KOSPI INDEX
Spain	IBEX 35
Sweden	OMX STOCKHOLM 30 (OMXS30)
Swiss	SWISS MARKET INDEX
Thailand	BANGKOK S.E.T.
Tunisia	TUNISIA TUNINDEX
Turkey	ISE NATIONAL 100
UK	FTSE 100
USA	S&P 500

Appendix B: The country with the index used from that country.

Appendix C

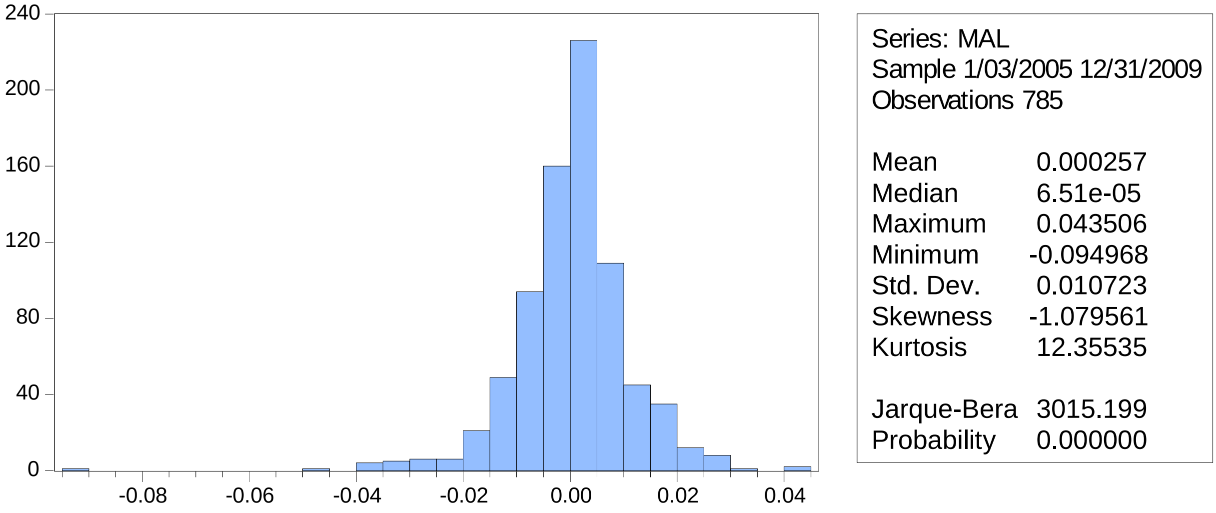
Standard and Poor's 500



Appendix C: The value of the Standard & Poor's 500 between 2007 and the end of 2009. The period between January 2007 and January 2008 is relatively stable. From May 2008 real declines are visible. In September 2008 the S&P 500 loses more than 30%.

Appendix D

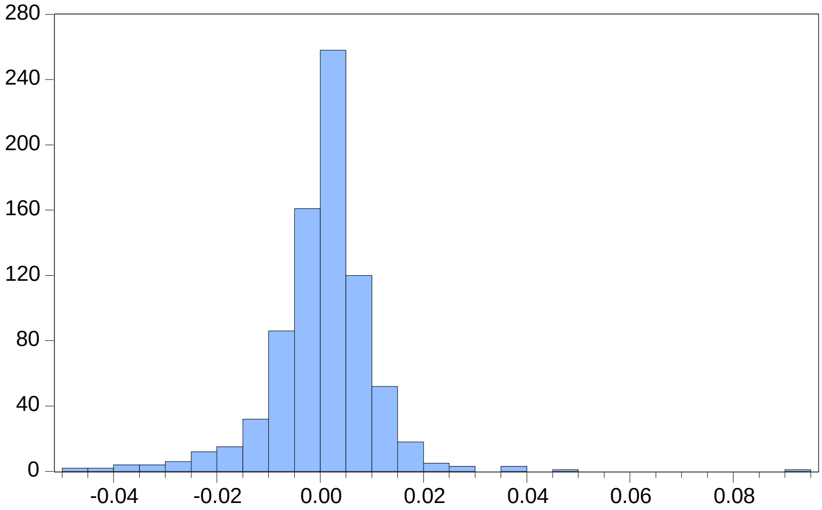
Negative skewness in Malaysia



Appendix D: A clear example of negative skewness in index returns. There are some negative outliers which make the distribution non-normal. The minimum and maximum returns do not correspond in absolute terms.

