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Effects of Brexit on the financial markets:

An empirical study using event study methodology and GARCH models

Master's thesis in Financial Economics
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Preface

This thesis constitutes the final work of the Master of Science program at the Norwegian University of Science and Technology (NTNU), at the Department of Economics, within the master specialization Financial Economics.

I would like to thank my supervisor, Professor Snorre Lindset, for his valuable guidance, constructive feedbacks, and inspiring discussion. Furthermore, I would like to thank Professor Kåre Johansen for his guidance regarding the econometric part of my thesis.

Last but not the least, I express my deepest gratitude to my beloved husband, Amin, who has been a constant source of support and encouragement during the challenges of graduate school and life.

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Abstract

In the current empirical analysis, I investigated whether Brexit was a surprise for financial markets. I studied evidence from currency and stock markets in the UK and EU, using event study methodology and GARCH models. In the first part of this study, I observed that the majority of abnormal returns before the Brexit are positive and the abnormal returns on the event day are negative. Therefore, Brexit vote came as a surprise for financial markets. In the second part, my findings based on the ARCH/GARCH model indicated that there is a heteroscedasticity in the returns of the stock markets. Furthermore, using GARCH (1, 1) model with dummy variable and studying the volatility clustering in the stock markets I concluded that the uncertainty before the Brexit led to increase in the volatility in this period. However realizing the outcome of the referendum and countermeasures taken by the UK government led to decrease in the volatility after the Brexit.

Keywords: Brexit, event study, GARCH (1, 1), abnormal returns, volatility

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Sammendrag

I denne empiriske analysen undersøkte jeg om Brexit var en overraskelse for finansmarkedene. Jeg studerte bevis fra valuta og aksjemarkeder i Storbritannia og EU ved hjelp av eventstudie metoden og GARCH-modeller. I den første delen av denne studien observert jeg at den unormale avkastningen er positive før Brexit og at den er negativ på hendelsesdagen. Derfor kom Brexit-avstemningen som en overraskelse for finansmarkedene. I den andre delen av studien, viste funnene mine basert på ARCH/GARCH modellen at det var en heteroscedasticitet i avkastningen på aksjemarkedene (betyr at variansen av residualene endre seg over tid, og den er ikke konstant lenger) . Videre, ved bruk av GARCH (1, 1) modell med dummy-variabel og ved å studere volatilitetsklyngen på aksjemarkedene konkluderte jeg med at usikkerheten før Brexit førte til økt i volatilitet i denne perioden. Ved å realisere utkommet av avstemningen og utføre hensiktsmessige tiltak av den britiske regjeringen, svingte volatiliteten etter Brexit.

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Summery

On June 23th 2016, the British people voted against remaining in the European Union (Brexit). In the current study, I want to answer the question that whether Brexit was a surprise or not, using evidence from financial markets in the UK and EU. I investigate the effects of Brexit on the currency and stock markets in the UK and European Union by using the event study methodology. Furthermore, I detect the ARCH/GARCH effects in the returns of stock markets and changes in the volatility in the period before and after the Brexit referendum.

My findings indicate that Brexit has a negative impact on the pound sterling (GBP/USD & GBP/euro) and euro (euro/USD) at the event day and this effect is much bigger on the pound sterling than euro. The weakening of the pound sterling after the Brexit indicating that Brexit came as a big surprise for the currency market. Moreover, the overall effect of the Brexit on the GBP in the period after the event is negative.

In terms of the stock markets, the highest abnormal returns in the event window recorded in the event day and it is negative, meaning that Brexit referendum has a negative significant effect on the British and European market indices. Furthermore, the positive sign of abnormal returns before the Brexit shows that Brexit was a surprise for these markets at the event day as well. Calculating of cumulative abnormal returns for British index shows that in the period after the event, the overall effect of the Brexit is positive, meaning that stock market could recover itself very fast and drop in the pound sterling is one of the major reasons for this recovery. But for the European index, the overall effect of Brexit after the event is negative.

My analysis regarding historical volatility shows that first of all, there is heteroscedasticity or ARCH effect in the returns of both indices (FTSE100 and FTSE EUROTOP100). Secondly, estimating the GARCH (1, 1) model with dummy variable for period before and after the Brexit indicates that volatility after the Brexit is less than volatility before the referendum and the reason is uncertainty before the Brexit and realizing the outcome after the referendum.

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List of abbreviations:

Brexit _ term used to refer to Britain's withdrawal from the European Union
UK _ United Kingdom
EU _ European Union
GBP _ Great Britain Pound
USD _ United States Dollar
AB _ abnormal return
CAR _ cumulative abnormal return
CAPM _ capital asset pricing model
EMH _ efficient market hypothesis
FOREX _ foreign exchange market
FTSE100 _ it is a share index of the 100 companies listed on the London Stock Exchange with the highest market capitalization
FTSE EUROTOP100_ 100 most highly capitalized blue chip companies in Europe
DAX _ German stock index
CAC40_ French stock index
ARCH _ autoregressive conditional heteroscedasticity
GARCH _ generalized autoregressive conditional heteroscedasticity

1. Introduction

1.1. Background

Ending World War II in 1945, Europe shifted towards cooperation after conflict. Many European nations felt it was a time to unite the European nations to form a union for the economic and social benefits. The European Union is the UK's largest business partner and it is a destination for around half of the UK's goods exports. Britain's vote to exit the EU is not only a deathblow to the EU, but also has significant effect on the UK's currency and stock market. History has indicated that currency markets and stock markets play a major role in any economy. Various macro and micro economic factors might impact these two markets.

Now the UK is the first member, which is finalizing its withdrawing process from the EU. On 23rd June 2016, it was a referendum in the UK which most of the British voted against remaining in the Union. The result of Brexit referendum sent shockwaves across global markets. It has a huge impact on the FOREX[1] and stock markets. One day after announcing the Brexit result, the pound sterling dropped to a 31-year low against the dollar and this fall continued in the following days after the event. Furthermore, in the two weeks following the Brexit, the pound fell 10% against the euro. The British FTSE100 index declined 3.15% on the June 24th and tried to recover itself in the days after the Brexit since the lower UK exchange rate helped stabilize the share market[2]. The European indices like FTSE EUROTOP 100, DAX, and CAC40 also reacted to the Brexit with a fall in all indices.

1 Foreign Exchange Market.

2 Data in this part is derived from www.uk.reuters.com.

1.2. Motivations and objectives

This topic is very interesting for me to study from many aspects. First of all, it was happened for the first time in the history that one of the European members exits the union, so it is a unique event. Furthermore, although withdrawing the UK from the EU was a British decision, it has global consequences in the financial markets from all over the world and many economists compare the consequences of this event with the global financial crisis in 2008 (Broomfield 2017, Rachman 2016, La Monica 2016, (Ragged 2016), Freeman 2017). Finally, there are just a few studies, which investigate the consequences of Brexit on the financial markets (Adesina 2017, Sathyanarayana & Gargesha 2016, and Raddant 2016). Therefore, there is no specific study, which investigate if Brexit was a surprise or not. So it made me question to study the behavior of financial markets regarding Brexit referendum using evidence from currency and stock markets in the UK and EU and investigate how corporate shares and volatility react to the new information and events.

2. Literature review

In the current study, I investigate whether Brexit was a surprise for financial markets or not. I use evidence from currency and stock markets in the UK and EU and study how corporate shares react to the new event like exiting the UK from the European Union, using event study methodology. Furthermore, I study how volatility in the stock market changes due to the Brexit event with help of estimating several GARCH models with Eviews software.

2.1. Brexit

By ending World War II, the European nations decided to have closer ties and cooperation with each other after half of a century of tension and conflict.
Britain joined the European Economic Community[3] (EEC) in 1973 and by keeping its membership, now it is one of the European Union member states. But until now Britain never fully accepted some regulations about European control of the British institutions in a way that other member states did. The UK, for instance, declined both joining the Schengen Area, which omitted internal border control, and Euro Zone.

There are some reasons behind increasing dissatisfaction of European Union that led to holding the referendum for leaving the bloc. For example, British politics have not trusted the deeper integration with the rest of Europe. This kind of skepticism has been intensified in recent years because the European Union has struggled with the consequences of the 2008 European financial crisis. Although, Britain wasn't affected by the crisis as severely as other member states, Britons started to think that the European membership could be dangerous for the UK.
Historically, the EU has increased its power over its member states so it is not far from mind that finally the UK has to join to the Eurozone or faced pressure to bail out countries, which get into trouble because of inefficient Eurozone economic policies (B. Lee and Beauchamp 2016). Therefore, this argument gave new incentive to the Eurosceptic

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3 The European Union community was created by the Treaty of Rome in 1957. It was the first of the three pillars, which embedded into the European Union. The second pillar was a Common Foreign & Security policy (CFSP) and the third one was Police & Judicial Cooperation in Criminal Matters (PJCCM) (Gabel 2010).

politicians to put the Prime Minister, David Cameron, under the pressure to hold a referendum.

In January 2013, Cameron gave a speech in which he pledged that if the Conservatives win the 2015 election, he would hold an in-out referendum on the UK's membership in the European Union before 2017. At that time, Cameron did not want to exit the European Union and he promised to renegotiate the conditions of the UK's membership and holding a subsequent referendum. He hoped to finally silence this troublesome wing of his party but his plan was failed. Finally, on June 23rd 2016, referendum was held and 52% of voters chose to leave the bloc. The day after, David Cameron resigned as Prime Minister and the pound fell to its lowest level since 1985 (Kennedy 2017).

In July 2016, Therese May became the UK's Prime Minister who triggered Article 50, the step that starts the timer on 2 years of Brexit negotiations. So Britain is scheduled to finally leave the EU by the end of March 2019.

Now that Britain hold a referendum for exiting the EU, voice of dissatisfaction from the Union has been heard from other member states. Now anti-EU politicians work harder and more serious than before to convince people to follow them. Although these far-end political parties were not selected in the last elections in the Netherlands and France, it does not mean they will not win in future elections. If it happens, they have promised to hold a referendum about leaving the European Union so the Nexit[4] or Fexit[5] are expected.

From the Brexit day until now many studies investigated the Brexit from different aspects. Goodwin & Heath (2016) and Hobolt (2016) studied the reasons behind the Britain's vote for the Brexit and showed how some factors like education, age, immigration, and ethnic diversity affected this vote. They indicated that exiting the EU is a common concern among less-educated, poorer and older voters, and those who expressed concerns about multi-culturalism and immigration.
In the other study, Dhingra et al. (2016) investigated the consequences of Brexit on the UK trade and living standards and indicated that the economic consequences of withdrawing the EU will depend on what policies the UK chooses following Brexit. But lower trade because of reduced integration in EU countries is likely to cost the UK economy more than its gained from lower contributions to the EU budget.

Another important topic related to the UK and Brexit is city of London. For example, Springford and Whyte (2014), Djankov (2017), McMahon (2017), and Thompson (2017) investigated the likely consequences of Brexit for the city of London as a financial hub in the world. London is placed as the leading global financial center, a head of New York,

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4 The Netherlands exit

5 France exit

Singapore, Hong-Kong and Tokyo. If the UK loses its passporting[6] right after Brexit, it is likely that most of the international subsidiaries or headquarter move to other European City. So it will have negative effects on the UK's trade and economy. It is very crucial for the UK to get a priority for this sector in the forthcoming negotiations with the EU.

From the Brexit vote until now, there have been many debates about how financial markets will be affected by the Brexit and in fact there is a lot of uncertainty in the markets. Now I want to investigate how currencies and corporate shares react to the Brexit as a new event and what are the consequences of Brexit on the financial markets?

2.2. Efficient Market

According to Fama (1970), in an efficient market, prices –at any point in time- "fully reflect" available information. Thus, any unexpected changes in equilibrium prices will reflect the movement of information available to market participants. In other words, if the stock market is efficient then stock prices adjust immediately to new information.

Fama (1970) backed his research by indicating the sufficient conditions to have capital market efficiency. The first condition is lack of transactions costs in trading securities. The second one is that all available information is available for all market participants without any cost. The last one is that the implications of current information for the current price and distributions of future prices of each security should be agreed by all the participants in the market. Therefore, in such a market, the current price of a security will "fully reflects" all available information.
Although the conditions above exist in frictionless market, which couldn't be found in the real world, but to some extent, these conditions are enough to ensure the reflection of the information on the security prices.

Fama(1970) proposed three forms of market efficiency:

1. *Weak form tests*, where the information set is just historical prices.
2. *Semi-strong form tests*, where it tests whether prices efficiently adjusts to other information that is obviously publicly available like announcements of annual earnings and stock splits.
3. *Strong form tests*, where tests if given investors have monopolistic access to any information.

6 Passporting rights mean that a company registered in EEA (European Economic Area) can do business with any other EEA countries and provide its services across the EU without having to request further authorization in that country. In the other words, it is kind of a passport that firms get to do business freely across the Europe(Market.Business.News 2017)

In this empirical study, I assume that the market is efficient. Then I use event study methodology to study behavior of corporate stocks regarding Brexit.

2.3. Event study

Today the event study methodology is one of the most applicable tools in econometrics, accounting and finance. This approach is a very important statistical technique for analyzing the impact of corporate actions such as stock split and earnings announcement.

Tracing the history of the event study methodology, James Dolley (1933) was the first person who used event study method to examine the returns effect of stock splits. Later, event study was employed by many researchers like Cannella Jr and Hambrick (1986), MacKinlay (1997),Chaney, Devinney, and Winer (1991), Kothari and Warner (2006), and Jeong and Lu (2008). The method of event study, which is used in this thesis was first introduced by Ball & Brown (1968) and Fama et al. (1969).

Event study methodology studies how corporate stocks and bond prices (returns) behave around specific events. In other words, it examines the effect of particular types of events on the returns within a given financial market, mostly performed on common stocks. The event study can be applied in different markets such as preferred stocks, bonds, options, commodities and currencies. Also it has been implemented to a variety of firm-specific and economy wide events like mergers & acquisitions, issues of new debt or equity, and earning announcement (MacKinlay 1997).

There are few applications of event study methodology in foreign exchange markets. Sheffrin & Russell (1984) investigates the impacts of North Sea Oil discoveries on the value of sterling by looking at foreign exchange market reactions to announcement of oil discoveries. According to the authors, there is no evidence which shows that oil discoveries led to an appreciation of sterling. In another study, Cosset & Rianderie (1985) analyzes how the announcement of changes in the business environment of a country affects the currency market. The results show that the news of political risk includes important information about a country's investment climate and leads to the variation in the country's exchange rate.

