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Article

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

Maximilian-Benedikt Herwarth Kohn1 and Pedro L. Valls Pereira2*

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 as on one hand as an econometrics explanation and on the other hand the behavioral finance as an psychological explanation. Contagion 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 prove the presence of structural changes during financial crisis.

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, Neal, & Wandschneider, 2006; Ofek & Richardson, 2001).

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.

In fact, 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 spillover 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 spillover 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 spillover 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, Ungureanu, Vilag, and Stoia (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, Dandapani, and Bhattacharya (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) Is it observed a contagion effect between the American and European stock markets in the presence of price bubbles, like the DotCom bubble?
(2) 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 (002). Nevertheless, the main focus lies on the DCC-GARCH model.

The paper is organized 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, describes the empirical strategy according to test for financial contagion and presents the results according to previous strategies. The 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 (1990) 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 (2005) 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 (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 (2005) 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 (2005) and Keynes (1935). This paper analyzes the technology-bubble—often mentioned as the DotCom-bubble. Ofek and Richardson (2001) were one of the first authors, who explained the internet bubble in the 1990s. 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. (1990) gives a good overview over the past famous bubbles and concludes that a bubble is a present phenomenon and will occur frequently.

From the econometrics point of view, several attempts to develop econometric tests have been made in the literature going back some decades (see Gurkaynar, 2008, for a recent review). But the papers by Phillips, Shi, and Yu (2013) and Phillips, Wu, and Yu (2011) recently proposed a recursive method which can detect exuberance in asset price series during an inflationary phase. The method is especially effective when there is a single bubble episode in the sample data, as in the 1990s Nasdaq episode analyzed in the Phillips, Wu, and Yu (2011) and this methodology is used in this paper to determined the time period of the Dot-Com Bubble.1.

2.2. Financial contagion

The literature about contagion effect in financial markets is that extensive to re-view here fully. The surveys from Kindleberger (1978), Kaminsky, Reinhart, and Vegh (2003) and Bae, Karolyi, and Stulz (2003) are only some of those, which have to be mentioned. In general, the focus of most literature 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 an-other 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 explained by the fundamentals.
For instance, de P Filleti, Hotta, and Zevallos (2008) analyzed the contagion between the Latin American economies and two emerging markets. Armada, Leitão, and Lobão (2011) tested the contagion effect between the financial markets of nine developed countries and Azad (2009) for the Asian market. Horta, Medes, and Vierra (2008) and as well Arruda and Pereira (2013) analyzed the contagion effects during the US Subprime crisis. Marçal, Pereira, Martins, and Nakamura (2011) evaluated the contagion in the financial crisis of Asia and Latin America. Rotta and Pereira (2016) evaluates the financial contagion between stock market returns of the United States (S&P500), United Kingdom (FTSE100), Brazil (IBOVESPA), and South Korea (KOSPI) from 1st of February 2003 to 20 of September 2012 using Regime Switching Dynamic Correlation (RSDC), originally presented by Pelletier (2006). A modification was made in the original RSDC model, the introduction of the GJR-GARCH-N and also GJR-GARCH-t.

Regarding to the technology-bubble, Anderson, Brooks, and Katsaris (2010) studied the proliferation of the technology-bubble. Most of the studies applied variations of (Engle & Sheppard, 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.

**Table 1. Overview of empirical researches**

| Author(s)/Year | Model | Specific Topic |
|----------------|-------|----------------|
| Chiang, Jeon and Li (2007) | DCC 8 Asian FMs | Financial crisis in Asia in 1997, the effect of credit rating agencies on the structure of correlation dynamic |
| Kuper and Lestano (2007) | DCC 6 Asian FMs | Effect of financial crisis on the interdependence of financial and FX markets |
| Cheung, Fung and Tam (2008) | DCC 11 EMEAP and US | Interdependence of financial markets, Contagion risk in EMEAP region |
| Cho and Parhizgari (2008) | DCC 8 Asian FMs | East Asian financial contagion under DCC-GARCH |
| Beirne, Caporale, Ghattas and Spagnolo (2009) | MGARCH in-mean 41 FMs: Asia, Latin America, Middle East | Global and Regional volatility spillover |
| Frank, Gonzalez-Hermosillo and Hesse (2009) | DCC GARCH and Hesse | Transmission of Liquidity Shocks: Evidence from 2007 Subprime Crisis |
| Munoz, Marquez and Chulia (2010) | TSFA, DCC 19 FMs: North America, Europe, Asia | Asian financial crisis, Dot-com crisis, Global financial crisis |
| Yiu, Ho and Choi (2010) | PCA, ADCC 11 EMEAP and US | Dynamic correlation analysis of financial contagion in Asian markets in global financial turmoil |
| Naoui, Khemiri and Kiouane (2010) | DCC 10 FMs: Asia, Latin America and US | Sub-prime crisis 2007 |
| Kenourgios, Samitas and Pallatidis (2011) | AG-DCC, copula DCC BRICS, UK, US | Five recent financial crisis |
| Marçal, Valls Pereira, Martin and Nakamura (2011) | 9 FMs: Argentina, Brazil, South Korea, US, Singapore, Malaysia, Mexico, Japan | Evaluating of contagion or interdependence in the financial crisis of Asia and Latin American, considering macroeconomics fundamentals |
| Kazi, Guesmi and Kaabia (2011) | DCC 17 FMs: OECD countries | Contagion effect of Financial Crisis on OECD Stock Markets |
| Celik (2012) | DCC GARCH 8 FMs: Japan, Malaysia, Denmark, Canada, China, Australia, Brazil | Contagion Effect on emerging markets. The evidence of DCC-GARCH model |
| Chittedi (2015) | DCC GARCH India and US | Financial Crisis and Contagion Effects to Indian Stock Market: DCC-GARCH Analysis |
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, Goedhart, and Wessels (2010), Phylaktis and Xia (2009), 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.

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 mispricing. Particularly, many well-known scientists—leading by (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.

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.

Figure 1. NASDAQ Composite and Compound Returns of NASDAQ 1990–2005.
3.2. Technology-bubbles and their development

The following section 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 shown development.

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 improve the productivity of a company and therefore increase their expected profits.

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

The chart of the index NASDAQ gives a good overview of this speculative bubble: 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. Especially during the technology-bubble, the demand of internet-companies was enormous, whereupon the expected profit, respectively 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 business-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 Ofek and Richardson (2001), Xiong (2013) and Brunnermeier and Nagel (2005) 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 therefore, the high stock prices. Figure 3 shows the INDU, DAX, FTSE100, SP500, SXXE, and IXIC. The graph shows the series with all indices normalized to 100 points on the first day of the sample, 1 December 1990. The 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.

This date was identified using (Phillips et al., 2013) methodology and Figure 3 shows the Critical Value for the test statistics. As can be seen the date of the maximum value for the test statistics is 9th of March 2000.

3.3. 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 investors, 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 and Statman (1984) and Simon (1979) point out. This irrational 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 behavioral finance and analyze those with the dotcom-bubble. The behavioral finance is a new behavioral-scientific approach, which explains stock volatilities during speculative bubbles 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 & Schueßler, 2011).

