MYKOLAS ROMERIS UNIVERSITY

FACULTY OF ECONOMCIS AND FINANCE MANGEMENT

DEPARTMENT OF BANKING AND INVESTMENTS

LUKAS URBAITIS

MODELLING AND FORECASTING STOCK MARKET VOLATILITY

Master thesis

Supervisor
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A master's thesis on finance markets

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INTRODUCTION 6
1. REVIEW OF PAPERS ANALYSING STOCK MARKET VOLATILITY 8
1.1. Early researches of financial market volatility 8
1.3. Researches of interdependency between emerging-developed countries financial markets 11
1.4. Volatility measurement: VIX index 15
1.5. Recent financial crisis and stock market fluctuations 16
1.6. Monetary policy decisions taken to resolve the financial crisis 21
2. METHODOLOGY 24
2.1. Description of data and sample 24
2.2. Modelling volatility using MV-GARCH 25
3. DESCRIPTIVE STATISTICS OF RESULTS 28
3.1. Hang Seng and FTSE 100 empirical result analysis till 2014 28
3.2. FTSE 100 and S&P 500 empirical result analysis till 2014 33
3.3. S&P 500 and Hang Seng empirical result analysis till 2014 39
3.4. Market reaction during 2015 Chinese financial crisis 45
4. CONCLUSIONS AND RECOMMENDATIONS 50
Literature 52
1 ANNEX 62
2 ANNEX 64

Tables

Table 1: Fear Index values 14
Table 2: Main sector breakdown 23
Table 3: Descriptive statistics of Hang Seng and FTSE 100 28
Table 4: Univariate GARCH (1, 1) model results 31
Table 5: CCC-GARCH model results 32
Table 6: Descriptive statistics of S&P 500 and FTSE 100 34
Table 7: Univariate GARCH (1, 1) variance equation 37
Table 8: CCC-GARCH model results 38
Table 9: Descriptive statistics of S&P 500 and Hang Seng 40
Table 10: Univariate GARCH (1, 1) variance equation 43
Table 11: CCC-GARCH model results 43

Figures

Figure 1: Weekly returns in percentages for S&P 500, Hang Seng and FTSE 100 26
Figure 2: Log changes for FTSE 100 and Hang Seng 27
Figure 3: Squared residuals of FTSE 100 and Hang Seng 29
Figure 4: Log changes on S&P 500 and FTSE 100 33
Figure 5: Market shocks in S&P 500 and FTSE 100 35
Figure 6: Log price changes on S&P 500 and Hang Seng 39
Figure 7: Market shocks of S&P 500 and Hang Seng 41
Figure 8: VIX index values for 2015 45
Figure 9: Chinas foreign exchange reserves 47
Figure 10: Chinas capital flows 48

INTRODUCTION

Relevance of the research

Nowadays, when more and more people from developing countries are experiencing income increase, financial markets are becoming even more important tool gaining wealth. After technological revolution trading from "pits" almost fully moved to electronic trading and it became much easier to start trading through platforms which are offered by brokers for individual investors with minimum starting capital. Additional capital flowing into financial industry since early 80s' till now has increased values of indexes like S&P 500 by 20 times or even more in emerging markets. Increase of wealth led to increase of consumption by middle class. Society moved from saving to consumption which required business to adapt to meet up with increased demand for goods. This was done by looking for opportunities to borrow additional capital and the best way was to offer part of business to investors through capital markets by offering to share part of profit with investors. This chain led to Initial public offerings (IPO's) for mass variety of different industry segments and the great capitalism dream became true. However, increasing capital flow to companies by unprofessional investors seeking to make easy money has led to one great unexplored field at that time – volatility. Although the beginning of calculating volatility lays with one of the first models ARCH (Autoregressive conditional heteroscedasticity) introduced in 1982 by Engle, until first major crisis in 1987 not many did value the possibility to keep track of this variable while trading. After the market crash it has become obvious – volatility is an important factor in investment world and it must be measured and tracked.

Problem of the research

The problem of this master thesis work is to identify what factors are triggering stock market volatility transmission from one market to another.

Object of the research

The object of this thesis is to analyse existing literature, identify possible models for volatility forecasting. After choosing a suitable model prepare an empirical analysis of United States, United Kingdom and China's financial markets volatility transmission.

Aim of the research

The aim of this thesis is to prove volatility clustering using MV-GARCH model and compare results with macroeconomic events.

Tasks of the research

1. To analyse researches of financial market volatility and interdependency between emerging-developed countries financial markets;
2. Describe methodology of MV-GARCH model. Choose statistical tests to check model reliability;
3. To identify the biggest shocks in recent years and to analyse the actions taken to stabilise markets;
4. To prove financial markets interdependency and volatility clustering by executing econometric analysis using MV-GARCH model;
5. To identify main factors which have an effect on volatility;
6. To analyse main aspects of China's financial crisis proving or denying the financial market turmoil transparency to other markets.

Methods of the research

1. Analysis of scientific research;
2. Econometric analysis of historical data using MV-GARCH model;
3. Systemic analysis of China's financial crisis main causes and effects on global economy.

Significance and novelty of the research

By identifying inter-dependency between markets thesis examines how monetary policy actions in chosen country changes the overall market volatility and tries to identify if volatility clustering exist. These interactions are important for financial institutions with large portfolios and the need to evade systemic risks of the market. With continued globalization and market integration it is becoming harder to evade systemic risks and this thesis tries to prove that even emerging markets can cause systemic shocks across the markets.

The novelty of this thesis lays in its focus on monetary policy actions and their interaction during China's financial crisis in 2015. Currently no empirical studies exists examining Chinas financial turmoil. Since China is one of world leading economies, the ongoing crisis can have a severe impact over the rest of the world, therefore it is important to analyse and identify risks.

1. REVIEW OF PAPERS ANALYSING STOCK MARKET VOLATILITY

1.1. Early researches of financial market volatility

Typically in a financial world volatility refers to an asset's degree of unpredictable price change over a specific period of time. In statistical terminology it is sample standard deviation (1).

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^2}, \quad \text{where} \quad \mu = \frac{1}{N}\sum_{i=1}^{N} x_i. \quad , (1)$$

Where x_i is the return on day *i*, and μ is the average return over the N – day period. Sometimes variance σ^2 can be used. However, standard deviation is more appropriate measure, since it has the same unit of measure as the mean. Same measurement makes it more convenient during analysis of volatile asset.

It is very common to compare volatility with risk, but it is not the same, because "as the degree of uncertainty in asset returns varies over time, the compensation required by risk averse economic agents for holding these assets, must also be varying" (Engle, Lilien & Robins, 1987, p. 391). It is very important to understand that volatility does not imply the direction of price movement – an asset which is volatile is likely to rise or fall in value more than one that is less volatile. According to Poon (2005) risk is associated with undesirable outcome, whereas volatility, as a measure of strictly uncertainty, could be due to a positive outcome.

Linear structure of volatility forecasting using sample standard deviation or variance measure brings a lot of challenges, since linear structure of time series is not able to identify important features of financial market data:

- Volatility clustering – tendency, which was noted by Mandelbrot (1963), that large movements in the trend are followed by the same large movements on next period, while small changes are followed by same small changes in next period of either sign;
- Leverage effect – it was noticed that large negative movement in stock markets have a greater effect comparing to positive movements along the trend;
- Leptokurtosis – also called as "fat tailed risk" which occur when the shape of a distribution is more peaked than that of a normal or "bellcurve" distribution.

All these features are playing a huge role in volatility models for developed and developing countries. Thus, it is important to evaluate all factors influencing volatility in these markets.

This master thesis covers not only volatility and how it is affecting major markets, but also the analysis of linkage between inter-connected markets and trying to prove, that even small movements transpose between major markets and that they have a positive correlation.

Latest financial market collapse on 2008 was only one of several collapses which have been experienced starting with great depression before World War II to Asians currency markets crash in 1997. All of these crashes appeared suddenly and had a dramatic effect. However, none of them could be explained by fundamental factors which would create such huge shocks. These facts have been under scrutiny by such figures, like Nobel Prize winner Robert J. Shiller, Fischer Black and Myron Scholes who introduced Black-Scholes model for derivative pricing.

Volatility as a phenomena became more important with more speculators entering the market. In the beginning of financial markets, scholars have divided into two camps. First camp believed that speculators acted as supporters of price stabilization during volatile times. Key figures, such as Smith (1776), Mill (1871), Kaldor (1960), Stein (1961), and others argued that speculators are making money from other losses and it is bringing a net loss for the economy. They believed that despite any events in capital market, large corporate and institutional investors should have a possibility to withhold any short-term swing in markets. However, smaller investors with limited leverage capabilities are experiencing significant losses which lead to greater instability to real economic growth.

In paper, written by Cutler, Poterba, and Summers (1989), it was identified that large negative moves are much more common than positive ones. In their research it was emphasized, that from 5 biggest daily moves in S&P500 index four of them were negative, and eight out of ten were negative as well. This fact has become an interesting study point. The early studies of volatility feedback were introduced by Pindyck (1984) and French, Schwert, and Stambaugh (1987). They have elaborated, that changes in volatility of magnitude may have important effects on required stock returns, which would affect stock price.

Secondly, Bollerslev (1987) has empirically proved after the crash of stock market on Oct. 19, 1987 that volatility is not the only factor influencing the stock price movement. He has identified that stock returns had excess kurtosis not only during the crash, but also after the stock returns moved back to normal distribution, calculated by standard deviation.

Thirdly, research done by Black (1976) has showed that volatility typically is higher after the stock market value contraction than after expansion. These observations have showed that stock returns are negatively correlated with future volatility. This effect was named “predictive asymmetry” and was discussed by Black. He has argued that it could be due to the increase in leverage that occurs when the

market value of a firm declines. However, it is important to note that studies done by Christie (1982) and Schwert (1989) have proved that leverage effect is too small to account for this phenomenon.

Volatility feedback can explain all these characteristics of returns even if the underlying shocks to the market are conditionally distributed. This conclusion is brought by a research done by Campbell and Hentschel (1992). The explanation is given with an example of good-bad news. If there is the big good news in the market about companies' performance it tends to have another large piece of news, so the first good news is increasing future expected volatility. This effect increases required rate of return on the company and lowers their current value, reducing the effect of the news. However, if the bad news is announced in the market the stock price is also decreased, because higher volatility raises required return on the company. At this stage negative volatility amplifies the impact of bad news therefore it is much more common that negative movements in the market will arise compared to the positive ones. And negative returns amplified by the bad news can show excess kurtosis.

On the other hand, latest researches denied conclusions done by Christie (1982) and Schwert (1989) about leverage effect and proved that it should not be ignored as "too small to account for". Many researches were done and they have identified that constant volatility model created by Black and Scholes is inconsistent between strike and market prices for derivative pricing. Wide research done by Poon and Granger (2003) showed that implied volatilities generally increase as the strike price decreases.

Another research, done by Whaley (2000), demonstrated the negative correlation between S&P 500 returns and changes in the VIX Index which is tracking volatility of S&P 500. His work has proved that relationship between these instruments is asymmetric – index falls more when VIX increases, however it does not rise as much when VIX is decreasing. Whaley's (2000) results proved following numbers – S&P 500 index balls by 0,707% for a 100bps increase in VIX and the S&P 500 index rises by 0,469% for a 100 bps drop in VIX.

These researches prove that leverage effect should not be ignored as stated in early researches. The inconsistency might be arising from the fundamental changes in the market and analytical tool accessibility. Early models and studies where done in the beginning of technological revolution and computer simulation models were not available at the time. Also derivative market expansion is amplifying leverage effects, since most of the market is based on margin and leverage trading. Above mentioned empirical studies focused on developed markets. However, to decompose all the aspects of volatility it is also important to understand how emerging markets are reacting to shocks and, furthermore, identify the measures which have a correlation between emerging – developed markets.

1.3. Researches of interdependency between emerging-developed countries financial markets

Scholars further continued to analyse conditional volatility and as stock markets in developing countries evolved the new insights on emerging markets specifics arose. Leeves (2007) has made a study, which was examining conditional volatility in stock return of emerging stock markets during the Asian crisis. "The findings identified asymmetry impacts from conditional volatility shocks indicating negative shocks led to greater volatility compare to positive shocks during crisis. The asymmetric response started to rise at the end of 1997 and then declined during 1999. Though, the Indonesian stock market turned to behave more symmetrically to shocks towards the end of 1999. At the same time the long run persistence effects declined" (Chong, 2011, p. 104).

These findings also have identified another difference between emerging and developed markets. Excess kurtosis can be even greater in emerging markets. Leeves (2007) argued that emerging markets have a tendency to overreact to negative shocks and underreact to positive shocks. This has led to even greater volatility during crisis period.

Moving on to reasons for market volatility another study conducted by G. De Santis (1994) has been trying to identify if any risk premium exists, which would cause higher volatility in emerging markets, if liberalisation has any effect on volatility and if the volatility is changing over time. Using Generalized AutoRegressive Conditional Heteroskedasticity GARCH model variations it is proved, that there is "strong evidence of time-varying volatility". It also shows higher volatility in emerging market. Also the fat-tailed distribution used for these models shows that big shocks are more often in these markets. However, it is stated that some of the developed markets also has this tendency. Last point about liberalisation on stock returns is rejected, as no empirical evidence exist that it has effect on volatility.

These empirical studies were focusing on individual market volatility. In this master thesis interdependency between markets volatility was of great importance. One of the studies made by Karunanayake (2010) was searching for linkages which would prove transparency of volatility from one market to another. Transmission of volatility is important for pricing securities, derivatives, trading strategies, hedging strategies, regulatory strategies within and across the markets (Brailsford 1996). A lot of empirical evidences already exist proving the volatility changes during financial crises. In addition, other studies have also evaluated influence of financial crises across different markets (Ellis and Lewis 2001, Polasek and Ren 2001 and Tsouma 2007). As Karunanayake stated based of Tsouma (2007), "the

nature of this volatility transmission can vary from one financial market to the other market in terms of magnitude and severity of the shocks arising from recent financial crises".

Bank for International Settlements (1999) has released an article about Asian financial crises. They have been analysing the chronology when the crises reached each market. Financial crisis in Asia started in mid-1997 with a collapse of Thai-baht, and afterwards spreading around Asia till mid-1998 eventually reaching Russia and other countries. Ellis and Lewis (2001) have identified, that Australia and New Zealand had delayed the effect of Asian financial crises. These markets felt the crises effect only in late 1998. According to Bank of International Settlement, chronology can be stated as following: 1994 to 30th of April 1997 is "Pre-crisis" period, from May 1st 1997 to August 1998 as "Asian Crisis", then from 1st of Sept 1998 to 31st of December 1998 "World crisis" and after the "post crisis" till late 1999. Even though not all studies are using this chronology as basis for Asian crisis, it still indicates the transparency of volatility between emerging-developed markets.

Subprime crisis and 2008 financial crisis was not a local accident in United States. It had effect all around the world and only few countries have managed not to fall to recession. Even though they have managed to avoid detraction of economy, volatility of their financial markets increased significantly as well. During the studies P. Dooley and M. Hutchison (2009) evaluated transmission of financial turmoil from United States to several regions. To overlook broad region of countries they divided markets to following segments which we will discuss further: Latin America (Argentina, Brazil, Chile, Colombia and Mexico), three countries in Asia (China, South Korea and Malaysia), four from central Europe (Czech Republic, Poland and Hungary) and three from other regions (Russia, South Africa and Turkey).

One of the points of view was Credit Default Swap (CDS) spreads to identify the volatility of the market. According to A. Kita (2013) CDS spreads can be used efficiently to forecast volatility in financial markets. According to A. Kita volatility risk alone consists of 55% of CDS spread and the remaining 45% is explained by "jump risk". Results of the paper showed how interdependent markets are. Major movements in United States affected all 14 tested markets. During collapse of Lehman Brothers all 14 markets CDS spreads increased from 7 basis points in China to more than 100 in Argentina.

Another point of investigation was equity price correlation. During Subprime crisis till May 2008 negative correlation is examined between U.S. and 13 out of 14 markets, the only exception is Argentina, which moved closely with S&P 500 throughout all investigated period. However, they have noticed that from May markets started to move in same direction again, which also supports previous studies discussed, that some of FOMC committee members started using "financial crisis" term already.

P. Dooley and M. Hutchison (2009) highlights that large economies like China and Brazil during 2007 – 2008 period outperformed U.S. market with "substantial margins", however, the volatility during this period was much higher than in United States, which also proves the statement done by Leeves (2007) about overreacting in emerging markets. Another thing which was discovered by P. Dooley and M. Hutchison (2009) was the correlation changes after mid-2008. They have discovered that correlation changed in 13 countries and Russia was the only country which was not affected by correlation changes. This might be argued with specifics of Russian financial markets and low integrity to global financial system in general. Two countries experienced negative correlation, which was a surprise for researchers, because both of these countries were in Asian region. Despite the fact that not all countries had an increased correlation, it still indicates strong linkages between financial markets. Such countries like Poland and Turkey had the correlation increased by more than two times. Overall, this study clearly shows interdependency between United States and emerging markets. Health of financial markets in U.S. strongly affects emerging markets and real economy.