Examining the stock market behavior was objects of many researches. Lamasigi (2002) studied the impact of presidential election in Indonesia Stock Market and found a huge impact. Lim, Brooks, & Hinich (2008) documented that important political events like general elections have a short-term impacts on stock markets. Sathyanarayana & Gargesha (2016) explored the effect of Brexit referendum on the Indian Stock Market and they found that there is a significant impact of Brexit referendum on Sensex and Nifty fifty indices on the event day.

Estimating the event's impact requires a measure of the abnormal return, which is defined as the actual return of the security minus the normal return. For calculating the normal return of the stock, some models are used which is described below. (See section 4.2 to find details about the structure of the event study)

2.3.1. Models for measuring normal performance

There are some approaches, which are available to calculate the normal return of a given security. Binder (1998) presents a comprehensive review of event study methodology. He provides five models: mean-adjusted, market adjusted, market model, one factor normal return estimate (like CAPM), and multifactor normal return estimate (like APT). MacKinlay (1997) classifies these approaches into two categories, statistical and economic. In the statistical group, models do not depend on the economic arguments and the behavior of asset returns is important. On the contrary, models in the economic group (CAPM & APT) depend on assumptions relates to investor's behavior and do not rely on statistical assumptions. In the empirical research the statistical assumptions should be added to the model when the economic models are applied. According to MacKinlay (1997), the potential advantage of economic models are that they give more precise measures of the normal return by using economic restrictions.
Previous studies offer different opinions on choosing best model for conducting an event study. Brown & Warner (1980, 1985) show that simpler models like Constant Mean Model give better result than more sophisticated ones, while MacKinlay (1997) suggests that economic models give more precise normal return.

Most of the studies imply that market model and the CAPM model would generate similar normal returns. But the market model is mostly preferred since it does not impose any restrictions while CAPM does; for example, intercept equals to risk free rate. Because of this additional restriction the variance of the error term in the CAPM model is larger than in the market model. This larger variance (standard deviation) of the error terms is used to construct the test statistics, so a larger error variance leads to a less powerful test. Therefore, market model is more preferred than CAPM. Cable & Holland (1999) analyze different models to get an insight on choosing the best specification model. Their results indicate that in the 21 cases market model is valid versus CAPM, which is valid in only 12 cases. So the market model performs better than CAPM and all in all, it outperforming the other model.
Other researchers who take a stand for market model in their study are Sorokina, Booth, & Thornton (2013). They state that although some models perform as well as the market model, this model remains the most commonly used approach. MacKinlay et al. (1997) believe that the market model represents a potential improvement over the constant-mean-return model. If a portion of the return that is related to variation in the market's return is removed, the variance of the abnormal return is reduced. It leads to increase the ability to detect the event effects. Therefore, the benefit of using the market model depends on the R-squared of the market model regression.

The important point here is although the market model is the most popular model for measuring normal performance; I cannot use it since I study a single event (Brexit), which may affect the market index. So in the current study, I need to choose another model that be close to the market model and be fit for my analysis, which is mean adjusted model.
Mean adjusted model in comparison with the market model is slightly simpler approach since one rather than two parameters are estimated and market returns are not required. Furthermore, by using the mean adjusted model, the abnormal returns are calculated in "one step" instead of two, meaning that when the market model is used, parameters are estimated in the first step and abnormal returns are calculated in the second step during the event period. But when mean adjusted model is used no statistical parameters need to be calculated (Binder 1998). I will use mean adjusted model to calculate the abnormal returns of the financial markets to study if Brexit was a surprise for this market or not.

2.4. Historical volatility and ARCH/GARCH effect

According to Raja and Selvam (2011), financial market volatility is an important indicator which shows the dynamic fluctuations in stock prices. Studying the volatility in stock market is important for determining the cost of capital and for assessing the investment since volatility is synonymous with risk (Premaratne and Balasubramanyan 2003).

I use the ARCH/GARCH models for studying the financial market volatility. These models are useful in describing time variation in conditional variance, which explains, at least partially, the fat-tail phenomenon in returns. I want to see if volatility clustering has evidence regarding that Brexit came as a surprise for financial markets.

Stock market returns show volatility clustering, meaning that large changes in the returns tend to be followed by large changes and small changes by small changes (Mandelbrot 1963). Volatility clusters are typical for financial prices, exchange rates, return series, and inflation rates. ARCH and GARCH methods are used to model these high frequency observations or volatility clustering.

Engle (1982) introduces The Autoregressive Conditional Heteroscedasticity Models (ARCH) to model volatility. After that, many studies on investment and financial market volatility have used ARCH models or studied the existence of ARCH effects. For example, Hsieh (1984), Engle (1990), and Engle and Mustafa (1992) used this models for various types of markets. Diebold (1988) and Drost and Nijman (1993) have showed that ARCH effects are highly significant with daily and weekly data and the effects actually weaken when frequency of the data decreases.
Bollerslev (1986) generalized the ARCH model by adding lagged values of the conditional variance. The GARCH model provides a wider range of behavior like a more persistent

volatility. The benefit of GARCH model is that a high order ARCH model may have a more parsimonious GARCH representation, which is much easier to identify and estimate.

There are couples of studies, which investigates volatility of stock returns and estimating the ARCH/GARCH effect on the stock markets in the period around the Brexit event; for example, Angabini and Wasiuzzaman (2011) investigated the change in volatility of the Malaysian stock market, with respect to the global financial crisis of 2007/2008. They used symmetric and asymmetric GARCH models and their found out that there was a significant increase in volatility and leverage effect due to the financial crisis. Sathyanarayana and Gargesha (2016) studied the historical volatility by calculating standard deviation of the abnormal returns of the India stock market. Another study was conducted by Raddant (2016) who investigated the response of European stock market to the Brexit. In order to analyze how far the volatility in different markets has changed after the Brexit vote he estimated a univarite GARCH model for some chosen European indices and he found out that although there is an increase in volatility in all market right after the Brexit vote, volatility has dropped towards pre-vote levels within three weeks.

The literature study shows that there is no any specific study regarding the effects of Brexit on the currency and stock markets of the UK and European union by using event study methodology. In the current study I will use this methodology to investigate the implications of Brexit on the FOREX and stock markets in the UK and EU and I will answer to the question that if the Brexit referendum was a surprise for these two markets or not. Furthermore, I will study how volatility changes regarding Brexit event.

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3. Theory and hypothesis

In the current study I investigate if Brexit was a surprise, using evidence from financial markets in the UK and EU. In this part I present briefly what is the reason behind choosing the variables for conducting this study?

3.1. UK and EU

Britain is a country, which decided to exit the European Union, which is one of the important trading partners for the UK. The relationship between the UK's trade and European Union is considerable. The EU is a destination for around half of the UK's goods exports (Office for national statistics 2015). If services' exports are accounted too, the share will be little bit lower but it is still considerable, around 45%. By taking into consideration that the total British export is 30.5% of its output, it means that the value of the goods and services exports to the EU is 14% of overall United Kingdom economy. UK trades with more than 60 countries freely since they have a free trade agreement with EU, meaning that 64% of the UK's trade happens because it is a member of the European Union (Zandi 2012), Figure 3-1.

Being a member of the EU has some benefits for the UK. The trade costs between the UK and EU have been decreased by the reduction of non-tariff barriers. Therefore the UK consumers will receive the goods and services, in some specific areas, cheaper and it makes the UK businesses to export more (Dhingra et al. 2016). On the contrary, by leaving the EU, Britain can independently pursue international trade deals with the USA, China, and India. In addition, it can import much cheaper agricultural goods from other countries outside the EU.

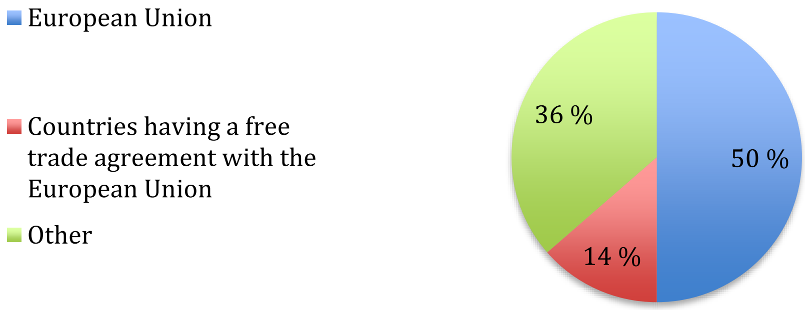

Figure 3-1. British goods export values by destination (% of total 2014)

Now the UK has decided to exit the union and the future relationship between these two partners are not clear yet. The expectations of investors and market participants reveal themselves in the British and European stock prices. Therefore, I use the evidence from stock and currency markets in the UK and EU to investigate if Brexit was surprise or not.

3.2. How stock market indices have been chosen for this study?

The Financial Times Stock Exchange 100 Index, also called the FTSE100 index is a share index of the largest 100 qualifying UK companies listed on the London Stock Exchange with the highest market capitalization[7]. These companies represent 81% of the entire market capitalization of the London Stock Exchange and each of them represents a specific economic sector of the UK; such as financial services, mining, oil & gas production, travel & leisure, and food producers. So, I choose this stock market for my study.
By the same reason, FTSE EUROTOP 100, which includes 100 most highly capitalized blue chip companies in Europe, has been chosen as a European Union's market index.

I need to use a market index for calculating the abnormal returns by the market model and for defining the mean equation in the GARCH model. According to MacKinlay (1997), in the empirical studies, a broad-based stock index is used for the market portfolio. Some of the most popular ones are the S&P500 index, the CRSP value-weighted index, and the CRSP equal-weighted index. In the current study I am looking for a market index, which not only should be a broad-based, but also should consist of European companies. For this purpose, the Global Dow has been chosen. This index includes the leading companies from around the world[8] in all industries.

3.3. Hypothesis testing

7 See appendix B

8 See appendix A for finding the country allocation in the Global Dow.

Here I define all hypotheses related to the currency and stock markets and historical volatility:

1. *For the currency market*

First hypothesis:

H_0: Brexit has no effect on the currency market on the event day or Brexit is not a surprise for this market. $AB_{\tau=0} = 0$
H_1: Brexit affects the currency market on the event day (negatively) and it is a surprise for this market. $AB_{\tau=0} < 0$

Second hypothesis:

H_0: Effect of Brexit on the pound sterling is less than euro at the event day.
H_1: Effect of Brexit on the pound sterling is more than euro at the event day.

2. *For the stock market*

First hypothesis:

H_0: Brexit has no effect on the stock markets on the event day or Brexit is not a surprise for this market. $AB_{\tau=0} = 0$
H_1: Brexit affects the British and European stock markets on the event day (negatively) and it is a surprise for these two indices. $AB_{\tau=0} < 0$

Second hypothesis:

H_0: Effect of Brexit on the British index is less than European index at the event day.
H_1: Effect of Brexit on the British index is more than European index at the event day.

3. *For the historical volatility*

First hypothesis:

H_0: There is no ARCH/GARCH effect on the rate of returns of the stock markets (homoscedasticity).
H_1: There is an ARCH/GARCH effect on the rate of returns of the stock markets (heteroscedasticity).

Second hypothesis:

H_0: Volatility of stock markets after the Brexit referendum is more than before the referendum.
H_1: Volatility of stock markets after the Brexit referendum is less than before the referendum.

4. Methodology

For answering the main question of this study, which is if Brexit came as a surprise or not, I have designed an empirical analysis involved two parts. In the first part, I use event study methodology to investigate how Brexit affects the financial markets in the UK and EU on the event day. In the next part, I estimate several GARCH models with dummy variables by Eviews to detect the volatility changes in the stock markets in the period before and after the Brexit to see how volatility reacts regarding the Brexit referendum.

4.1. Effects of Brexit on FOREX and stock markets

In this part, event study methodology is introduced in order to study how Brexit affected currency and corporate stocks. I will use this methodology to study the effects of Brexit on the pound sterling, euro and two chosen British and European indices in the event window. Calculating the abnormal returns for all the mentioned variables in the event window help me to see the trend of changing the value of the exchange rates and rate of returns in the currency and stock markets, respectively. Conducting an event study requires to go through some steps such as defining the event of interest, identifying the estimation and event window, choosing model for calculating abnormal returns, and calculating abnormal and cumulative abnormal returns.
Following, I discuss the event study structure in details.

4.2. Event study structure

4.2.1. Define the event of interest

For conducting an event study the initial task is to define the event of interest. In the current study, Brexit vote is chosen as the event of interest. It is a unique event in the modern economic history, which took place on 23rd June 2016 and the result came in late

on the same day. Since markets react to the Brexit on the next trading day, I have selected 24th of June as the event day (day 0).
There are a couple of studies, which investigate the effects of Brexit by help of the event study methodology and both of them, Ramiah, Pham, and Moosa (2017) and Bonchev (2017), also chose June 24th as an event day.

4.2.2. Identify the estimation and event window

Next step is identifying the length of the period over which the price of security involves with this event, the event window.

Assume $\tau = 0$ is the event date so according to the Figure 4-1, $L_1 = T_1 - T_0$ and $L_2 = T_2 - T_1$ are the length of the estimation window and the event window, respectively. The estimation window is the period of trading days, before the event date, which is applied to estimate the expected return for each currency/stock.
The event window is the period of the trading days, which the abnormal returns are calculated over them. According to MacKinlay et al. (1997), the abnormal return over the event window is interpreted as a measure of the impact of the event on the value of the corporate stock. $L_3 = T_3 - T_2$ is the length of the post-event window, which is shown in the Figure 4-1.

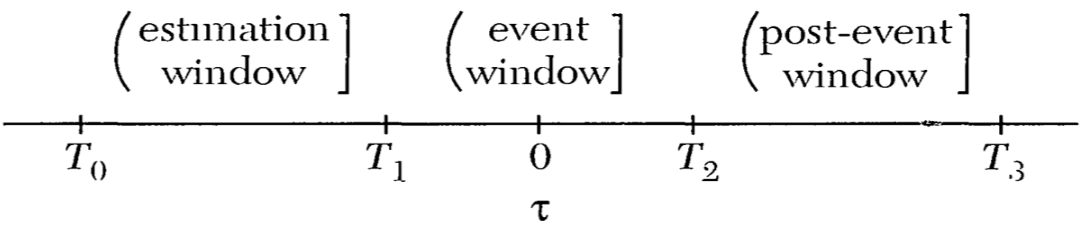

Figure 4-1 Time line for an event study

The trading days prior to the event day, which are part of the event window are not part of the estimation window, meaning that the estimation window and event window do not overlap.

