Speculative bubbles and contagion: analysis of volatility’s clusters during the DotCom bubble based on the dynamic conditional correlation model

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Abstract

Reviewing the definition and measurement of speculative bubbles in context of contagion, this paper analyses the DotCom bubble in American and European equity markets using the dynamic conditional correlation (DCC) model proposed by Engle and Sheppard (2001) as an econometrical - and on the other hand the behavioural finance as an psychological explanation. Conta-gion is defined in this context as the statistical break in the computed DCCs as measured by the shifts in their means and medians. Even it is astonishing, that the contagion is lower during price bubbles, the main finding indicates the presence of contagion in the different indices among those two continents and proves the presence of structural changes during financial crisis.

KEY WORDS: speculative bubbles, behavioral finance, financial contagion, DCC.
JEL CODES:

1 Introduction

The deviation of market prices from fundamental values is not only a phenomenon of the present, but is also observed since the last centuries, e.g.: The Tulipomania in Netherlands, the South Sea Bubble in Great Britain or even the DotCom bubble, see Carlos et al. (2006) or Ofek and Richardson (2003).

During those last centuries, the analysis of patterns of international spread of financial events became the subject of many academic studies. Especially, during price-bubbles, empirical research focused on volatility models and tried to answer the international markets’ phenomena of high correlated markets.

De facto, financial markets around the world are getting more and more integrated. In those highly integrated markets any shock in a single market can quickly lead to a spillo-ver to other markets. The reason behind this can have different sources, for instance: financial, geopolitical, and political relations between those countries. Empirical studies of contagion events, which focus only on the fundamental relations among economies, are not able to explain satisfactorily those spillovers.
from one market to another. The behavioral finance theories offer a behavioral-psychological explanation for those different stock market anomalies and their spillover effects. Shock spillovers and thereby contagion can be attributed to irrational behavior of investors and for instance linked to a herding behavior among them, shown by Hirshleifer and Teoh (2009) and Ionescu et al. (2009).

The term contagion has been gone through a lot of different definitions and measurements, always trying to define and answer the process in a context of cross-country analysis. In the beginning, it was defined as a simple static measure of correlation between two market stock returns of two different countries, which identified and transferred the relation to their respective equity markets and to a cross-country portfolio diversification, shown by Cho and Parhizgari (2008). Later on, researches – like Darbar and Deb (1997), Karolyi and Stulz (1996), and Parhizgari et al. (1994) – on correlation analyses tried to develop new measures and techniques by including co-movements, causality and error-correction models among cross-country market returns.

Meanwhile, like Forbes and Rigobon (2002) have shown, the estimation of correlations requires additional statistical refinements. Engle and Sheppard (2001) demonstrated that those estimations have to consider the dynamics - the time-varying and the constant - aspect of correlations, which is called dynamic conditional correlations (DCC).

In consideration of previous studies, this paper answers the following questions and closes thereby a rarely mentioned topic in the literature about the correlation of market indices and the evaluation of financial contagion between stock-market returns:
1. What is a speculative bubble and how can be indicated a typical price bubble?
2. Holds the - in many cases assumed - contagion effect between the American and European stock markets in the presence of price bubbles, like the DotCom bubble?
3. Which model is the best for analyzing the phenomenon of financial contagion between stock market returns of different countries?

In this context, the goals of this study are to analyze the DotCom price bubble as well to evaluate the financial contagion between American and European stock market returns in this context. Therefore, three multivariate conditional correlation volatility models will be used, the DCC-GARCH by Engle and Sheppard (2001), the constant conditional correlation (CCC) by Bollerslev (1990) and the varying conditional correlation (VCC) by Tse and Tsui (2002). Nevertheless, the main focus lies on the DCC-GARCH model.

The paper is constructed as follows: Section 2 gives a short overview about the literatures of price bubbles and financial contagion. Section 3 defines generally price-bubbles and their development, subsequently the DotCom bubble is explained as well shortly analyzed. Section 4 starts with a short descriptive statistic of the considered data set and describes the empirical strategy according to test for financial contagion. Section 5 presents the results according to previous strategies and the last section concludes and compares the results with former findings.