3.3.1. 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 Long, Shleifer, Summers, and Waldmann (1990a) shows that rational arbitragers intensify more than dissolve the price volatilities under certain circumstances. The model implies three investor types, based on Long 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 & Naoui, 2011) showed that rational investors tend to destabilize than to stabilize.
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, specula-
tors 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 mispric-
ing’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

### Table 2. Descriptive statistics of compounded stock market returns

|        | Mean  | Min    | Max    | Std. dev. | Kurtosis | Skewness | Jarque-Bera |
|--------|-------|--------|--------|-----------|----------|----------|-------------|
| Panel A: Descriptive statistic
| 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 | 0.01908 | 11.34602 | -0.15072 | 17294.31 |
| SP500   | 0.00031 | -0.09470 | 0.10957 | 0.01157 | 11.78717 | -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    |
|----------|---------|---------|---------|----------|---------|---------|
| FTSE100  | 1.00000 | 0.75810 | 0.50847 | 0.83884  | 0.44186 |
| DAX      | 1.00000 | 0.55048 | 0.55373 | 0.90782  | 0.50494 |
| INDU     | 1.00000 | 0.96170 | 0.54172 | 0.78351  | 0.78351 |
| SP500    | 1.00000 | 0.54935 | 0.87168 |
| SXSE     | 1.00000 | 0.48908 |
| IXIC     | 1.00000 |

|          | FTSE100 | DAX     | INDU    | SP500    | SXSE    | IXIC    |
|----------|---------|---------|---------|----------|---------|---------|
| FTSE100  | 1.00000 | 0.67992 | 0.42409 | 0.78999  | 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 |

|          | FPE    | AIC    | HQIC    | S       |
|----------|--------|--------|---------|---------|
| 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      |

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, specula-
tors 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 mispric-
ing’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 Long, Shleifer, Summers, and Waldmann (1990b).

3.3.2. 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 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 returns and expected growth.

Another effect is called the bandwagon effect or as well the herding behavior, based on Bondt 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 majority. 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) analyzed this specific behavior.

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 | 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 |
| SXSE                 | −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 |

Table 4. Order selection

| Sample: 5–5,951 | N obs: 5,947 |
|-----------------|--------------|
| lag             | LL | LR | df | FPE | AIC | HQIC | SBIC |
| 0               | 127,377.0 |    |    | 1.00E-26 | −42.8352 | −42.8329 | −42.83 |
| 1               | 128,188.0 | 1,622.9 | 36 | 7.54E-27* | −43.1318 * | −43.0796 | −43.05 * |
| 2               | 128,289.0 | 202.96 | 36 | 7.60E-27 | −43.1180 | −43.0875 * | −43.03 |
| 3               | 128,367.0 | 154.16 | 36 | 7.55E-28 | −43.0960 | −43.0873 | −43.03 |
| 4               | 128,397.0 | 60.263 * | 36 | 7.56E-28 | −43.1299 | −43.0712 | −42.96 |

Endogenous: FTSE100 DAX INDU SP500 SXSE IXIC
Exogenous: constant
Table 5. Dynamic conditional correlation (DCC)

| DCC               | log likelihood | Coef.     | Std. Err  | t-stat | p-value | [95% Conf. Interval] |
|-------------------|----------------|-----------|-----------|--------|---------|----------------------|
| GARCH_FTSE100     |                | arch L1   | 0.0637757 | 0.003932 | 16.22   | 0.0000               | 0.0560691   |
|                   |                | garch L1  | 0.9284701 | 0.0043591 | 212.99  | 0.0000               | 0.9199264   |
|                   |                | _cons     | 1.32E-06  | 1.69E-07  | 7.79    | 0.0000               | 9.85E-07   |
| GARCH_DAX         |                | arch L1   | 0.0656224 | 0.0035701 | 18.38   | 0.0000               | 0.0586252   |
|                   |                | garch L1  | 0.9247539 | 0.0039471 | 234.29  | 0.0000               | 0.9170178   |
|                   |                | _cons     | 2.62E-06  | 2.56E-07  | 10.23   | 0.0000               | 2.12E-06   |
| GARCH_INDU        |                | arch L1   | 0.048682  | 0.0027567 | 17.65   | 0.0000               | 0.0432751   |
|                   |                | garch L1  | 0.9431361 | 0.003256  | 289.66  | 0.0000               | 0.9367545   |
|                   |                | _cons     | 9.69E-07  | 1.09E-07  | 8.86    | 0.0000               | 7.55E-07   |
| GARCH_SP500       |                | arch L1   | 0.0482413 | 0.0024765 | 19.48   | 0.0000               | 0.0433875   |
|                   |                | garch L1  | 0.944511  | 0.0028662 | 329.53  | 0.0000               | 0.9388934   |
|                   |                | _cons     | 9.41E-07  | 9.82E-08  | 9.58    | 0.0000               | 7.49E-07   |
| ARCH_SXXE         |                | arch L1   | 0.0686716 | 0.0036709 | 18.71   | 0.0000               | 0.0614767   |
|                   |                | garch L1  | 0.9229969 | 0.0041044 | 224.88  | 0.0000               | 0.9149524   |
|                   |                | _cons     | 2.32E-06  | 2.33E-07  | 9.98    | 0.0000               | 1.87E-06   |
| GARCH_IXIC        |                | arch L1   | 0.0501756 | 0.0029842 | 16.81   | 0.0000               | 0.0443267   |
|                   |                | garch L1  | 0.9441076 | 0.0033041 | 285.74  | 0.0000               | 0.9376317   |
|                   |                | _cons     | 1.24E-06  | 1.55E-07  | 7.99    | 0.0000               | 9.33E-07   |
| corr(FTSE100, DAX)|                | 0.821963  | 0.0180374 | 45.57   | 0.0000   | 0.7866103            |
| corr(FTSE100, INDU)|               | 0.5322808 | 0.0386091 | 13.79   | 0.0000   | 0.4566083            |
| corr(FTSE100, SP500)|              | 0.5233292 | 0.0389469 | 13.44   | 0.0000   | 0.4469947            |
| corr(FTSE100, SXXE)|               | 0.8531915 | 0.0148766 | 57.35   | 0.0000   | 0.824034             |
| corr(FTSE100, IXIC)|                | 0.478945  | 0.0412931 | 11.6    | 0.0000   | 0.398012             |
| corr(DAX, INDU)   |                | 0.5584386 | 0.0367332 | 15.2    | 0.0000   | 0.4864428            |
| corr(DAX, SP500)  |                | 0.550688  | 0.0370227 | 14.87   | 0.0000   | 0.4781249            |
| corr(DAX, SXXE)   |                | 0.9538348 | 0.0056143 | 169.89  | 0.0000   | 0.9428309            |
| corr(DAX, IXIC)   |                | 0.5290064 | 0.0384327 | 13.76   | 0.0000   | 0.4536796            |
| corr(INDU, SP500) |                | 0.9681275 | 0.0034649 | 279.41  | 0.0000   | 0.9613365            |
| corr(INDU, SXXE)  |                | 0.5657075 | 0.0364892 | 15.5    | 0.0000   | 0.49619              |
| corr(INDU, IXIC)  |                | 0.8703043 | 0.013504  | 64.45   | 0.0000   | 0.8438368            |
| corr(SP500, SXXE) |                | 0.5590736 | 0.0367229 | 15.22   | 0.0000   | 0.4870981            |
| corr(SP500, IXIC) |                | 0.9308737 | 0.0076038 | 122.42  | 0.0000   | 0.9159706            |

(Continued)
Another aspect that occurs during a bubble is the Narrow Framing, researched and introduced by Barberies and Thaler (2003) and Barberis, Huang, and Thaler (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 investor.