Appendix E

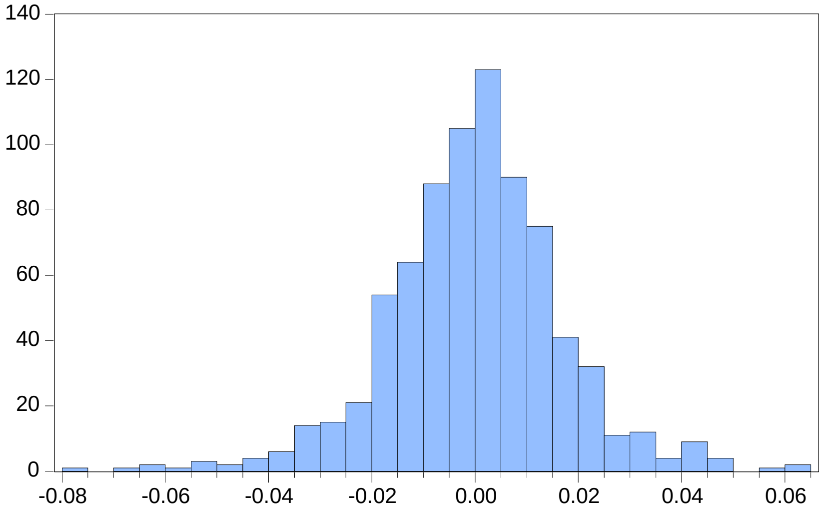
High kurtosis in Chile



Series: CHILE
Sample 1/03/2005 12/31/2009
Observations 785

Mean	0.000325
Median	0.000657
Maximum	0.094807
Minimum	-0.048930
Std. Dev.	0.010315
Skewness	0.219848
Kurtosis	15.13739
Jarque-Bera	4824.793
Probability	0.000000

Low kurtosis in Poland



Series: POL
Sample 1/03/2005 12/31/2009
Observations 785

Mean	-0.000153
Median	0.000000
Maximum	0.062726
Minimum	-0.079546
Std. Dev.	0.016924
Skewness	-0.182497
Kurtosis	4.997582
Jarque-Bera	134.8746
Probability	0.000000

Appendix E: The differences between the distribution of returns between Chile and Poland are very clear. Poland has a smooth distribution around the mean while Chile has a high peak.

Appendix F

White's test

	F-statistic	p-value	Obs*R-squared	p-value	Scaled explained SS	p-value
Argentina	85.43	0.000	151.36	0.000	576.26	0.000
Australia	34.37	0.000	65.44	0.000	219.72	0.000
Belgium	43.34	0.000	81.44	0.000	409.59	0.000
Brazil	51.90	0.000	96.34	0.000	381.22	0.000
Canada	56.37	0.000	103.99	0.000	990.40	0.000
Chile	0.36	0.697	0.72	0.697	6.55	0.038
China	0.95	0.386	1.91	0.385	5.10	0.078
France	61.06	0.000	111.89	0.000	701.69	0.000
Germany	91.46	0.000	160.72	0.000	680.17	0.000
Greece	15.29	0.000	29.94	0.000	98.96	0.000
Hong Kong	94.28	0.000	165.06	0.000	685.18	0.000
India	2.76	0.063	5.52	0.063	23.16	0.000
Italy	108.50	0.000	186.38	0.000	1,202.34	0.000
Japan	16.28	0.000	31.85	0.000	186.59	0.000
Kuwait	21.67	0.000	42.04	0.000	135.91	0.000
Malaysia	6.45	0.002	12.80	0.002	94.82	0.000
Mexico	18.16	0.000	35.41	0.000	123.08	0.000
Morocco	0.51	0.601	1.02	0.600	3.22	0.199
Netherlands	77.60	0.000	138.96	0.000	829.15	0.000
Poland	14.86	0.000	29.13	0.000	63.50	0.000
Portugal	66.53	0.000	120.99	0.000	786.54	0.000
Russia	49.27	0.000	91.80	0.000	614.70	0.000
Singapore	22.20	0.000	43.03	0.000	135.15	0.000
South Africa	25.34	0.000	48.90	0.000	118.00	0.000
South Korea	21.86	0.000	42.40	0.000	181.77	0.000
Spain	59.63	0.000	109.50	0.000	650.24	0.000
Sweden	66.94	0.000	121.66	0.000	360.41	0.000
Swiss	76.32	0.000	136.91	0.000	649.91	0.000
Thailand	2.02	0.134	4.03	0.133	35.37	0.000
Tunisia	0.24	0.790	0.47	0.790	3.36	0.186
Turkey	2.41	0.090	4.81	0.090	12.19	0.002
UK	42.62	0.000	80.18	0.000	461.48	0.000

Appendix F: White's Test. The p-values suggest for almost every country that there is heteroskedasticity in the asset returns.