Although the estimation window determines the amount of asset price history needed for the event study, previous literatures do not suggest unanimously a specific length for it. Cox & Peterson (1994) suggests 100 days for estimation window, while Carow & Kane (2002) and MacKinlay (1997) use 200 days and 250 days, respectively. It is common that the estimation window is usually around 250 days (average trading year), which ends to either 10 or 20 days prior to the event day (Benninga 1978). By taking all mentioned theory into consideration, I choose the estimation window of 200 days for the current study.

In terms of the event window, MacKinlay et al.(1997) suggested (-1, +1) event window while Kanas (2005) uses (-3,+3) length for the event window for testing pure contagion effects in international banking. Event studies on mergers and acquisition (M&A) often use 40 trading days prior to the M&A announcement. For studying the effects of Brexit on the currency and stock markets, I choose the event window includes 11 days (-5, +5), five days before and after the Brexit referendum.

4.2.3. Choosing model for calculating abnormal returns

In the literature review five models for measuring the normal performance are presented in details. By concluding all points in that section, mean adjusted model has been chosen for conducting an event study. However, some of the calculations in the stock market will be presented by both mean adjusted model and market model to confirm my claim regarding that in the current study market model will make a bias in the calculations.

Below these two models for measuring normal performance are described.

I. *Mean Adjusted Return Model*

For calculating the mean adjusted return, the average return for stock i during the estimation period, $\bar{R}_i$, should be subtracted from the stock's return during the event period, $\tilde{R}_{i,t}$. This method does not control for the risk of the stock or the return on the market portfolio during the event period (Binder 1998).

For any security/currency i, the mean adjusted return is:

$$A_{i,t} = \tilde{R}_{i,t} - \bar{R}_i,$$

$$\bar{R}_i = \frac{1}{200} \sum_{t=-220}^{-21} \tilde{R}_{i,t}$$

II. *Market model*

Market model is a statistical model, which shows a linear relationship between the return of any given security to the return of the market portfolio. In this model the joint normality of asset returns is assumed. For any security i the market model is:

$$R_{it} = \alpha_i + \beta_i R_{mt} + \epsilon_{it}$$
$$E[\epsilon_{it}] = 0$$
$$VAR[\epsilon_{it}] = \sigma^2_{\epsilon_i},$$

Where, R_{it} is the daily exchange rate of the currency compare to the numeraire in the logarithmic form, R_{mt} is the return on market portfolio, ϵ_{it} is Zero mean disturbance term, and α_i and β_i are parameters of the market model which are estimated by the OLS regression:

$$\hat{\beta}_i = \frac{\sum_{\tau=T_0+1}^{T_1}(R_{it} - \hat{\mu}_i)(R_{mt} - \hat{\mu}_m)}{\sum_{\tau=T_0+1}^{T_1}(R_{mt} - \hat{\mu}_m)^2}$$

$$\hat{\alpha}_i = \hat{\mu}_i - \hat{\beta}_i\hat{\mu}_m$$

$$\hat{\sigma}_{\epsilon_i}^2 = \frac{1}{L_1 - 2}\sum_{\tau=T_0+1}^{T_1}(R_{it} - \hat{\alpha}_i - \hat{\beta}_i R_{mt})^2,$$

where, $\hat{\mu}_i = \frac{1}{L_1}\sum_{\tau=T_0+1}^{T_1} R_{it}$ *and* $\hat{\mu}_m = \frac{1}{L_1}\sum_{\tau=T_0+1}^{T_1} R_{mt}$

4.2.4. Abnormal Returns

To conduct an event study, a measure of abnormal return is required. The Abnormal return is the actual return of the security minus the normal return of the firm. The normal return is defined as the return that might be expected if the event did not take place. For firm i and event date t the abnormal return is:

$$AR_{it} = R_{it} - E[R_{it}|X_t],$$

where, AR_{it} is the abnormal return, R_{it} is the actual return, $E[R_{it}|X_t]$ is the expected return, and X_t is the conditioning information for the normal return model. In this formula, $E[R_{it}|X_t]$ is estimated by the mean adjusted model, which is described in the previous part (MacKinlay et al. 1997).

4.2.5. Aggregation of abnormal returns

Aggregation is used to get rid of some potential problems, which may rise up when using abnormal returns. Aggregation can be performed through two dimensions, through time (in the event window) and across securities. I use aggregation through time for obtaining the overall effects of Brexit (as a single event) on the financial markets in the event window[9].

[9]If the number of the events/firms is more than one, AAR and CAAR can be estimated by the following formulas:

$$AAR_t = \frac{1}{N}\sum_{i=1}^{N} AR_{it} \;\&\; CAAR_t(\tau_1, \tau_2) = \sum_{t=\tau_1}^{t=\tau_2} AAR_{it}$$

Assume $CAR_i(\tau_1, \tau_2)$ is the cumulative abnormal return for security i from τ_1 to τ_2. Then the formula is:

$$CAR_i(\tau_1, \tau_2) = \sum_{\tau=\tau_1}^{\tau=\tau_2} AR_{i\tau}$$

4.2.1. Test-Statistics

The test-statistics provide a mechanism for making quantitative decision about a process. The obtained abnormal returns and cumulative abnormal returns should be tested for significance. The most widely used parametric test is student t-test. In the current analysis, I use t-test to find if AR and CAR have significance performance.

$$T_{AR_t} = \frac{AR_t}{S_{AR}},$$

where, T_{AR_t} is the t-statistic, AR_t is the abnormal return for time t, and S_{AR} is the standard deviation of abnormal returns in the estimation window,

$$S_{AR}^2 = \frac{1}{M-2}\sum_{t=\tau_0}^{\tau_1}(AR_t^2),$$

where, M is the number of observations.

In terms of t statistics for cumulative abnormal return, the formula is:

$$T_{CAR} = \frac{CAR}{S_{CAR}},$$

where, T_{CAR} is the CAR t-statistic and CAR is the cumulative abnormal return, and S_{CAR} is the standard deviation of cumulative abnormal returns in the estimation window.

$$S_{CAR}^2 = L_2 S_{AR}^2,$$

where, L_2 is the length of the estimation window ($L_2 = T_2 - T_1$), see Figure 4-1.

4.3. Historical volatility and ARCH/GARCH effect

The basic ARCH (q) model has two equations, a conditional mean equation and a conditional variance equation. Since the variance is a function of the mean, both equations must be estimated simultaneously. It is very important to get the mean equation correctly specified before estimating the ARCH model. The mean equation estimates the conditional mean of the variable and typically it is modeled as an AR process. This AR might be combined with other explanatory variables. The variance equation estimates the autoregressive variance process. Both equations combine a system, which is estimated using maximum likelihood. The ARCH model shows a type of

moving average in the variance process. Like for AR and MA model, the mean and variance equation can be used the duality to find the simpler specification by combining the two process into an ARMA type of process.
A simple ARCH (1) with an autoregressive first order mean and first order variance equation is:

$$y_t = a_0 + a_1 y_{t-1} + \varepsilon_t,$$

where, $\varepsilon \sim D(0,\ h_t)$ and,

$$h_t = \omega + \alpha_1 \hat{\varepsilon}_{t-1}^2$$

In a more general way, the ARCH (q) process can be rewrite as, the mean process:

$$y_t = E\{y_t | I_t\} + \varepsilon_t,$$

where, $\varepsilon \sim D\ (0,\ h_t)$ and, the variance process:

$$h_t = \omega + \sum_{i=1}^{q} \alpha_i \varepsilon_{t-i}^2$$

The residual process can be also written as

$$\varepsilon_t = v_t h_t^{1/2},$$

where, $v_t | I_{t-1}$ is $v_t \sim N\ (0,1)$.

The Generalized Autoregressive Conditional Heteroscedasticity model of order q, p GARCH (q, p) is:

$$h_t = \omega + \sum_{i=1}^{q} \alpha_i \varepsilon_{t-i}^2 + \sum_{i=1}^{p} \beta_i h_{t-i},$$

here the value of α and β should be greater than zero since standard deviation and variance cannot be negative and value of betas should be less than one in order to have a stationary process.

If there are no ARCH and GARCH effects, the sum of the coefficients should be zero, $\sum_{i=1}^{q} \alpha_i \varepsilon_{t-i}^2 + \sum_{i=1}^{p} \beta_i h_{t-i} = 0$. It means that the variable ω is the residual variance and $\omega = \sigma^2$.

In the current study, I use the most typical model of GARCH in empirical work, GARCH (1, 1).

4.3.1. Distribution of the error term

In the current study, two distributions of error term are introduced and used. The first one is normal distribution and the second one is student-t distribution.

1. Normal distribution

The probability density function of Z_t is given as follows:

$$F(Z_t) = \frac{1}{\sqrt{2\pi\sigma^2}} exp\left\{-\frac{1}{2}(\frac{Z_t-\mu}{\sigma})^2\right\},$$

where, μ is mean and σ is standard deviation.

2. Student-t distribution

The probability density function of Z_t is given as follows,

$$F(Z_t) = \frac{\Gamma\left(\frac{v+1}{2}\right)}{\Gamma\left(\frac{v}{2}\right)\sqrt{(v-2)\pi}}(1+\frac{Z_t^2}{v-2})^{-\frac{1}{2}(v+1)},$$

where, Γ is gamma function and v is the number of degree of freedom, $2 < v \leq \infty$.
When $v \to \infty$, the student-t distribution is nearly equals to the normal distribution. In the situation that v gets lower amount, the tail of the distribution is fatter.
For detecting the volatility before and after the Brexit, I will use both of the mentioned distributions, which are available in Eviews to estimate the GARCH model

4.3.2. Lagrange Multiplier Test

McLeod and Li (1983) presented a more formal Lagrange multiplier test for ARCH errors. The methodology involves the two following steps:

Step1: Estimate the most appropriate regression equation or ARMA model by OLS and save the squared residuals $\hat{\varepsilon}_t^2$.

Step2: Regress these squared residuals on a constant and on the q lagged values. The estimated regression should be the form of:

$$\hat{\varepsilon}_t^2 = \alpha_0 + \alpha_1\hat{\varepsilon}_{t-1}^2 + \alpha_2\hat{\varepsilon}_{t-2}^2 + \cdots + \alpha_q\hat{\varepsilon}_{t-q}^2$$

If there are no ARCH and GARCH effects, the estimated value of $\alpha_1$through α_q should be equal to zero. Under the null hypothesis of no ARCH errors and using a sample of T residuals, the best statistic TR^2 converges to a χ^2 distributions with q degrees of freedom. The null hypothesis of no ARCH effect would be rejected where TR^2 is sufficiently large. On the other hand, the null hypothesis would be accepted where TR^2 is sufficiently low. The test is available in Eviews and I use it further in the empirical section.

4.3.3. Jarque–Bera statistic

The Jarque-Bera test (Jarque et al. 1987) is a two-sided goodness-of-fit test for normality. The null hypothesis for this test is returns series are normal distribution and skewness and kurtosis are equal to zero and the alternative hypothesis is non-normality. The Jarque-Bera test statistic is :

$$JB = \frac{T}{6}\left[SK^2 - \frac{(Kurt-3)^2}{4}\right],$$

where T is the sample size. SK and $Kurt$ are, respectively, the sample skewness and kurtosis.

This test statistic can be compared with the χ^2 distributions with 2 degrees of freedom. If the calculated test statistic exceeds a critical value from the χ^2 distribution, the null hypothesis of normality is rejected. This test is available in Eviews and I will use it for testing normality of the stock market returns, see section 5.2.

5. Data

5.1. Currency market and stock market

For investigating effects of Brexit on the currency market, the British pound (GBP) and euro have been chosen for this study. The daily exchange rates of GBP/USD, GBP/euro, and euro/USD are collected for the time horizon 01/July/2015 to 29/July/2016, providing a total of 283 business days of data, which are obtained from "Investing" database[10].
In order to have the same number of observations for all exchange rates, I have removed four days in the euro/USD data set which did not exist in the GBP data set[11].

In terms of the stock markets, the sample of data used in this study is the daily closing prices of FTSE 100, FTSE EUROTOP100, DAX, and CAC40, which are respectively the British, European, German, and French stock market indices. Data collected from 01/July/2015 to 29/July/2016, providing a total of 275 business days of data from "Investing" database.
In this part of the analysis, I calculate the abnormal returns by two normal performance models; mean adjusted model and market model. I have chosen the Global Dow index as a market index in the market model and since the unit of currency was in USD, I use the GBP/USD daily exchange rate to transfer the unit to the pound sterling.

I calculate returns as:

$$r_t = 100 * \ln(\frac{Price_t}{Price_{t-1}})$$

10 www.investing.com
11 10/07/2016, 17/07/2016, 24/07/2016, and 31/07/2016

5.2. Volatility changes and ARCH/GARCH effect

In terms of studying the volatility changes and ARCH/GARCH effect on the stock market's returns, the daily close price of FTSE100 and FTSE EUROTOP100 indices for two years from 23/June/2015 to 23/June/2017 are collected from the Investing database. The statistical software, which I use to estimate the models in this part is Eviews[12].