Another study conducted by Michelfelder and Pandya (2005) also examined emerging and developed markets. Their research described in paper "Volatility of stock returns: emerging and mature markets" compared U.S. and Japan markets with emerging stock markets: India, South Korea, Hong Kong, Malaysia, Singapore, Taiwan. Empirical findings support the previous findings of higher volatility in emerging markets and the transparency from U.S. shocks moving to Asia. However, even though authors identified a significant interdependency between market volatility, research did not explain the difference in shock time. Emerging markets had shorter shocks periods compared to matured ones.

In related work Abdallah Fayyad and Kevin Daly (2010) "The volatility of market returns: a comparative study of emerging versus mature markets" were analysing equity markets of Gulf countries (Kuwait and United Arab Emirates), which are still treated as emerging, and developed countries (United States and United Kingdom). Their findings identified volatility clustering during financial crisis between emerging and developed markets: "<…> since the relation between the regional markets of (Kuwait & UAE) and Global markets of (USA & UK) is increased during the financial crisis). However, this research was focused fully on statistical data and provided results based on it and no explanations for the reasons of change were provided.

All mentioned studies fully support the transparency from market to market giving incentive for our further analysis how market movements can be predicted by using volatility calculations of another market.

Studies which are analysing interdependencies are becoming more and more interesting due to actuality in real economy. Article written by Aymne Ben Rejeb and Mongi Arfaoui (2015) "Financial market interdependencies: A quantile regression analysis of volatility spill over" is focusing on interdependency between emerging markets in Asia and Latin America and developed markets of USA and Japan. In their work using GARCH model quantile regression approach empirical evidence support volatility transmission between financial markets. Findings provide important information for future researches about asymmetric interdependency between emerging markets. Results from Ben Rejeb and Mongi Arfaoui (2015) also support Stelios Bekiros (2013) findings about financial crisis effects on emerging markets, even though research methodologies are different in paper works and the comparisons of countries are not identical (Bekiros is analysing BRIC countries, while Rejb and Arfaoui take a broader range of countries versus same developing markets). Initial findings in paper "Contagion, decoupling and the spillover effects of the U.S. financial crisis: Evidence from the BRIC markets" gives the following results. One of the most interesting findings is that all markets became more integrated after U.S. financial crisis and this interdependency increased even more after sovereign debt crisis in Eurozone. All tests using linear causality provides empirical evidence that China does not have such a significant impact as an economic leader comparing to United States. Interesting fact is located about linkages about BRIC countries – BRIC countries are the leaders of world economic growth and those countries are interconnected by energy demand.

Although similarities of these papers are undeniable, the latest research of Rejeb and Mongi Arfaoui (2015) prove some points to be different from previous research. Firstly, they do not elaborate the difference of volatility effects from emerging to developed and vice versa. Rejeb and Arfaoui (2015) argue that this interconnection between markets can be explained by increased financial integration and empirical evidence show that after crisis this dependency increased even more. One of the key findings in their paper is that geographical regions have an asymmetric interdependency and the linkages vary depending on the market tendencies. Results show that regions co-movements intensify during bullish period, but this drops with market moving to bullish. This finding can explain some of the phenomena, like China's or Norway's ability to withstand financial turmoil, despite huge losses in net value of stock market.

1.4.Volatility measurement: VIX index

VIX index is an important measurement for volatility. Initially it was introduced in 1993 by *Chicago Board Options Exchange*. In the early stages on evaluating volatility, VIX used to track 30 day volatility implied by at the money S&P 100 Index option prices. Key concept for this index was to represent "fear" factor in the market. Till 2003 due to its calculation methodology VIX had more theoretical benefits, however, after updated calculation methodology, when wide range of out-of-the-money strike prices were included in the evaluation, VIX became one of the best indexes tracking expectations of the market. VIX itself is not a tradable instrument, however, CBOE (Chicago Board Options Exchange) tradable future and option contracts were introduced for S&P 500 volatility and it became one of the most tradable instruments to hedge against turmoil's in the market due to its high negative correlation with S&P 500 index value. According to G.D'Anne Hancock (2012) VIX option and future trading by 2008 has reached 100.000 contracts a day. In her research she gives the interpretation of VIX index values as followed by the market (see Table 1).

Table 1. Fear Index values

5-10	Extreme complacency
10-15	Very low anxiety=high complacency
15-20	Low anxiety = moderate complacency
20-25	Moderate anxiety = low complacency
25-30	Moderately high anxiety
30-35	High anxiety
35-40	Very high anxiety
40-45	Extremely high anxiety
45-50	Near panic
50-55	Moderate panic
55-60	Panic
60-65	Intense panic
65+	Extreme panic

Source: VIX and VIX Futures Pricing Algorithms: Cultivating Understanding

This table is only a guide line of expectations by market participants signalling the possibility of movements in the market. Low value shows that no sharp movements in the market are expected and with

incensement of the value the possibility of sharp movements in the market increases. It is important to mention, that VIX index values do not show a direction to which the market will be moving. One of the studies done forecasting movements in the markets using VIX index was introduced by A.E. Clements and J. Fuller in their paper "Forecasting increase in the VIX: A time-varying long volatility hedge for equities" (2012).

During their research of forecasting VIX future values they have identified that it is possible to fully hedge your positions using volatility indexes versus equity portfolio. A.E. Clemens and J. Fuller used semi-parametric method to forecast implied volatility. This method of calculation gave an advantage for long periods of volatility, since simple time-series does not provide accuracy over longer periods. Their research showed that during extended volatility periods, when equity returns are at their lower levels of mean, it is possible to predict VIX movements and using future indexes fully hedge outstanding positions.

1.5. Recent financial crisis and stock market fluctuations

Latest financial crisis started in 2007 in the U.S. starting with a collapse of the subprime mortgage market. Subprime mortgage market crash caused Lehman Brothers bankruptcy, after which a full scale global financial catastrophe started. All market stopped trading and a liquidity crisis in derivative market created a glut, which dragged remaining markets to a recession. Furthermore, this crisis affected majority of markets within a few months after it started in U.S. Since 2008, financial crisis due to its vast effect to economy and volatility is compared to Great Depression.

Main reasons which have given incentive for the beginning of the crisis can be divided into two parts: macroeconomic, consisting of government policies and firm level decisions. Also H. Erkens (2012) highlights that complex structure of securitized products contributed to economic crisis.

Macroeconomic reasons lay way before the actual crisis, which started in 2007. According to Wignall (2008) this financial crisis was not independent itself, it has been caused by "incentives created by past policy actions". His research highlights four main reasons, which ignited an economic bubble in mortgage market in the United States:

- In 2004 President's G. Bush Administrations "American Dream"[1] proposals of zero equity mortgage have been announced, to help low income families to receive a mortgage for their houses.
- Regulators of Federal National Mortgage Association (Fannie Mae) and Federal Home Loan Mortgage Corporation (Freddie Mac) imposed higher requirements and balance sheet controls for these institutions. As these two institutions were the key figure in the mortgage market, higher requirements for these institutions made it possible for banks to enter the secondary mortgage market. With banks entering low income mortgage market even more money has been drowned to this risky market increasing its volatility.
- Basel II requirements from Basel Committee on Banking Supervision which belongs to Bank for International Settlement (BIS) was published on 2004, which had some flaws and opened an arbitrage opportunity for banks and off-balance sheet activities increased significantly.
- Securities Exchange Commission (SEC) allowed investment banks to choose on their own how to manage their risk. They had an opportunity to calculate their capital requirements under "consolidated supervised entities program". Prior to this program investment banks were not allowed to have a higher ratio of 15:1 debt to net equity. However, with this new program banks were allowed to have leverage ratios towards 40:1 with an oversight of SEC.

These changes during 2004 boosted bank off-balance-sheet investments and the new "emerging" market was the securitized mortgage loans, which in most cases were treated as highest investment grade by rating agencies.

Furthermore, favourable monetary policy gave incentive for the crisis. According to Adrian and Shin (2008) loose monetary policy with low short-term interest rates reduced the costs for intermediaries, leading those intermediaries to build-up leverage, which have caused banks to take more risk. Those risks included not only credit risk, but also liquidity risk. Additional leverage helped to increase profits in short-term in both sides. With increased revenue additional supply and demand for credits (mortgages) was expected which caused asset prices to rise. However, this is relatively narrow view. As IMF working paper (2010) highlights, monetary policy had imbalances around the globe. One of the reasons for imbalances around the world was high capital inflows which have reduced long-term interest rates. This has caused institutional investors to search for new opportunities with greater yields. In search for higher yields investors had to take more risky strategies which eventually ended up with a financial crisis.

[1] Press release of President George W. Bush, "Increasing Affordable Housing and Expanding Home Ownership", 2nd of September 2004.

Second reason of economical imbalance was programmed in emerging markets. According to Caballero, Farhi and Gourinchas (2008) emerging markets due to their excess growth could not provide financial market safe financial assets. Without safe financial assets investors moved to advanced economies stemming up cash inflows into those countries, pushing the nominal long term rates down and lowering the yields for local investors, who had to search for new instruments with higher yields. Furthermore, during economic expansion banks had to reach targeted returns on equity (ROE), which with lowering yields became harder to reach and gave banks incentive to expand balance sheets and increase leverage. IMF working paper (2010) has combined all above mentioned facts to an empirical analysis in order to provide robust evidence to support or deny certain statements.

First finding by IMF proved financial sector imbalances relation to current state of countries current account balances. In their research it was proved that countries with current accounts surplus and net capital outflows reduces leverage effect in banking sector, while current account deficit and net cash flow inflow is increasing leverage. Furthermore, IMF has proved the linkage between long and short-term spreads with leverage ratios in banking sector. Such linkage proves how compression of spreads pushed banks to take additional risk in order to meet their target goals. Actions taken by banks to reach their target goals are also discussed afterwards in firm level decision section. IMF identifies only one of the angles of monetary policy effect on crisis. Another study, conducted before financial crisis of 2008, was done by Jean Boivin (2005), which showed the shifts of monetary policy by Federal Open Market Committee (FOMC). In his working paper" Has U.S. monetary policy Changed? Evidence from drifting coefficients and real-time data" he identified several facts, proving that monetary policy changes brought an improved economic performance for United States economy. In his paper he identified that during previous crisis of 1970's actions of monetary policy towards inflation were very weak and after mid 1980's it became stable. Actions of monetary policy makers have been severe to end stagflation period. However, as the findings of Boivin (2005) show, decisions done by Federal Reserve had a delayed effect on economy and transition taken affect only after few years. This gives us further incentive to analyse FED and FOMC decisions and their timing. As Boivin (2005) states, his findings are "consistent with monetary factors playing a role in the improved economic outcomes of the last two decades", but results should be compared with non-monetary indicators in order to reject an opinion that decisions have been a "simple luck".

Moving forward in research of macroeconomic decisions FED reaction in pre-crisis period must be analysed. Main decision-making body, the Federal Open Market Committee (FOMC), is responsible for identifying the financial market risks and taking actions to prevent them. However, during the Subprime

crisis and even after the meltdown of financial crisis they have failed to act to prevent future losses. FOMC meeting held every six weeks is one of the main events in the financial markets, as they are responsible for monetary policy making in the United States. As Holmes (2014) highlights, this is one of the most tracked meetings, since they announce upcoming trajectory of the economy. Fligstein, Brundage and Schultz (2014) were looking into chronology of the FOMC meetings and were analysing the shifts of leading personas thinking during the crisis. They have identified that committee has failed to see how closely financial markets were connected in twenty first century. They have also identified that members of FOMC solely relied on macroeconomic data and ignored the trends of other indicators while announcing their view on economic outlook.

To understand FOMC inability to act, article emphasizes several speeches held after "big" events. After 2007, Subprime market crash committee identifies this crash as "economic rebalance" and they do not see any threats to economy as a whole: "We had a sector that was clearly bubble-like with excessive spending, and now we are getting the retrenchment, which is taking a bit longer than we expected. But the good news is that we are going through a rebalancing <…>". Fligstein (2014) brings up front that housing is not even the greatest concern in this meeting, and not even the economic growth – FOMC is only concerned about inflation. Committee still lingers to old module, where each sector gives contribution to net GDP growth and ignores effects of secondary market where sectors are connected (MBS, CDO's belong to housing and financial sector at the same time). Despite the fact that some of the members in late 2007 started to speak about financial crisis, committee itself still remained devoted to their thinking and speeches were full of optimism that problem is only local: "<…> I sense that the stresses in the economy vary significantly by region <…>" [2]. After the September 15, when Lehman Brothers filed for bankruptcy, one of the FOMC members, Dennis Lockhart said: "My view on the national outlook for the economy has not changed materially since our August meeting". After largest bankruptcy in United States history, board members still ignored the problems in financial market and their focus was still on economic growth and inflation. Only in October FOMC has started a plan with other central banks while coordinating interest rate cuts to save economy, however, the meltdown has been already felt not only in United States, but in other countries as well.

Above mentioned reasons are not the only ones, which have led to economic bubble. However, it is believed that they have given an incentive for the beginning of a race to crisis. According to statistics collected by Wignall (2008), three largest banks increased their revenue in fixed income assets during 2005 and 2006 by at least 10% (Goldman Sachs from 8.75bn USD to 10.4bn USD in 2006, Citigroup

[2] FOMC meeting in 2007 December speech given by Charles Plosser

from 9.25 to 10.5bn USD and Deutsche bank from 9 to 11.5bn USD). Profit chasing and trying to meet up the expectations of shareholders led all the banks to go for fixed income business at any cost. Wignall (2008) gives an example of UBS strategy shift, when after the analysis of the market, in which it has been identified that UBS is far behind the market leaders in fixed income business, UBS decided to change their top risk managers with people from sales department to increase the sales. Shareholders report released on April, 2008, few months before Lehman Brothers collapse, already indicated huge exposure to AAA Collateralized Debt Obligation, however, senior management was willing to take up the risk of investment banking and relied that the risk is "well managed". UBS in their report (2008) stated: "... on speeding up approvals as opposed to ensuring that the process achieved the goal of delivering substantive and holistic risk assessment of the proposal presented". This is only one of several examples mentioned by Wignall, how risky decisions were made before the crisis.

It is important to mention, that most of the securitized mortgage business was focused in U.S., so majority of the cash flow was going to that market. The reason for this was the tax system, which is much more convenient for investment banks and citizens when it comes to mortgage. Article "The current financial crisis: causes and policy issues" (2008) indicated the following reasons. Firstly, the income tax law, which states that mortgage interest is tax deductible in the United States, gives incentive for citizens to buy houses and save on their taxes. Secondly, 1986 tax reform act allowed companies to issue multiple-class pass through securities without paying an entity-level tax, which increased attractiveness of secondary mortgage market. Third reason lays in the 1997 tax change, which exempted homes from capital gains tax. This law allowed speculation with part of real estate without paying capital gain tax (this did not apply to financial assets like stocks). In addition to firms following their need to satisfy stakeholders ROE requirements some extreme methods have been taken by some of the largest banks in Europe. One of the most quoted reference rates London Interbank Offered Rate (LIBOR) has been manipulated since 2007.

LIBOR rate is used as a reference rate for large banks where they quote rates at which one bank is willing to borrow the other for short-term. Research conducted by Hou (2014) confirmed previous studies about market liquidity problems as well as noticed certain unexpected behaviour. Hou (2014) highlights that prior to 2007 LIBOR moved closely to Overnight Index Swap rate and treasury yields, however, after August 2007 it has started to show a significantly increased volatility. This fact is consistent with other researches about upcoming financial crisis, despite the forgery scandal which came up in 2012. However, scandal brought negative reputation and financial consequences for major banks in Europe. Despite the increased volatility of LIBOR rates, banks submitted lower rates purposely in order to show their health

during the financial crisis. With lower rates their balance sheet liabilities did not indicated potential problems, even though no actual borrowing was available at that time in the market. Since derivative market is treated as a zero-sum game, LIBOR manipulation brought enormous losses to non-financial institutions with same profits for financial institutions elevating the profits on major banks that were able to influence LIBOR. According to Hou (2014), U.S. municipalities alone lost over 10 billion US dollars due to higher LIBOR rates. All these actions done by certain financial institutions, monetary policy makers and firms were only part of the reasons why financial crisis began. Other part is related to the complexity of financial markets, as well as the ignored or not seen signs in financial markets.