2 Overview of Relevant Literature

According to the different parts of this study, the overview of relevant literature has to be split as well into two main parts: The first part deals with the definition of bubble and their different explanations. The second part deals about the contagion effect among the different indices.
2.1 Price Bubbles

The discussion how to define and identify a bubble is not a new topic. Garber (2000) explains a bubble as “a fuzzy word filled with import but lacking any solid operational definition.” He defines both sides of a bubble, the positive as well as the negative. He suggests that a bubble can best be explained by “a price movement that is inexplicable based on fundamentals.” The main task of this definition is that a bubble can only be determined after it has been occurred, as O’Hara (2008) mentioned. For instance, Kindleberger and Aliber (1996) defines that “a bubble is an upward price movement over an extended range that then implodes.” The most important assumptions to define a bubble are the irrationality versus the rationality. Arrow (1982) gives a short summary over the difference between individual rationality and irrationality and markets.

Blanchard and Watson (1982) published one of the first papers about bubbles in the financial markets regarding the rational expectations. The more recent paper by O’Hara (2008) summarized the overview of literature about bubbles in detail. In her paper, she distinguished different theories of bubbles. Therefore, she differentiated between rational and irrational traders, as well rational and irrational markets. Tirole (1982) and Brunnermeier and Nagel (2004) showed that a bubble could even occur under the assumption of rational investors and rational markets. The theory behind the irrationality of the markets is based on the theory of Kindleberger and Aliber (1996) and Keynes (1935). This paper analyzes the technology-bubble – often mentioned as the DotCom-bubble. Ofek and Richardson (2003) were one of the first authors, who explained the internet bubble in the 1990’s. Their conclusion is that the technology-bubble “burst to the unprecedented level of lockup expirations and insider selling”. This study assumes also rational markets, like Ross (2005) and Aschinger (1991) did. Garber (1990) gives a good overview over the past famous bubbles and concludes that a bubble is a present phenomenon and will occur frequently.

2.2 Financial Contagion

The literature about contagion effect in financial markets is that extensive to review here fully. The surveys from Kindleberger (1978), Kaminsky et al. (2003) and Bae et al. (2003) are only some of those, which have to be mentioned. In general, the focus of most literatures is the contagion effect across countries. Therefore, the spread of crises from one country to another has been one of the most discussed issues in international finance since the last decades. This is caused by the frequently occurrence of the last crisis. Financial contagion characterizes situations in which local shocks are transmitted to others financial sectors or even countries. This is comparable with a pandemic, for instance an epidemic of infectious disease. One of the most known definition explains a contagion as a “structural change in the mechanism of the proliferation of shocks arising from a particular event or group of events associated with a particular financial crisis”; see Arruda and Pereira (2013). Applied to a financial crisis means this that a specific shock can propagate like a virus, starting in a country and overlapping even to other continents.

An interesting way to define contagion is the five-step definition by Pericolo and Sbracia (2001). According to the authors, contagion can be explained by a) an increased probability of a crisis in a country by a crisis in another - different - country; b) highly stock volatility as an uncertainty from crisis of a country to the financial market of another country; c) higher co-movements in stock prices or quantities between financial markets with and without crisis in the markets; d) difference in transmission mechanism or channel for contagion in and after the crisis; and e) co-movements which can not be explained by the fundamentals.

For instance, Filleti et al. (2008) analyzed the contagion between the Latin American economies
and two emerging markets. Armada et al. (2011) tested the contagion effect between the financial markets of nine developed countries and Azad (2009) for the Asian market. Horta et al. (2008) and as well Arruda and Pereira (2013) analyzed the contagion effects during the US Subprime crisis. Marcal et al. (2011) evaluated the contagion in the financial crisis of Asia and Latin America.

Regarding to the technology-bubble, Anderson et al. (2010) studied the proliferation of the technology-bubble. Most of the studies applied variations of Engle and Sheppard’s (2001) DCC model. Table 1 gives a short overview about the different researches, which mainly focus on the effect of financial crisis on emerging markets.

None of the previous studies analyzed only the contagion effect between American and European indices during the technology-bubble, most of the studies related the contagion between developing, industrialized and emerging countries.

Consequently, this paper will confirm the hypothesis of financial contagion during the technology-bubble, if structural breaks are identified. In contrast to previous papers, like Anderson et al. (2010), Koller et al. (2010), Phylaktis and Xia (2006), which analyzed the financial contagion among several industry-sectors in a specific country, this paper will focus on the contagion within different countries during the technology-bubble. The presence of a contagion effect can be determined by the increase in conditional correlations of the indices during the period of crisis compared to the previous periods.
Table 1: Overview of Empirical Researches