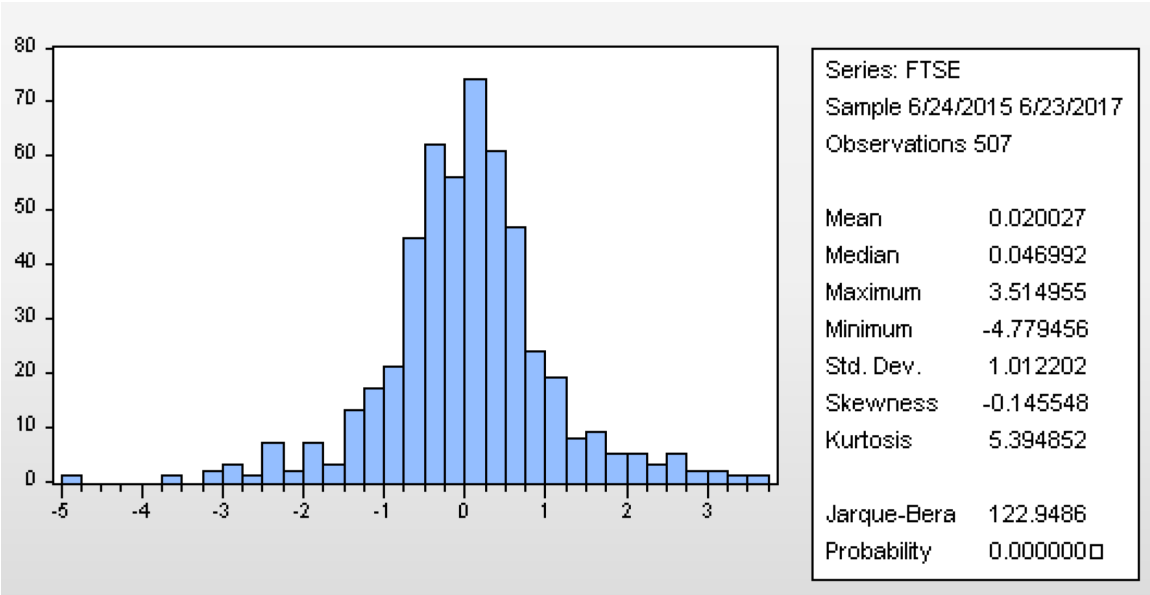

Figure 5-1. Descriptive statistics and histogram for returns of FTSE 100

Figure 5-1 shows the descriptive statistics of returns of FTSE100. According to the table, I can see that there is a large difference between the maximum and minimum returns of the index. The mean of the stock market is close to zero as is expected for a time series of returns. The standard deviation is equal to one and it means that if the deviation of some returns from the mean is more than one, there is volatility in the data. In the Figure 5-3, I can see that there are many returns, which are above the standard deviation, so it indicates that data does not have constant volatility. The skewness is -0.145, indicating an asymmetric tail, which exceeds more towards negative values rather than positive ones and presents the non-symmetric returns for the index. The kurtosis of returns is larger than three and it indicates that returns are leptokurtic and have a fat-tailed distribution. The next row shows the results for Jarque and Bera (1980) test for normality and it confirms the results based on skewness and kurtosis regarding non-normality in the time series and reject normality at the 1% level.

12 Available at: http://www.eviews.com/home.html

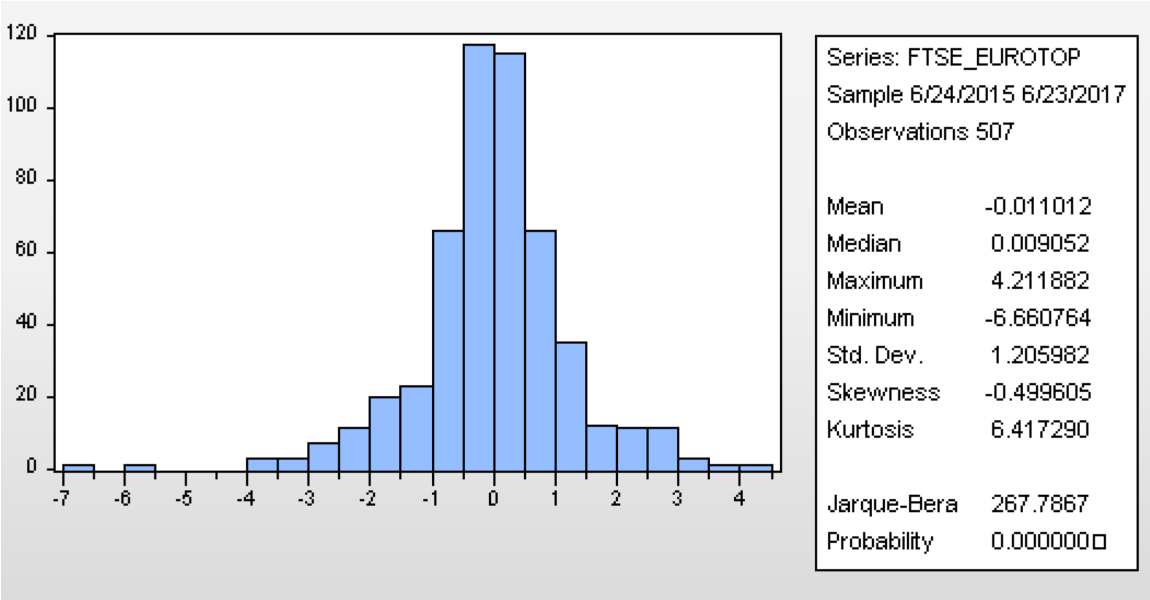

Figure 5-2. Descriptive statistics and histogram for returns of FTSE EUROTOP100

Figure 5-2 shows the descriptive statistics for returns of FTSE EUROTOP100. The interpretation of numbers is the same as FTSE100. In this case the hypothesis of normality distribution is rejected as well.

According to Figure 5-3 and Figure 5-4, there is a high volatility in the rate of return of both stock indices. Both figures show that the volatility changes over time and it tends to cluster with periods of low volatility and periods of high volatility. So it indicates that the homoscedasticity assumption (constant variance) is no longer hold for the current data set. I perform more tests regarding existence of heteroscedasticity in returns in the section 6.3.

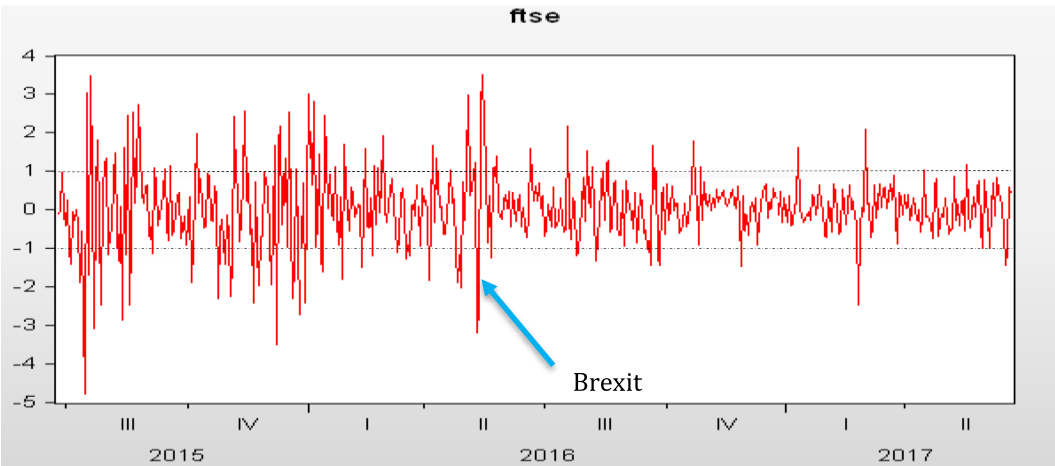

Figure 5-3. . Volatility clustering of daily return in the FTSE100 from June 2015 to June 2017[13]

***Dashed lines show the amount of standard deviation.**

13 Note that the x-axis represents the year and the y-axis represents the returns of the FTSE 100

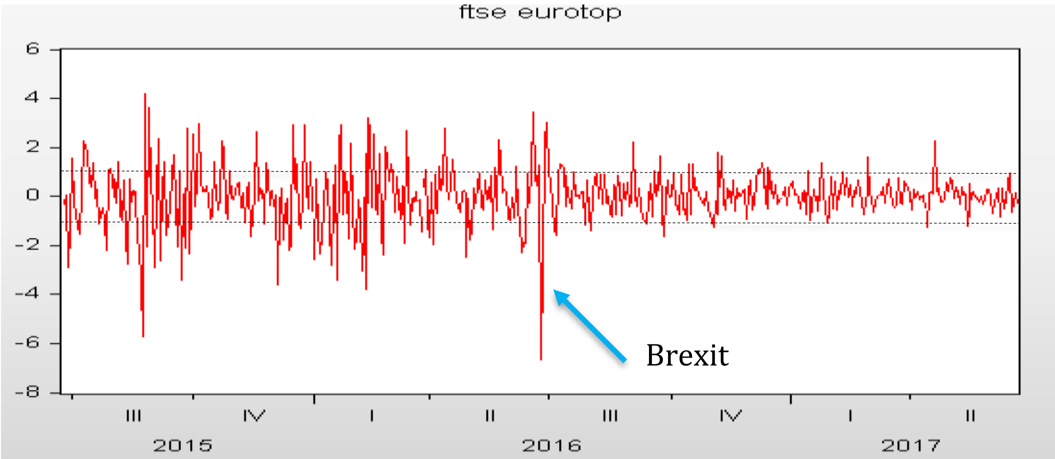

Figure 5-4. Volatility clustering of daily return in the FTSE EUROTOP100 from July 2015 to July 2017

6. Empirical results

6.1. Effects of Brexit on the currency market[14]

So far, the event study methodology, abnormal returns formula, and models for measuring normal performance have been discussed. Now I want to investigate how exiting the UK from the European Union affects the currency market, using evidence from the daily exchange rates of pound sterling and euro. In other words, I will answer to the question that *if Brexit was a surprise for the currency market or not.* For this purpose, United States dollar (USD) is given as a numeraire for GBP and euro. Then the abnormal returns for these currencies will be calculated. Furthermore, for studying how pound sterling changes compare to the euro, GBP/euro exchange rate is taken into consideration. As it was mentioned in section 4.2.3, mean adjusted model is used for calculating the abnormal returns.

Table 6-1. The abnormal returns and T-values for GBP/USD in the event window

	GBP/USD	
T	**Date**	**Abnormal return**
-5	17.06.2016	1.12% (2.03)**
-4	20.06.2016	2.38% (4.32)***
-3	21.06.2016	-0.32% (-0.58)
-2	22.06.2016	0.45% (0.81)
-1	23.06.2016	1.19% (2.16)**
0	24.06.2016	-8.37% (-15.20)***
1	27.06.2016	-3.39% (-6.16)***
2	28.06.2016	0.96% (1.74)*
3	29.06.2016	0.66% (1.20)
4	30.06.2016	-0.827% (-1.50)
5	01.07.2016	-0.33% (-0.60)

Where with *** is denoted significance at 1%, with **- at 5%, and with *- at 10%.

14 All calculations in this part are available in appendix C

According to Table 6-1, in case of studying the abnormal returns of the GBP, the highest abnormal return recorded on the event day with the value of -8.37% with a t-value of -15.20 (highly significant at 1%, 5%, and 10% significance level), means that Brexit has a strong negative impact on the GBP on the event day. After the event day, the highest abnormal return is recorded on day 1, with a value of -3.39%, which is negative and statistically significant from zero with a good margin.

In the event period of -5 to +5 days, the abnormal returns on days -5, -4, -1, 0, 1, and, 2 are significantly different from zero. Before the Brexit referendum, the majority of abnormal returns are positive and at the event day the abnormal return is high and negative, indicating that Brexit was a surprise for the British currency market at the event day (see Figure 6-1). So the null hypothesis of "Brexit has no effect on the GBP/USD at the event day" is rejected.

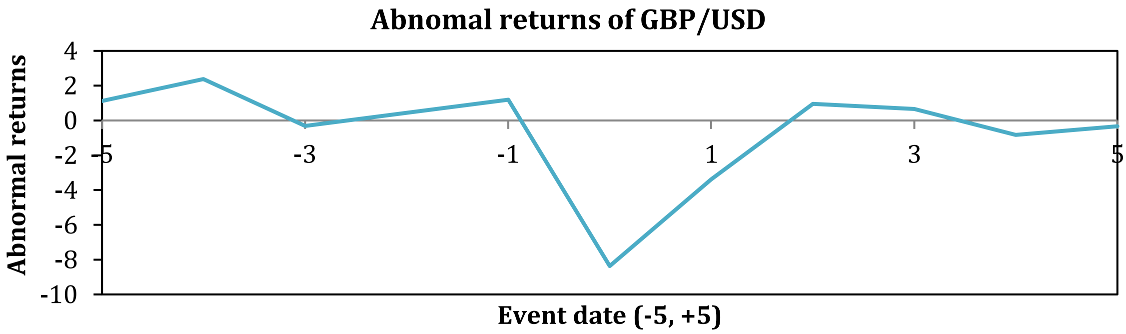

Figure 6-1. Abnormal returns of GBP/USD in the (-5, +5) event window

In case of euro, the highest abnormal return recorded on the event day with the value of -2.42% with the t-value of -3.82% (statistically significant at 1%, 5% and, 10% level), meaning that Brexit referendum has a negative significant effect on the euro on the event day (the null hypothesis is rejected), see Table 6-2.

Although other abnormal returns in the event window are not statistically significant, I can see that on 4 days before the event day AB's are positive and on the days 0, 1, and 4 AB's are negative, meaning that Brexit was a surprise for euro on the event day, see Figure 6-2.

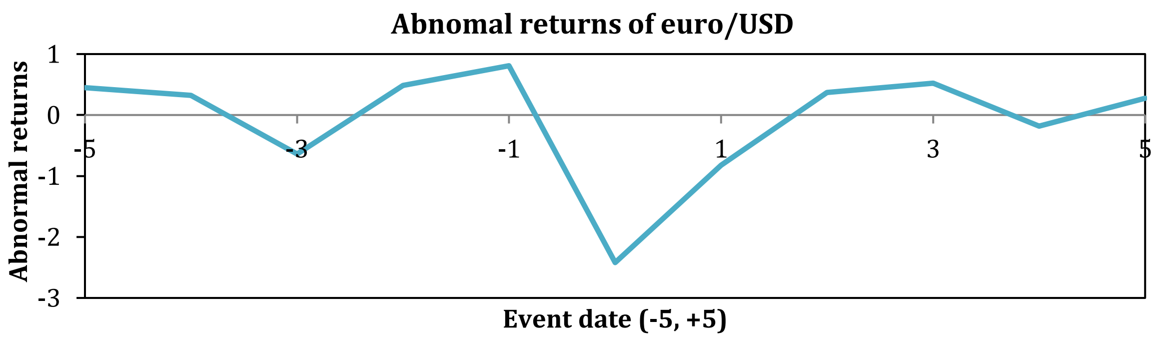

Figure 6-2. Abnormal returns of euro/USD in the (-5, +5) event window

Table 6-2. The abnormal returns and T-values for euro/USD in the event window

	EUR/USD	
T	**Date**	**Abnormal return**
-5	17.06.2016	0.45% (0.71)
-4	20.06.2016	0.32% (0.51)
-3	21.06.2016	-0.64% (-1.01)
-2	22.06.2016	0.48% (0.78)
-1	23.06.2016	0.81% (1.28)
0	24.06.2016	-2.42% (-3.82)***
1	27.06.2016	-0.82% (-1.30)
2	28.06.2016	0.37% (0.58)
3	29.06.2016	0.52% (0.82)
4	30.06.2016	-0.18% (-0.29)
5	01.07.2016	0.28% (0.44)

Comparing results in Table 6-1 and Table 6-2 indicates that effects of Brexit on the GBP are more severe than euro especially on the event day. The reason might be that pound sterling is only used in the UK, which decides to exit the European Union but euro is a currency, which is used in 19 out of 28 EU countries. One of the benefits of using a common currency is that it eliminates the fluctuations of exchange rate. This characteristic makes the euro stronger and more stable in confront the events than a single currency like pound sterling.