The signs of crisis were visible in stock market at 2007, after Subprime crisis began. Research done by Dooley and Hutchison (2009) examines long, but small and smooth decline of U.S. equities value from the beginning of Subprime crisis till September 2008. Chong (2011) research focused on Subprime effects to volatility clustering, persistence of shocks to the volatility of returns and compared U.S. stock market behaviour at different stages of the crisis. Chong's findings during the research proved that volatility tends to cluster through all the period of Subprime crisis. Also research showed that, even though volatility significantly increased throughout all the crisis period, the stock returns did not have a negative correlation in all the periods. Another important fact noticed was that, although Lehman Brothers collapse had a huge impact on stock market volatility, it did not have an effect on stock market returns.

1.6.Monetary policy decisions taken to resolve the financial crisis

Unprecedented actions had to be taken by central bank in order to save economy. First glimpse of FED monetary easing can be identified with crash of sub-prime mortgage crisis. As Mishkin (2014) notes, in 2007 GDP growth in United States was nearly 3% and inflation was rising, but FOMC decided to cut federal fund rate target by 50 basis point. This can be identified as a very unusual act for an institution like FOMC, as we have previously identified that FOMC had a very conservative view over the financial crisis. Furthermore, by May 2008 fund rate was down by 325 basis points even though the consumer price index was still rising, which is one of leading indicators of inflation. As Mishkin (2014) states, such monetary policy actions emphasized how powerless FED was over the turmoil of financial markets.

Second action identified by Mishkin (2014) which can be seen as unusual for central bank, was the newly established liquidity facilities. These facilities have been established with main purpose of providing liquidity for market therefore Federal Reserve fixed low interest rates 25 basis points above federal fund rate. However, it was also an unsuccessful attempt to give moment to stagnating market since

market participants were afraid to use this mechanism, because it would indicate their weak balance sheet and risk would greatly increase for even higher fluctuations in their own stock. Failure to provide liquidity with credit facilities pushed Federal Reserve to encourage additional borrowing with "Term Auction Facility" (TAF). First auction started with 20 billion dollars and over the crisis rose to over 400 billion. TAF has been active till 2010. During the last auction in March, 2010 25 billion dollars were conducted at 0.5% rate, however, bidders placed orders for only 3.4 billion[3]. TAF was not the only newly established facility over the crisis period, which helped stabilize the economy. According to Mishkin (2014), over 8 different facilities have been established in order to stabilize different financial market segments. FED scope covered MBS, ABS, commercial paper, money market mutual fund assets and etc. Full coverage over the period of 2007-2009 expanded the balance sheet of Federal Reserve over 1.5 trillion dollars. Effects of such cash flows are also discussed in analytical part related to multivariate GARCH model.

Further involvement of Federal Reserve in order to manage the market volatility has made the FED last resort for international central banks. ECB and Swiss National bank swap lines open since December 2007, which allowed central banks to receive dollar cash flows in order to lend that money to domestic banks, which were experiencing losses due to huge market fluctuations. However, after Lehman Brothers collapse same lines have been opened for central banks for both emerging and developed countries, such as Canada, Sweden, Norway, Denmark, Japan or Mexico, Brazil etc. According to Mishkin (2014), total swap lines at their peak were around 600 billion dollars.

Forth action taken by FED and later copied by ECB was the quantitative easing, later named QE. Mishkin (2014) separates three QE programs, however changes over 2015 suggests that a QE4 can be started. According to Mishkin (2014), the start of QE program is marked with first Federal Reserve banks intervention over the couple of decades in financial markets, when open market operations by FED included not only short-term government securities, but also mortgage-backed securities, which were guaranteed by Fannie Mae and Freddie Mac. First quantitative easing was marked with a 1.25 trillion MBS purchase over the period from December, 2008 to March, 2010. With such cash flows and federal rate at 0%, economy was still stagnating and a second round of QE was conducted in order to lower longer-term interest rates. With the end of QE2 in 2012, markets have been relatively calm, but due to poor outlooks in macroeconomic data third round of QE has been announced. However, a key shift by Federal Reserve was taken in this program – it was announced that it will continue "if the outlook for the labour market does not improve substantially."

[3]Federal Reserve press release March 9, 2010

Fifth action taken by Central Bank to save collapsing financial markets was taken when Bear Stearns was unable to roll over repurchase agreements since banks refused to lend money. At that time FED worried that failure of Bear Stearns would "trigger a full-fledge financial crisis", so it has brokered a deal with JP Morgan/Chase to purchase toxic assets of Bear Stearns and keep them on their books. According to Mishkin (2014), main reason why FED has arranged a bailout decision worth 30 billion was that JP Morgan did not agree to take hard-to-value assets and required guarantees from FED. However, after couple of months Lehman Brothers collapse was a similar case as Bear Stearns, but FED did not intervene in this crash. Mishkin (2014) argues that Federal Reserve and Treasury department made a conscious decision not to bail out Lehman Brothers. However, crash of Lehman Brothers brought another big player of derivative market to brink of collapse. American International Group (AIG) Financial product division had to write down 400 billion dollars in credit default swaps after crash of Lehman Brothers and they were unable to meet the payments to the buyers of derivatives and faced default. However, this time FED intervened and gave 85 billion dollar loan, according to Mishkin (2014), in order to prevent Lehman Brothers' destiny. It is important to mention that these two companies were not the only ones who had technical defaults. However, examples like Merrill Lynch acquisition by Bank of America with help of FED showed how FED has been involved in attempts to stabilize the financial markets.

Last action taken by Federal Reserve was after Lehman Brothers' collapse. TARP (Troubled Asset Relief Plan) has been announced on 3rd of October, 2008. This program has allowed United States treasury to inject capital to troubled companies directly and by doing so improve balance sheets of those companies. Another action done by Treasury has been announced with Guarantee Program for money markets funds. This program has guaranteed investors that the minimum value of funds would not drop below 1$. Other programs have been announced as well, in order to boost liquidity in banking system and stabilize the economy. All these unprecedented actions helped to stabilize the economy eventually. However, it is important to understand, that Central Banks took actions only after the surge of volatility and crash of markets and monetary policy actions themselves can cause shifts in volatility only if they deviate from the expectations.

2. METHODOLOGY

2.1. Description of data and sample

This paper is using closing daily price data of three major market indexes in the world. Each of them is representing one of regions: United States, Europe and Asia. For United States there is S&P 500 index used, as it is one of the most widely followed indexes in the world representing stock markets with companies market capitalization over 19 trillion U.S. dollars. For Asian market it was chosen Hang Seng index (HS), due to several reasons. First of all, due to specifics of Chinese market it is not allowed for foreign investors to invest into same stocks as for citizens of China. This diversification has constructed A and B type stocks in mainland China therefore mainland China indexes are misrepresentative, since they cover only part of market capitalization. Secondly, Hang Seng index, which is following 50 largest companies by capitalization in Hong Kong, has been established in late 60's and data availability for it suits the needs for this thesis. For European market index it was chosen FTSE 100 listed in London Stock Exchange. Even though DAX is more widely used as a benchmark for European market, it does not fit our needs due to its specific composition. DAX index differs from the remaining index due to its weighed allocation to industrial sectors like chemistry, automobile manufacturing, etc. FTSE 100 index is heavily weighted by financial sector and oil and gas companies followed by consumer goods companies, therefore, these three indexes represent more even industries as a whole (Table 2).

Table 2. Main sector breakdown

	S&P 500	FTSE 100	Hang Seng
Financial	16.2%	22%	44.88%
Energy	7.1%	17%	6.53%
Consumer good	13.2%	16%	3.84%
Information Technology	20.8%	1.63%	11.34%
Health care	14.6%	10%	N/A

Source: Prepared by author

Closing daily prices have been chosen since the previous studies done by Chong (2011), Aktan et al (2010) have showed that daily frequency is more suited then weekly or monthly data because weekly and monthly movement data is not sufficient to perform the tests. If data would be chosen more frequent,

like four hours or hourly intervals, due to high sample it becomes very complicated to make calculation for long periods, because time series gets white noise and further analysis cannot be applied.

Data for all indexes is extracted from Bloomberg data base and all data is adjusted to US dollars so that it could be comparable. The period for which calculations have been made starts at 2005 and ends with last closing price of 30th of October in all markets. Observations sample consists of 2724 values for S&P 500, 2737 for Hang Seng Index and 2678 values for FTSE 100 index.

Since the aim of the thesis is to analyse the volatility and connect the macro-economic behaviour to the transparency of volatility between markets, the results are divided into two parts. The first part of results is empirical results of MV-GARCH model till 2014. Second part is dedicated to MV-GARCH model result analysis and overviewing macroeconomic factors during 2015 financial crisis in China.

Since the MV-GARCH model is built on a bivariate model, two sets of results will be tested. In this thesis the volatility transparency from Asia to Europe and from Europe to Asia was tested. In order to make the results more accurate, the data has been adjusted and all trading days when only one of the markets is open will be emitted.

To module volatility of stock markets many software's are available, like EViews, R, Gretl, Matlab and excel add-ins make it available to calculate GARCH models. In this thesis Matlab software has been chosen since it's algorithm for calculating the MAX likelihood is considered to be one of the best for GARCH optimization according to Alexander (2008).

2.2. Modelling volatility using MV-GARCH

There are more than 300 different GARCH variations and in this master thesis it was chosen only one of possible variations. Each and every GARCH modification is focusing on different things like fat-tail distributions, asymmetries or spillovers.

Modelling volatility using GARCH model can be a challenging task. In its own nature GARCH model is not very complicated, however, before using certain model, preparations must be done in order to make a trustworthy model:

- Descriptive data must be analysed, so that it would satisfy the requirements of model.
- Descriptive properties of data must be applicable and comparable.
- Analysis of outcome parameters must be initiated to check their meaningfulness.

In this thesis chosen GARCH model variation can be defined as below equation:

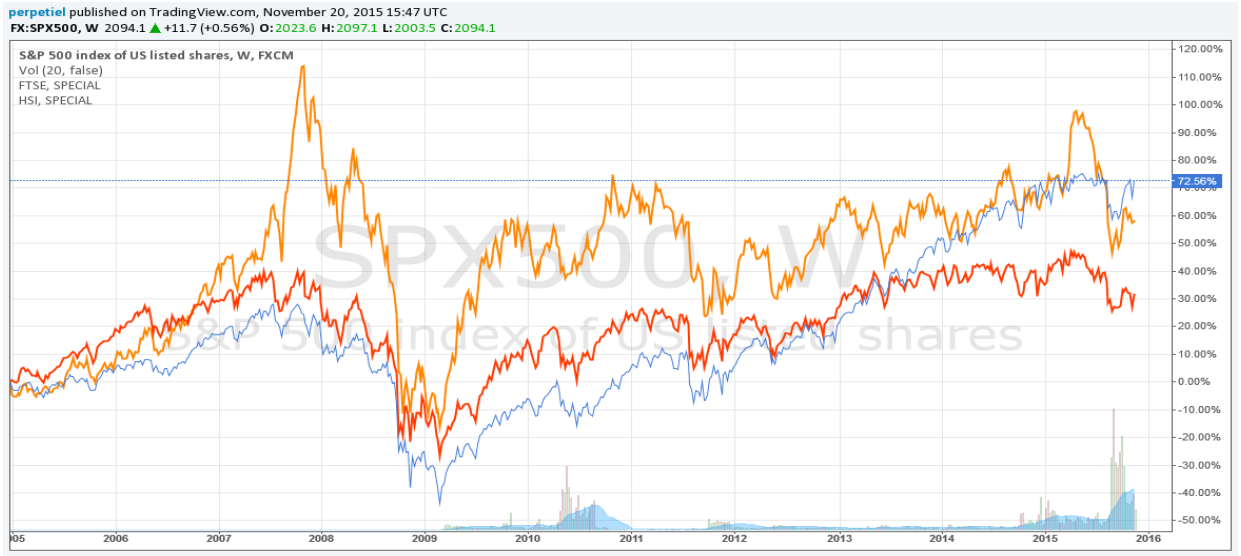
$$\sigma_t^2 = \omega + \alpha\varepsilon_{t-1}^2 + \beta\sigma_{t-1}^2, \qquad (2),$$

In this equation omega (ω) is a constant parameter which determines long term unconditional volatility level. The higher the value of omega the higher level of long term volatility is influencing future volatility. Alpha (α) parameter determines sensitivity of conditional volatility during market shocks, the higher the value the greater conditional volatility is experienced. Beta (β) shows how persistent conditional volatility is. Higher values indicated that it takes longer time for the long term volatility to fade out. Weights of these three parameters must sum to one. Before starting to build up a model in order to receive basic descriptive statistics daily changes in price have been acquired by using natural logarithm:

$$R_t = ln(P_t) - ln(P_{t-1}) \qquad (3),$$

Log returns are time consistent, which allows valuing the changes in price over time and it is needed for GARCH modelling. In this study to find all needed parameters of equation a two-step procedure is done. Firstly ARMA model is used to find conditional mean. The residuals identified by ARMA model are inserted to GARCH equation to extract conditional variance. Later univariate GARCH results are checked in MV-GARCH model. In order to prove that results are statistically correct several tests are done.

To proceed with ARMA model stationary had to be checked. According to Alexander (2007) ARMA (p, q) model can be used only if the returns are stationary. Brooks (2008) also confirms the requirement of data stationary arguing that non-stationary data will misrepresent the model. Firstly stationary has high influence on time series behaviour and properties. One of the main problems with non-stationary data is its persistence property, which is contradicting with all long term volatility theories stating that coefficients should be fading away. With non-stationary data volatility in t+1 and t+2 would be persistent and if a shock was experienced at time t it would be constant in future and forecasting would be useless (Brooks, 2008). For stationary data the unexpected changes in values will have a declining meaning for future periods and will eventually fade away. For visual check of non-stationarity in a time series data following picture can be used:



Source: www.tradingview.com platform

Fig. 1. Weekly returns in percentages for S&P500, HS and FTSE100

To check for stationary Augmented Dickey–Fuller (ADF) test is executed. A H_0 hypothesis indicated the time series is non-stationary and H_1 indicated that time series is stationary. In order not to reject null hypothesis unit root test value must be higher than its critical value and p parameter value indicates the likelihood of correctly executed test (the lower the value, the greater probability of correct test). All of these arguments prove the need of stationary data for further analysis.

Also ARMA model helps us identify if any autocorrelation between day to day prices exist. Extracted information about residuals from ARMA model can be used in further calculations of GARCH parameters. Matlab is used to compute maximum likelihood of alpha, beta and omega.

The analytical part of this thesis is built in the following structure:

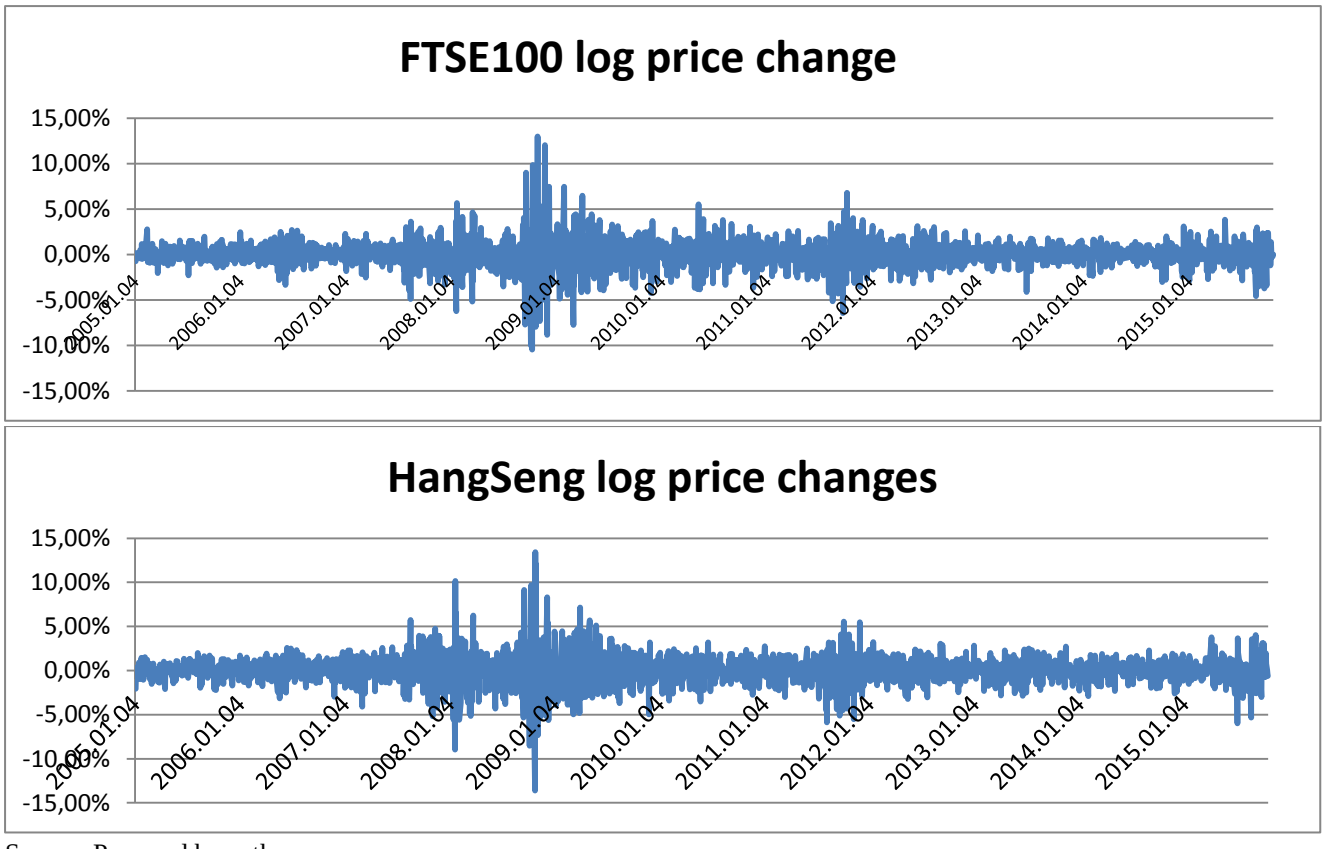
- Hang Seng and FTSE 100 empirical results are analysed in the period from 2005 till 2014;
- FTSE 100 and S&P 500 empirical results are analysed in the period from 2005 till 2014;
- S&P 500 and Hang Seng empirical results are analysed in the period from 2005 till 2014;
- Empirical results of all analysed markets are analysed in context of Chinas financial crisis and compared with implied volatility index (VIX)

3. DESCRIPTIVE STATISTICS OF RESULTS

3.1. Hang Seng and FTSE 100 empirical result analysis till 2014

Original data for Hang Seng index consists of 2 665 observations, while FTSE100 was trading for 2 731 days. The difference of days trading in indexes appears due to different number of days during holiday period. Hang Seng index more often is closed in late January to early February, when Chinese are celebrating Lunar New Year. After filtering the un-common trading days 2 630 observations remain. The return means ranges from -0.0187% to -0.0027% in FTSE100 index. Such small returns are helpful in ARMA zero mean residuals, since they will closely resemble return process.