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 (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) and Kugler and Hanusch (1992).

4. Methodology and empirical specification
In following section, the data-set will be analyzed as well as the 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), Financial Times Stock Exchange (FTSE100), Deutscher Aktienindex (DAX), and Euro STOXX Index (SXXE) for the US, the UK, and Germany (All indices are shown in Figure 7). 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 1 December 1990 to 31 December 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. 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:

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

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

Figure 6 indicates those compounded market returns and identifies some clusters, especially in times of crisis and bubbles. As Figure 6 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 series the standard deviations are larger than the mean values and varies from 1.05 to 1.45%. The

| CCC     | log likelihood | 132433.3 | Coef. | Std. Err | t-stat | p-value | [95% Conf. Interval] |
|---------|----------------|----------|-------|----------|--------|---------|----------------------|
| GARCH_FTSE100 | arch L1       | 0.0566933 | 0.0043693 | 12.98    | 0.0000 | 0.0481296 | 0.065257             |
|         | garch L1      | 0.9170612 | 0.0063143 | 145.24   | 0.0000 | 0.9064854 | 0.9294369            |
|         | _cons         | 2.36E-06  | 2.72E-07  | 8.69     | 0.0000 | 1.83E-06  | 2.90E-06             |
| GARCH_DAX  | arch L1       | 0.0567807 | 0.0038654 | 14.69    | 0.0000 | 0.0492047 | 0.0643568            |
|         | garch L1      | 0.912734  | 0.0059912 | 163.24   | 0.0000 | 0.9017754 | 0.9236296            |
|         | _cons         | 4.71E-06  | 4.16E-07  | 11.31    | 0.0000 | 3.89E-06  | 5.52E-06             |
| GARCH_INDU | arch L1       | 0.0482843 | 0.003167  | 14.5     | 0.0000 | 0.0422251 | 0.0554235            |
|         | garch L1      | 0.9230098 | 0.0052205 | 176.8    | 0.0000 | 0.9127778 | 0.9332419            |
|         | _cons         | 2.33E-06  | 2.20E-07  | 10.59    | 0.0000 | 1.90E-06  | 2.76E-06             |
| GARCH_SP500 | arch L1       | 0.0487081 | 0.0029914 | 16.28    | 0.0000 | 0.0428451 | 0.0545712            |
|         | garch L1      | 0.9252955 | 0.0044994 | 205.65   | 0.0000 | 0.9164769 | 0.9341142            |
|         | _cons         | 2.25E-06  | 1.93E-07  | 11.66    | 0.0000 | 1.87E-06  | 2.62E-06             |
| GARCH_SXXE | arch L1       | 0.0572276 | 0.0039392 | 15.93    | 0.0000 | 0.0501874 | 0.0642677            |
|         | garch L1      | 0.9122415 | 0.0053578 | 170.26   | 0.0000 | 0.9017403 | 0.9227427            |
|         | _cons         | 4.09E-06  | 3.57E-07  | 11.44    | 0.0000 | 3.39E-06  | 4.79E-06             |
| GARCH_IXIC | arch L1       | 0.0564031 | 0.0041244 | 13.68    | 0.0000 | 0.0483193 | 0.0644868            |
|         | garch L1      | 0.9201043 | 0.0056235 | 163.62   | 0.0000 | 0.9090824 | 0.9311262            |
|         | _cons         | 3.29E-06  | 3.24E-07  | 10.15    | 0.0000 | 2.66E-06  | 3.93E-06             |
| corr(FTSE100, DAX) | 0.7207753 | 0.0062651 | 115.05   | 0.0000 | 0.708496  | 0.7330547            |
| corr(FTSE100, INDU) | 0.4836002 | 0.0099302 | 48.7     | 0.0000 | 0.4641374 | 0.5030629            |
| corr(FTSE100, SP500) | 0.4890056 | 0.0098663 | 49.56    | 0.0000 | 0.4696681 | 0.5083431            |
| corr(FTSE100, SXXE) | 0.7949716 | 0.0048163 | 160.6    | 0.0000 | 0.7855319 | 0.8041133            |
| corr(FTSE100, IXIC) | 0.4502268 | 0.0103378 | 43.55    | 0.0000 | 0.4299651 | 0.4704885            |
| corr(DAX, INDU) | 0.5009551 | 0.009725  | 51.47    | 0.0000 | 0.4814903 | 0.5196117            |
| corr(DAX, SP500) | 0.5019937 | 0.0097125 | 51.69    | 0.0000 | 0.4829576 | 0.5210298            |
| corr(DAX, SXXE) | 0.9017632 | 0.0024279 | 371.42   | 0.0000 | 0.8970046 | 0.9065218            |
| corr(DAX, IXIC) | 0.4781202 | 0.0100103 | 47.76    | 0.0000 | 0.4585003 | 0.4977401            |
| corr(INDU, SP500) | 0.9507579 | 0.0012527 | 758.94   | 0.0000 | 0.9483026 | 0.9592132            |
| corr(INDU, SXXE) | 0.5075809 | 0.009623  | 52.75    | 0.0000 | 0.4887201 | 0.5264416            |
| corr(INDU, IXIC) | 0.7933353 | 0.0048023 | 165.24   | 0.0000 | 0.7841211 | 0.8029458            |
| corr(SXXE, IXIC) | 0.5133557 | 0.0095353 | 53.73    | 0.0000 | 0.4946292 | 0.5320783            |
| corr(SXXE, IXIC) | 0.8832718 | 0.0028555 | 309.32   | 0.0000 | 0.877675  | 0.8888685            |
| corr(SXXE, IXIC) | 0.4854565 | 0.0099103 | 48.99    | 0.0000 | 0.4660327 | 0.5048804            |
| VCC        | log likelihood  | Coef.     | Std. Err | t-stat | p-value | [95% Conf. Interval] |
|------------|------------------|-----------|----------|--------|---------|---------------------|
| GARCH_FTSE100 | arch L1          | 0.0544271 | 0.0035372 | 15.39  | 0.0000  | 0.0474943           |
|            |                  | 0.0096982 | 0.0006687 | 14.5   | 0.0000  | 0.0083875           |
|            | garch L1         | 0.9350071 | 0.004138  | 225.96 | 0.0000  | 0.9268686           |
|            |                  | 0.9857504 | 0.001007  | 978.88 | 0.0000  | 0.9837767           |
|            | _cons            | 1.10E-06  | 1.46E-07  | 7.49   | 0.0000  | 0.001007            |
| GARCH_DAX  | arch L1          | 0.0576292 | 0.003266  | 17.65  | 0.0000  | 0.0512281           |
|            |                  | 0.9482422 | 0.0031278 | 303.17 | 0.0000  | 0.9421119           |
|            | garch L1         | 0.9293052 | 0.003799  | 244.62 | 0.0000  | 0.9218593           |
|            |                  | 2.14E-07  | 9.35E-08  | 8.7    | 0.0000  | 0.9543726           |
|            | _cons            | 8.14E-07  | 8.36E-08  | 9.56   | 0.0000  | 9.64E-07            |
| GARCH_INDU | arch L1          | 0.0421658 | 0.0025885 | 16.29  | 0.0000  | 0.9441913           |
|            |                  | 1.84E-06  | 1.39E-07  | 9.55   | 0.0000  | 2.22E-06            |
|            | garch L1         | 0.948913  | 0.0027878 | 340.39 | 0.0000  | 0.9434491           |
|            |                  | 0.045179  | 0.0029277 | 15.43  | 0.0000  | 0.0394407           |
|            | _cons            | 8.00E-07  | 8.36E-08  | 9.56   | 0.0000  | 6.36E-07            |
| GARCH_SP500 | arch L1          | 0.042539  | 0.0023652 | 17.89  | 0.0000  | 0.0376682           |
|            |                  | 0.9472675 | 0.0033381 | 283.78 | 0.0000  | 0.940725            |
|            | garch L1         | 0.948913  | 0.0027878 | 340.39 | 0.0000  | 0.9434491           |
|            |                  | 0.045179  | 0.0029277 | 15.43  | 0.0000  | 0.0394407           |
|            | _cons            | 8.00E-07  | 8.36E-08  | 9.56   | 0.0000  | 6.36E-07            |
| GARCH_SXXE | arch L1          | 0.059196  | 0.0032934 | 17.97  | 0.0000  | 0.9216067           |
|            |                  | 1.84E-06  | 1.39E-07  | 9.55   | 0.0000  | 2.22E-06            |
|            | garch L1         | 0.948913  | 0.0027878 | 340.39 | 0.0000  | 0.9434491           |
|            |                  | 0.045179  | 0.0029277 | 15.43  | 0.0000  | 0.0394407           |
|            | _cons            | 8.00E-07  | 8.36E-08  | 9.56   | 0.0000  | 6.36E-07            |
| GARCH_IXIC | arch L1          | 0.042539  | 0.0023652 | 17.89  | 0.0000  | 0.0376682           |
|            |                  | 0.9472675 | 0.0033381 | 283.78 | 0.0000  | 0.940725            |
|            | garch L1         | 0.948913  | 0.0027878 | 340.39 | 0.0000  | 0.9434491           |
|            |                  | 0.045179  | 0.0029277 | 15.43  | 0.0000  | 0.0394407           |
|            | _cons            | 8.00E-07  | 8.36E-08  | 9.56   | 0.0000  | 6.36E-07            |
| corr(FTSE100, DAX) |           | 0.8283366 | 0.0141773 | 58.43  | 0.0000  | 0.8005496           |
| corr(FTSE100, INDU) |          | 0.5972023 | 0.0278819 | 21.42  | 0.0000  | 0.5425548           |
| corr(FTSE100, SP500) |          | 0.5944924 | 0.0279476 | 21.27  | 0.0000  | 0.5397161           |
| corr(FTSE100, SXXE) |          | 0.8797772 | 0.0112918 | 77.91  | 0.0000  | 0.8576458           |
| corr(FTSE100, IXIC) |          | 0.5510388 | 0.0298334 | 18.47  | 0.0000  | 0.525664            |
| corr(DAX, INDU) |          | 0.6245571 | 0.0262502 | 23.55  | 0.0000  | 0.572585            |
| corr(DAX, SP500) |          | 0.6244122 | 0.0265098 | 23.55  | 0.0000  | 0.572454            |
| corr(DAX, SXXE) |          | 0.9515905 | 0.0045002 | 211.46 | 0.0000  | 0.9427704           |
| corr(DAX, IXIC) |          | 0.6110261 | 0.0277104 | 22.05  | 0.0000  | 0.5567148           |
| corr(INDU, SP500) |          | 0.9798125 | 0.0024536 | 399.34 | 0.0000  | 0.9750035           |
| corr(INDU, SXXE) |          | 0.6262688 | 0.0261806 | 23.92  | 0.0000  | 0.5749138           |
| corr(INDU, IXIC) |          | 0.8951593 | 0.0010099 | 88.71  | 0.0000  | 0.8753814           |
| corr(SPP500, SXXE) |          | 0.6291264 | 0.026123  | 24.08  | 0.0000  | 0.579263            |
| corr(SPP500, IXIC) |          | 0.9442859 | 0.0057635 | 163.84 | 0.0000  | 0.9329896           |
| corr(SXXE, IXIC) |          | 0.6000664 | 0.0277685 | 21.61  | 0.0000  | 0.5456412           |
| Adjustment | \[\lambda_1\] | 0.0096982 | 0.0006687 | 14.5   | 0.0000  | 0.0083875           |
|           | \[\lambda_2\] | 0.9857504 | 0.001007  | 978.88 | 0.0000  | 0.9837767           |
| Table 8. Dynamic conditional correlation (DCC)—DotCom |
|--------------------------------------------------|
| **DCC-DotCom log likelihood** | 16,454.45 |