For getting the better insight about how return of GBP changes compare to the euro, I calculate the abnormal return for GBP/euro exchange rate. Table 6-3 indicates that GBP compares to euro is affected negatively by the Brexit and at the event day the abnormal return is -5.96%, which is less than calculated abnormal return for GBP/USD which was -8.37%. The reason is that euro is impacted by the Brexit itself and this currency is already weakened by the event.

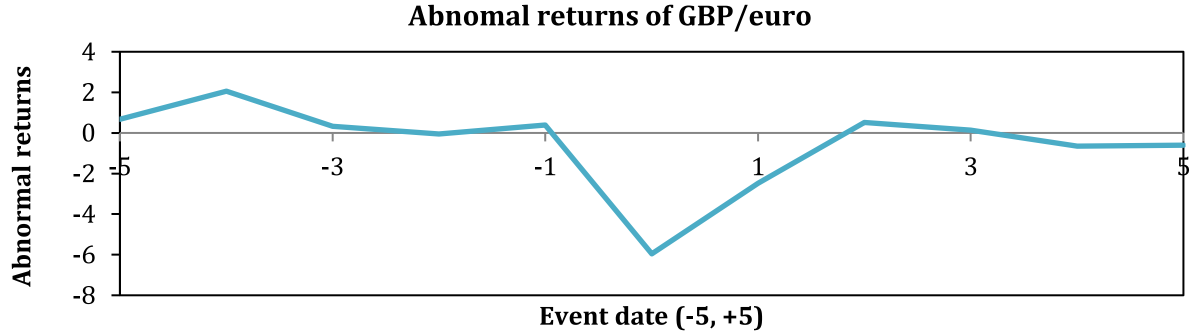

Figure 6-3. Abnormal returns of GBP/euro in the (-5, +5) event window

Table 6-3. The abnormal returns and T-values for GBP/euro exchange rate

	GBP/Euro	
T	**Date**	**Abnormal return**
-5	17.06.2016	0.67% (1.10)
-4	20.06.2016	2.06% (3.37)***
-3	21.06.2016	0.33% (0.54)
-2	22.06.2016	-0.05% (-0.08)
-1	23.06.2016	0.39% (0.64)
0	24.06.2016	-5.96% (-9.75)***
1	27.06.2016	-2.48% (-4.06)***
2	28.06.2016	0.51% (0.83)
3	29.06.2016	0.14% (0.22)
4	30.06.2016	-0.64% (-1.06)
5	01.07.2016	-0.60% (-0.99)

For measuring the overall effect of the Brexit referendum on GBP and euro in the event window, the cumulative abnormal returns through time are calculated. Abnormal return calculations provide a measure of the stock's performance at a specific time but it does not consider fluctuations that naturally occur over the period. For considering these normal variations, the cumulative abnormal return calculation is adopted. For this purpose, CAR (-5, +5), CAR (-3, +3), CAR (-3, +5), and CAR (0, +5) are defined to estimate.

Table 6-4. The cumulative abnormal returns for 4 different event windows for both currencies

Date	GBP/USD	Euro/USD	GBP/Euro
CAR (-5, +5)	-6.48% (-2.43)**	-0.83% (-0.404)	-5.64% (-3.09)***
CAR (-3, +3)	-8.82% (-4.14)***	-1.70% (-1.035)	-7.12% (-4.89)***
CAR (-3, +5)	-9.98% (-4.13)***	-1.61% (-0.865)	-8.38% (-5.07)***
CAR (0, +5)	-11.30% (-5.73)***	-2.26% (-1.49)	-9.05% (-6.07)***

Table 6-4 shows that the overall effect of Brexit referendum on the GBP in the all given period is negative and significant and the largest impact is for period after the Brexit (0, +5). According to the table, effect of Brexit on the GBP compare to the USD is more than GBP compare to the euro in the all defined windows and both are much more than effects of Brexit on euro.
The negative abnormal returns of all exchange rates show that Brexit had a negative impact on the currency market on the all defined event windows. However, this impact is not significant for euro.

So far effects of Brexit on the pound sterling and euro was studied. The result of calculating the abnormal returns indicate that Brexit referendum has a negative impact on the pound sterling and euro on the event day and it was a surprise for currency market. Furthermore, the effect of Brexit on the GBP is much higher than euro. So both null hypothesis, which are defined in section 3.3 are rejected and the alternative hypothesis are accepted.

6.2. Effects of Brexit on the stock markets

In this part, I study if Brexit came as a surprise for stock markets in the UK and EU, using evidence from daily stock prices of FTSE100 (British stock market index) and FTSE EUROTOP100 (European stock market index). The same as currency market, the abnormal returns for these two chosen market indices are calculated in the (-5, +5) event window.
In the section 4.2.3 I have described why I choose mean adjusted model for calculating the abnormal returns. For proofing my claim mathematically, in this section, I present the results calculated by both market model and mean-adjusted model and compare them with each other.
According to Table 6-5, calculating the abnormal returns for the FTSE 100 shows that Brexit has a negative impact on this index on the event day. The highest negative abnormal returns recorded on the event day and day (+1), respectively and both are statistically significant at 1%, 5%, and 10% significance levels. Furthermore, in the period before the Brexit all the abnormal returns are positive, therefore it confirms that Brexit was a surprise for British index at the event day.

Table 6-5. The abnormal returns and T-values for FTSE100 in the event window

FTSE100			
T	**Date**	**Abnormal returns (calculated by Market Model)**	**Abnormal returns (calculated by Mean Adjusted Model)**
-5	17.06.2016	1.87% (2.46)**	1.22% (1.60)
-4	20.06.2016	3.85% (5.07)***	3.03% (3.99)***
-3	21.06.2016	-0.16% (-0.22)	0.40% (0.52)
-2	22.06.2016	0.60% (0.79)	0.59% (0.78)
-1	23.06.2016	0.77% (1.01)	1.26% (1.65)*
0	24.06.2016	-5.53% (-7.27)***	-3.16% (-4.16)***
1	27.06.2016	-3.84% (-5.06)***	-2.55% (-3.35)***
2	28.06.2016	2.27% (2.99)***	2.65% (3.48)***
3	29.06.2016	1.91% (2.51)**	3.55% (4.67)***
4	30.06.2016	0.45% (0.59)	2.28% (3.00)***
5	01.07.2016	0.24% (0.32)	1.16% (1.53)

Another point that I derive from the table is that the AB's calculated by the market model are higher than the AB's calculated by the mean adjusted model. It indicates that my statement regarding overestimation in the market model is correct.

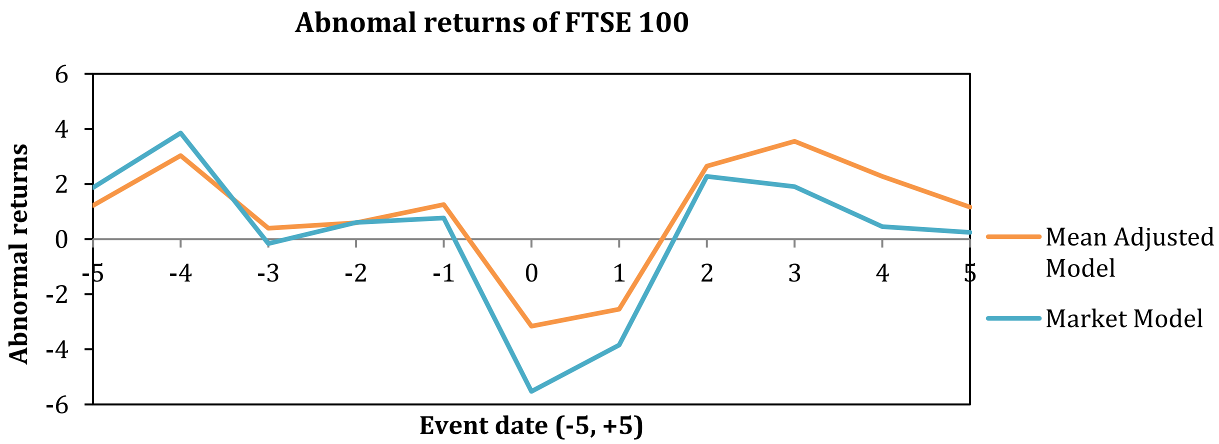

Figure 6-4. Abnormal returns of FTSE100 in the event window (-5, +5)

Figure 6-4 shows how market model overestimates the effects of Brexit on the FTSE 100 in a negative way. Furthermore, figure shows that AB's calculated by the mean adjusted model, get a negative value only in 2 days in the event window (-5, +5) and not only they are positive in days before the Brexit but also they are positive after the Brexit. It means that the index could recover itself very fast. But *why the decreasing trend in the returns of index did not continue after the Brexit referendum like in the currency market?*

There are three reasons for answering this question. First of all The bank of England governor, Mark Carney, assured that the interest rates would be cut[15], therefore, it prevented further slump of FTSE100 index after the Brexit day and helped market to recover faster in the following days. Furthermore, as mentioned in the literature review, pound sterling fell to a 31-year low against the dollar, which resulted in large earnings in dollars for some companies involved in FTSE100. The large earning for these companies also helped the index recovery in the following days after vote. The last reason could be rising in the gold price, which is a safe investment in troublesome times. As a result, the mining firms involved in the index were strengthened and positively affected the market index. On the contrary, other sectors like financial firms, banks, and house-builders were more prone to the Brexit.

In case of FTSE EUROTOP100, the highest abnormal return is recorded at the event date with the value of -9.26% and -6.58%, calculated by the market model and mean adjusted model, respectively. These numbers indicate that Brexit had a negative significant effect on the European index and it came as a surprise for it. Furthermore, the results confirm the statement that abnormal returns calculated by the mean adjusted model are less than market model, see Table 6-6.

Table 6-6. The abnormal returns and T-values for FTSE EUROTOP100 in the event window

FTSE EUROTOP 100			
T	**Date**	**Abnormal return (calculated by Market Model)**	**Abnormal return (calculated by Mean Adjusted Model)**
-5	17.06.2016	1.87% (1.92)*	1.13% (1.16)
-4	20.06.2016	4.441% (4.56)***	3.51% (3.60)***
-3	21.06.2016	0.22% (0.22)	0.86% (0.88)
-2	22.06.2016	0.55% (0.57)	0.54% (0.55)
-1	23.06.2016	0.80% (0.82)	1.36% (1.39)
0	24.06.2016	-9.26% (-9.52)***	-6.58% (-6.76)***
1	27.06.2016	-4.30% (-4.42)***	-2.83% (-2.91)***
2	28.06.2016	1.91% (1.97)**	2.34% (2.40)**
3	29.06.2016	1.22% (1.26)	3.08% (3.17)***
4	30.06.2016	-1.02% (-1.05)	1.05% (1.08)
5	01.07.2016	-0.31% (-0.32)	0.73% (0.75)

15 The Guardian, 08/07/2016

Figure 6-5 shows the implications of Brexit on the European index in the event window (-5, +5). This figure indicates again that market model overestimates the return negatively and for the higher return this overestimation is more. Furthermore, it shows that Brexit came as a surprise for stock market at the event day.

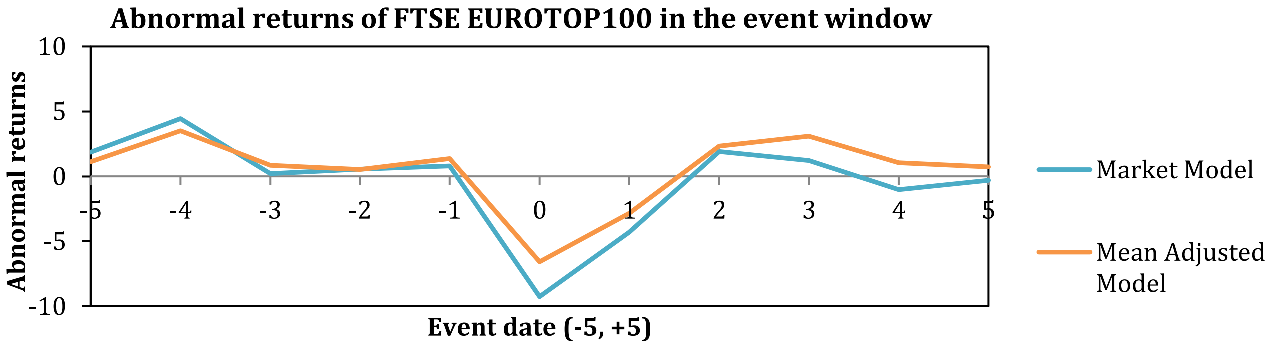

Figure 6-5. Abnormal returns of FTSE EUROTOP100 in the event window (-5, +5)

Both models indicate that Brexit referendum has a high negative impact on the FTSE EUROTOP100 on the event date, which is significantly different from zero at 1%, 5%, and 10% significance level. The interesting point here is that the abnormal return at the event day for European index (-6.58%) is more than the abnormal return in the event day in case of the FTSE100 (-3.16%). *What is the reason?*

Taking a look at the list of the companies in the FTSE EORTOP100 index (see appendix C), I have found that many British companies are in the list. So this index does not consider only European companies skipping the British ones. Since exiting the UK from the European Union has not happened completely yet, it is not possible to find a European market index which does not include the British companies. So I have concluded that the results for the European index have a little bias and overestimation. But in total, the negative effect of the Brexit on the European stock market at the event day is accepted.