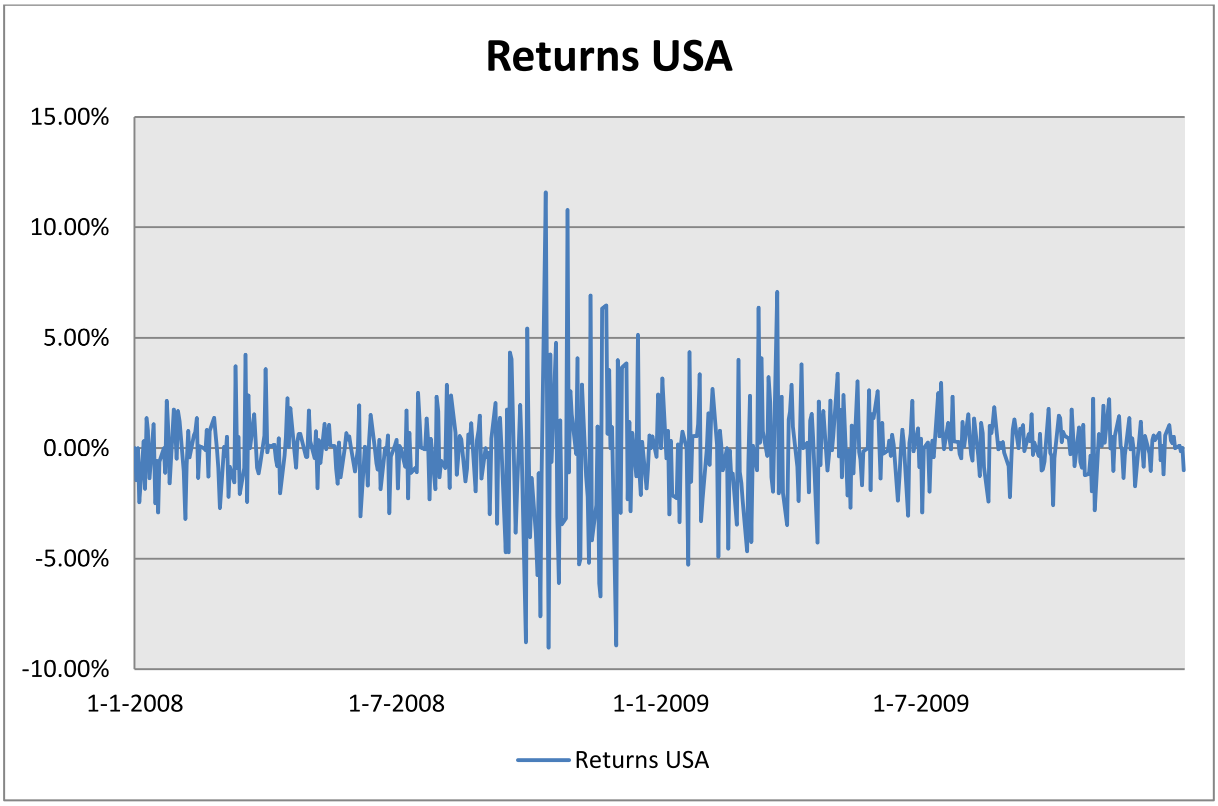
Appendix G

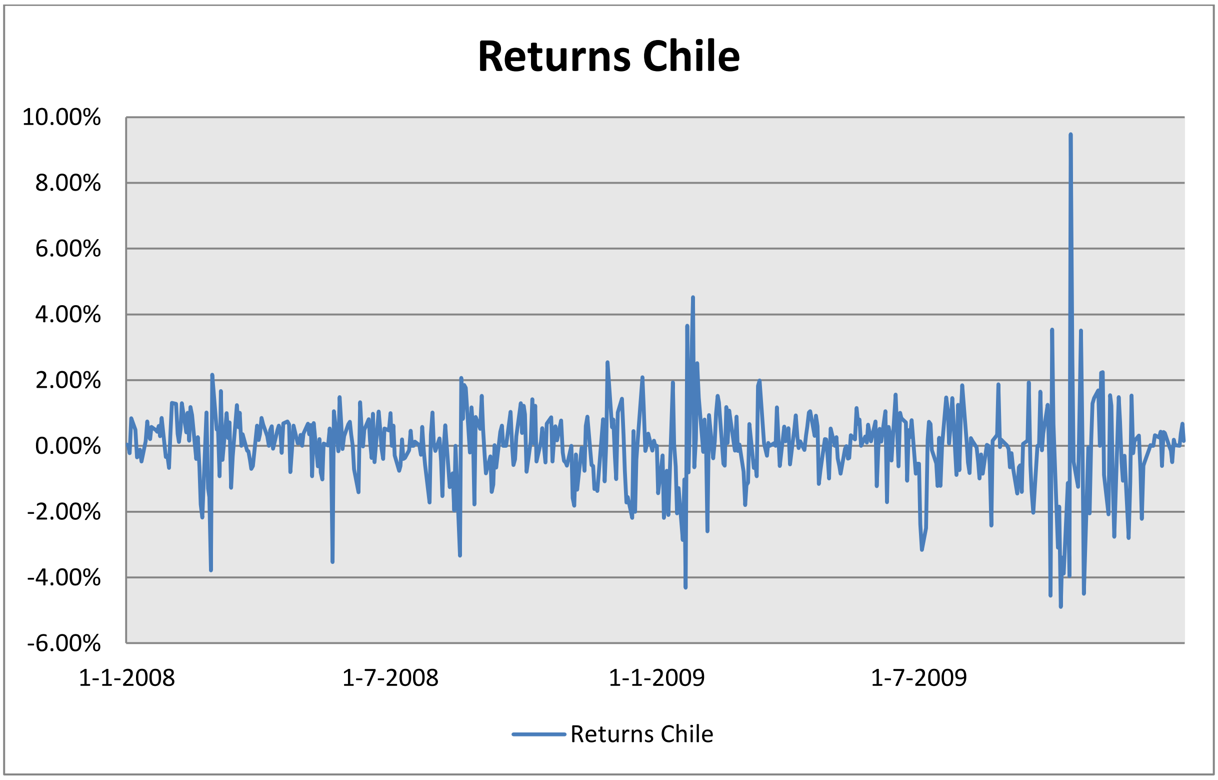
Trading hours in different countries

	Australia	Japan	Germany	United Kingdom	Brazil	United States
Time Zone	GMT+10	GMT+9	GMT+1	GMT	GMT-4	GMT-5
11:00 PM						
12:00 AM						
1:00 AM						
2:00 AM						
3:00 AM						
4:00 AM						
5:00 AM						
6:00 AM						
7:00 AM						
8:00 AM						
9:00 AM						
10:00 AM						
11:00 AM						
12:00 PM						
1:00 PM						
2:00 PM						
3:00 PM						
4:00 PM						
5:00 PM						
6:00 PM						
7:00 PM						
8:00 PM						
9:00 PM						

Appendix G: The green squares represent the hours with active trading in a specified market. The hours in the first column are based on the hours when the London Stock Exchange is open for trading (between 9 AM and 4 PM). For example, the graph shows that the stock markets in Japan are already closed when the London Stock Exchange opens.

Appendix H





Appendix H: Returns of the S&P 500 and the Chilean stock exchange. It is clear that there is no link at al between these two markets.

Appendix I

$$R_{i,t} = \beta_1 + \beta_2 R_{s\&p\ 500}(-1) + u_t$$

$$\sigma_{i,t}^2 = \alpha_0 + \alpha_1 u_{t-1}^2 + \beta\sigma_{t-1}^2 \quad (10)$$