| | Coef. | Std. Err | t-stat | p-value | [95% Conf. Interval] |
|---|---|---|---|---|---|
| **GARCH_FTSE100** | | | | | |
| arch L1 | 0.04813 | 0.01168 | 4.12000 | 0.00000 | 0.0325271 0.0637459 |
| garch L1 | 0.92158 | 0.02165 | 42.58000 | 0.00000 | 0.8791574 0.9640074 |
| _cons | 0.00001 | 0.00000 | 2.31000 | 0.02100 | 0.0000021 0.0000022 |
| **GARCH_DAX** | | | | | |
| arch L1 | 0.05385 | 0.00977 | 5.51000 | 0.00000 | 0.0347031 0.0729936 |
| garch L1 | 0.92078 | 0.01626 | 56.64000 | 0.00000 | 0.8889207 0.9526409 |
| _cons | 0.00001 | 0.00000 | 2.92000 | 0.00400 | 0.0000021 0.0000022 |
| **GARCH_INDU** | | | | | |
| arch L1 | 0.05979 | 0.01194 | 5.01000 | 0.00000 | 0.0363957 0.0831853 |
| garch L1 | 0.85660 | 0.02902 | 29.52000 | 0.00000 | 0.80973 0.9034672 |
| _cons | 0.00001 | 0.00000 | 3.71000 | 0.00000 | 0.0000021 0.0000022 |
| **GARCH_SP500** | | | | | |
| arch L1 | 0.06688 | 0.01054 | 6.35000 | 0.00000 | 0.0462315 0.0875359 |
| garch L1 | 0.86026 | 0.02075 | 41.45000 | 0.00000 | 0.819855 0.9000942 |
| _cons | 0.00001 | 0.00000 | 4.66000 | 0.00000 | 0.0000021 0.0000022 |
| **GARCH_SXXE** | | | | | |
| arch L1 | 0.09105 | 0.01594 | 5.71000 | 0.00000 | 0.0598043 0.1222965 |
| garch L1 | 0.87565 | 0.02073 | 42.24000 | 0.00000 | 0.8378043 0.9162824 |
| _cons | 0.00002 | 0.00000 | 3.64000 | 0.00000 | 0.0000021 0.0000022 |

| Adjustment | \( \chi^2 \) | \( \lambda \) | \( \phi \) | \( \lambda \) | \( \phi \) |
|---|---|---|---|---|---|
| 1 | 0.0253714 | 0.0093194 | 0.0093194 | 0.0253714 | 0.0093194 |
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 and 90\%, and the American Indices: INDU, SP500, and IXIC, have nearly 78 to 96\%. The correlations between the