Like the analysis in the currency market, in order to see the overall effect of the Brexit on the stock markets, I aggregate the abnormal returns through time.
Since FTSE EUROTOP 100 includes some British companies as well, it leads to the little bias in the calculations, so I have decided to study the German index (DAX) and French index (CAC 40) as independent European indices.

Table 6-7 shows the overall effect of Brexit vote on the FTSE100, FTSE EUROTOP100, DAX, and CAC40. By looking at the first column of table, I can see that all cumulative abnormal returns in the given periods for FTSE 100 are positive. As I mentioned before, Brexit made an immediate fall in FTSE 100 on the event day but after that, index recover itself. Therefore, the cumulative abnormal returns for all four event-windows are positive. The lowest CAR is for the event window (-3, +3), which is closer to the event day and has fewer days compare to the other event windows. So the deduction of abnormal return at the event day affects this amount.

Table 6-7. The cumulative abnormal returns for 4 different event windows for 4 chosen stock indices

Date	FTSE 100	FTSE EUROTOP100	DAX[16]	CAC40[17]
CAR (-5, +5)	10.42% (4.14)***	5.18% (1.70)*	3.00% (0.59)	3.68% (1.43)
CAR (-3, +3)	2.74% (1.37)	-1.24% (-0.48)	-3.15% (-0.77)	-2.90% (-1.41)
CAR (-3, +5)	6.18% (2.70)***	0.56% (0.19)	-1.33% (-0.29)	-0.86% (-0.38)
CAR (0, +5)	3.93% (1.30)	-2.21% (-0.93)	-4.44% (-1.17)	-3.95% (-2.19)**

The results of CAR for German and French index markets indicate that Brexit vote has a negative effect on these two indices as well. The amount of abnormal returns on the event day for DAX and CAC40 is -7% and -8.3%, respectively[18]. And the abnormal returns before the event are positive. It means that Brexit referendum was a huge surprise for these two indices and affected them negatively on the event day.

According to Goldman Sachs bank, "all of the major European indices are highly negatively correlated to the UK's risks, but Brexit hit the German and French indices worse". One of the reasons is that falling in the value of sterling makes German and French companies less competitive rather than their UK's counterparts. Furthermore, these indices suffer in terms of weaker UK domestic demand for their sales in UK (Brinded 2016).

6.3. ARCH/GARCH effect and volatility changes in the stock market returns

In this part of the thesis, I will study the ARCH/GARCH effects and show how Brexit referendum affected the volatility of the financial markets, using evidence from stock markets in the UK and EU. In other words, I seek to answer the following questions:

1. *Is there any ARCH/GARCH effect (heteroscedasticity) in the returns of the chosen indices?*
2. *How Brexit affects the volatility of the chosen indices in the period before and after the Brexit?*

In the data section, the descriptive statistics and volatility clustering of daily returns of FTSE100 and FTSE EUROTOP100 were presented. According to them, the volatility of residuals changes over time and it is not constant. The biggest change in volatility happened in the Brexit day and it shows again that the Brexit came as a surprise for the stock markets.

16 The German stock market index

17 The French stock market index

18 See the Appendix C for finding all calculation

Now following Eviews User's Guide[19] I need to go through 2 steps before estimating the volatility of daily returns by GARCH model:

Step 1: Test for stationarity

First of all, I need to check whether the data is stationary or non-stationary and it is found out by unit root test, which is conducted by Augmented Dickey-Fuller (ADF) test (Dickey and Fuller 1979). Here the null hypothesis is the presence of a unit root and the alternative hypothesis is that there is no unit root or time series are stationary.

Table 6-8. Augmented Dickey Fuller unit root test

		T-statistic	Probability
ADF test statistics (FTSE100)		-22.294	0.000
ADF test statistics (FTSE EUROTOP100)		-21.907	0.000
Test critical values:	1% level	-3.443	
	5% level	-2.867	
	10% level	-2.569	

Table 6-8 shows that for both markets the p-value of ADF is less than 0.05, means that the null hypothesis is rejected at 1% level with a critical value of -3.44. So the alternative hypothesis, which is a stationary time series, is accepted (no unit root). I conclude that both time series are stationary and the mean is constant across time.

Step 2: Test for heteroscedasticity or LM test

In the next step, I examine the residuals for the evidence of heteroscedasticity. It is an important test before applying the GARCH methodology since if there is no ARCH effect in the returns, I cannot use ARCH/GARCH model. Lagrange Multiplier (LM) test is used to test the presence of heteroscedasticity in residuals of the return series. Here the null hypothesis is that there is no ARCH effect and the alternative hypothesis is that there is an ARCH effect in the time series.

Table 6-9. Heteroscedasticity test: ARCH

FTSE100			
F-statistic	65.773	Prob. F (1, 504)	0.000
Obs*R-squared	58.411	Prob. Chi-Squared (1)	0.000
FTSE EUROTOP100			
F-statistic	22.155	Prob. F (1, 504)	0.000
Obs*R-squared	21.306	Prob. Chi-Squared (1)	0.000

19 http://www.eviews.com/help/helpintro.html#page/content%2Farch-Working_with_ARCH_Models.html%23

Table 6-9 shows a significant presence of ARCH effect with low p-value of 0.000. So, the null hypothesis of "no ARCH effect" is rejected at 1% level, which confirms the presence of ARCH effects in the residual of time series models. Therefore, the results warrant for the estimation of GARCH model.

6.3.1. Specification of GARCH (1, 1) model

The main interest of the GARCH model compared with the ARCH model is that often the GARCH (1, 1) specification is enough to capture most dynamic in volatility. Hence, the number of unknown parameters is reduced considerably.
Now, I will use GARCH (1, 1) model in order to capture the volatility in the returns of both indices for the period before and after the Brexit vote. Firstly, I will see if Brexit leads to increase/decrease in the volatility in the pre-Brexit period. So I add a dummy variable in both mean and variance equation in the GARCH model. If the dummy variable is positive it means that volatility increases before the Brexit referendum. After that I will go a step further and investigate whether volatility increase/decrease after Brexit by re-specifying the model and put dummy variable equal to one for post-Brexit period.

The mean equation of GARCH model can be an ARMA model with an explanatory variable. Different ARMA models with different lags were examined to choose the best model based on significance of coefficient, adjusted R squared, and Bayesian information criteria (Akaike & Schwarz criterion). For both series (FTSE 100 and FTSE EUROTOP100), ARMA (0, 0) or AR (0) has been chosen as the best process for modeling the conditional mean since the relevant Bayesian information criteria (BIC) was at minimum and adjusted R-squared was the highest. Also all variables in the variance equation were significantly different from zero.

Mean equation

$$FTR = C_1 + C_2GDR + e \qquad (6.1)$$

$$FTER = C_1 + C_2GDR + e \qquad (6.2)$$

where, FTR (FTSE100 Returns) and $FTER$ (FTSE EUROTOP 100 Returns) are dependent variables, GDR (Global Dow Returns) is independent variable, and e is residuals.

Variance Equation:

$$H_t = \omega + \alpha e_{t-1}^2 + \beta H_{t-1} + \delta * D \qquad (6.3)$$

Note: Residuals derived from mean equation (6.1) and (6.2) are used in making variance equation (6.3).

where, H_t is variance of the residuals (error terms) derived from equation (6.1),(it is also known as current day's variance or volatility of returns). H_{t-1} is the previous day's variance or volatility of returns or GARCH term, e_{t-1}^2 is previous periods squared residuals derived from equation (6.1) or ARCH term, and D is a dummy variable.

Before estimating GARCH model with dummy variable, I estimate the GARCH (1, 1) model for both indices to check if all coefficients in the variance equation are significant. The models are estimated for both series using Quasi-Maximum likelihood assuming the Gaussian normal distribution.

Table 6-10. Estimation of a GARCH (1, 1) model for daily log-returns for FTSE100 and FTSEEUROTOP100

Coefficients	FTSE100	FTSE EUROTOP100
ω	0.067 (3.620)***	0.015 (1.818)*
α	0.186 (4.777)***	0.131 (6.267)***
β	0.744 (14.918)***	0.861 (34.967)***
$\alpha + \beta$	0.93	0.992
Log-likelihood	-650.189	-644.561

Numbers in parenthesis indicate the t-statistic of the variables.

Table 6-10 shows that the coefficients of ARCH and GARCH parameters are significant in 1%, 5%, and 10% significance level. Furthermore, I notice that sum of α and β for the European index is close to one ($\alpha + \beta \approx 1$), so that the conditional variance is nearly integrated (Integrated GARCH model, IGARCH). I estimate the FTSE EUROTOP100 with IGARCH. In this case all the coefficients are significant again but the amount of log-likelihood is more than the GARCH model and other information criteria are approximately the same. So I have decided to continue my analysis with the normal GARCH model, see appendices E and F for finding the Eviews results for this part.

6.3.2. GARCH model with dummy variable

- ***The first model is detecting change in volatility before the Brexit:***

Dummy variable (D) = 1 if pre-Brexit period (one year before the Brexit referendum)
Otherwise = 0

For studying the volatility before the Brexit, I estimate the GARCH equation with a dummy variable equal to one for one year before Brexit and equal to zero for one year after the Brexit referendum. First I put dummy variable in both mean and variance equations but since the dummy in the mean equation is not statistically significant, it is skipped. According to Table 6-11, all variables in the variance equation are statistically significant in 5% and the coefficient of dummy variable is positive with an amount of 0.145, means that the volatility of returns in the FTSE100 increases before the Brexit.

- ***The second model is detecting change in volatility after the Brexit:***

Dummy variable (D) = 1 if post-Brexit period (one year after the Brexit referendum)

Otherwise = 0

Now I re-estimate the GARCH (1, 1) model with dummy variable equal to one for period after the Brexit. According to the Table 6-12, all parameters in the variance equation are statistically significant at 5% significance level. The sign of the coefficient of dummy variable is negative, means that volatility decreases after the Brexit with a small amount of 0.142.

Table 6-11. GARCH (1, 1) with a dummy variable equal one for pre-Brexit period in FTSE100

Variable	Coefficient	Std. Error	z-Statistic	Prob.
C	0.036383	0.033920	1.072619	0.2834
GLOBAL_DOW	0.082276	0.045547	1.806396	0.0709
Variance Equation				
C	0.080811	0.028039	2.882056	0.0040
RESID(-1)^2	0.169394	0.048466	3.495109	0.0005
GARCH(-1)	0.663887	0.095834	6.927501	0.0000
@DATE<@DATEVAL("2016/06/23")	0.145343	0.066484	2.186134	0.0288
R-squared	0.004519	Mean dependent var		0.020027
Adjusted R-squared	0.002548	S.D. dependent var		1.012202
S.E. of regression	1.010912	Akaike info criterion		2.555341
Sum squared resid	516.0811	Schwarz criterion		2.605382
Log likelihood	-641.7789	Hannan-Quinn criter.		2.574965
Durbin-Watson stat	1.961638			

Table 6-12. GARCH (1, 1) with a dummy variable equal one for post-Brexit period in FTSE100

Variable	Coefficient	Std. Error	z-Statistic	Prob.
C	0.036193	0.033942	1.066321	0.2863
GLOBAL_DOW	0.081975	0.045536	1.800222	0.0718
Variance Equation				
C	0.222489	0.089192	2.494496	0.0126
RESID(-1)^2	0.170152	0.048415	3.514418	0.0004
GARCH(-1)	0.665076	0.095123	6.991775	0.0000
@DATE>@DATEVAL("2016/06/23")	-0.142049	0.065248	-2.177067	0.0295
R-squared	0.004529	Mean dependent var		0.020027
Adjusted R-squared	0.002558	S.D. dependent var		1.012202
S.E. of regression	1.010907	Akaike info criterion		2.556265
Sum squared resid	516.0758	Schwarz criterion		2.606306
Log likelihood	-642.0131	Hannan-Quinn criter.		2.575889
Durbin-Watson stat	1.961743			

In case of FTSE EUROTOP 100, I estimate the GARCH (1, 1) model with dummy variable for both pre-Brexit and post Brexit period and the result of changing the volatility is the same as the FTSE100, see Table 6-13. All variables in the variance equation are significant from zero. Furthermore, after the Brexit the dummy variable is negative with an amount of -0.115, which is significantly different form zero, means volatility decreases and before the Brexit the volatility increases with an amount of +0.104. See appendix G for all results from the E-views.

Table 6-13. Estimation of GARCH (1, 1) with dummy variable for before and after the Brexit

FTSE EUROTOP100	Before the Brexit	After the Brexit
ω	0.032 (2.25)**	0.150 (2.41)**
α	0.10 (2.93)***	0.096 (2.79)***
β	0.811 (13.40)***	0.804 (12.22)***
Dummy variable (D)	0.104 (2.46)**	-0.115 (-2.38)**

It is not far from expectation that the result of historical volatility for these two indices is the same, since the UK is one of the important trading partners for European Union and many huge British companies are included in the FTSE EUROTOP 100, so the UK and EU have a close tie with each other in terms of trade and financial markets.

For increasing robustness of the estimation and being sure that the result is trustworthy, I estimate the model in different periods for example, 2 months before and after the Brexit, 2 weeks before and after the Brexit, and 5 days before and after the event ((-5, +5) the event window which was defined in the first part of study). The results of the new estimations are the same as the current results, meaning that volatility increases before the Brexit and decreases after the Brexit. Furthermore, I have changed the mean equation of the GARCH model by removing the explanatory variable (market index) and adding more lags in the dependent variable (trying different AR models) but the result was the same. Furthermore, Figure 5-3 and Figure 5-4 clearly indicate that the current result regarding the change in the volatility clustering is correct. My results seem to agree with the finding of Madhavi (2017).

Discussion: What is the reason behind this behavior of volatility?

Although every uncertainty may not cause volatility, uncertainty about major events can result in volatile market. For example, an investor wants to travel to the warm place for a Christmas holiday and she should choose between Spain and Portugal. The outcome, whichever it is, will not increase the volatility. Something that might create the volatility here is a “wild card” outcome, which is beyond the limited range of Spain-Portugal uncertainties, like the chance of violent street protests or a sudden popular concert. In terms of the global economy, when high volatility appears in the markets, central banks help the markets to be stable by countercyclical act (with injection of liquidity). But before major events, investors lose their trust to the central bank to be able to have policies that positively interfere with the market. As the event passes, the realization of the outcome appear to reduce the need for the risk premiums to be introduced to the market thus the implied volatility is reduced.