The observations from Hang Seng index have identified interesting results. The highest gain of 13.43% was observed on 28th of October 2008, while the biggest drop was on 27th of October same year. FTSE 100 index has experienced biggest gain one day after Hang Seng biggest gain on 29th of October 2008 and biggest drop was on 10th of October 2008. It is important to mention, that all these results are very closely related to Subprime mortgage crisis in United States. Changes for indexes are showed below:



Source: Prepared by author

Fig. 2. Log changes for FTSE 100 and Hang Seng

Despite the fact that Subprime crisis was in United States, there are clear evidences how inter-connected the markets are and the dependency of vast amount of news in one country had affected other markets. Also, latest movements in China during the 2015 market turmoil had a correlation in both markets, however, larger movements are visible in Hang Seng index. Later a deeper analysis is provided for these co-movements

Another interesting fact can be identified from return series. China, as one of the biggest economies in the world, is still a developing country experiencing higher volatility. From return data it is seen that maximum gains and losses are larger than in developed countries index and also standard deviation is larger in both filtered and unfiltered data sets. Standard deviation, also known as simple volatility, is also higher in Hang Seng with results of 0.0159 compared to FTSE 100 - 0.0149. However, one interesting fact is noticed in skewness and kurtosis indicators. FTSE 100 and HS are skewed in to opposite sides, which are indicating that HS is much more exposed to significant negative losses compared to FTSE 100. Despite that FTSE 100 has higher kurtosis, both indexes have values way above the normal distribution, which is 3. Extremely high excess kurtosis indicates that future returns of both indexes can be extremely large or extremely small, since the distribution is non-normal. The summary of descriptive statistics can be seen below:

Table 3. Descriptive statistics of Hang Seng and FTSE 100

Hang Seng descriptive statistics				**FTSE 100 descriptive statistics**		
	Unfiltered	Filtered			Original	Overlap
# observations	2.664	2.629		# observations	2.730	2.629
Mean	0,02%	0,02%		Mean	0,00%	0,00%
Median	0,06%	0,06%		Median	0,07%	0,07%
Min	-13,43%	-13,43%		Min	-12,99%	-12,99%
Max	13,59%	13,59%		Max	10,47%	10,47%
Std. deviation	0,01587	0,01596		Std. deviation	0,01461	0,01493
Skewness	(0,0301)	(0,0343)		Skewness	0,0482	0,0241
Kurtosis	12,1196	12,0091		Kurtosis	12,9780	12,8668

Source: Matlab

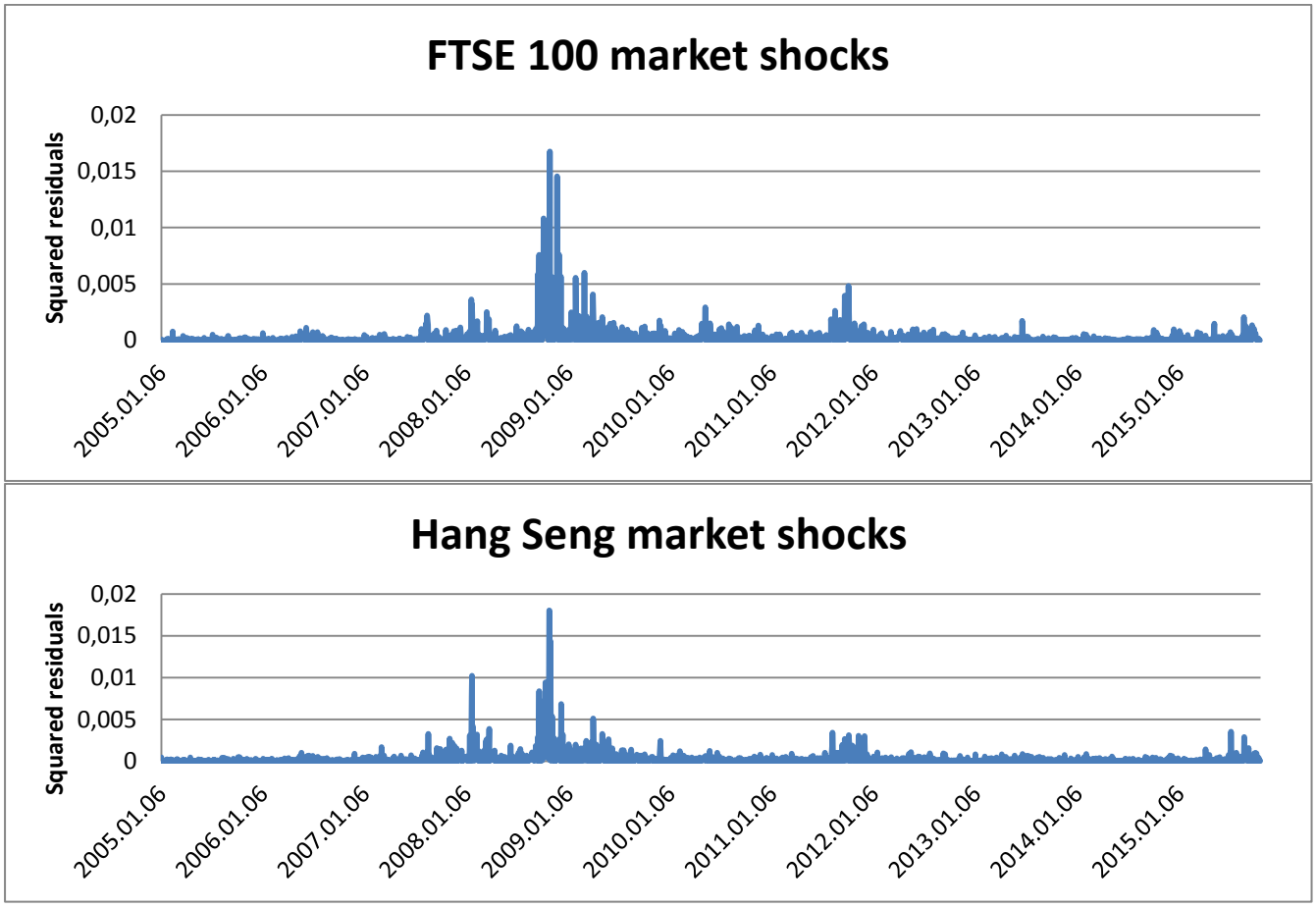
Another thesis point of volatility clustering is proved from data. Indices experience volatility clustering, where large or small movements in volatility are followed by the same reaction in next period

of either sign. This phenomenon is especially noticeable in Hang Seng during turmoil of financial sector during late 2008. Also, close volatility jumps in time indicate the possibility of modelling the volatility simultaneously.

Augmented Dickey Fuller (ADF) test has been done to check for price and return series stationarity. The null hypothesis was required for further testing in price series. Results of ADF test for Hang Seng index were sufficient in order not to reject null hypothesis. Test statistical value was -0.8818 while critical value was -1.9416. According to methodology, statistic value must be greater than the critical value. P-value of 0.329 also increased the likelihood of correctly done test. FTSE 100 Unit-root test had the following values: test value -0.459, critical value -1.9416 and p-value 0.496.The results at significant level of 5% for both indices indicate correct data.

All these results add up to unconditional correlation coefficient of 0.44. This coefficient indicates very high inter-dependency between markets with positive relationship.

In further analysis building ARMA model a market shock interpretation has been built. By extracting squared residuals a following market shocks figure is prepared:



Source: Prepared by author

Fig. 3. Squared residuals of FTSE 100 and Hang Seng Indexes

From the plot figures we can identify that volatility clustering is very clear between the markets. However, an interesting trend can be noticed in the period before 2008 financial crisis. FTSE 100 index has experienced slightly higher turbulence in the market during 2005 to late 2007 and after 2009, while Hang Seng until the dawn of financial crisis in 2007 had extremely low squared residual meanings without any spikes. Pro-longed volatility in FTSE 100 since 2010 can be explained by Greek debt crisis which evolved to a European debt crisis, which finally was transmitted to Far East in 2012. To understand the reasons for that it is useful to briefly describe European debt crisis in the period from 2010 to 2014.

April 10th, 2012 was the date when official Greek recession was announced, because three distinct quarterly results of GDP growth had negative values. According to Eurostat, Greece debt to GDP ratio rose from 112% in 2008 to 146% in 2010. In 2010 European Commission, European Central Bank (ECB) and International Monetary Fund (IMF), later called Troika, have announced a rescue plan consisting of 110 billion Euros to help stabilize Greek finance. The funding did have a slight impact on FTSE 100, however, Hang Seng index volatility has not reacted to this announcement, as it did not have a big impact on world economy at that time. It is important to mention that reactions to this announcement were very different. Since United Kingdom does not belong to Euro area and their financial system is not so incorporated to European Union's (EU), low volatility impact is noticeable, however, in comparison VDAX index, which is following Germany's stock market index DAX volatility, had a significant impact. VDAX on 2nd of May, when the bailout was announced, has risen by more than 50% from 20.66 to 33.35 points.

The situation has worsened over the next year, which is visible in obtained market shocks results as well, and 2011 was the year when debt crisis in Greece gotten even worse. Austerity measures, privatization and structural reforms embedded by Troika were not being implemented in Greece at required pace and a second bailout was needed for Greece in order to avoid insolvency. Second bailout was met with huge losses of bond investors and it is reflected in analysable market shocks. 130 billion Euros program including recapitalization package for banks was announced and half of Greek government bond face value has been written down. In addition to reducing face value maturities, interest rates have also been extended. Greek economy did not show any signs of healing and EU began to stagnate as well. In 2013 bank rate have been cut twice by ECB and on 7th of November it reached at that time record low of 0.25%, while deposit ratio remained at 0%. 2014 was a historical year for EU, as deposit rates for the first time in history was set below zero and decreased again twice in a year to -0.2%. The showdown of

the EU crisis has been in late 2014 when early election has been called in Greece and radical left party "Syriza" won election to start a still ongoing show of resistance to meet creditor requirements.

EU debt crisis led by Greece increased volatility in all markets and the political events led by Siriza party is worth a separate thesis, therefore there will not be evaluation in detail of all events during 2015, especially because Greece problems were highly out weighted by China's crisis in middle of 2015, of which there will be a discussion in the following part of thesis.

Moving forward to empirical results univariate GARCH models are evaluated. Alpha measures are small and close in value to each other indicating that they have similar sensitivity to conditional volatility. Beta value of Hang Seng is higher compared to FTSE 100 indicating that it takes more time for volatility impact to fade out. However conditional long term volatility values are higher for FTSE 100, which might be a result of higher effects of European debt crisis, which has increased the volatility of FTSE 100 index. This is also supported by mean lag variance count in days, which resembles how much time it takes for index to recover from volatility. FTSE 100 index compared to Hang Seng recovers 2 days sooner, respectively it takes 10.61 days for FTSE 100 and for Hang Seng it takes 12.65 days to recover. Summary of results are showed in following tables:

Table 4. Univariate GARCH (1, 1) model results

Univariate GARCH(1,1) variance equation				
	Hang Seng	*t-ratio*	FTSE 100	*t-ratio*
ω	0,00000176	*7.539.998,32*	0,00000141	*8.092.876,59*
α	0,070	*942,03*	0,089	*910,45*
β	0,921	*10.858,97*	0,906	*9.844,61*
LT volatility	22,35%		26,50%	
Mean lag variance (days)	12,65		10,61	
Max likelihood	7.755,63		7.931,99	

Source: Matlab

After forming CCC-GARCH model both Hang Seng and FTSE 100 indexes have increased their long term volatility by several basis points, while the period in which the variance fades away has decreased. Hang Seng index decreased the time it takes to fade out the volatility by 20% from more than 12 days to a bit more than 10 days, while FTSE 100 has decreased only about 10%. Below table shows all the univariate CCC-GARCH model results:

Table 5. CCC-GARCH model results

Multivariate CCC-GARCH(1,1) variance equation				
	Hang Seng	*t-ratio*	FTSE 100	*t-ratio*
ω	0,00000251	*3.995.021,91*	0,00000174	*4.939.021,79*
α	0,085	*581,86*	0,100	*550,92*
β	0,903	*5.126,63*	0,895	*5.021,00*
LT volatility	23,64%		28,72%	
Mean lag variance (days)	10,36		9,49	
Max likelihood	15.909,76		15.909,76	
Correlation coefficient	0,3972	*1184,00*	0,3972	*1184,00*

Source: Matlab

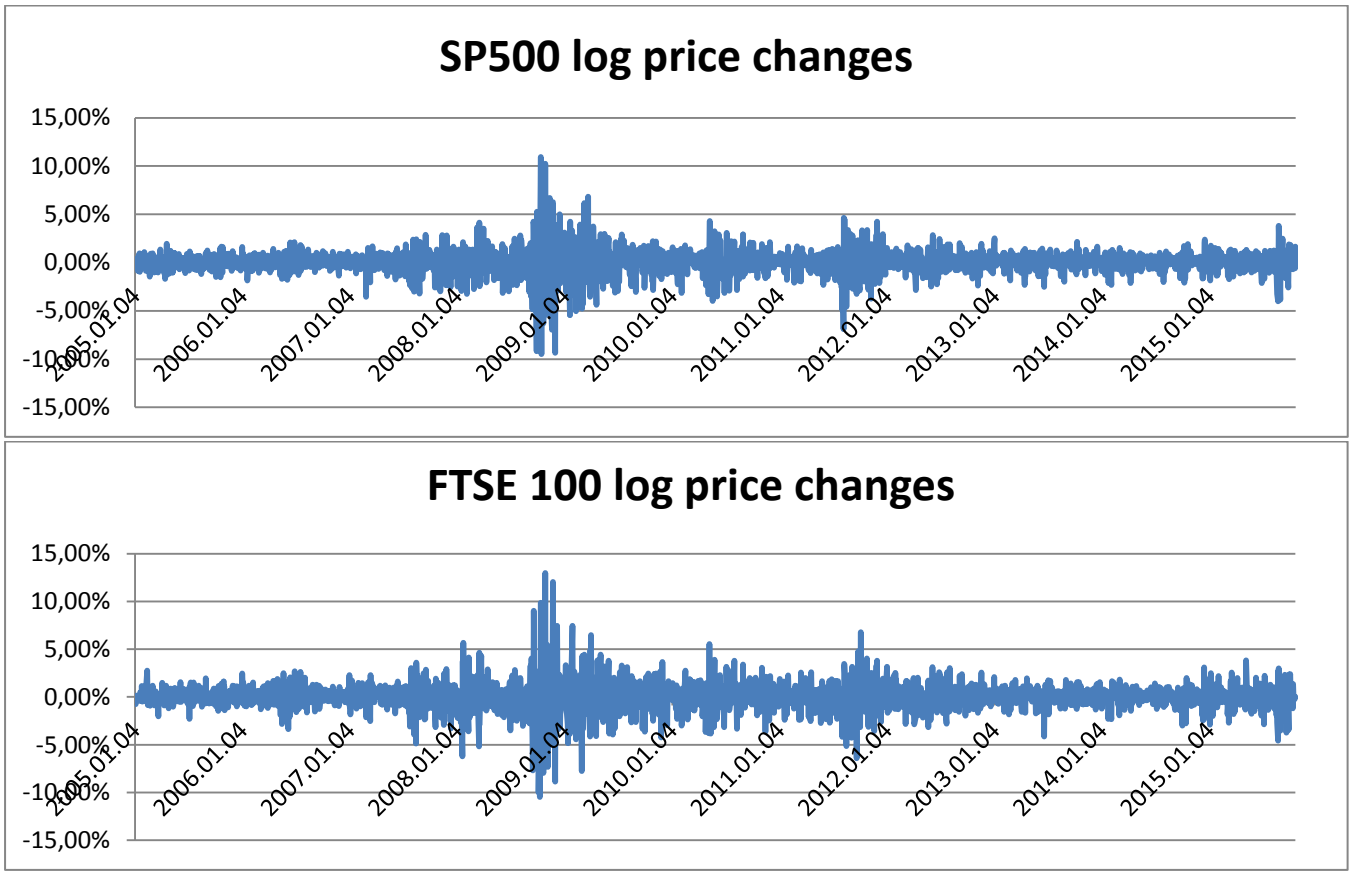
Data from model and macroeconomic events over the course of 2005-2014 correspond to each other. Empirical results are consistent with chronology of events which were discussed over analysed period. Stagnating economy of European Union and their problems with member states, which are unable to meet up their obligations to cover their debts, rose volatility in financial markets. Also it is important to mention that economic problems in Greece have not been resolved and news, good or bad, will be met with increased volatility.