	Stable Period 6M		Turmoil Period 6M				
Country	Coefficient	Std. Dev.	Coefficient	Std. Dev.	T>S	t-value	p-value
Argentina	-0.04	0.09	0.18	0.09	TRUE	20.68	0.000
Australia	0.74	0.07	0.40	0.05	FALSE	-47.60	0.000
Belgium	0.23	0.10	0.22	0.07	FALSE	-0.34	0.367
Brazil	-0.07	0.12	0.06	0.12	TRUE	8.67	0.000
Canada	-0.12	0.09	0.05	0.08	TRUE	16.13	0.000
Chile	0.06	0.05	0.02	0.03	FALSE	-7.75	0.000
China	-0.05	0.13	-0.05	0.04	FALSE	-0.25	0.403
France	0.22	0.10	0.35	0.07	TRUE	12.20	0.000
Germany	0.16	0.10	0.22	0.08	TRUE	5.54	0.000
Greece	0.45	0.11	0.27	0.07	FALSE	-15.63	0.000
Hong Kong	0.68	0.12	0.44	0.07	FALSE	-20.10	0.000
India	0.68	0.14	0.16	0.07	FALSE	-37.17	0.000
Italy	0.27	0.01	0.34	0.07	TRUE	11.66	0.000
Japan	0.73	0.09	0.56	0.06	FALSE	-18.59	0.000
Kuwait	0.11	0.05	0.04	0.05	FALSE	-11.12	0.000
Malaysia	0.29	0.00	0.13	0.03	FALSE	-60.40	0.000
Mexico	-0.11	0.09	0.02	0.09	TRUE	11.83	0.000
Morocco	0.04	0.06	0.00	0.02	FALSE	-8.32	0.000
Netherlands	0.22	0.10	0.32	0.09	TRUE	9.28	0.000
Poland	0.29	0.09	0.27	0.05	FALSE	-2.97	0.002
Portugal	0.27	0.07	0.26	0.05	FALSE	-1.91	0.028
Russia	0.34	0.11	0.55	0.13	TRUE	14.17	0.000
Singapore	0.56	0.07	0.22	0.07	FALSE	-38.98	0.000
South Africa	0.24	0.07	0.37	0.06	TRUE	15.27	0.000
South Korea	0.55	0.09	0.40	0.06	FALSE	-15.77	0.000
Spain	0.15	0.11	0.29	0.06	TRUE	12.35	0.000
Sweden	0.37	0.12	0.26	0.08	FALSE	-9.29	0.000
Swiss	0.35	0.09	0.27	0.06	FALSE	-8.45	0.000
Thailand	0.27	0.07	0.22	0.07	FALSE	-5.18	0.000
Tunisia	-0.01	0.03	-0.01	0.01	FALSE	-0.74	0.229
Turkey	0.19	0.10	0.01	0.06	FALSE	-18.36	0.000
UK	0.24	0.09	0.33	0.07	TRUE	8.73	0.000
Observations	130		130				

Appendix I: Coefficients represent the value of β_2 generated from the GARCH (1, 1) model with lagged returns and a 6 month crisis period. High standard deviations make the results less reliable. If T>S then the turmoil period is bigger than the coefficient of the stable period. T-values are calculated with the use of formula (6).

Appendix J

$$R_{i,t} = \alpha + \beta_1\sigma + \beta_2 R_{s\&p\ 500}(-1) + u_t \quad (11)$$

$$\sigma_{i,t}^2 = \alpha_0 + \alpha_1 u_{t-1}^2 + \beta\sigma_{t-1}^2 + \delta X_{usa,t}(-1)$$

	Stable Period		Whole Period				
	β_2	p-value	β_2	p-value	W>S	t-value	p-value
Argentina	0.083	0.241	0.109	0.080	TRUE	6.276	0.000
Australia	0.696	0.000	0.584	0.000	FALSE	-37.842	0.000
Belgium	0.297	0.000	0.270	0.000	FALSE	-7.339	0.000
Brazil	0.032	0.666	0.015	0.836	FALSE	-3.557	0.000
Canada	-0.038	0.492	-0.029	0.540	TRUE	2.749	0.003
Chile	-0.026	0.235	0.001	0.940	TRUE	22.015	0.000
China	-0.056	0.438	-0.041	0.278	TRUE	3.931	0.000
France	0.254	0.000	0.274	0.000	TRUE	4.807	0.000
Germany	0.225	0.000	0.228	0.000	TRUE	0.954	0.170
Greece	0.343	0.000	0.311	0.000	FALSE	-8.919	0.000
Hong Kong	0.811	0.000	0.704	0.000	FALSE	-23.757	0.000
India	0.593	0.000	0.422	0.000	FALSE	-37.406	0.000
Italy	0.223	0.000	0.255	0.000	TRUE	8.951	0.000
Japan	0.635	0.000	0.625	0.000	FALSE	-3.064	0.001
Kuwait	0.007	0.849	0.052	0.102	TRUE	20.706	0.000
Malaysia	0.437	0.000	0.263	0.000	FALSE	-68.318	0.000
Mexico	-0.002	0.752	-0.001	0.989	TRUE	0.345	0.365
Morocco	-0.015	0.665	0.003	0.867	TRUE	9.850	0.000
Netherlands	0.266	0.000	0.276	0.000	TRUE	2.865	0.002
Poland	0.353	0.000	0.315	0.000	FALSE	-10.132	0.000
Portugal	0.257	0.000	0.254	0.000	FALSE	-1.043	0.148
Russia	0.435	0.000	0.438	0.000	TRUE	0.629	0.265
Singapore	0.670	0.000	0.528	0.000	FALSE	-39.868	0.000
South Africa	0.343	0.000	0.357	0.000	TRUE	3.763	0.000
South Korea	0.632	0.000	0.567	0.000	FALSE	-17.699	0.000
Spain	0.201	0.003	0.229	0.000	TRUE	7.082	0.000
Sweden	0.391	0.000	0.332	0.000	FALSE	-14.941	0.000
Swiss	0.321	0.000	0.302	0.000	FALSE	-5.789	0.000
Thailand	0.336	0.000	0.310	0.000	FALSE	-8.324	0.000
Tunisia	-0.017	0.387	-0.014	0.099	TRUE	2.790	0.003
Turkey	-0.003	0.962	0.011	0.775	TRUE	4.111	0.000
UK	0.240	0.000	0.264	0.000	TRUE	6.277	0.000
Observations	435		565				