### Table 9. Constant conditional correlation (CCC)—DotCom

| CCC-DotCom  | log likelihood | 16387.2 | Coef.  | Std. Err | t-stat | p-value | [95% Conf. Interval] |
|-------------|----------------|---------|--------|----------|--------|---------|---------------------|
| GARCH_FTSE100 arch L1 | | | 0.0406604 | 0.0114597 | 3.55 | 0 | 0.0181999 0.063121 |
| garch L1 | | | 0.9266378 | 0.0242197 | 38.26 | 0 | 0.879168 0.9741076 |
| _cons | | | 5.35E-06 | 2.54E-06 | 2.11 | 0.035 | 3.83E-07 0.000103 |
| GARCH_DAX arch L1 | | | 0.0436849 | 0.0094803 | 4.61 | 0 | 0.0251038 0.0622659 |
| garch L1 | | | 0.9304494 | 0.0172803 | 53.84 | 0 | 0.8965805 0.9643182 |
| _cons | | | 7.1E-06 | 2.64E-06 | 2.69 | 0.007 | 1.92E-06 0.000123 |
| GARCH_INDU arch L1 | | | 0.0505734 | 0.0118154 | 4.28 | 0 | 0.0274156 0.0737312 |
| garch L1 | | | 0.8473798 | 0.0365116 | 23.21 | 0 | 0.7758183 0.9189413 |
| _cons | | | 0.0000166 | 4.85E-06 | 3.43 | 0.001 | 7.1E-06 0.000261 |
| GARCH_SP500 arch L1 | | | 0.0591682 | 0.0109687 | 5.39 | 0 | 0.0376699 0.0806666 |
| garch L1 | | | 0.8526132 | 0.0251974 | 33.84 | 0 | 0.8032271 0.9019992 |
| _cons | | | 0.0000165 | 2.63E-06 | 3.75 | 0 | 9.38E-06 0.000236 |
| GARCH_SXXE arch L1 | | | 0.0386898 | 0.0068942 | 5.61 | 0 | 0.0251775 0.0522022 |
| garch L1 | | | 0.9405349 | 0.0128117 | 73.41 | 0 | 0.9154245 0.9656453 |
| _cons | | | 5.07E-06 | 1.8E-06 | 3.43 | 0.001 | 1.45E-06 8.69E-06 |
| GARCH_IXIC arch L1 | | | 0.0850577 | 0.0169785 | 5.01 | 0 | 0.0517803 0.118335 |
| garch L1 | | | 0.8745564 | 0.0237552 | 36.82 | 0 | 0.8279971 0.9211157 |
| _cons | | | 0.000025 | 6.65E-06 | 3.75 | 0 | 0.0000119 0.00038 |
| corr(FTSE100, DAX) | | | 0.7195707 | 0.0169403 | 42.48 | 0 | 0.6863683 0.7527731 |
| corr(FTSE100, INDU) | | | 0.4144243 | 0.0290111 | 14.28 | 0 | 0.3572816 0.4710029 |
| corr(FTSE100, SP500) | | | 0.4467607 | 0.0280144 | 15.95 | 0 | 0.3918534 0.5016679 |
| corr(FTSE100, SXXE) | | | 0.7963725 | 0.0129173 | 59.56 | 0 | 0.771055 0.82169 |
| corr(FTSE100, IXIC) | | | 0.3990754 | 0.0294381 | 13.56 | 0 | 0.3413778 0.4567729 |
| corr(DAX, INDU) | | | 0.475894 | 0.0272097 | 17.49 | 0 | 0.422564 0.529239 |
| corr(DAX, SP500) | | | 0.5030593 | 0.0262335 | 19.18 | 0 | 0.4516427 0.554476 |
| corr(DAX, SXXE) | | | 0.8928582 | 0.070794 | 126.12 | 0 | 0.8789827 0.9067336 |
| corr(DAX, IXIC) | | | 0.4721105 | 0.027278 | 17.31 | 0 | 0.4186466 0.5255744 |
| corr(INDU, SP500) | | | 0.9113788 | 0.0059619 | 152.87 | 0 | 0.8996938 0.9230639 |
| corr(INDU, SXXE) | | | 0.4391554 | 0.028336 | 15.5 | 0 | 0.3836179 0.4946929 |
| corr(INDU, IXIC) | | | 0.6583122 | 0.0198526 | 33.16 | 0 | 0.6194018 0.6972225 |
| corr(SP500, SXXE) | | | 0.477985 | 0.0270862 | 17.65 | 0 | 0.424897 0.531073 |
| corr(SP500, IXIC) | | | 0.8567238 | 0.0093123 | 92 | 0 | 0.838472 0.8749756 |
| corr(SXXE, IXIC) | | | 0.4572583 | 0.0277682 | 16.47 | 0 | 0.402833 0.5116831 |
## Table 10. Varying conditional correlation (VCC)—DotCom