| Author(s)            | Year | Model          | Specific Topic                                                                 |
|----------------------|------|----------------|-------------------------------------------------------------------------------|
| Chiang, Jeon and Li  | 2007 | DCC            | Financial crisis in Asia in 1997, the effect of credit rating agencies on the structure of correlation dynamic risk |
| Kuper and Lestano    | 2007 | DCC            | Effect of financial crisis on the interdependence of financial and FX markets |
| Cheung, Fung and Tam | 2008 | DCC            | Financial crisis in Asia in 1997, the effect of credit rating agencies on the structure of correlation dynamic risk |
| Kuper and Lestano    | 2009 | DCC-Asian FMs  | East Asian financial contagion under DCC-GARCH model                           |
| Cheung, Fung and Tam | 2009 | DCC-Asian FMs  | East Asian financial contagion under DCC-GARCH model                           |
| Cho and Parhizgari   | 2009 | DCC-Asian FMs  | East Asian financial contagion under DCC-GARCH model                           |
| Beirne, Caporale,    | 2009 | MGARCH in-mean | Global and Regional volatility spillover                                        |
| Ghattas, Spagnolo    | 2009 | DCC-GARCH      | Transmission of Liquidity Shocks: Evidence from Subprime Crisis                |
| Frank, Gonzalez-Hermosillo and Hess | 2009 | DCC-GARCH      | Transmission of Liquidity Shocks: Evidence from Subprime Crisis                |
| Munoz, Marquez and Chulia | 2010 | DCC-GARCH      | Transmission of Liquidity Shocks: Evidence from Subprime Crisis                |
| Chulia               | 2010 | DCC-GARCH      | Transmission of Liquidity Shocks: Evidence from Subprime Crisis                |
| Yiu, Ho and Choi     | 2010 | DCC-GARCH      | Transmission of Liquidity Shocks: Evidence from Subprime Crisis                |
| Naoui, Khemiri and Kiouane | 2011 | DCC-GARCH      | Transmission of Liquidity Shocks: Evidence from Subprime Crisis                |
| Kenourgios, Samitas and Paltalidis | 2011 | DCC-GARCH      | Transmission of Liquidity Shocks: Evidence from Subprime Crisis                |
| Martin and Nakamura  | 2012 | DCC-GARCH      | Transmission of Liquidity Shocks: Evidence from Subprime Crisis                |
| Kazi, Guesani and Kaabia | 2015 | DCC-GARCH      | Transmission of Liquidity Shocks: Evidence from Subprime Crisis                |
| Celik                 | 2015 | DCC-GARCH      | Transmission of Liquidity Shocks: Evidence from Subprime Crisis                |
3 Price-Bubbles and Their Identification

"A market in which prices always fully reflect available information is called efficient" by Fama (1970)

3.1 Introduction and Definitions

As mentioned before, many papers focus on the explication, proof and analysis of market mis-pricing. Particularly, many well-known scientists - leading by Shiller (2000) and Fama (1965) - are engaged in the detection of bubbles. There are different opinions how to define a price-bubble. There are two kinds of bubbles: The deterministic bubble, which will burst in a specific time or the stochastic, which will increase to infinite, as seen in Figure 1. Trivially said and knew from the efficient-market hypothesis of Fama (1970): An investor cannot score abnormal returns, because all relevant and available information are included in stock prices.

Nevertheless, at the beginning of every speculative price-bubble there is a belief of high probability of excess returns, see therefore Garber (1990). In an efficient market, stock-market changes are only justified with new information. During the development of a speculative bubble the investor knows that the prices are over-valuated. Even normally no new information are published, which could explain those high stock-prices.

Notwithstanding, one of the most-known definitions is following: A positive price-bubble is the deviation of market price from the expected discounted dividends (this is called the fundamental value) and is based on the dividend model of William (1938):

\[ P_t > \sum_{i=1}^{\infty} \frac{E(D_i)}{(1 + \mu)^{t-i}} \]  

\( P_t \) defines market price, \( D_i \) dividends and \( \mu \) returns.

Speculative bubbles can arise from stock's price-expectation. As mentioned before, there are two types of bubbles. The main focus of this paper, as those of Scherbina (2013), Jarchow (1997), will be stochastic bubbles. Those can burst with a specific probability during the time-period. In contrast to stochastic bubbles, deterministic bubbles increase to infinite. If a bubble burst, there are two following opportunities:

1) The market price will fall behind in the fundamental value, or
2) the market price will fall below the fundamental value.

Figure 1, based on the theory of Aschinger (1991) and Jarchow (1997), shows the different two scenarios: a deterministic Bdet and a stochastic bubble (Bstoch) under the assumption that the fundamental value stays constant during time.