	Stable Period		Whole Period				
	δ	p-value	δ	p-value	W>S	t-value	p-value
Argentina	0.047	0.221	0.088	0.008	TRUE	17.838	0.000
Australia	0.104	0.013	0.096	0.001	FALSE	-3.466	0.000
Belgium	0.073	0.007	0.049	0.006	FALSE	-16.197	0.000
Brazil	-0.035	0.114	0.087	0.100	TRUE	49.437	0.000
Canada	0.036	0.218	0.053	0.023	TRUE	9.850	0.000
Chile	-0.003	0.448	0.000	0.796	TRUE	16.814	0.000
China	-0.015	0.148	0.003	0.246	TRUE	35.239	0.000
France	0.092	0.002	0.095	0.000	TRUE	2.296	0.011
Germany	0.078	0.001	0.081	0.000	TRUE	3.006	0.001
Greece	0.036	0.099	0.036	0.024	FALSE	-0.096	0.462
Hong Kong	0.220	0.005	0.189	0.001	FALSE	-6.897	0.000
India	0.177	0.001	0.092	0.001	FALSE	-31.445	0.000
Italy	0.082	0.008	0.103	0.000	TRUE	11.582	0.000
Japan	0.053	0.000	0.057	0.000	TRUE	5.988	0.000
Kuwait	0.030	0.098	0.027	0.000	FALSE	-3.326	0.000
Malaysia	0.041	0.108	0.015	0.082	FALSE	-20.222	0.000
Mexico	-0.221	0.000	0.029	0.114	TRUE	321.444	0.000
Morocco	-0.040	0.002	-0.004	0.015	TRUE	58.682	0.000
Netherlands	0.071	0.005	0.082	0.000	TRUE	7.310	0.000
Poland	0.098	0.061	0.076	0.017	FALSE	-7.807	0.000
Portugal	0.074	0.004	0.047	0.007	FALSE	-18.705	0.000
Russia	0.074	0.003	0.070	0.002	FALSE	-2.452	0.007
Singapore	0.086	0.056	0.093	0.006	TRUE	2.517	0.006
South Africa	0.133	0.017	0.109	0.005	FALSE	-7.712	0.000
South Korea	0.109	0.011	0.129	0.001	TRUE	7.417	0.000
Spain	0.094	0.000	0.088	0.000	FALSE	-3.657	0.000
Sweden	0.096	0.000	0.107	0.002	TRUE	7.934	0.000
Swiss	0.076	0.019	0.064	0.009	FALSE	-6.538	0.000
Thailand	0.034	0.094	0.054	0.011	TRUE	15.264	0.000
Tunisia	-0.002	0.528	0.000	0.055	TRUE	10.508	0.000
Turkey	-0.049	0.115	0.002	0.746	TRUE	33.705	0.000
UK	0.099	0.008	0.085	0.002	FALSE	-6.567	0.000
Observations	435		565				

Appendix J: The results of the extended GARCH (1, 1)-M model with both lagged returns and lagged squared residuals. The first table gives the coefficients of the effect of the lagged returns of the S&P 500. The second table gives the coefficients of the effect of the lagged squared residuals.