| Coef.          | Std. Err. | t-stat | P-value | [95% Conf. Interval] |
|---------------|-----------|--------|---------|----------------------|
| GARCH_FTSE100 | 0.0446747 | 0.015974 | 3.55 | 0.999999997 | 0.019448 0.060112 |
| arch L1       | 0.0541857 | 0.0107783 | 4.91 | 0.0000126 0.9999997 |
| garch L1      | 0.9233681 | 0.0228421 | 40.42 | 0.9999999995 | 0.8785985 0.9681378 |
| _cons         | 7.44E-06 | 0.0232196 | 4.006 | 0.9999999997 | 0.735E-06 7.17E-06 |
| GARCH_DAX     | 0.0518547 | 0.0107783 | 4.81 | 0.9999999997 | 0.0302997 0.0734097 |
| arch L1       | 0.0541857 | 0.0107783 | 4.91 | 0.0000126 0.9999997 |
| garch L1      | 0.9209443 | 0.0184293 | 49.97 | 0.9999999997 | 0.8845985 0.957065 |
| _cons         | 7.44E-06 | 0.0232196 | 4.006 | 0.9999999997 | 0.735E-06 7.17E-06 |
| GARCH_INDU    | 0.0669699 | 0.0140671 | 4.76 | 0.0000126 0.9999997 |
| arch L1       | 0.0541857 | 0.0107783 | 4.91 | 0.0000126 0.9999997 |
| garch L1      | 0.8381196 | 0.0340613 | 24.61 | 0.9999999997 | 0.7705428 0.9048786 |
| _cons         | 0.000016 | 0.0000007 | 2.23 | 0.0260000 0.00000225 |
| GARCH_SP500   | 0.0770498 | 0.0126339 | 6.1 | 0.0000126 0.9999997 |
| arch L1       | 0.0541857 | 0.0107783 | 4.91 | 0.0000126 0.9999997 |
| garch L1      | 0.844753 | 0.0228421 | 36.86 | 0.9999999997 | 0.7998382 0.9048786 |
| _cons         | 0.0000153 | 0.0000007 | 3.69 | 0.0000126 0.9999997 |
| GARCH_SXXE    | 0.0445476 | 0.0078917 | 5.64 | 0.9999999997 | 0.0270498 0.0620553 |
| arch L1       | 0.0541857 | 0.0107783 | 4.91 | 0.0000126 0.9999997 |
| garch L1      | 0.9342018 | 0.013852 | 67.44 | 0.9999999997 | 0.9070542 0.9613511 |
| _cons         | 5.17E-06 | 0.0000007 | 2.23 | 0.0260000 0.00000225 |
| GARCH_IXIC    | 0.1013787 | 0.0186211 | 5.44 | 0.9999999997 | 0.0523957 0.1503607 |
| arch L1       | 0.0541857 | 0.0107783 | 4.91 | 0.0000126 0.9999997 |
| garch L1      | 0.8602625 | 0.0232196 | 38.46 | 0.9999999997 | 0.8141815 0.9003416 |
| _cons         | 0.0000025 | 0.0000007 | 2.23 | 0.0260000 0.00000225 |
| corr(FTSE100, DAX) | 0.7166286 | 0.0192357 | 37.26 | 0.9999999997 | 0.6789274 0.7543298 |
| corr(FTSE100, INDU) | 0.4289278 | 0.0323449 | 13.26 | 0.9999999997 | 0.365533 0.4923226 |
| corr(FTSE100, SP500) | 0.4582491 | 0.0313423 | 14.62 | 0.9999999997 | 0.3968194 0.5196788 |
| corr(FTSE100, SXXE) | 0.7963533 | 0.0146158 | 54.49 | 0.9999999997 | 0.7677068 0.8249998 |
| corr(FTSE100, IXIC) | 0.4052418 | 0.0330293 | 12.27 | 0.9999999997 | 0.3405055 0.4699758 |
| corr(DAX, INDU) | 0.4961525 | 0.0303153 | 16.37 | 0.9999999997 | 0.4367357 0.5555694 |
| corr(DAX, SP500) | 0.5201536 | 0.0309253 | 17.08 | 0.9999999997 | 0.4624858 0.5789615 |
| corr(DAX, SXXE) | 0.8933449 | 0.0079944 | 111.75 | 0.9999999997 | 0.8776762 0.912815 |
| corr(DAX, IXIC) | 0.4828363 | 0.0306359 | 15.76 | 0.9999999997 | 0.4227912 0.5428815 |
| corr(INDU, SP500) | 0.9203974 | 0.0063063 | 145.95 | 0.9999999997 | 0.9080374 0.9327555 |
| corr(INDU, SXXE) | 0.4596004 | 0.031595 | 14.55 | 0.9999999997 | 0.3976253 0.5215295 |
| corr(INDU, IXIC) | 0.6839871 | 0.021553 | 31.74 | 0.9999999997 | 0.6417441 0.726301 |
| corr(SP500, SXXE) | 0.498375 | 0.0302599 | 16.47 | 0.9999999997 | 0.4390668 0.5578682 |
| corr(SP500, IXIC) | 0.8632602 | 0.0102195 | 84.47 | 0.9999999997 | 0.8427912 0.8832899 |
| corr(SXXE, IXIC) | 0.4729598 | 0.031049 | 15.23 | 0.9999999997 | 0.4121049 0.5338166 |
| Adjust.       | 1.0117483 | 0.0315576 | 3.61 | 0.0000126 0.9999997 |
| λ_1           | 0.00536265 | 0.00005576 | 9.771 | 0.0000126 0.9999997 |
| λ_2           | 0.0075881 | 0.00259884 | 2.9 | 0.0000126 0.9999997 |

Note: The table presents varying conditional correlation (VCC) estimates for different stock indices. The table includes log likelihood values and standard errors for each model.
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.

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 using ADF and PP and the test does not reject the null of stationarity, indicating that the return series are stationary.

| Table 11. Wald-test full sample |
|---------------------------------|
| $H_0^*$: $\lambda_1 = \lambda_2 = 0$ |
| $\mathbb{N}(2)$ stat | 5.5E + 06 |
| $p$-value | 0.0E + 00 |

| Table 12. Wald-test DotCom |
|---------------------------|
| $H_0^*$: $\lambda_1 = \lambda_2 = 0$ |
| $\mathbb{N}(2)$ stat | 17776.8 |
| $p$-value | 0.0E + 00 |

| Table 13. Dynamic conditional correlation—Full sample vs. DotCom |
|---------------------------------------------------------------|
| **DCC: Full sample** |
| FTSE100 | DAX | INDU | SP500 | SXSE | IXIC |
| FTSE100 | 1 | 0.8220 | 0.5323 | 0.5233 | 0.8532 | 0.4789 |
| DAX | 0.8220 | 1 | 0.5584 | 0.5507 | 0.9538 | 0.5290 |
| INDU | 0.5323 | 0.5584 | 1 | 0.9681 | 0.5657 | 0.8703 |
| SP500 | 0.5233 | 0.5507 | 0.9681 | 1 | 0.5591 | 0.9309 |
| SXSE | 0.8532 | 0.9538 | 0.5657 | 0.5591 | 1 | 0.5249 |
| IXIC | 0.4789 | 0.5290 | 0.8703 | 0.9309 | 0.5249 | 1 |

| **DCC: DotCom Bubble** |
| FTSE100 | DAX | INDU | SP500 | SXSE | IXIC |
| FTSE100 | 1 | 0.7034 | 0.4221 | 0.4595 | 0.7820 | 0.3808 |
| DAX | 0.7034 | 1 | 0.5304 | 0.5491 | 0.8927 | 0.4767 |
| INDU | 0.4221 | 0.5304 | 1 | 0.9121 | 0.4741 | 0.6710 |
| SP500 | 0.4595 | 0.5491 | 0.9121 | 1 | 0.5135 | 0.8615 |
| SXSE | 0.7820 | 0.8927 | 0.4741 | 0.5135 | 1 | 0.4582 |
| IXIC | 0.3808 | 0.4767 | 0.6710 | 0.8615 | 0.4582 | 1 |

| **DCC: Full Sample vs DotCom Bubble** |
| FTSE100 | DAX | INDU | SP500 | SXSE | IXIC |
| FTSE100 | 1 | YES | YES | YES | YES |
| DAX | YES | 1 | YES | YES | YES |
| INDU | YES | YES | 1 | YES | YES |
| SP500 | YES | YES | YES | 1 | YES |
| SXSE | YES | YES | YES | YES | 1 |
| IXIC | YES | YES | YES | YES | 1 |
Figure 7 depicts the scatter 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.

5. 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:

\[ r_t = \mu + \sum_{s=1}^{p} \Phi_s r_{t-s} + \varepsilon_t \quad \text{for} \ t = 1, \ldots, T, \]

\[ \varepsilon_t | \Omega_{t-1} \sim \mathcal{N}(0, \Sigma_t), \]  

where \( r_t \) is a \( 6 \times 1 \) vector of stock market index returns.