3.2 Typical Developments of Bubbles

The majority opinion about a typically development of a bubble is based on Kindleberger and Aliber (2005), Rosser et al. (2012) and Aschinger (1991). Below, the characteristics and phases of a speculative bubble are illustrated generally - as well - compared to the technology-bubble:

1) The beginning of each bubble is initiated with an exogenous shock, which implicates pervasive economical changes. In this phase a full branch of an industry can be changed. The exogenous shock can be caused by economical or political reasons; some are even caused by new technological developments. Structural changes raise the optimism of investors, banks and companies. The
optimism and the expectation of a new welfare and new expected profit of the companies encourages investments to risky stocks. The expectation of stock market is positive. Therefore, investors hope for higher returns than in status quo ante.

2) The next step of a speculative bubble - the boom - is reached by the expectation of always continuing raising returns and a potential new market. By dint of equation 1 means that, that the market price is now a multiple of its proper fundamental value.

3) In consequence to the phase of the boom, interest rates are generally reduced, credit activities are increased and therefore, the total money supply increases. This behavior intensifies the proper boom-phase. The demand for credit increases permanently.

4) The abnormal increase of the stocks allures speculators and the credit activities are expanded by lower interest rates. A perpetual growing spectrum of participants from wealthy investors, debt-financed investors, and in the end speculators characterizes the climax of each bubble, the euphoria.

5) A disproportionately high return-expectation arouses even more investors, who are investing even more capital in the price-bubble. In this phase behavioral and irrational factors determine the investors’ buying behavior. For instance, bandwagon effects are incorporated into behavioral effects: Following the motto, if others are buying, I will also buy. Those herd instincts happen avalanche-like and increase the capital inflow of each bubble, as Weil (2010) showed.

6) Due to higher interest rates, stagnant price trends or rejection of new technologies the expectation can dramatically change. The first disembark of insiders, who would like to liquidate their winnings, triggers speculations of declining stock prices.

7) Professional investors escape. The others, the much bigger mass of non-professional investors, are trying to liquidate their winnings as well. This will lead to a huge increase of the demand of liquids funds in fear of illiquidity. The mass gets into a kind of a panic and sells their stocks at any price. Because the order of selling dominates, the prices will decline strongly. The speculative bubble burns, and the prices will go back to their fundamental value. This is caused to the microeconomic model supply and demand; stock prices will decrease at oversupply.

3.3 Technology-Bubbles and their Development

The following chapter will give a short overview about the technology-bubble - also called DotCom bubble because of the domain ending COM - and analyze it with the help of the previous
The technology-bubble started not at a fix time, it grew during the early 90’s caused to a new technology-era- the Internet sector and it’s associated industry sectors. The start of the technology-bubble was caused by the hope, that the internet can im-prove the productivity of a company and therefore increase their expected profits.

As Xiong (2013) and Scherbina (2012) have shown the interest of achieving excess re-turns grew in times of the technology boom, especially of private investors.

The chart of the index NASDAQ gives a good overview of this speculative bub-ble: The NASDAQ increased since the end of the 90’s. It doubled up in the time period between 1996 and 1998 and even quadrupled in the time between 1998 and 2000. Es-pecially during the technology-bubble, the demand of internet-companies was enor-mous, whereupon the expected profit, respec-tively the winning-probability, of those companies were excluded and evaluated even illusory. The basic idea behind the trade of those stocks was trivially: One thought that the companies would offer their services for free at the beginning, thus would improve their market share and would generate some sales at a future date. Many of those new founded companies had the same busi-ness-idea and competed against each other. The technology-bubble burst in March 2000. Analog to the foundation of many new companies with similar business-ideas and their parallel increase in stock-prices, many of those companies moved avalanche-like - as well - to the other direction up to bankruptcy in March 2000. Discussed by Scherbina (2012), Ofek and Richardson (2003), Xiong (2013) and Brunnermeier and Nagel (2004) as well.

Figure 2 shows on the left hand the NASDAQ Composite (IXIC) as well on the right hand the compounded NASDAQ Composite. Those figures illustrate exemplary the typical trend of a speculative bubble with their high volatility around the peak.

The technology-bubble triggered an enormous worldwide financial crisis and showed the influences of overoptimistic perspectives for the Internet industry and there-fore, the high stock prices. Figure 3 shows the INDU, DAX, FTSE100, SP500, SXSE, and IXIC. The graph shows the series with all indices normalized to 100 points on the first day of the sample, 1 December 1990.
indices are normalized to illustrate better the relative performance of the initial value of each index.