In the UK and Europe economy, there are many things that people are uncertain about like elections and policy changes and most of them are not a wild card however, exiting the UK from the EU is. Before the Brexit, people were uncertain about the result of the referendum and they needed more risk premium for investing in the stock markets, which led to the increase in the volatility. After announcing the result and realizing the outcome, the uncertainty of this major event decreased so investors didn't need to have a high risk premium, which made the market less volatile.

6.3.3. Residual diagnostics

Now I want to check whether these two GARCH models for before and after the Brexit vote have adequately captured the persistence in volatility and there is no ARCH effect left in the residual of models, so the ARCH-LM test is conducted again.

Table 6-14. GARCH models residual diagnostic for FTSE100

Before Brexit			
F-statistic	0.299	Prob. F (1, 504)	0.584
Obs*R-squared	0.300	Prob. Chi-Squared (1)	0.584
After Brexit			
F-statistic	0.300	Prob. F (1, 504)	0.583
Obs*R-squared	0.301	Prob. Chi-Squared (1)	0.582

Table 6-15. GARCH models residual diagnostic for FTSE EUROTOP100

Before Brexit			
F-statistic	0.010	Prob. F (1, 504)	0.918
Obs*R-squared	0.010	Prob. Chi-Squared (1)	0.917
After Brexit			
F-statistic	0.017	Prob. F (1, 504)	0.895
Obs*R-squared	0.017	Prob. Chi-Squared (1)	0.895

The results of Table 6-14 and Table 6-15 show that all p-values are more than 0.05, meaning the null hypothesis of no ARCH effect is accepted. Therefore, the GARCH models are correctly specified for both market indices.

To investigate the existence of autocorrelation in the residuals, Q-statistics test was conducted. If there is no serial correlation in the residuals, the autocorrelation and partial autocorrelation at all lags should be almost zero and all Q-statistics should be insignificant with p-value bigger than 0.05, meaning that GARCH models are successful at modeling the serial correlation in conditional means and conditional variance, see appendix H for result obtained by Eviews.

In the case of FTSE 100, all probabilities are more than 0.05, meaning that there is no autocorrelation between the residuals. But in terms of the FTSE EUROTOP100, the results based on standardized residuals and standardized squared residuals indicate that there is evidence of autocorrelation between the residuals in this index in 2 lags (number 4 and 5). However, other lags are not significant. So the GARCH models for this index are not correctly specified, see table below.

Table 6-16. Correlogram of standardize squared residuals

	FTSE100				FTSE EUROTOP 100			
No. of lags	Pre-Brexit		Post-Brexit		Pre-Brexit		Post-Brexit	
	Q-stat	Prob.	Q-stat	Prob.	Q-stat	Prob.	Q-stat	Prob.
1	0.3024	0.582	0.3040	0.581	0.0107	0.917	0.0175	0.895
2	0.5360	0.765	0.5379	0.764	1.2457	0.536	1.2323	0.540
3	1.0482	0.790	1.0500	0.789	2.6713	0.445	2.6436	0.450
4	2.3519	0.671	2.3084	0.679	11.633	0.020	11.685	0.020
5	2.4613	0.782	2.4125	0.790	11.816	0.037	11.860	0.037
6	2.8763	0.824	2.8312	0.830	11.830	0.066	11.867	0.065
7	3.4894	0.836	3.4516	0.840	11.836	0.106	11.868	0.105
8	3.5313	0.897	3.4943	0.900	11.916	0.155	11.967	0.153
9	3.6862	0.931	3.6471	0.933	12.370	0.193	12.415	0.191
10	5.1914	0.878	5.1522	0.881	12.671	0.243	12.744	0.238
11	5.4547	0.907	5.4220	0.909	12.771	0.309	12.812	0.306
12	5.4547	0.941	5.4220	0.942	12.817	0.382	12.872	0.378

7. Conclusion

Exiting the UK from the European Union (Brexit) has a huge impact on the UK and EU financial markets, particularly the foreign exchange and stock markets. Current study conducted to investigate empirically if Brexit came as a surprise for financial markets, using evidence from currency and stock markets in the Britain and European Union. For this purpose, pound sterling, and euro as currency and FTSE100 and FTSE EUROTOP100 as British and European stock market indices have been chosen. Event study methodology is used to examine if Brexit was a surprise for these markets at the event day. Defining a 200-day estimation window (-220, -21) and calculating the abnormal returns in the 11-day event window (-5, +5), indicates the important following findings:

- Impacts of Brexit on the currency market

The highest abnormal return in the event window recorded at the event day for both currencies. The abnormal returns of -8.37%, -5.96%, and -2.42% are calculated for GBP/USD, GBP/euro, and euro/USD, respectively. These negative numbers indicate that firstly, Brexit had a significant negative impact on the currency market at the event day. Secondly, the impact of Brexit on pound sterling was much more than euro. Furthermore, since the majority of abnormal returns before the Brexit event were positive, Brexit referendum was a surprise for this market at the event day. Finally, obtaining the negative cumulative abnormal return for these currencies in the period after the Brexit (0, +5) shows that market could not recover itself fast and it needed more time to getting back to the pre-Brexit trend.

- Impacts of Brexit on the stock markets

In terms of the FTSE100 and FTSE EUROTOP100, the highest abnormal returns in the event window are recorded at the event day, which are -3.16% and -6.58%, respectively. By taking in to consideration that the majority of abnormal returns before the Brexit referendum were positive, Brexit was a surprise for these two indices and had a negative significant effect on them at the event day. The calculated negative abnormal return for the European index is more than the British one. The reason is that the involvement of some British companies in the European index may bring bias in the calculations and it causes overestimating the effects of Brexit.
The cumulative abnormal returns for the event window (0, +5) are 3.93%, -2.21%, -4.44%, and -3.95% for FTSE100, FTSE EUROTP100, DAX, and CAC40, respectively. The positive abnormal returns after Brexit hints some relations between the currency and stock market in the UK. In other words, weaker pound sterling might have led to the higher income in dollar for some companies involved in FTSE100 and it helped the market to recover itself soon after the Brexit event.

Moreover, the results based on the mean adjusted model are more reliable than results based on the market model. This is because Brexit referendum is a single event, which affects the whole market and I cannot choose an independent market index in the market model.

- ARCH/GARCH effect and historical volatility

The findings in this section indicate that there is ARCH effect on the rate of returns of both UK and EU stock markets indices. Furthermore, estimating the GARCH (1, 1) model with dummy variable for detecting the trend of historical volatility shows that for both indices the volatility of returns increases before the Brexit and decreases after the Brexit. Lots of uncertainty before the Brexit brought this increase in the volatility and realizing the outcome of the referendum and cutting the interest rate by the central bank resulted in investors asking less risk premium which led to the decrease in volatility of the stock markets. Furthermore, the results based on ARCH-LM test show that there is no ARCH effect left after estimating the GARCH models and the GARCH models are correctly specified in both indices.

So was Brexit a surprise for financial markets?

My Empirical study shows that the result of Brexit referendum was a surprise for financial markets and it led to fall in the currency and stock market indices in the UK and EU on the event day.

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Appendices

Appendix A. Country allocation in the Global Dow stock market

Country	% Of share
USA	42.27%
Japan	9.97%
Great Britain	8.30%
France	6.85%
Germany	4.74%
Switzerland	4.62%
China	3.05%
India	2.39%
Spain	2.29%
Hong Kong	2.20%
Brazil	1.86%
Canada	1.64%
South Korea	1.52%
Australia	1.37%
Italy	1.15%
Mexico	0.96%
Taiwan	0.79%
Portugal	0.73%
Finland	0.68%
Sweden	0.64%
Russia	0.54%
Greece	0.44%
Norway	0.40%
Denmark	0.32%
Netherlands	0.29%

Appendix B. Table lists the FTSE100 companies after change on 15/01/2018. The index consists of 100 companies[20]

Company	Ticker	FTSE Sector
3i	III	Financial Services
Admiral Group	ADM	Nonlife Insurance
Anglo American plc	AAL	Mining
Antofagasta	ANTO	Mining
Ashtead Group	AHT	Support Services
Associated British Foods	ABF	Food Producers
AstraZeneca	AZN	Pharmaceuticals & Biotechnology
Aviva	AV.	Life Insurance
BAE Systems	BA.	Aerospace & Defense
Barclays	BARC	Banks
Barratt Developments	BDEV	Household Goods & Home Construction
Berkeley Group Holdings	BKG	Household Goods & Home Construction
BHP	BLT	Mining
BP	BP.	Oil & Gas Producers
British American Tobacco	BATS	Tobacco
British Land	BLND	Real Estate Investment Trusts
BT Group	BT.A	Fixed Line Telecommunications
Bunzl	BNZL	Support Services
Burberry	BRBY	Personal Goods
Carnival Corporation & plc	CCL	Travel & Leisure
Centrica	CNA	Gas, Water & Multiutilities
Coca-Cola HBC AG	CCH	Beverages
Compass Group	CPG	Travel & Leisure
CRH plc	CRH	Construction & Materials
Croda International	CRDA	Chemicals
DCC plc	DCC	Support Services
Diageo	DGE	Beverages
Direct Line Group	DLG	Nonlife Insurance
easyJet	EZJ	Travel & Leisure
Evraz	EVR	Industrial Metals & Mining
Experian	EXPN	Support Services
Ferguson plc	FERG	Support Services
Fresnillo plc	FRES	Mining
G4S	GFS	Support Services
GKN	GKN	Automobiles & Parts
GlaxoSmithKline	GSK	Pharmaceuticals & Biotechnology
Glencore	GLEN	Mining
Halma	HLMA	Electronic & Electrical Equipment
Hammerson	HMSO	Real Estate Investment Trusts

20 http://www.londonstockexchange.com/

Hargreaves Lansdown	HL.	Financial Services
HSBC	HSBA	Banks
Imperial Brands	IMB	Tobacco
Informa	INF	Media
InterContinental Hotels Group	IHG	Travel & Leisure
International Airlines Group	IAG	Travel & Leisure
Intertek	ITRK	Support Services
ITV plc	ITV	Media
Johnson Matthey	JMAT	Chemicals
Just Eat	JE.	General Retailers
Kingfisher plc	KGF	General Retailers
Land Securities	LAND	Real Estate Investment Trusts
Legal & General	LGEN	Life Insurance
Lloyds Banking Group	LLOY	Banks
London Stock Exchange Group	LSE	Financial Services
Marks & Spencer	MKS	General Retailers
Mediclinic International	MDC	Health Care Equipment & Services
Micro Focus	MCRO	Software & Computer Services
Mondi	MNDI	Forestry & Paper
Morrisons	MRW	Food & Drug Retailers
National Grid plc	NG.	Gas, Water & Multiutilities
Next plc	NXT	General Retailers
NMC Health	NMC	Health Care Equipment & Services
Old Mutual	OML	Life Insurance
Paddy Power Betfair	PPB	Travel & Leisure
Pearson PLC	PSON	Media
Persimmon plc	PSN	Household Goods & Home Construction
Prudential plc	PRU	Life Insurance
Randgold Resources	RRS	Mining
Reckitt Benckiser	RB.	Household Goods & Home Construction
RELX Group	REL	Media
Rentokil Initial	RTO	Support Services
Rio Tinto Group	RIO	Mining
Rolls-Royce Holdings	RR.	Aerospace & Defense
The Royal Bank of Scotland Group	RBS	Banks
Royal Dutch Shell	RDSA	Oil & Gas Producers
RSA Insurance Group	RSA	Nonlife Insurance
Sage Group	SGE	Software & Computer Services
Sainsbury's	SBRY	Food & Drug Retailers
Schroders	SDR	Financial Services
Scottish Mortgage Investment Trust	SMT	Equity Investment Instruments
Segro	SGRO	Real Estate Investment Trusts
Severn Trent	SVT	Gas, Water & Multiutilities
Shire plc	SHP	Pharmaceuticals & Biotechnology
Sky plc	SKY	Media
Smith & Nephew	SN.	Health Care Equipment &

		Services
Smith, D.S.	SMDS	General Industrials
Smiths Group	SMIN	General Industrials
Smurfit Kappa	SKG	General Industrials
SSE plc	SSE	Electricity
Standard Chartered	STAN	Banks
Standard Life Aberdeen	SLA	Financial Services
St. James's Place plc	STJ	Life Insurance
Taylor Wimpey	TW.	Household Goods & Home Construction
Tesco	TSCO	Food & Drug Retailers
TUI Group	TUI	Travel & Leisure
Unilever	ULVR	Personal Goods
United Utilities	UU.	Gas, Water & Multiutilities
Vodafone Group	VOD	Mobile Telecommunications
Whitbread	WTB	Retail hospitality
WPP plc	WPP	Media