3.2. FTSE 100 and S&P 500 empirical result analysis till 2014

Original data for FTSE100 index consists of 2 731 observations, while S&P 500 was trading for 2 721 days. The difference of days trading in indexes appears due specific holidays in each country, however, since most major holidays are similar in both countries, data filtering removed a small portion of data. After filtering the un-common trading days 2 672 observations remain. The return means ranges from -0.0205% to -0.0027% in FTSE100 index. Such small returns are helpful in ARMA zero mean residuals, since they will closely resemble return process. However, it is worth noticing that S&P 500 mean has a much larger value compared to UK index. This might be expected due to sample period. Financial crisis had a severe impact on both countries. However, United States has taken several monetary policy actions in order to manage the crisis and the index value shows results of those actions – in 2013 the price of the index has reached its previous peak points, while FTSE100 is still struggling below its

peak, which was reached at 2007. Later a broader analysis is conducted about emergency plans in United States and United Kingdom

Further descriptive statistics of model returns revealed following information. The highest gain of 10.47% was observed on 29th of October 2008, while the biggest drop was on 10th of October 2008. Both of these values have been fixated in FTSE 100 index. S&P 500 index highest gain and biggest loss have been smaller, which resulted in lower standard deviation. Following pictures show return distribution for both indices.



Source: Prepared by author

Fig. 4. Log changes on S&P 500 and FTSE 100

From return series figures it is seen that both indices move almost in tangent, except few shocks. Such movements confirm the statement about markets transparency. From descriptive statistics table it is seen that both markets have positive skewness values. However, a larger value in S&P 500 index indicates that it is less exposed to negative shocks compared to FTSE 100. However, with smaller exposure to negative shocks excess kurtosis is larger in S&P 500 index, which indicates that future returns will experience extremely large or small movements. Kurtosis value on both indexes exceeds normal

distribution value of 3, which indicates a non–normal distribution. Summary of descriptive statistics is provided in Table 6:

Table 6. Descriptive statistics of S&P 500 and FTSE 100

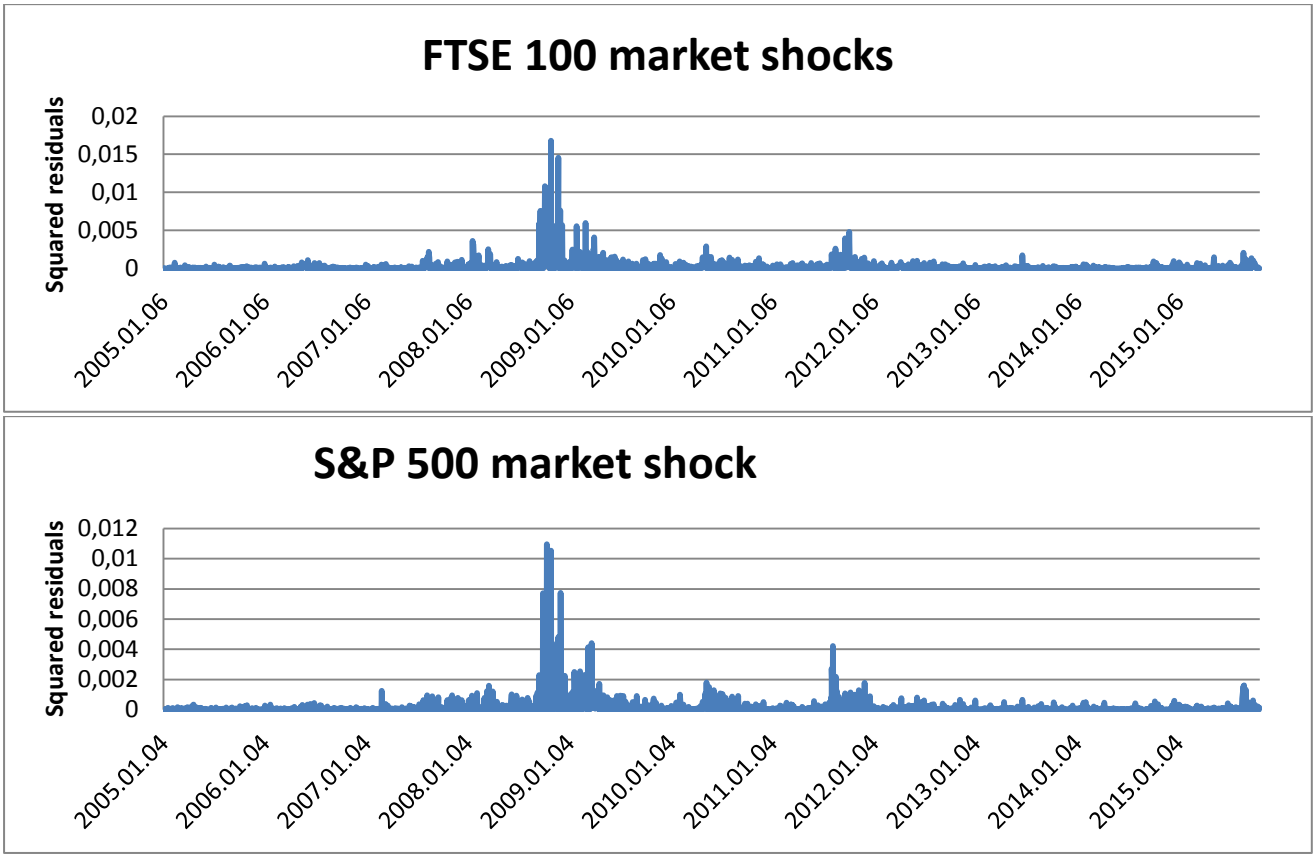
Unfiltered time series				**Filtered return observations**		
	S&P 500	FTSE 100			S&P 500	FTSE 100
# observations	2.720	2.730		# observations	2.671	2.671
Mean	-0,0197%	-0,0026%		Mean	-0,0205%	-0,0027%
Median	(0,00073)	(0,00068)		Median	(0,00074)	(0,00065)
Min	-10,96%	-12,99%		Min	-10,96%	-12,99%
Max	9,47%	10,47%		Max	9,47%	10,47%
Std. deviation	1,27%	1,46%		Std. deviation	1,28%	1,47%
Skewness	0,33122	0,04819		Skewness	0,34009	0,04189
Kurtosis	13,95327	12,97797		Kurtosis	13,71305	12,81381

Source: Matlab

For further analysis Augmented Dickey Fuller (ADF) test has been done to check for price and return series stationarity. The null hypothesis was required for further testing in price series. Results of ADF test for S&P 500 index were sufficient in order not to reject null hypothesis. Test statistical value was -1.5, while critical value was -1.9. According to methodology, statistic value must be greater than the critical value. P-value of 0.12 also increased the likelihood of correctly done test. FTSE 100 Unit-root test had the following values: test value -0.459, critical value -1.9416 and p-value 0.496. The results at significant level of 5% for both indices indicate correct data.

All these results add up to unconditional correlation coefficient of 0.57. This coefficient indicates very high inter-dependency between markets with positive relationship.

In further analysis building ARMA model a market shock interpretation has been built. By extracting squared residuals a following market shocks figure is prepared:



Source: Matlab

Fig. 5. Market shocks in S&P 500and FTSE100

Market shock graphs made from squared residuals show a similar trend to previous study. However, there is a difference in market volatility clustering in the period during debt crisis in Europe. S&P 500 index was reacting to jumps in volatility during the period from 2010 to 2013. Few reasons have caused higher volatility over the course of this time. On August 2011, several bad news have been announced which had an effect on both sides of Atlantic Ocean. First of all, it was feared that contagious disease of Greek inability to pay their debts will be transmitted to two other large markets of Europe: Italy and Spain. Furthermore, on August 6th, 2011 Standard & Poor's credit agency has downgraded United States credit rating from AAA to AA+ and first time in history U.S. has lost highest rating. The losses from this downgrade were severe all over the world, except China, which according to our data did not suffer severe impact. On 8th of August market fell by 6.9% in S&P 500 and FTSE 100 had a drop of -3.5%. It is worth mentioning that the downgrading was already expected and markets were already adjusting to a possible downgrade, however, the news itself had a big effect on markets. It is worth analysing the reasons of S&P's agency decision to downgrade U.S. economy rating and effects of quantitative easing to economy.

After financial crisis both analysed markets, U.S. and UK, have taken a simultaneous step by Central Banks in order to manage the crisis. However, the amount spent on economy has been quite different. The monetary policy action, called quantitative easing (QE), was used by central banks. Both countries announced about buying financial assets from banks and other financial institutions. By doing so, CBs increased money supply and lowered the yields of debt instruments. Also, by buying debt instruments a lot of free cash has flown into the markets and due to negative yields on debt instruments cash went to stock markets increasing the returns and at the same time volatility of it. Even though QE programs pushed yields of U.S. government to record lows at that time and it seemed that budget deficit in U.S. will not be a problem, a debt ceiling was reached in 2011. August 2nd was a deadline when debt ceiling had to be raised and due to political reasons this was dragged to the last moment. Such political pressure on Obama's Administration was put by Congress and it dragged the country to period of instability, which is clearly reflected by the market returns during the period from May to August, 2011. Political instability was one of the key reasons announced by S&P credit agency why the downgrade was done for U.S. Another point done by agency was the revenue: "Compared with previous projections, our revised base case scenario now assumes that the 2001 and 2003 tax cuts, due to expire by the end of 2012, remain in place. We have changed our assumption on this because the majority of Republicans in Congress continue to resist any measure that would raise revenues, a position we believe Congress reinforced by passing the act" (Standard & Poor's research update, 2011). Despite the problems arising due to debt ceiling, QE was not stopped and economic stimulus was continued. The effects of 2 trillion balance sheet expansion by U.S. Federal Reserve managed to stabilize the economy over couple of years and S&P 500 values reached its pre-crisis values by 2013. Despite the managed crisis, quantitative easing itself should be questioned.

As previously mentioned, QE main intention was to provide liquidity for financial institutions, which could lend out money to consumers and firms to stem up economy. During the analysis of quantitative easing interesting facts were found. During second QE, when Federal Reserve has announced 85 billion dollars monthly bond buying program, not much cash has actually reached the economy. According to Federal Reserve Bank of St. Louis excess reserves by depository institutions, which had to sell treasuries to Federal Reserve, increased from around 800 billion in 2008 to over 1.8 trillion dollars in 2013. Keeping in mind that at that time FED program has disbursed around 2.2 trillion dollars at time, only part of 400 billion remaining has reached real economy[4]. These findings contradict with our previous statements about QE reaching real economy. However, effects by QE program to volatility can be

[4] Some of those 400 billion had to be kept as required reserves in Federal Reserve

explained not by actual cash flows into economy, but by the fact itself, that government is intervening in order to boost economy and further econometric analysis confirms this.

Moving forward to our empirical results univariate GARCH models have been evaluated. Alpha measures are small and close in value to each other indicating that they have similar sensitivity to conditional volatility. Beta value of S&P 500 is lower compared to FTSE 100 indicating that it takes less time for volatility impact to fade out. Also conditional long term volatility values are higher for FTSE 100, which might be a result of higher effects of European debt crisis, which has increased the volatility of FTSE 100 index. This is also supported by mean lag variance count in days, which resembles how much time it takes for index to recover from volatility. S&P 500 index compared to FTSE 100 recovers 2.5 days faster. Respectively it takes 11.13 days for FTSE 100 and for S&P 500 it takes only 8.58 days to recover. Summary of results are showed in following table:

Table 7. Univariate GARCH (1, 1) variance equation

Overlap Univariate GARCH(1,1) variance equation				
	S&P 500	*t-ratio*	FTSE 100	*t-ratio*
ω	0,00000187	*11.460.415,41*	0,00000118	*8.574.691,14*
α	0,101	*817,78*	0,086	*965,22*
β	0,883	*6.281,71*	0,910	*10.946,13*
LT volatility	17,62%		26,13%	
Mean lag variance (days)	8,58		11,13	
Max likelihood	8.610,44		8.109,18	

Source: Matlab

After forming CCC-GARCH model both S&P 500 and FTSE 100 indexes have increased their long term volatility. The biggest difference between the models is identified by the changes in long term volatility and mean lag variance. Long term volatility has significantly increased for S&P 500 and the time it takes to fade out has increased as well. Even though FTSE 100 has a slightly increased volatility it's time to fade out volatility has decreased a bit.

Table 8. CCC-GARCH model results

Multivariate CCC-GARCH(1,1) variance equation				
	S&P 500	*t-ratio*	FTSE 100	*t-ratio*
ω	0,00000251	*3.995.021,91*	0,00000174	*4.939.021,79*
α	0,085	*581,86*	0,100	*550,92*
β	0,903	*5.126,63*	0,895	*5.021,00*
LT volatility	23,64%		28,72%	
Mean lag variance (days)	10,36		9,49	
Max likelihood	15.909,76		15.909,76	
Correlation coefficient	0,3972	*1184,00*	0,3972	*1184,00*

Source: Matlab

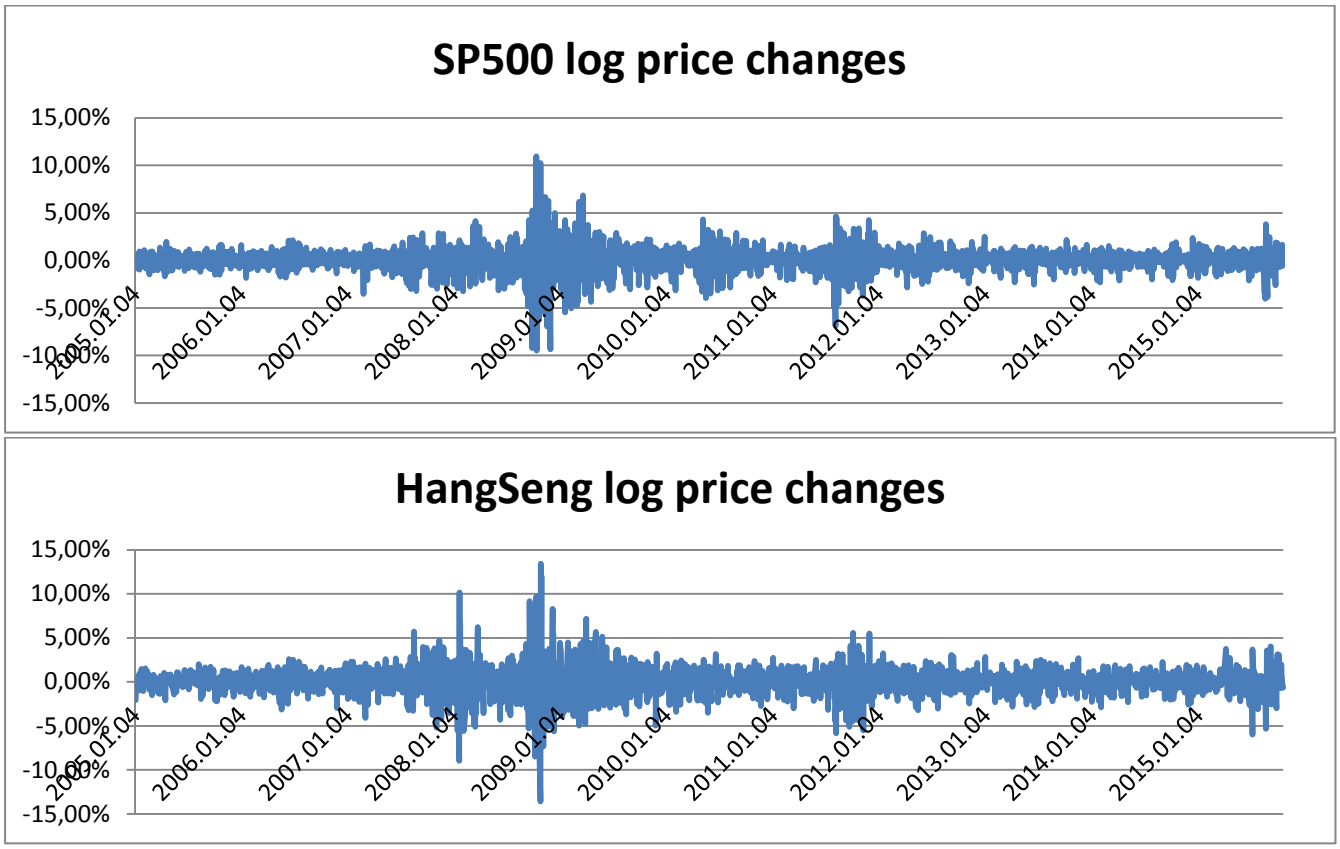
Our empirical results confirm that quantitative easing had an effect for volatility over the analyzed period. Despite the arguments about how much cash has actually reached the economy actions themselves did help improving health of financial markets in United States and United Kingdom.