As one can see, all graphs have a similar trend and the series are not stationary. The peak of the technology bubble was in March 2000, but the impact of the technology bubble is different. For instance, some markets are highly volatile, like IXIC or SXXE, others like FTSE100 shows a more stationary trend behavior.

Nevertheless, one can identify some volatility cluster and show that this holds even for the compounded returns - as will be shown later on in section 4.

3.4 Behavioral Finance

A main important part of the puzzle of a speculative bubble is the assumption of a Homo Oeconomicus, a fully rational individual. But especially individuals, like inves-tors, tend to overreact or make decision regarding irrelevant information’s. This is in contrast to the assumption of a full-rational investor, who will always make rational, utility-maximizing decisions, like Shefrin (1983) and Simon (1979) point out. This irra-tional behavior tends to result in excess volatility clusters. Therefore, to understand more in detail which physiological factors drive a bubble, this chapter will focus on the behav-ioral finance and analyze those with the dotcom-bubble. The behavioral finance is a new behavioral-scientific approach, which explains stock volatilities during speculative bub-bles with the help of psychologies and rational models. Employing behavioral-scientific approaches, the processing of relevant information’s are analyzed to explain speculative bubbles. (Nguyen and Schueßler 2011)
3.4.1 Feedback Trading Model

One of the main discussed models of the behavioral finance is the Feedback Trading model at the stock market. This model produces a speculative bubble under the assumption that the stock demand of an investor’s group is based only on historical trading information’s. The mechanism of those models allows a bubble to grow with more capital inflow until a certain time. At the moment when the capital inflow will rapidly decrease, the bubble will break down.

The following example will explain this theory:

Caused by positive news of a company their stock price increases. Some investor groups buy those stocks with the expectation that the stocks will increase in the future and therefore, the return increases as well. The first step is to define the trading volume as the amount of trading stocks of those companies. The demand after those stocks increases with the expectation of growing returns and involving that the stock price will be higher than the fundamental value. The trading volume increases also because of the amount of money. Those will attract as well other Feedback Traders, who are expecting that the price will still grow. This schematic repeats as long as no capital is invested anymore. At this point, the price will not grow anymore. Investors would like to sell their stocks profitably. The necessary demand of capital threatens the bubble- it can and will burst, see Scherbina (2013) for more details.

A bubble will burst therefore, when the supply of capital is exhausted. To grow a speculative bubble need to get more new invested capital. Once the capital inflow will decrease, the prices will fluctuate. The result of this will change the optimistic mood, which will deflate the bubble as well. In fact, there are some indicators that a bubble will burst as soon as a huge amount of unprofessional investors are speculating with those overpriced stocks, as Scherbina (2013) showed.

Many behavioral models assume that competitive arbitragers limit the huge price volatilities. The following model by De Long et al. (1990a) shows that rational arbitragers intensify more than dissolve the price volatilities under certain circumstances. The model implies three investor types, based on DeLong et al. (1990a) and Scherbina and Schlusche (2012):

1) Positive Feedback Trader: The base of the stock demand is based only on past prices changes.
2) Passive Trader: The trading base is dependent on the asset value relative to their fundamental value.
3) Informed rational speculators: The foundations of their trading’s are news about the fundamental value as a hypothesis for future price movements.

With the help of those models Belhoula and Naoui (2011) showed that rational investors tend to destabilize than to stabilize stock prices. One assumption is that the rational investors know the Feedback Traders based their future demand on the base of past price changes. To get higher price volatility, speculators have a higher demand of trading than in absence of Feedback Trader. If Feedback Traders entrance the market, the speculators invert their trading’s and earn the profit from the Feedback Trader’s expense.

The model shows clearly that rational speculators are not trading against expected future mispricing’s, which occurs as a result of an overreaction of the Feedback Traders to past prices changes. Instead, rational speculators anticipate the behavior of positive Feedback Traders and drift the prices up. In following rational trader will gain from those mispricing’s and buy the stocks to sell those later to inflationary prices. The rational arbitragers will benefit from the bandwagon effect instead of trading against the mispricing’s. All in all, a bubble arises from those rational, speculative behaviors. Those findings coincide with the conclusions of Abreu and Brunnermeier (2003) and DeLong et al. (1990b).
3.4.2 Other Behavioral Explanations

This following section will discuss some more behavioral aspects to understand better the behavioral explanation of a speculative bubble. Overconfidence and over-optimism are important for the evaluation of stock prices, as De Bondt (1998) found out. Individuals tend to be overoptimistic if they have an own influence on stock prices. The phenomenon of overconfidence explains that every individual has a higher confidence in his own expectation and evaluation. Both phenomena’s are documented by experiments: Stocks, which are held in their own portfolios, are getting overvaulted belong their re-turns and expected growth.