The error term, \( \varepsilon_t \), from the mean equations of stock market indices can be presented as follows with \( z_t \) is a \( 6 \times 1 \) vector of i.i.d errors:

\[ \varepsilon_t = (\varepsilon_{\text{FTSE100,t}}, \varepsilon_{\text{DAX,t}}, \varepsilon_{\text{INDU,t}}, \varepsilon_{\text{SP500,t}}, \varepsilon_{\text{SXXE,t}}, \varepsilon_{\text{IXIC,t}})' = H_t^{1/2} z_t, \]

with \( z_t \sim \mathcal{N}(0, I_6) \).

\( H_t \) is the conditional covariance matrix that is

\[ H_t = \mathbb{E}(\varepsilon_t \varepsilon_t' | \Omega_{t-1}). \]

The conditional covariance matrix \( H_t \) is defined by two components on the DCC model, which are estimated independent of each other: the sample correlations \( R_t \) and the diagonal matrix of time varying volatilities \( D_t \). Therefore, the conditional covariance matrix is given by following equations:

\[ H_t = D_t R_t D_t, \]

where \( D_t = \text{diag}(\sigma_{\text{FTSE100,t}}, \sigma_{\text{DAX,t}}, \sigma_{\text{INDU,t}}, \sigma_{\text{SP500,t}}, \sigma_{\text{SXXE,t}}, \sigma_{\text{IXIC,t}}) \) is a \( 6 \times 6 \) diagonal matrix of time varying standard deviations from univariate GARCH models, for example:

\[ \sigma_{t,t}^2 = \omega_t + \alpha_t \varepsilon_{t-1}^2 + \beta_t \sigma_{t-1}^2, \]
for $i = \text{FTSE100}, \text{DAX}, \text{INDU}, \text{SP500}, \text{SXXE}, \text{IXIC}$, and the time varying conditional correlation matrix is defined by:

$$R_t = \{ \rho_{i,j,t} \}. \tag{7}$$

In order to obtain the DCC-GARCH model, two steps have to be taken. The first one is to estimate the univariate GARCH model for each asset. The second stage is to define the vector of standardized residuals, $\eta_{i,t} = \frac{r_{i,t}}{\sigma_{i,t}}$ to develop the DCC correlation specification:

$$R_t = \left[ \text{diag}\left( \sqrt{q_{11}} \ldots \sqrt{q_{66}} \right) | Q_t | \text{diag}\left( \sqrt{q_{11}} \ldots \sqrt{q_{66}} \right) \right], \tag{8}$$

where $Q_t = \left( q_{i,j,t} \right)$ is a symmetric—positive defined—matrix varies as a GARCH-type process as follows:

$$Q_t = (1 - \theta_1 - \theta_2) \tilde{Q} + \theta_1 \eta_{i,t-1} \eta_{i,t-1}^\top + \theta_2 Q_{t-1}. \tag{9}$$

The parameters $\theta_1$ and $\theta_2$ are positive, $\theta_1 \geq 0$ and $\theta_2 \geq 0$ and, therefore, $\theta_1 + \theta_2 < 1$. These parameters which are the same for every pair, capture the effect of previous shocks and previous DCC on current dynamic correlation. $\tilde{Q}$ is the sample unconditional variance–covariance matrix of all standardized residuals $\eta_{i,t}$ with a correlation estimation like following:

---

**Table 14. Constant conditional correlation: Full sample vs. DotCom**

|                | FTSE100 | DAX | INDU | SP500 | SXXE | IXIC |
|----------------|---------|-----|------|-------|------|------|
| **CCC: Full Sample** |         |     |      |       |      |      |
| FTSE100       | 1       | 0.7208 | 0.4836 | 0.4890 | 0.7950 | 0.4502 |
| DAX           | 0.7208 | 1   | 0.5006 | 0.5020 | 0.9018 | 0.4781 |
| INDU          | 0.4836 | 0.5006 | 1     | 0.9508 | 0.5076 | 0.7935 |
| SP500         | 0.4890 | 0.5020 | 0.9508 | 1     | 0.5134 | 0.8833 |
| SXXE          | 0.7950 | 0.9018 | 0.5076 | 0.5134 | 1     | 0.4855 |
| IXIC          | 0.4502 | 0.4781 | 0.7935 | 0.8833 | 0.4855 | 1     |
| **CCC: DotCom Bubble** |         |     |      |       |      |      |
| FTSE100       | 1       | 0.7196 | 0.4141 | 0.4468 | 0.7964 | 0.3991 |
| DAX           | 0.7196 | 1   | 0.4759 | 0.5031 | 0.9114 | 0.4392 |
| INDU          | 0.4141 | 0.4759 | 1     | 0.9114 | 0.4392 | 0.6583 |
| SP500         | 0.4468 | 0.5031 | 0.9114 | 1     | 0.4780 | 0.8567 |
| SXXE          | 0.7964 | 0.8929 | 0.4392 | 0.4780 | 1     | 0.4573 |
| IXIC          | 0.3991 | 0.4721 | 0.6583 | 0.8567 | 0.4573 | 1     |
| **CCC: Full Sample vs. DotCom Bubble** |         |     |      |       |      |      |
| FTSE100       | 1       | YES | YES | YES | NO | YES |
| DAX           | YES | 1 | YES | NO | YES | YES |
| INDU          | YES | YES | 1 | YES | YES | YES |
| SP500         | YES | NO | YES | 1 | YES | YES |
| SXXE          | NO | YES | YES | YES | 1 | YES |
| IXIC          | YES | YES | YES | YES | YES | 1 |
As Aielli (2013) pointed out in the DCC model the choice of $Q$ is not obvious as $Q_t$ is neither a conditional variance nor correlation, even $E(\eta_{t-1}^\prime \eta_{t-1}^\prime)$ seems to be inconsistent for the target because of $Q_t$ not having a martingale representation. Aielli (2013) solved the issue of the lack of consistency and the existence of biased estimation parameters by introducing a corrected DCC model (cDCC). This model has nearly the same specification as Engle and Sheppard (2001) DCC model, except the correlation $Q_t$.

5.1. Empirical results

Table 4 reports the final prediction error (FPE), Akaike’s information criterion (AIC), Schwarz’s Bayesian information criterion (SBIC), and the Hannan and Quinn information criterion (HQIC) for the lag length selection.

Table 15. Varying conditional correlation (VCC): Full sample vs. DotCom

| VCC: Full sample | FTSE100 | DAX | INDU | SP500 | SXXE | IXIC |
|------------------|---------|-----|------|-------|------|------|
| FTSE100          | 1       | 0.8283 | 0.5972 | 0.5945 | 0.8798 | 0.5510 |
| DAX              | 0.8283 | 1   | 0.6246 | 0.6244 | 0.9516 | 0.6110 |
| INDU             | 0.5972 | 0.6246 | 1   | 0.9798 | 0.6262 | 0.8952 |
| SP500            | 0.5945 | 0.6244 | 0.9798 | 1   | 0.6291 | 0.9463 |
| SXXE             | 0.8798 | 0.9516 | 0.6262 | 0.6291 | 1   | 0.6001 |
| IXIC             | 0.5510 | 0.6110 | 0.8952 | 0.9443 | 0.6001 | 1   |