3.3. S&P 500 and Hang Seng empirical result analysis till 2014

S&P 500 and China observation filtering removed the biggest amount of observations. From 2671 observations in Hang Seng index only 2598 common days remained with S&P 500. As we have discusses previously this was greatly affected due to moon calendar's holidays in China. Changes in mean returns had a slight effect for filtered and unfiltered results of analysis. Mean in Hang Seng changed from -0.017% to 0.0183% and mean return of S&P shifted from -0.0197% to 0.0206. Result filtering did not affect minimum and maximum changes in the index.

As previously mentioned Hang Seng highest gain of 13.43% was observed on 28th of October 2008, while the biggest drop was on 27th of October same year by -13.43%. An interesting observation can be identified on S&P 500 largest gain and drops. Biggest gain was fixed on 13th of October, 2008 and it was the largest gain ever recorded in S&P 500 history. One trading day before, 10th of October market closed below a psychological level of 900 points for the first time since 2003, so a possible retrace was expected by technical analysis tools and high frequency trading platforms. Monday was a correction day after two weeks of decline, however, it was just a temporary increase, because 15th of October was the worst day for S&P 500 since the 1987 market crash. Market has dropped by 9.47% and closed at 907.84

points and it took another week for the market to close below 900 points again. During last weeks of October another jump of more than 10% and a drop of more than 6% were recorded making it the most volatile month ever recorded with average daily market movement of 4.2%. In comparison, the average daily movement of S&P 500 is only 0.82% and the analysis showed that standard deviation was 1.29%. Hang Seng followed a very similar trend of extreme volatility during this period, which is also visible from the below comparison on returns:



Source: Matlab

Fig. 6. Log price changes on S&P500 and Hang Seng

After filtering the data some changes have been noticed. Skewness in S&P 500 data did not change a lot however, Hang Seng had a significant change. Negative skewness after filtered observation received a positive meaning. Even though skewness still remains close to zero confirming symmetric data results, it is still an important sign that skew shifted from left side to the right side, meaning that during the synchronized trading days with S&P 500 data Hang Seng experienced fewer significant negative movements from the mean. Excess kurtosis for the compared indexes is still very high indicating

possibility of extremely large movements to either side. The summary of descriptive statistics is showed below:

Table 9. Descriptive statistics of S&P 500 and Hang Seng

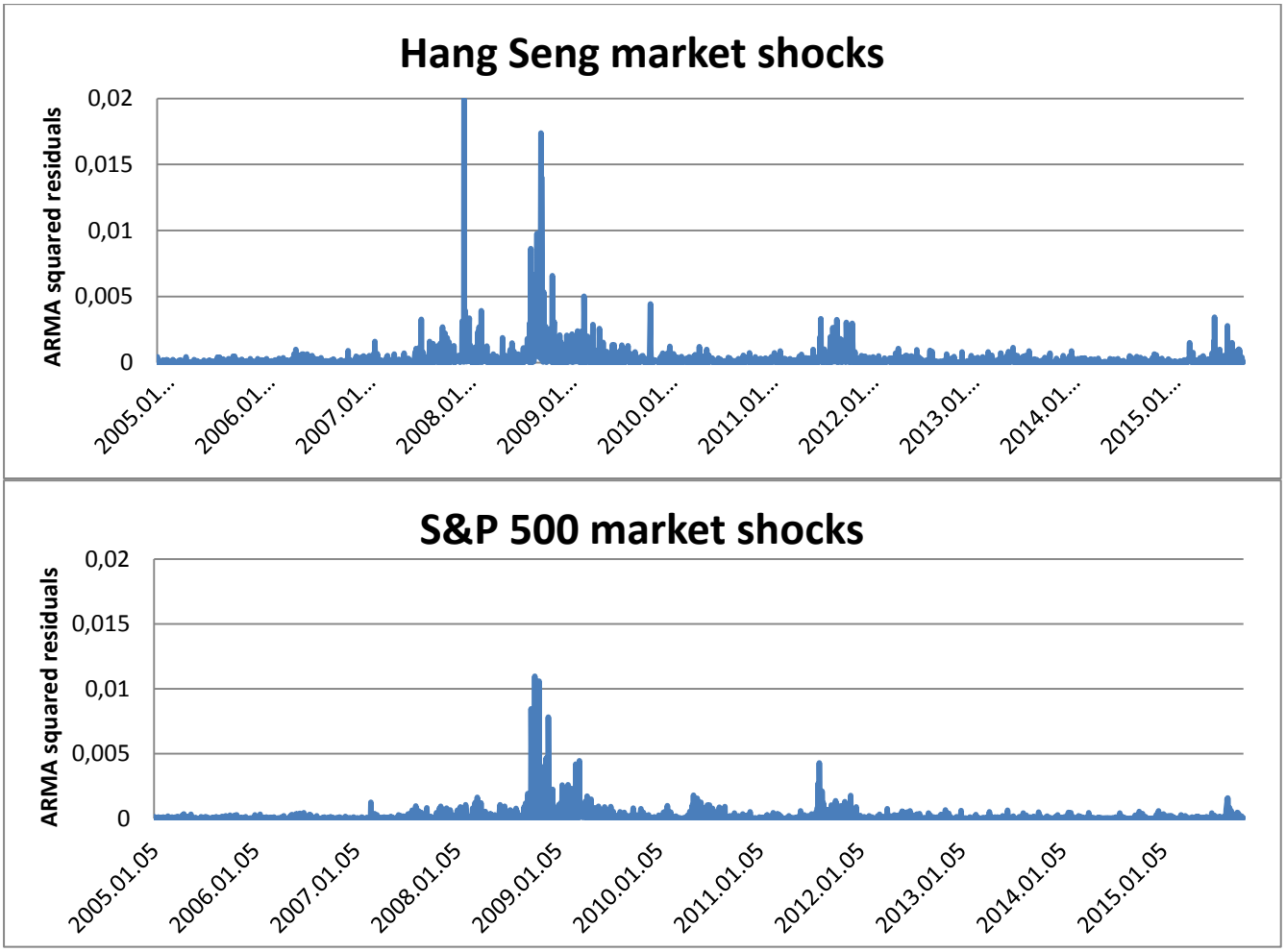
S&P 500 descriptive statistics				**Hang Seng descriptive statistics**		
	Unfiltered	Filtered			Original	Overlap
# observations	2.720	2.598		# observations	2.671	2.598
Mean	-0,02%	-0,02%		Mean	-0,02%	-0,02%
Median	-0,07%	-0,07%		Median	-0,06%	-0,06%
Min	-10,96%	-10,96%		Min	-13,43%	-13,43%
Max	9,47%	9,47%		Max	13,59%	14,69%
Std. deviation	0,01268	0,01293		Std. deviation	0,01585	0,01621
Skewness	0,3312	0,3257		Skewness	(0,0316)	0,1866
Kurtosis	13,9533	13,6562		Kurtosis	12,1338	13,7268

Source: Matlab

Augmented Dickey Fuller (ADF) test has been done to check for price and return series stationarity. The null hypothesis was required for further testing in price series. Results of ADF test for Hang Seng index were sufficient in order not to reject null hypothesis. Test statistical value was -0.42, while critical value was -1.9. According to methodology, statistic value must be greater than the critical value. P-value of 0.5 also increased the likelihood of correctly done test. S&P 500 unit-root test had the following values: test value -1.5, critical value -1.9 and p-value 0.12. The results at significant level of 5% for both indices indicate correct data.

Although ADF test and other data is sufficient to continue further analysis, unconditional correlation of 0.27 shows that linkage between S&P 500 and Hang Seng is the smallest of all the investigated markets.

After building ARMA model squared residuals for market shocks have been extracted and showed on below figure:



Source: Matlab

Fig. 7. Market shocks of S&P 500 and Hang Seng

As it is seen market shocks are following a similar trend throughout our analysed period with S&P 500 having lower values in general. An interesting fact can be observed on Hang Seng index on 23th of January, 2008. At that time "financial crisis" was still not discussed, though Sub-prime mortgage crisis was at its early stages. From the graph it is seen that from late 2007, when sales started to drop in Sub-prime mortgage, volatility has increased in both markets, but it remained relatively stable in United States. On 22nd of January FOMC committee has announced a sharp decrease of 75 basis points from 4.25% to 3.5% (FOMC 2008 Press Release). During that time such sharp decline of interest rate sent a signal over global markets about possibility of recession in U.S. economy and this news was met with sharp increase of volatility in other markets, which is proved from our data of Hang Seng and FTSE 100. Although Chinese market has reacted next day with a large decrease in value, U.S. had just a minor effect of that due to several reasons. Firstly, United States was still considered as a stable economy and a decrease in

interest rates would make it possible for businesses to borrow cheaper allowing an expansion of economy. Second thing was the Sub-prime crisis roots. At early beginning of 2008 no one was speaking about the influence of derivative instruments to other markets. Thirdly, FOMC sent signals about short volatility period, which will pass. As Fligstein, Brundage and Schultz (2014) showed in their research, FOMC committee did not forecast any threats to economy and even after the crash of Lehman Brothers FOMC still kept to their old economical model.

During the later periods after financial meltdown in 2008, Hang Seng index experienced an overall larger volatility, which was already discussed in descriptive statistic part related to standard deviations. Also, few discrepancies rose in the period from 2009 till the end of 2014. China's political decisions to invest in Middle East brought institutional investors searching for opportunities in logistics and transportation to use a company "Dubai World", which supervises projects for Government of Dubai and at that time generating about 18 billion USD revenue yearly. When company announced about financial difficulties on 26th of November, 2009, Chinese market reacted with a steep dive of 4.97%. U.S. companies did not have any significant stakes at this company and was not affected by its financial difficulties. However, despite U.S. economy's resistance to certain types of localized shocks, previously discussed European debt crisis left a larger mark of volatility in U.S. market compared to Hang Seng. Despite the larger initial shock of debt crisis, U.S. market managed to disperse the effects of volatility quicker. Further studies of univariate GARCH model showed the assumptions of market dispersion.

Alpha measures are small and close in value to each other indicating that they have similar sensitivity to conditional volatility. Beta value of S&P 500 is lower compared to Hang Seng indicating that it takes less time for volatility impact to fade out. Conditional long term volatility is higher for S&P 500, however the difference is small and no assumptions could be made from such small changes. Other two measures of long term volatility and mean lag variance counted in days identifies a big difference between the markets. S&P 500 recovers from shocks in 7.91 days, while it takes 11.65 for Hang Seng to recover. Combined with long term volatility of 23.11% Hang Seng shows much higher volatility and higher risk of loss. Summary of results are showed below:

Table 10. Univariate GARCH (1, 1) variance equation

Univariate GARCH(1,1) variance equation				
	S&P 500	*t-ratio*	Hang Seng	*t-ratio*
ω	0,00000212	*10.632.894,35*	0,00000203	*6.890.011,67*
α	0,110	*740,15*	0,076	*885,78*
β	0,874	*5.256,68*	0,914	*9.428,61*
LT volatility	17,94%		23,11%	
Mean lag variance (days)	7,91		11,65	
Max likelihood	8.354,68		7.630,39	

Source: Matlab

After forming CCC-GARCH model both S&P 500 and Hang Seng indexes have increased their long term volatility. The biggest difference between the models is identified by the change of mean lag variance in Hang Seng index. Mean lag variance has significantly decreased from 11.65 to 9.75 days. Correlation coefficient for multivariate conditional correlation GARCH model was 0.2246. Summary of CCC-GARCH model is showed below:

Table 11. CCC-GARCH model results

Multivariate CCC-GARCH(1,1) variance equation				
	S&P 500	*t-ratio*	Hang Seng	*t-ratio*
ω	0,00000228	*8.334.695,15*	0,00000277	*3.640.354,54*
α	0,116	*705,57*	0,091	*474,57*
β	0,867	*4.827,36*	0,897	*4.064,28*
LT volatility	18,49%		24,34%	
Mean lag variance (days)	7,54		9,75	
Max likelihood	16.049,72		16.049,72	
Correlation coefficient	0,2246	*581,62*	0,2246	*581,62*

Source: Matlab

From the following results certain conclusions have been made. First of all volatility clustering between markets has been proved. Secondly, thesis has identified that highest correlation exist between FTSE 100 and S&P 500. Such finding proves that developed countries have more interaction with each other. Furthermore findings show that European debt crisis had a limited impact to China overall, while

United States had a delayed reaction to crisis. Also thesis has proved that developed countries disperse long term volatility faster than emerging market. Combined with other statistical measures: standard deviation, skewness and kurtosis, overall higher stability of developed countries is proved over long term.

3.4. Market reaction during 2015 Chinese financial crisis

In the beginning of 2015 China started to show signs of weakening economy. On March 1st China's purchasing managers' index dropped below 50 points, which is indicating growth. All our analysed markets did not show any indication of worry at that time. China, as being one of largest net oil importers in the world, was benefiting from dropping oil prices in 2015 and central bank has already cut interest rates twice during 2014. However, the economy was still stagnating even with dropping oil prices and another market rate cut was announced on 19th of April. This was followed by drop of 2% in Hang Seng index and a flat day on S&P 500 and FTSE 100. Another interest rate cut was announced on 10th of May, less than a month after the previous one. China's Central Bank reduced benchmark one-year term lending by 25 basis points to 5.1% and deposit rate as well by 25 basis points to 2.25%. Even though interest rate cuts allow companies to borrow cheaper expectations for companies were still decreasing. During the first trading week of May Hang Seng had 4 negative trading sessions out of 5. However Hang Seng index was still holding up.

Period from May to June was rather calm. Market movements in this period were below analysed periods movements. However decisions in mainland China brought a huge surge of volatility throughout the markets on 3th of July (Friday). First trading day after the weekend Hang Seng plunged more than 3% while other two analysed markets lost small portion of their value as well. Decisions of China's government to stop initial public offerings (IPO's) as well as creation of market stabilization fund were taken due to huge losses of value in mainland China indexes. According to Bloomberg, Shanghai composite Index has lost 29% of value since peak in June 12. Total losses were valued of 2.8 trillion dollars. In comparison FTSE 100 has gained around 0.01% in this time, S&P 500 lost less than 0.01% and Hang Seng lost 4%. This shows that even though Hang Seng had resistance to negative impact of mainland China crisis, it was still affected much more than rest of the world at that time. During July Hang Seng lost 6.5% in a month with an average daily change of 1.36%, which is above long term change of 1%. Also on July Hang Seng has fixated largest loss in 2015 with an index drop of 5.98%. Another important fact is mainland China's actions taken during the increased volatility period. Until August government has not been intervening directly. In other stock markets, like Shanghai or Shenzhen, stock

exchanges have started halting trading for companies. According to Bloomberg compiled data, 1.4 trillion dollar worth of shares have been halted on 7th of July, which is 21% of Shanghai capitalization. Beginning of Chinese market turmoil has also affected other markets. The most widely used volatility index in United States, also often referred as "fear index", VIX has increased its value by more than 10% in the beginning of July. In below figure we can see VIX dynamics for 2015:

Source: tradingview.com

Fig. 8. VIX index values for 2015

VIX values also confirms the statement about volatile month in the world, however it was still believed that the crisis in China is "manageable". However, shifts in China's politics during August have brought a real turmoil into the market. On August 11th, People's Bank of China (PBOC) has devaluated renminbi (official currency of mainland China) by 2% against U.S. dollar. This action has been rather unexpected in the market. The devaluation of currency itself did not bring huge shock to the global markets. This action raised worries and ignited a decline of stock markets which brought to "Black Monday" in China and rest of the world. However, to understand how devaluation of currency brought the market to a second financial crisis since 2008, certain facts should be mentioned.