Another effect is called the bandwagon effect or as well the herding behavior, based on DeBondt and Forbes (1999). This phenomenon explains the buying behavior, which is influenced by the buying behaviors of others. This means: A non-professional investor buys/sells stocks analog to the market/investors-majority in a speculative bubble. He makes his decision based on other market participants, which emblematize the major-ity. This behavior is relevant: On the right hand, he does not deviate from the majority opinion, because the majority cannot be wrong. On the other hand, he is not willing to swim against the stream and be against the majority. Nguyen and Schueßler (2011) ana-lyzed this specific behavior.

Another aspect that occurs during a bubble is the Narrow Framing, researched and in-troduced by Barberis and Thaler (2002) and Barberis et al. (2006). This means that individuals judge differently over identical stocks in the same decision situations, if the stock or portfolio strategy is positive described. In the initial stage of the technology-bubble one assumed a huge benefit of new technology innovations. In those times stocks of companies, which expected an extensive excess profit regarding to the new technologies, get an even higher rating than if they were objective rated. Non-professional investors tends also to hold bad-performed stocks to long, so that, they do not have to realize their loses. That loss-aversion affects the behaviorism of each inves-tor.

To understand the formation phase of a speculative bubble you have to take those previous behaviors in consideration. Under rational assumption, it does not make sense to invest in stocks, which have a higher market value than their fundamental value. But this happens explicit during bubbles as shown by Weil (2010) and as well by Ngu-yen and Schueßler (2011). Non-rational investing means not only that stock prices are determined not always objective by future expectations but also biased by individual characters and their emotional factors, as respectively shown by the studies of Barberis et al. (2006), Kugler and Hanusch (1992).

4 Methodology and Empirical Specification

In following section, the data set will be analyzed as well as the dynamic condi-tional correlation (DCC) model will be explained.

4.1 Data

The data on stock market prices consists of the Standard and Poor’s 500 (SP500), Dow Jones Industrial Average (INDU), NASDAQ Composite (IXIC), Finan-cial Times Stock Exchange (FTSE100), Deutscher Aktienindex (DAX) and Euro STOXX Index (SXXE) for U.S., U.K. and Germany. (All indices are shown in figure 6 in the appendix.) The reason for choosing this group of countries is the idea of having three representatives for American and as well three for European markets. The daily data are collected over the period from December 1, 1990 to December 31, 2014.
All data are obtained from Bloomberg. Daily data are used in order to retain a high number of observations to adequately capture the rapidity and intensity of the dynamic interactions between markets.

Figure 4 presents the normalized stock market indices with an interesting pattern. Using normalized stock market prices; the figure illustrates better the relative performance of the initial value of each index than plotting all indices naturally, as seen in Figure 5 in the Appendix. Figure 4 identifies a period of joint fall in all the indices concentrated during the highlighted period (from July of 1998 to October of 2001).

Regarding the sample definition, the intention was to select an extensive set of historical data with approximately a 24-year period, which amounted to 5952 observations for each series. Compounded market returns $i$ (index $i$) at time $t$ are computed as following:

$$r_{i,t} = \log \left( \frac{P_{i,t}}{P_{i,t-1}} \right)$$

where $P_{i,t}$ and $P_{i,t-1}$ are the closing prices for day $t$ and $t - 1$, respectively.

Figure 7 indicates those compounded market returns and identifies some clusters, especially in times of crisis and bubbles. As Figure 7 clearly shows, the volatility cluster during the DotCom period seems to be more sprawled than the subprime crisis, which had highly returns in a short-term.

### 4.2 Descriptive Statistics

The descriptive statistics of the data are given in table 2, which is divided in two panels A and B. As seen from panel A, the mean value for each return series is close to zero and for each return
Figure 5: All Stock Market Indices

Figure 6: Stock Market Indices
series the standard deviations are larger than the mean values and varies from 1.05% to 1.45%. The minimum alters from -8.20% to -10.17% and the maximum varies from 9.38% to 13.26%. Each compounded market return displays a small negative amount of skewness and large amount of kurtosis - varies between 8.06 to 11.78 - indicating that there are bigger tails than the normal distribution and therefore, the returns are not normally distributed.