| VCC: DotCom Bubble | FTSE100 | DAX | INDU | SP500 | SXXE | IXIC |
|--------------------|---------|-----|------|-------|------|------|
| FTSE100            | 1       | 0.7166 | 0.4289 | 0.4582 | 0.7964 | 0.4052 |
| DAX                | 0.7166 | 1   | 0.4962 | 0.5202 | 0.8933 | 0.4828 |
| INDU               | 0.4289 | 0.4962 | 1   | 0.9204 | 0.4596 | 0.6840 |
| SP500              | 0.4582 | 0.5202 | 0.9204 | 1   | 0.4984 | 0.8633 |
| SXXE               | 0.7964 | 0.8933 | 0.4596 | 0.4984 | 1   | 0.4730 |
| IXIC               | 0.4052 | 0.4828 | 0.6840 | 0.8633 | 0.4730 | 1   |

| VCC: Full Sample vs DotCom Bubble | FTSE100 | DAX | INDU | SP500 | SXXE | IXIC |
|-----------------------------------|---------|-----|------|-------|------|------|
| FTSE100                           | 1       | YES | YES  | YES   | YES  | YES  |
| DAX                               | YES     | 1   | YES  | YES   | YES  | YES  |
| INDU                              | YES     | YES | 1    | YES   | YES  | YES  |
| SP500                             | YES     | YES | YES  | 1    | YES  | YES  |
| SXXE                              | YES     | YES | YES  | YES   | 1    | YES  |
| IXIC                              | YES     | YES | YES  | YES   | YES  | 1    |

\[ \rho_{i,j,t} = \frac{q_{i,t}}{\sqrt{q_{i,t} q_{j,t}}}. \] (10)

As Aielli (2013) pointed out in the DCC model the choice of \( \tilde{Q} \) is not obvious as \( Q \) is neither a conditional variance nor correlation, even \( E(\eta_{t-1}^\prime \eta_{t-1}^\prime) \) seems to be inconsistent for the target because of \( Q \) not having a martingale representation. Aielli (2013) solved the issue of the lack of consistency and the existence of biased estimation parameters by introducing a corrected DCC model (cDCC). This model has nearly the same specification as Engle and Sheppard (2001) DCC model, except the correlation \( Q \):

\[ Q_t = (1 - \theta_1 - \theta_2) \tilde{Q} + \theta_1 \eta_{t-1}^\prime \eta_{t-1}^\prime \eta_t^\prime + \theta_2 Q_{t-1} \quad \text{where} \quad \eta_t^\prime = \text{diag}(Q_t) \eta_t. \] (11)

5.1. Empirical results

Table 4 reports the final prediction error (FPE), Akaike’s information criterion (AIC), Schwarz’s Bayesian information criterion (SBIC), and the Hannan and Quinn information criterion (HQIC) for the lag length selection.

The *** indicates the optimal lag. The HQIC has chosen a model with two lags, whereas FPE, AIC and even the SBIC have selected a model with only one lag. The conditional variance equation for each indices. A GARCH(1,1) will be used. Table 5 shows the DCC estimation with GARCH(1,1).
As Table 5 shows, all estimated conditional quasi correlations are high and positive between the volatilities of the 6 different indices. For instance, the estimated conditional correlation between INDU and IXIC is 0.8703. This means that high volatility in the INDU is related to a high volatility in the IXIC and vice versa. The DCCs within the American indices are between 0.87 and 9.97. The European estimated correlations have in contrast to the American indices a little smaller interval, between 0.82 and 0.95. Finally, Table 5 presents the results for the adjustment parameters $\lambda_1$ and $\lambda_2$. Both estimated values for $\lambda_1$ and $\lambda_2$ are statistically significant. The estimations for the CCC as well the VCC can be found in Tables 6 and 7.

The same methodologies of the DCC, CCC, and VCC are used for the specific time frame of the DotCom, which is illustrated in Tables 8–10.

If $\lambda_1 = \lambda_2 = 0$, than the DCC model reduces the CCC model. Table 11 (and Table 12 for the DotCom time frame) shows the result of the Wald test—see Wald (1943)—with the null hypothesis that $\lambda_1 = \lambda_2 = 0$ at all conventional levels. The result below indicates that the assumption of constant (time invariant) conditional correlations supposed by the CCC model is too restrictive for the data-set of 6 indices.

An interesting finding can be even seen in Tables 13–15. Those tables indicate the different conditional correlation matrix and compared them with the null hypothesis that the correlation between different stock markets is lower during a bubble than sometimes else. The table on the right hand indicates that hypothesis. “Yes” means, the null hypothesis is not rejected. Meaning that during the DotCom the correlation between the different indices were lower than in the time without bubble. “No” indicates that the conditional correlation is higher during the DotCom. Table 13 indicates the different conditional correlation in two different time frames. As one can see, every conditional correlation is higher in the full sample as in the DotCom time frame. The findings from the conditional correlation of the CCC and the VCC models confirm this result as well.

![Figure 8. Estimated dynamic correlation coefficients.](image-url)
Figure 9. Conditional variances of the returns.

Figure 10. Estimated dynamic correlation coefficients DotCom.
Figure 11. Conditional variances of returns DotCom.

Figure 8 visualizes the computed individually DCC plots for pairwise countries with the different contagion source countries.

The breakpoint dates are represented by vertical dash circles, which indicate the two main crises, DotCom (1999–2001) as well the Subprime Crisis (2006–2007). An interesting outcome is that it seems—even with a general high correlation among the contingents - that during a bubble or crisis the contagion decreases. Having a closer look to the DotCom Bubble time, another graphs are plotted, can be seen in Figure 8. The time frame is July 1998 to October 2001.

Having estimated the DCC model, the conditional variance is forecasted for the next 50 time periods into the future. Figure 9 shows the result of those forecasts. From those conditional variances, one can see the impact of crisis to the different stock markets. As Figure 10 illustrates that the variance in period of the DotCom bubble persist longer than the Subprime crisis. On the other hand, it is shown that during the Subprime crisis there was an even higher variance. Getting as well a deeper look to the DotCom bubble, Figure 11 illustrates this specific time frame.

6. Summary and conclusions

Given the main objective of this paper to analyze the phenomenon of financial contagion between stock market returns of different continents, the empirical analysis in this paper examined the co-movements and spillover effects in the stock market returns of American and European markets between 1990 and 2014.

Three multivariate conditional correlation volatility models were used: the DCC-GARCH by Engle and Sheppard (2001), the CCC by Bollerslev (1990) and the VCC by Tse and Tsui (2002). Throughout the work, these methodologies were applied to daily returns of SP500, INDU, and IXIC (all United States), FTSE100 (UK), DAX (Germany) and SXXE (Europe) for the period from 12/01/1990 to 01/01/2015 and confronted with other models most widespread in the literature on the subject.

The result does not reject the hypothesis of higher contagion in American and European stock markets during crisis. Especially, during the DotCom bubble there was contagion, but not that significant as observed for the full time sample. All three contagion tests show that multivariate estimates
were significant for all returns in those models and therefore, demonstrate that there have been changes in the structure of dependence between American and European markets.

The empirical findings showed that the American and European (as well separately UK and German) markets were highly correlated since the end of 1995 with the beginning of the DotCom bubble. These results confirm the presence of spillover effects between those stock markets.

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1. We are not going to present the econometrics methods used to detect the time of the bubble which can be seen in the Phillips et al. (2013, 2011) papers. We will used their methodology to identify the period of the bubble as will be seen in Figure 3.

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