Chinese economy growth for the past two decades has been built solely on exports. In order to be competitive in global trade world China had something other countries did not. Chinese currency was artificially devaluated by pegging it to US dollar with certain fluctuation limits. Till 2015 it was believed that yuan is undervalued, however, due to limited and questionable information from Chinese central bank, no real studies have been done to asses by how much. Central bank managed the fluctuations by

buying US dollars and selling yuans. By increasing the central bank reserves of US dollars China built up a reserve, which was believed to hold up any crisis. However, IMF (Press release) on 26th of May announced that according to them, yuan is not undervalued anymore. Not long after that, on 11th of August, yuan was devaluated, and on 12th they went for second devaluation again. Such movements magnified short-term market reactions to a bloom. However, what happened on 24th of August, no one has predicted. As analysis shows, volatility in the market from ARMA model increased twice in S&P 500 on 24th. Fear index has increased to more than 50 points, also more than twice compared to previous day and more than 3 times since previous week. Currently no empirical studies exist about this crash. Therefore this thesis will with all previously mentioned facts provide systemic explanation of crash.

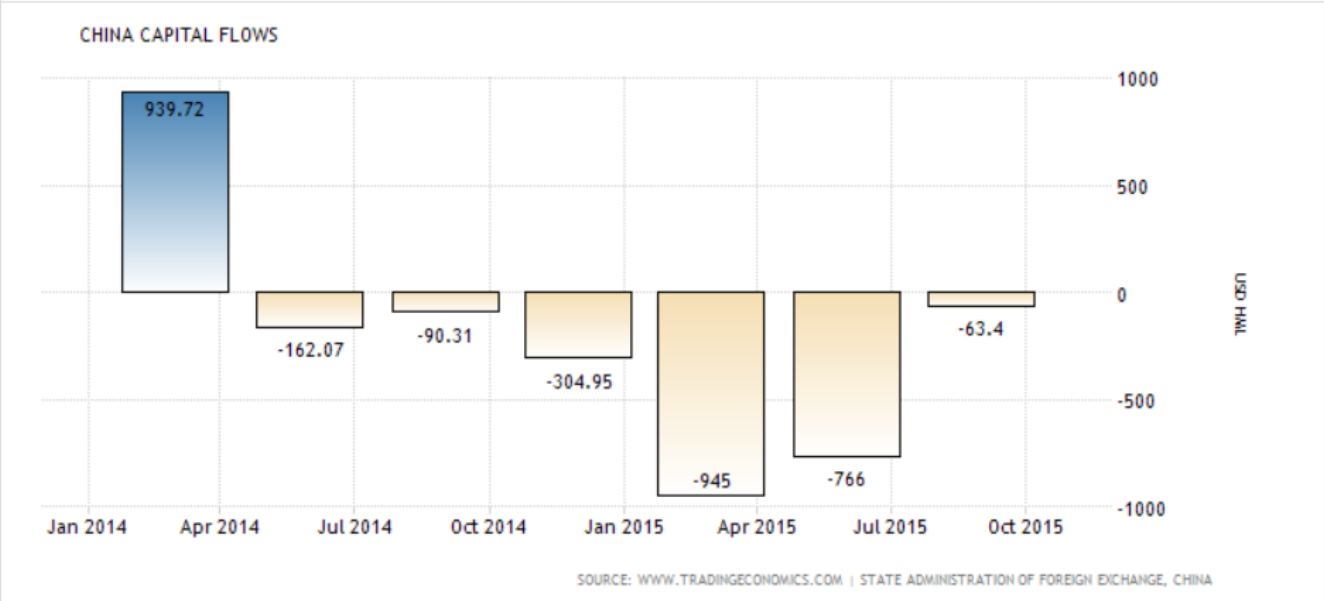
Sudden actions of PBOC by devaluating currency, freezing IPO's and etc. caused the increased volatility. Large investment companies, brokerage firms in order to protect themselves from market crash significantly increased instrument buying which are able to protect them from sudden market moves. One of the options to protect portfolio is to buy put options. However, while demand for put options increased and firms hedged their exposure, dealers had to go long in the market. After a movement down in the market reached certain point where options started moving "in the money", a major sell off began. On normal terms this should not matter, as dealers would sell off their asset and stay neutral, however, due to market reaction no one was willing to buy, dealers could not sell and market started plunging.

Another problem was market liquidity. Surplus of selling side amounts was so vast, that there were not enough buy side traders willing to buy the assets. Another problem was that stock dumping began in pre-market auctions, before all trading floor started business day. These factors, combined with bad macroeconomic data, such like lowest in six years manufacturing data, made a perfect storm in Far East. Despite all these factors markets managed to resist huge shocks, of course with help of central bank intervention. PBOC pumped its reserves into market creating additional liquidity to stabilize the markets. The change in China's foreign exchange reserves can be seen in below figure:

Source: tradingeconomics.com

Fig. 9. China foreign exchange reserves

China has spent more than 10% of their total foreign exchange reserves from the historical peak of 400 trillion US dollars to less than 360 trillion. Such vast amount of money spent over several months helped to put the China's market into a more stable period. China used its reserves to stabilize the yuan after the central bank devalued the currency. However, the main problems lay not in the action itself, but in consequences which lay ahead of such action. Firstly, POBC have nearly 30% of all holdings held by central banks world-wide. United States are extremely exposed to problems in China, since 40% of foreign reserves held by China's central bank are in U.S. treasuries, which account for around 1.27 trillion dollars according to data from Treasury Department. Such vast amount of U.S. treasuries could make severe damage to U.S. bond market if selling pressure would increase in near future. After expansion of balance sheet Federal Reserve pushed the yields of bond to record lows, but China can push the prices down if additional foreign reserves would be needed. By doing so, bond market would face a period of increased volatility, because by increasing the supply of treasuries prices would go down and yields would increase. Such shifts in bond market would also have effect on stock markets, since signs of additional intervention by China's central bank would increase uncertainty in the market and cash would flow from stock markets to bond markets since investors would receive higher yields in the bond market as well as a safety if economy would face a recession. Another problem for PBOC in upcoming months will be to weight the need of foreign reserves versus pressure on local currency. China is experiencing huge capital outflows for the past months, with values in below figure:



Source: tradingeconomics.com

Fig. 10. China capital flows

Such shifts in capital flow are indicating an even bigger problem in near future for China. For the past decade yuan has been appreciating and institutional investors, companies fuelled economy with expectations that even if investment itself would not be successful, changes in currency value would cover part of losses. This has changed with devaluation of yuan and signs of slowing economy are reducing expectations of uptrend market, therefore cash outflow from China is expected in near future.

Despite of all actions taken in China, global economy is still stagnating. Low oil prices, conflicts in Middle East, refugee crisis in Europe and Greek debt crisis are lowering expectations of world economic growth. Volatility over the markets will remain above its mean value for a while with upcoming events in near future. From fundamental perspective upcoming months will reveal true state of two economical engines of the world. In December FED will announce their decision if interest rates will be increased first time in a decade, and ECB will announce if QE program will be extended. With increased interest rates and expanded QE in Europe possible formation of liquidity vortexes can arise due to movements from EUR currency to USD. However, pushing down the exchange rates in EUR will increase volatility in markets, but there is a possibility of economic stabilization in Europe due to these actions. Stability in Europe and United States would reduce the risk of market turmoil's around the world.

4. CONCLUSIONS AND RECOMMENDATIONS

1. Early researches of financial market volatility used to focus on individual market volatility. Therefore, scholars' interest was laid on financial market volatility clustering and relations between emerging and developed countries. This has encouraged looking into interdependency between main financial markets of the world: USA, Europe and Asia.
2. To represent the main financial markets the following indexes were chosen: FTSE100 (United Kingdom), Hang Seng (China), S&P 500 (USA). From MV-GARCH model results general movement of prices in financial markets have been identified, however they were not moving in tangent. Despite the differences in price movements, a strong relationship (correlation) has been found in volatility analysis. Final volatility series show that over the period from 2010 to 2015 certain macroeconomic factors did not cause volatility clustering over all analysed markets.
3. MV-GARCH model showed that all markets correlate to each other, the highest correlation was revieled between two developed markets – USA and UK. Such interdependency might be partly explained by similar actions taken during financial crisis by monetary policy makers (QE programs).
4. European debt crisis had a large impact over United Kingdom and United States, but China reacted to these macro events only after some time, when expectations of markets gotten worse due to overall default risk in more than one European country. Before, either good or bad news of Europe's economy did not have a high influence over China's financial markets. Correlation between FTSE100 and Hang Seng according to the used model is 0.42, which shows quiet high interdependency.
5. Correlation between S&P500 and Hang Seng is 0.27, which shows weaker interdependency. However, after recent financial crisis in China USA became more exposed to China's market volatility due to devaluation of currency, huge usage of foreign reserves and capital outflow from China's economy. Combined with vast amounts of money received from China selling government bonds, United States can have a severe impact if China's economy will continue to slow down at current rate and "soft" landing will not happen.
6. Quantitive Easing (QE) effect on volatility and economy has been proved. QE programs pushed the bond market yields to record lows, which has caused the cash movement from fixed income markets to stock markets. This has caused increased volatility in stock market, although effects by QE program to volatility can be explained not by actual cash flows into economy, but by the fact

itself, that government is intervening in order to boost economy and it helped to restore the trust in financial markets.

7. Main factors which have an effect on volatility might be divided into main groups: political and monetary policy decisions by main leading economies, global economic news and macroeconomic outlooks.
8. During the analysis main drawback of MV-GARCH model has been identified. GARCH models overall heavily relay on historical data and all forecasting is done solely on previous changes. Over this study drawbacks can be seen over certain periods of time. Any "unexpected" events over the course of day cannot be predicted using GARCH model, since model itself does not include expectations into calculations. For this reason implied volatility models, like VDAX or VIX, are more often used in finance world. The main pros of implied volatility models lay in the methodology of calculation, since they are using options to forecast volatility, and the changes in option prices catches the shifts in expectations by financial world, giving an advantage for investors to hedge against fluctuations in the market.
9. Despite the drawback of this model, study has unveiled strong interdependency between all three major markets and evidences show that they are extremely exposed to volatility spillovers. International investors, governments and companies should further examine the risks of volatility clustering over short-term. United States is especially exposed to these risks, since their monetary policy actions have a strongest effect on volatility over all analysed markets.
10. MV-GARCH model is more proficient for modelling volatility over long periods and is useful for forecasting volatility for short period of time taken into consideration that no "big news" are going to be announced in forecasted period. Stochastic volatility models should not be used alone to predict future market movements. Therefore it is recommended to combine this type of models with implied volatility models.
11. Our MV-GARCH model is using constant conditional correlation to forecast future movements. Thesis results show that not all events have a similar effect across the analysed markets therefore, future studies should consider using dynamic conditional correlation in order to correctly weight asymmetric affects in volatility. In addition DCC specification can be extended to include exogenous factors.

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ABSTRACT

The aim of the thesis is to empirically examine volatility clustering over three major markets: United States, United Kingdom and China. The thesis aims to investigate how macroeconomic factors influence stock market volatility and tries to prove linkages of inter-dependency between financial markets. Using the MV-GARCH thesis identifies how strongly major financial markets are connected and how local economic situation is influencing other markets. The findings of this thesis show that during 2008 financial crisis and later during European debt crisis as well as Chinas financial market turmoil, markets had different effects on volatility. Finally, thesis shows that volatility clustering does not have persistency over all periods and certain events did not trigger volatility transmission over to other financial markets until certain level.

Key word: MV-GARCH, volatility clustering, financial market inter-dependency, China's financial crisis 2015

Urbaitis L. Akcijų rinkos kintamumo modeliavimas ir prognozavimas / Finansų rinkų magistro baigiamasis darbas. Darbo vadovas Doc. dr. D. Teresienė. – Vilnius: Mykolo Romerio Universitetas, Bankininkystės ir investiciju katedra, 2015

ANOTACIJA

Pagrindinis šio magistrinio darbo tikslas naudojant empirinius tyrimus įrodyti finansinių rinkų svyravimų sąsają tarp trijų didžiausių finansinių rinkų: Jungtinių Amerikos Valstijų, Didžiosios Britanijos, Kinijos. Darbo eigoje yra tiriama, kaip makroekonominiai veiksniai daro įtaką kintamumui akcijų rinkose, taip pat yra tiriama sąsaja tarp bendrų finansinių rinkų. Taikant MV-GARCH modelį yra įrodoma sąsaja ir jos priklausomybė nuo vietinių ekonominių faktorių lokaliose rinkose ir jų svyravimų perkėlimo į kitas rinkas. Rezultatai parodo, kaip per didžiąją finansų krizę 2008 metais ir po jos sekusiose Europos skolų krizės bei Kinijos finansų rinkų svyravimai veikė visų rinkų kintamumą. Taip pat rezultatai parodo, kad kintamumo ryšys kitose rinkose nėra pastovus ir specifiniais periodais tam tikri vietinės reikšmės ekonominiai įvykiai neturėjo reikšmės kitoms finansų rinkoms.

Raktiniai žodžiai: MV-GARCH modelis, kintamumo sąsaja, finanų rinkų priklausomybė, Kinijos finansų krizė 2015 metais

SUMMARY

Actuality of master thesis topic is not questionable. Nowadays every firm is hoping to go public someday and receive capital injections through capital markets. Financial institutions, pension funds and other firms are looking for opportunities where to invest excess cash reserves. With money flowing into financial markets, it is becoming even more important to be able to diversify investment portfolios to evade excess losses during volatile periods. After the economic boom, which has ended with collapse of Subprime mortgage market and global recession, it became clear that complexity of financial markets raises the risk of large fluctuations in the markets. With risk of experiencing large fluctuations in the markets financial institutions use different models to forecast financial markets volatility. One of models for forecasting market volatility is used in this thesis: MV-GARCH.

Since GARCH specification models are based on historical volatility affects, thesis has examined not only the empirical results of model itself, but the factors which have caused the volatility as well. Analytical part is divided into four sub-categories. First section proves the inter-dependency between Hang Seng and FTSE 100 indexes. Second part proves same relationship between FTSE 100 and S&P 500. Results of this part shows, that correlation between markets is highest between all the analysed markets. Third part consists of result analysis between S&P 500 and Hang Seng. Fourth part is dedicated to recent financial crisis in China. Since no empirical studies exist at the moment for this crisis, thesis focuses on several different factors, which have caused the fluctuations in the market. Main points of the crisis are still explained via monetary policy actions; however, such factors as market participant expectation shifts from positive to negative, outlook of macroeconomic situation in the world are also included.

Each sub-category analysing inter-dependency between the markets is built of two structural blocks. First block consists of empirical results received from daily changes in price for the past ten years for a period of 2005-2015. From price changes MV-GARCH model with constant conditional correlation is built up to forecast future fluctuations. All empirical analysis confirms hypothesis that markets experience volatility clustering and their inter-dependency. Second block consists of evaluation of monetary policy over the analysed period. During the analysis of monetary policy actions, certain facts have been found. First of all, expansionary monetary policy by Central Banks had a huge influence over the financial markets. Quantitative easing programs in United States and Europe helped to stabilise the economy in regions. Despite the findings that QE programs in United States did not reach real economy, actions themselves helped the financial markets to restore trust in the economy. Such results of QE program questions the limitations of used model. The problem with MV-GARCH model is that it does not

include expectations in the market. Despite the missing variable in the model, MV-GARCH results highly correlate with other implied volatility indexes, like VDAX and VIX.

Despite that all empirical results are statistically correct and they are in-line with econometric methodology used, certain problems in forecasting have been identified. Actions by monetary policy makers in China can cause severe impact on volatility in United States due to exposure of currency needs by China. Thesis highlights that systemic issues in macroeconomic environment in China are not only Chinas problems, but also are of high importance for United States investors.

SANTRAUKA

Šio magistrinio darbo aktualumas yra nekvestionuojamas. Šiais laikais visos įmonės tikisi tapti listinguojamos ir gauti papildomų pajamų iš pirminio akcijų platinimo. Finansų institucijos, pensijų fondai ir kitos įmonės ieško galimybių, kur galėtų investuoti savo grynuosius aktyvus. Didėjant pinigų srautams finansų rinkose tampa vis svarbiau priimti teisingus sprendimus, kurie padėtų diversifikuoti investicinius portfelius, kad būtų išvengta didelių nuostolių. Po ekonominio pakilimo laikotarpio, kuris baigėsi viena didžiausių krizių šiais laikais tapo aišku, kad finansinių rinkų sudėtingumas ir įvairumas didina didelių svyravimų riziką finansų rinkose. Esant tokiai situacijai finansų rinkų dalyviai skiria vis didesnį dėmesį kintamumo modelių analizei ir jų taikymo galimybėms. Vienas iš galimų modelių, kuriais galima įvertinti rinkų kintamumą yra naudojamas šiame magistriniame darbe: MV-GARCH.