In panel B, unconditional correlation coefficients in stock market index returns indicate strong pairwise correlations. The correlations within the different continents are highly positive over the full sample. The European indices: FTSE100, DAX and SXXE, have a correlation between 76% to 90% and the American Indices: INDU, SP500 and IXIC, have nearly 78% to 96%. The correlations between the different continents are even high; every correlation is bigger than 44%. Those high positive unconditional correlations are the first indicators for a strong contagion effect.
Table 2: Descriptive Statistics of Compounded Stock Market Returns

| Panel A: Descriptive statistic | Mean  | Min   | Max   | Std.dev. | Kurtosis | Skewness | Jarque-Bera |
|-------------------------------|-------|-------|-------|----------|----------|----------|-------------|
| FTSE100                       | 0.00019 | -0.09265 | 0.09384 | 0.01133  | 9.10535  | -0.07465  | 9248.26     |
| DAX                           | 0.00032 | -0.09871 | 0.10797 | 0.01454  | 8.06284  | -0.11492  | 6368.85     |
| INDU                          | 0.00033 | -0.08201 | 0.10508 | 0.01098  | 11.34602 | -0.15072  | 17294.31    |
| SP500                         | 0.00031 | -0.09470 | 0.10957 | 0.01157  | 11.77817 | -0.24339  | 19165.48    |
| SXSE                          | 0.00021 | -0.08208 | 0.10438 | 0.01386  | 8.23300  | -0.06048  | 6793.79     |
| IXIC                          | 0.00043 | -0.10168 | 0.13255 | 0.01522  | 9.01064  | -0.08929  | 8966.10     |

| Panel B: Summary of unconditional correlation matrix of compounded stock market returns |
|----------------------------------|----------------|----------------|----------------|----------------|----------------|----------------|
|                                  | FTSE100         | DAX            | INDU           | SP500          | SXSE           | IXIC           |
| Full sample                      | 1.00000         | 0.75810        | 0.50847        | 0.51457        | 0.83884        | 0.44186        |
| FTSE100                         | 1.00000         | 0.55048        | 0.55373        | 0.90782        | 0.50494        |                |
| DAX                             | 1.00000         | 0.96170        | 0.54172        | 0.78351        |                |                |
| INDU                            | 1.00000         | 0.59435        | 0.87168        |                |                |                |
| SP500                           | 1.00000         | 1.00000        | 0.48908        |                |                |                |
| SXSE                            |                |                |                |                |                |                |
| IXIC                            |                |                |                |                |                |                |
| Dot-Com - 1990-2005              | 1.00000         | 0.4165         | 0.4392         | 0.8095         | 0.36347        |                |
| FTSE100                         | 1.00000         | 0.42409        | 0.43012        | 0.78959        | 0.36347        |                |
| DAX                             | 1.00000         | 0.48555        | 0.49270        | 0.87797        | 0.44362        |                |
| INDU                            | 1.00000         | 0.94085        | 0.46156        | 0.69273        |                |                |
| SP500                           | 1.00000         | 0.47211        | 0.82992        |                |                |                |
| SXSE                            |                |                | 1.00000        | 0.42028        |                |                |
| IXIC                            |                |                |                | 1.00000        |                |                |
| Dot-Com - July 1998-Ocotber 2001 |                |                |                |                |                |                |
| FTSE100                         | 1               | 0.7383         | 0.4165         | 0.4392         | 0.8095         | 0.3713         |
| DAX                             | 1               | 0.4802         | 0.4983         | 0.8950         | 0.4549         |                |
| INDU                            | 1               | 0.9158         | 0.4412         | 0.6408         |                |                |
| SP500                           | 1               | 0.4712         | 0.84063        |                |                |                |
| SXSE                            | 1               | 0.4301         |                |                |                |                |
| IXIC                            |                |                |                |                |                | 1              |
The results of the unit root tests for the market returns are summarized in Table 3. The Augmented Dickey-Fuller (ADF), Phillips-Perron (PP) and Kwiatkowski, Phillips, Schmidt, and Shin (KPSS) tests are used to explore the existence of unit roots in individual series. The results of unit root tests have rejected the null hypothesis of the unit root for all market returns, indicating that the return series are trend stationary.