Kadangi GARCH modelių kintamumo analizė remiasi istoriniais kintamumo poveikiais, šis magistrinis darbas tiria ne tik empirinius rezultatus, kurie buvo gauti iš pasirinkto modelio, bet ir veiksniai, kurie galėjo padidinti kintamumo svyravimus. Analitinė dalis yra padalinta į keturias dalis. Pirmojoje dalyje yra įrodomas priklausomybės ryšys tarp Hang Seng ir FTSE 100 indeksų. Antrojoje dalyje šis ryšys yra įrodomas tarp FTSE 100 ir S&P 500 indeksų. Šios dalies rezultatai taip pat parodo, kad šių dviejų indeksų koreliacija yra didžiausia iš visų tirtų porų. Trečioji dalis skirta S&P 500 ir Hang Seng indeksų. Ketvirtoji dalis skirta 2015 Kinijos ekonominiai krizei. Kadangi šiuo metu neegzistuoja jokių empirinių tyrimų šia tema, šis magistrinis darbas akcentuoja keletą pagrindinių veiksnių, kurie turėjo įtakos rinkų kintamumui. Pagrindinis kintamumą įtakojantis veiksnys yra išskiriamas, kaip monetarinė politika, tačiau taip pat yra įvertinami ir rinkų dalyvių lūkesčių pokytis iš teigiamų į neigiamus. Bendros pasaulio ekonomikos tendencijos taip pat yra įvertinamos.

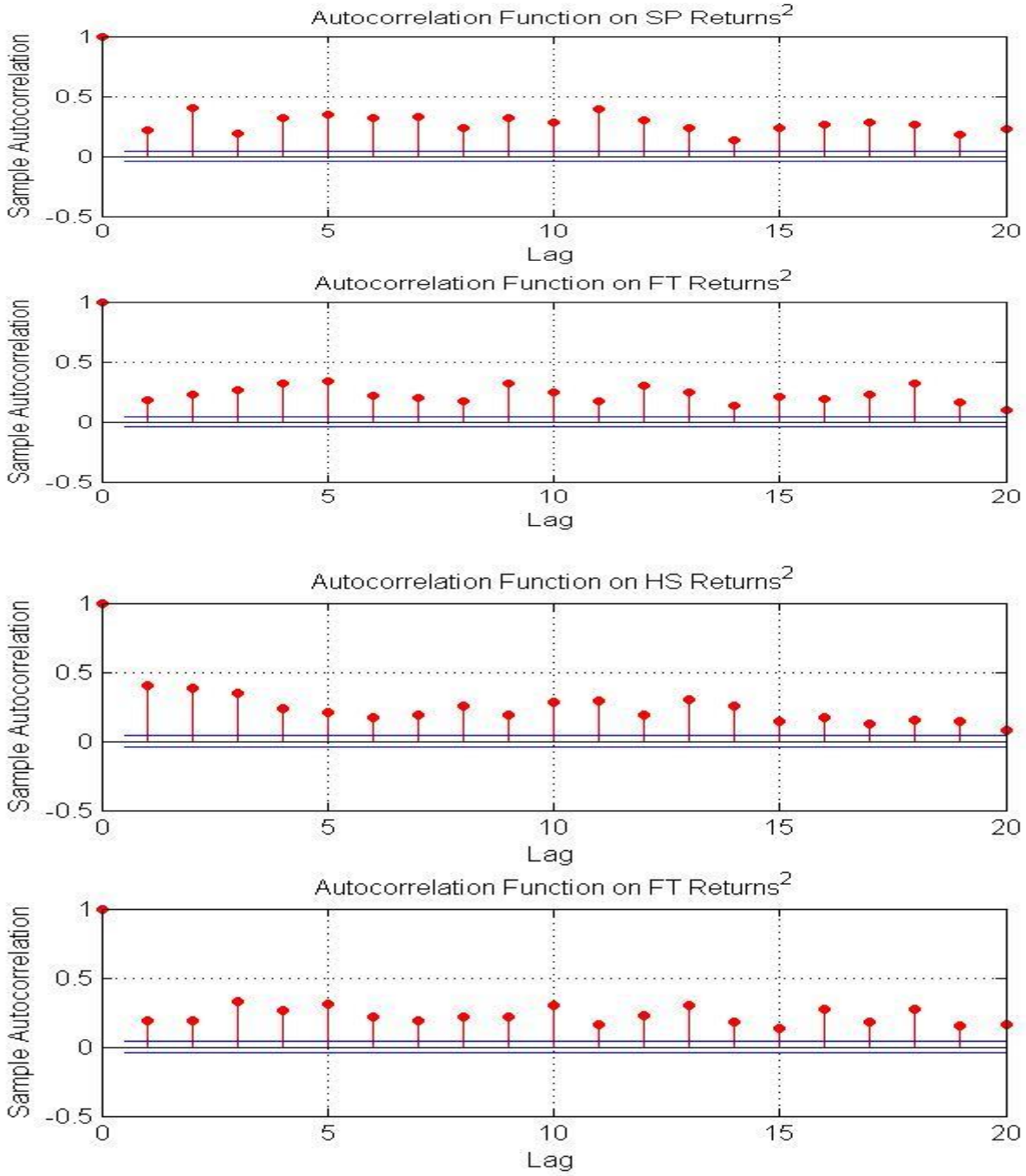
Kiekvienas skyrius yra padalintas į du struktūrinius blokus. Pirmąjį bloką sudaro empiriniai rezultatai, kurie yra gauti naudojant dieninius kainų pokyčius nuo 2015 metų iki 2015. Iš kainų pokyčių yra sudaromas MV-GARCH modelis su pastovia sąlygine koreliacija, kad būtų galima įvertinti ateities kintamumą. Visi empiriniai rezultatai patvirtina išsikeltą hipotezę, kad finansų rinkos patiria kintamumo

susidūrimus ir kintamumo persikėlimą iš vienos rinkos į kitą. Antrąjį bloką sudaro monetarinės politikos vertinimas per analizuojamą periodą. Kiekybinio skatinimo programos Amerikoje ir Europoje padėjo stabilizuoti šių regionų ekonomikas. Nepaisant rastų įrodymų, kad kiekybinio skatinimo programos Amerikoje nepasiekė realios ekonomikos pats centrinio banko noras buvo įvertintas teigiamai rinkos dalyvių ir padėjo atgaivinti pasitikėjimą finansų rinkomis. Šie kiekybinio skatinimo rezultatai atskleidžia naudojamo modelio trūkumus. Pagrindinė MV-GARCH modelio problema yra ta, kad jis neįvertina lūkesčio įtakos finansų rinkoms. Nepaisant šio veiksnio nebuvimo modelyje, MV-GARCH modelio rezultatai stipriai koreliuoja su kitais indeksais, tokiais kaip VDAX arba VIX.

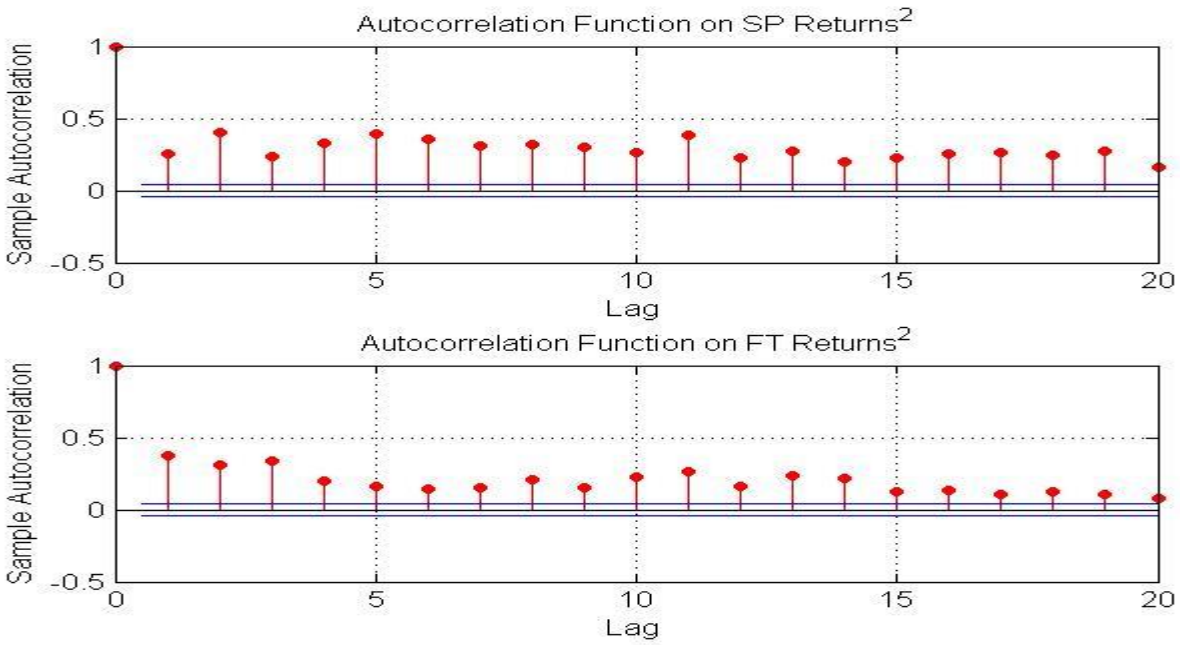
Nepaisant to, kad visi empiriniai rezultatai yra statistiškai teisingi ir atitinka visas ekonometrines taisykles, tam tikri modelio trukumai buvo identifikuoti. Centrinio bankai veiksmai Kinijoje gali ypatingai padidinti svyravimus JAV, kadangi jos yra ypatingai priklausomos nuo Kinijos poreikio turėti JAV valiutos. Šis magistrinis darbas pabrėžia sisteminę riziką makroekonominėje aplinkoje Kinijoje ir įrodo, kad Kinijos problemos yra ypatingai svarbios ir investuotojams kitose rinkose.

ANNEXES

1 ANNEX



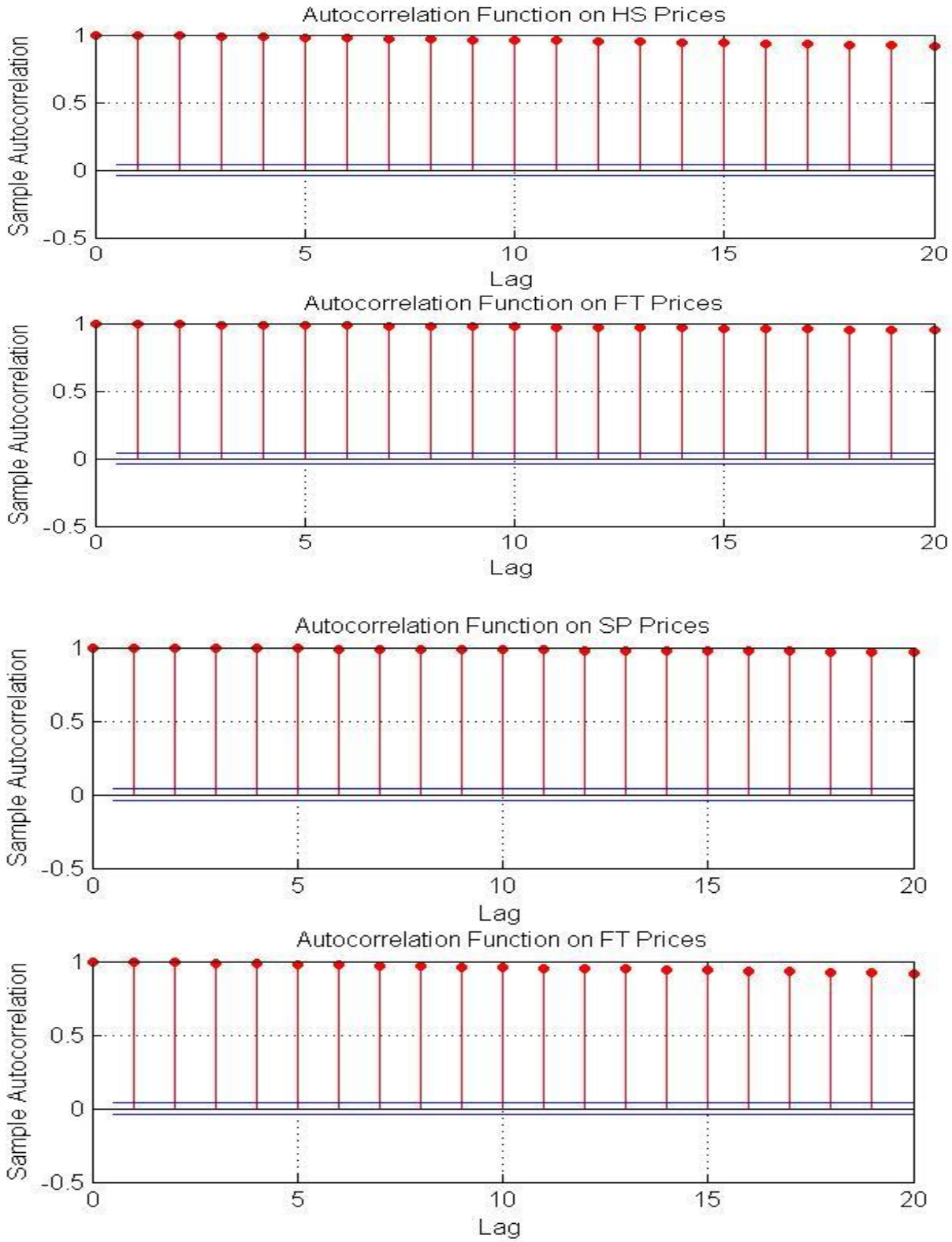
Continue of Fig. 1



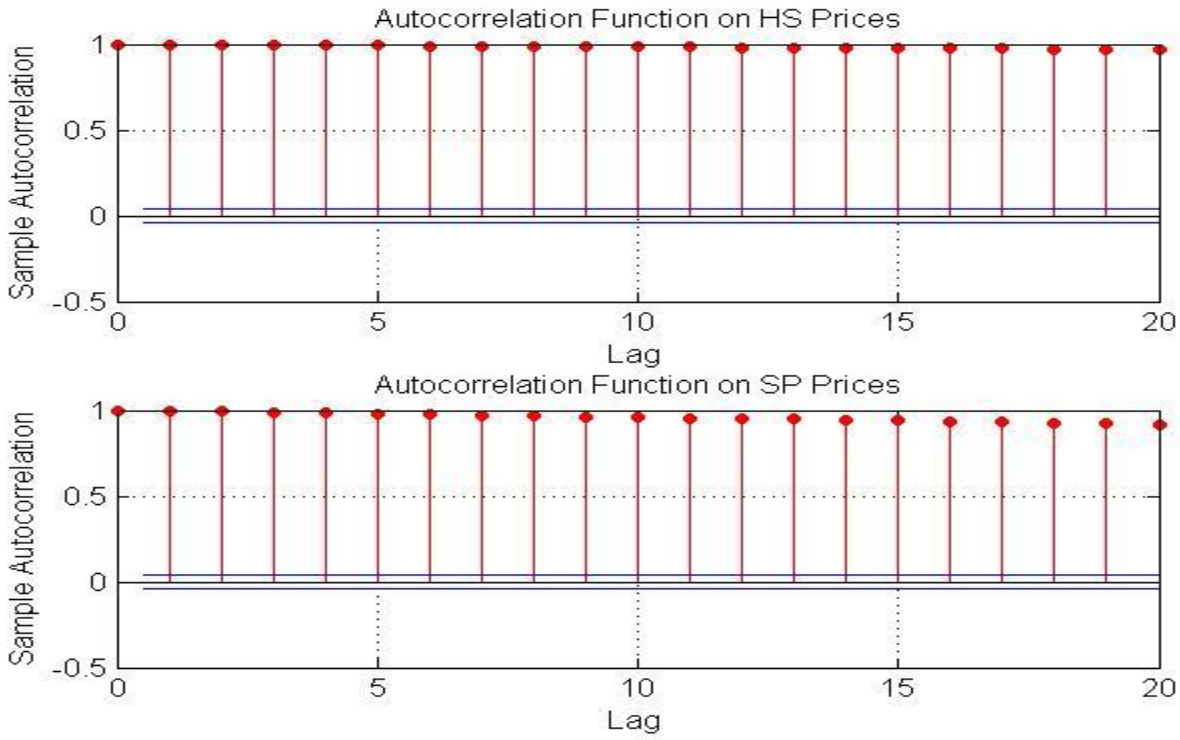
Source: Matlab

Fig 1. Autocorrelation Function of returns for all indexes

2 ANNEX



Continue of Fig. 2



Source: Matlab

Fig 2. Autocorrelation Function of all index prices