Table 3: Unit root tests: Augmented Dickey-Fuller (ADF), Phillips-Perron (PP) and Kwiatkowski, Phillips, Schmidt, and Shin (KPSS)

| Stock market returns | ADF statistics | PP statistics | KPSS statistics |
|----------------------|----------------|--------------|----------------|
|                      | None | Constant | Time Trend | Constant and time trend |
| FTSE100              | -34.660 | -34.695 | -34.746 | -34.730 | -78.060 | 0.049 |
| DAX                  | -77.373 | -77.405 | -77.413 | -77.418 | -77.386 | 0.062 |
| INDU                 | -58.259 | -58.338 | -58.363 | -58.358 | -81.073 | 0.073 |
| SP500                | -58.727 | -58.793 | -58.814 | -58.813 | -81.931 | 0.094 |
| SXXE                 | -36.975 | -37.000 | -37.061 | -37.032 | -78.214 | 0.064 |
| IXIC                 | -57.165 | -57.231 | -57.255 | -57.251 | -77.670 | 0.113 |

Figure 8 depicts the plots between every indices. Visually, one can see a higher relationship between indices from the same continent, for instance SP500 and INDU, or DAX and SXXE. It is not a perfect relationship, because not all points are lying exactly on the straight lines. The closer they are to the line (taken altogether), the stronger would be the relationship between the variables. These relationships between the series are line-ary fitted by straight red lines.

### 4.3 Model Selection

The econometric method is based on the modeling of multivariate time-varying volatilities. One of widely used models is DCC one of Engle and Sheppard (2001) and Tse and Tsui (2002), which captures the dynamic of time-varying conditional correlations, contrary to the benchmark CCC model by Bollerslev (1990) which keeps the conditional correlation constant. The main idea of this models is that the covariance matrix, $H_t$, can be decomposed into conditional standard deviations, $D_t$, and a correlation matrix, $R_t$. $D_t$ as well $R_t$ are designed to be time-varying in the DCC GARCH model.

The specification of the DCC model can be explained as follows:

$$
\begin{align*}
\mathbf{r}_t &= \mu + \sum_{s=1}^{p} \Phi_s \mathbf{r}_{t-s} + \boldsymbol{\epsilon}_t \quad \text{for } t = 1, \ldots, T \\
\boldsymbol{\epsilon}_t | I_{t-1} &\sim N(0, H_t)
\end{align*}
$$

where $\mathbf{r}_t$ is a $6 \times 1$ vector of stock market index returns.

The error term, $\boldsymbol{\epsilon}_t$, from the mean equations of stock market indices can be presented as follows with $\mathbf{z}_t$ is a $6 \times 1$ vector of i.i.d errors:

$$
\boldsymbol{\epsilon}_t = (\varepsilon_{\text{FTSE100},t}, \varepsilon_{\text{DAX},t}, \varepsilon_{\text{INDU},t}, \varepsilon_{\text{SP500},t}, \varepsilon_{\text{SXXE},t}, \varepsilon_{\text{IXIC},t})' = H_t^{1/2} \mathbf{z}_t
$$
with $\mathbf{z}_t \sim N(0, I_6)$.

$H_t$ is the conditional covariance matrix that is

$$H_t = E(\mathbf{e}_t \mathbf{e}_t'| \mathbf{I}_{t-1})$$

(5)

Therefore, the equation can be written for the 6 different market indices:

$$
\begin{bmatrix}
    r_{FTSE100,t} \\
    r_{DAX,t} \\
    r_{INDU,t} \\
    r_{SP500,t} \\
    r_{SXXE,t} \\
    r_{IXIC,t}
\end{bmatrix}
+ \sum_{s=1}^{p}
\begin{bmatrix}
    \phi_{11,s} & \phi_{12,s} & \phi_{13,s} & \phi_{14,s} & \phi_{15,s} & \phi_{16,s} \\
    \phi_{21,s} & \phi_{22,s} & \phi_{23,s} & \phi_{24,s} & \phi_{25,s} & \phi_{26,s} \\
    \phi_{31,s} & \phi_{32,s} & \phi_{33,s} & \phi_{34,s} & \phi_{35,s} & \phi_{36,s} \\
    \phi_{41,s} & \phi_{42,s} & \phi_{43,s} & \phi_{44,s} & \phi_{45,s} & \phi_{46,s} \\
    \phi_{51,s} & \phi_{52,s} & \phi_{53,s} & \phi_{54,s} & \phi_{55,s} & \phi_{56,s} \\
    \phi_{61,s} & \phi_{62,s} & \phi_{63,s} & \phi_{64,s} & \phi_{65,s} & \phi_{66,s}
\end{bmatrix}
\begin{bmatrix}
    r_{FTSE100,t-s} \\
    r_{DAX,t-s} \\
    r_{INDU,t-s} \\
    r_{SP500,t-s} \\
    r_{SXXE,t-s} \\
    r_{IXIC,t-s}
\end{bmatrix}
$$

(6)