Appendix C. List of members of the FTSE EUROTOP100

Company	Country
ABBNABB	SIX VIRT-X Exchange (Switzerland)
AIRAirbus Group S.E.	Euronext Paris (France)
AIAir Liquide	Euronext Paris (France)
ALVAllianz SE	Frankfurt Stock Exchange (Germany)
AALAnglo American	London Stock Exchange (United Kingdom)
ABIAnheuser-Busch Inbev	Euronext Brussels (Belgium)
MAERSK-AA.P. Moller - Maersk Class A	Copenhagen Stock Exchange (Denmark)
MAERSK-BA.P. Moller - Maersk Class B	Copenhagen Stock Exchange (Denmark)
MTArcelor Mittal SA (NL)	Euronext Amsterdam (Netherlands)
ASMLASML Holdings	Euronext Amsterdam (Netherlands)
AZNAstraZeneca	London Stock Exchange (United Kingdom)
ATCO-AAtlas Copco class A	Stockholm Stock Exchange (Sweden)
ATCO-BAtlas Copco class B	Stockholm Stock Exchange (Sweden)
CSAXA	Euronext Paris (France)
BBVABanco Bilbao Vizcaya Argentaria	Madrid Stock Exchange (Spain)
SANBanco Santander	Madrid Stock Exchange (Spain)
BARCBarclays	London Stock Exchange (United Kingdom)
BASBASF SE	Frankfurt Stock Exchange (Germany)
BAYNBayer AG	Frankfurt Stock Exchange (Germany)
BMWBayerische Motoren Werke AG	Frankfurt Stock Exchange (Germany)
BLTBHP Billiton	London Stock Exchange (United Kingdom)
BNPBNP Paribas	Euronext Paris (France)
BPBP	London Stock Exchange (United Kingdom)
BATSBritish American Tobacco	London Stock Exchange (United Kingdom)
BT.ABT Group	London Stock Exchange (United Kingdom)
CNACentrica	London Stock Exchange (United Kingdom)
CDIChristian Dior	Euronext Paris (France)
CSGNCredit Suisse	SIX VIRT-X Exchange (Switzerland)
DAIDaimler AG	Frankfurt Stock Exchange (Germany)
BNDanone	Euronext Paris (France)
DBKDeutsche Bank AG	Frankfurt Stock Exchange (Germany)
DTEDeutsche Telekom AG	Frankfurt Stock Exchange (Germany)
DGEDiageo	London Stock Exchange (United Kingdom)
EDFEDF	Euronext Paris (France)
ENELENEL	Italian Stock Exchange (Italy)
ENGIEngie (BE)	Euronext Brussels (Belgium)
ENGIEngie (FR)	Euronext Paris (France)
ENIENI	Italian Stock Exchange (Italy)
EOANE.ON AG	Frankfurt Stock Exchange (Germany)
FMEFresenius Medical Care AG	Frankfurt Stock Exchange (Germany)
GSKGlaxoSmithKline	London Stock Exchange (United Kingdom)
GLENGlencore	London Stock Exchange (United Kingdom)
HEIAHeineken	Euronext Amsterdam (Netherlands)
HENHenkel AG	Frankfurt Stock Exchange (Germany)
HEN3Henkel AG & Co KGAA	Frankfurt Stock Exchange (Germany)
RMSHermes International	Euronext Paris (France)
HSBAHSBC Holdings	London Stock Exchange (United Kingdom)
IBEIberdrola	Madrid Stock Exchange (Spain)
IMBImperial Brands	London Stock Exchange (United Kingdom)
ITXIndustria de Diseno Textil - Ind...	Madrid Stock Exchange (Spain)
INGAING Groep	Euronext Amsterdam (Netherlands)
ISPIntesa SanPaolo	Italian Stock Exchange (Italy)
LINLinde AG	Frankfurt Stock Exchange (Germany)

LLOYLloyds Banking Group	London Stock Exchange (United Kingdom)
ORL'Oreal	Euronext Paris (France)
MCLVMH	Euronext Paris (France)
MUV2Munchener Ruckversicherungs AG	Frankfurt Stock Exchange (Germany)
NGNational Grid	London Stock Exchange (United Kingdom)
NESNNestle	SIX VIRT-X Exchange (Switzerland)
NDA-SEKNordea Bank	Stockholm Stock Exchange (Sweden)
NOVNNovartis	SIX VIRT-X Exchange (Switzerland)
ORAOrange	Euronext Paris (France)
RIPernod Ricard	Euronext Paris (France)
PHIAPhilips (Koninklijke)	Euronext Amsterdam (Netherlands)
PRUPrudential	London Stock Exchange (United Kingdom)
RBReckitt Benckiser	London Stock Exchange (United Kingdom)
CFRRichemont	SIX VIRT-X Exchange (Switzerland)
RIORio Tinto	London Stock Exchange (United Kingdom)
ROGRoche	SIX VIRT-X Exchange (Switzerland)
RRRolls-Royce Group	London Stock Exchange (United Kingdom)
RBSRoyal Bank of Scotland	London Stock Exchange (United Kingdom)
RDSARoyal Dutch Shell 'A' (UK)	London Stock Exchange (United Kingdom)
RDSBRoyal Dutch Shell 'B' (UK)	London Stock Exchange (United Kingdom)
RWERWE AG	Frankfurt Stock Exchange (Germany)
SGOSaint Gobain	Euronext Paris (France)
SANSanofi	Euronext Paris (France)
SAPSAP AG	Frankfurt Stock Exchange (Germany)
SUSchneider Electric	Euronext Paris (France)
SIESiemens AG	Frankfurt Stock Exchange (Germany)
STANStandard Chartered	London Stock Exchange (United Kingdom)
UHRNSwatch Group	SIX Swiss Exchange (Switzerland)
UHRSwatch Group I	SIX VIRT-X Exchange (Switzerland)
SRENSwiss Re	SIX VIRT-X Exchange (Switzerland)
SYNNSyngenta	SIX VIRT-X Exchange (Switzerland)
TEFTelefonica SA	Madrid Stock Exchange (Spain)
TSCOTesco	London Stock Exchange (United Kingdom)
FPTotal	Euronext Paris (France)
UBSNUBS AG	SIX VIRT-X Exchange (Switzerland)
ULVRUnilever	London Stock Exchange (United Kingdom)
DGVinci	Euronext Paris (France)
VIVVivendi	Euronext Paris (France)
VODVodafone Group	London Stock Exchange (United Kingdom)
VOWVolkswagon AG	Frankfurt Stock Exchange (Germany)
VOLV-BVolvo B	Stockholm Stock Exchange (Sweden)
ZURNZurich Insurance Group AG Ltd	SIX VIRT-X Exchange (Switzerland)
ABBNABB	SIX VIRT-X Exchange (Switzerland)

Appendix D. Calculation of abnormal return for currency and stock markets

Event Study for effects of Brexit on the currency market on Jun 24, 2016 on GBP/USD (mean adjusted model)												
Event	***t***	***Date***	***Currency***	***Numeraire***	***Estimation Window Length***	***Pointer to end of Estimation Window***	***End of Estimation Window***	***STDEV***	***Actual Return***	***Estimated Return***	***Abnormal Return***	***t-values***
	-5	17-Jun-16							1.085		1.119	1.390
	-4	20-Jun-16							2.347		2.381	2.958
	-3	21-Jun-16							-0.354		-0.321	-0.398
	-2	22-Jun-16							0.416		0.449	0.558
	-1	23-Jun-16							1.156		1.190	1.478
1	0	24-Jun-16	GBP	USD	200	27	18-May-16	0.805	-8.402	-0.034	-8.368	-10.395
	1	27-Jun-16							-3.428		-3.394	-4.216
	2	28-Jun-16							0.926		0.960	1.192
	3	29-Jun-16							0.628		0.661	0.822
	4	30-Jun-16							-0.860		-0.826	-1.027
	5	1-Jul-16							-0.369		-0.335	-0.416

Event Study for effects of Brexit on the currency market on Jun 24, 2016 on GBP/euro (mean adjusted model)													
Event	***t***	***Date***	***currency***	***Numeraire***	***Estimation Window Length***	***Pointer to end of Estimation Window***	***End of Estimation Window***	***STDEV***	***Actual Return***	***Estimated Return***	***Abnormal Return***	***t-values***
	-5	17-Jun-16							0.638		0.675	1.225
	-4	20-Jun-16							2.022		2.058	3.736
	-3	21-Jun-16							0.292		0.328	0.596
	-2	22-Jun-16							-0.084		-0.048	-0.087
	-1	23-Jun-16							0.353		0.389	0.706
1	0	24-Jun-16	GBP	Euro	200	27	18-May-16	0.551	-5.993	-0.036	-5.957	-10.815
	1	27-Jun-16							-2.518		-2.482	-4.506
	2	28-Jun-16							0.474		0.510	0.926
	3	29-Jun-16							0.099		0.136	0.247
	4	30-Jun-16							-0.682		-0.645	-1.172
	5	1-Jul-16							-0.644		-0.608	-1.104

Event Study for effects of Brexit on the currency market on Jun 24, 2016 on EUR/USD (mean adjusted model)													
Event	***t***	***Date***	***Currency***	***Numeraire***	***Estimation Window Length***	***Pointer to end of Estimation Window***	***End of Estimation Window***	***STDEV***	***Actual Return***	***Estimated Return***	***Abnormal Return***	***t-values***
	-5	17-Jun-16							0.453		0.451	0.724
	-4	20-Jun-16							0.328		0.325	0.522
	-3	21-Jun-16							-0.638		-0.641	-1.031
	-2	22-Jun-16							0.488		0.485	0.780
	-1	23-Jun-16							0.811		0.808	1.300
1	0	24-Jun-16	EUR	USD	200	27	18-May-16	0.622	-2.417	0.003	-2.420	-3.891
	1	27-Jun-16							-0.822		-0.825	-1.326
	2	28-Jun-16							0.371		0.368	0.592
	3	29-Jun-16							0.523		0.520	0.836
	4	30-Jun-16							-0.180		-0.183	-0.294
	5	1-Jul-16							0.279		0.276	0.444

Event Study for studying effects of Brexit on the FTSE100 on Jun 24, 2016 conducted by Market Model														
Event	***t***	***Date***	***Index***	***Currency***	***Estimation Window Length***	***Pointer to end of Estimation Window***	***End of Estimation Window***	***Alpha***	***Beta***	***STEYX***	***Actual Return***	***Estimated Return***	***Abnormal Return***	***t-values***
	-5	17-Jun-16									1.180	-0.689	1.869	2.460
	-4	20-Jun-16									2.993	-0.861	3.853	5.072
	-3	21-Jun-16									0.363	0.528	-0.165	-0.217
	-2	22-Jun-16									0.555	-0.049	0.603	0.794
	-1	23-Jun-16									1.221	0.452	0.769	1.012
1	0	24-Jun-16	FTSE100	GBP	200	21	25-May-16	-0.023	0.965	0.760	-3.197	2.331	-5.527	-7.275
	1	27-Jun-16									-2.582	1.260	-3.842	-5.057
	2	28-Jun-16									2.610	0.336	2.274	2.993
	3	29-Jun-16									3.515	1.605	1.910	2.514
	4	30-Jun-16									2.243	1.792	0.451	0.593
	5	1-Jul-16									1.124	0.883	0.240	0.317

Event Study for studying effects of Brexit on the FTSE100 on Jun 24, 2016 conducted by Mean Adjusted Model												
Event	***T***	***Date***	***Index***	***Currency***	***Estimation Window Length***	***Pointer to end of Estimation Window***	***End of Estimation Window***	***STDEV***	***Actual Return***	***Estimated Return***	***Abnormal Return***	***T-values***
	-5	17-Jun-16							1.180		1.216	1.601
	-4	20-Jun-16							2.993		3.029	3.987
	-3	21-Jun-16							0.363		0.399	0.525
	-2	22-Jun-16							0.555		0.591	0.778
	-1	23-Jun-16							1.221		1.257	1.655
1	0	24-Jun-16	FTSE100	GBP	200	21	25-May-16	0.760	-3.197	-0.036	-3.160	-4.160
	1	27-Jun-16							-2.582		-2.546	-3.351
	2	28-Jun-16							2.610		2.646	3.483
	3	29-Jun-16							3.515		3.551	4.674
	4	30-Jun-16							2.243		2.279	3.000
	5	1-Jul-16							1.124		1.160	1.527

Event Study for studying effects of Brexit on the FTSE EUROTOP100 on Jun 24, 2016 conducted by Market Model														
Event	***t***	***Date***	***Index***	***Currency***	***Estimation Window Length***	***Pointer to end of Estimation Window***	***End of Estimation Window***	***Alpha***	***Beta***	***STEYX***	***Actual Return***	***Estimated Return***	***Abnormal Return***	***t-values***
	-5	17-Jun-16									1.050	-0.823	1.872	1.921
	-4	20-Jun-16									3.424	-1.017	4.441	4.556
	-3	21-Jun-16									0.775	0.558	0.218	0.223
	-2	22-Jun-16									0.456	-0.096	0.552	0.566
	-1	23-Jun-16									1.274	0.472	0.802	0.823
1	0	24-Jun-16	EURO100	GBP	200	21	25-May-16	-0.067	1.094	0.974	-6.661	2.602	-9.263	-9.502
	1	27-Jun-16									-2.917	1.388	-4.305	-4.416
	2	28-Jun-16									2.255	0.340	1.914	1.963
	3	29-Jun-16									3.001	1.779	1.222	1.253
	4	30-Jun-16									0.969	1.992	-1.023	-1.049
	5	1-Jul-16									0.645	0.961	-0.315	-0.323

Event Study for studying effects of Brexit on the FTSE EUROTOP100 on Jun 24, 2016 conducted by Mean Adjusted Model												
Event	***T***	***Date***	***Index***	***Currency***	***Estimation Window Length***	***Pointer to end of Estimation Window***	***End of Estimation Window***	***STDEV***	***Actual Return***	***Estimated Return***	***Abnormal Return***	***T-values***
	-5	17-Jun-16							1.050		1.133	1.162
	-4	20-Jun-16							3.424		3.507	3.597
	-3	21-Jun-16							0.775		0.858	0.881
	-2	22-Jun-16							0.456		0.539	0.553
	-1	23-Jun-16							1.274		1.357	1.392
1	0	24-Jun-16	EURO100	GBP	200	21	25-May-16	0.9748	-6.661	-0.083	-6.578	-6.748
	1	27-Jun-16							-2.917		-2.834	-2.907
	2	28-Jun-16							2.255		2.338	2.398
	3	29-Jun-16							3.001		3.084	3.163
	4	30-Jun-16							0.969		1.052	1.079
	5	1-Jul-16							0.645		0.728	0.747

Event Study for studying effects of Brexit on the DAX on Jun 24, 2016 conducted by Mean Adjusted Model												
Event	***t***	***Date***	***Index***	***Currency***	***Estimation Window Length***	***Pointer to end of Estimation Window***	***End of Estimation Window***	***STEYX***	***Actual Return***	***Estimated Return***	***Abnormal Return***	***t-values***
	-5	17-Jun-16							0.843		0.904	0.589
	-4	20-Jun-16							3.376		3.437	2.237
	-3	21-Jun-16							0.536		0.597	0.388
	-2	22-Jun-16							0.553		0.614	0.399
	-1	23-Jun-16							1.830		1.891	1.231
1	0	24-Jun-16	EURO100	Euro	200	21	25-May-16	1.536	-7.067	-0.061	-7.006	-4.560
	1	27-Jun-16							-3.065		-3.004	-1.955
	2	28-Jun-16							1.909		1.970	1.282
	3	29-Jun-16							1.731		1.792	1.166
	4	30-Jun-16							0.703		0.764	0.497
	5	1-Jul-16							0.987		1.048	0.682

Event Study for studying effects of Brexit on the CAC 40 on Jun 24, 2016 conducted by Mean Adjusted Model												
Event	***t***	***Date***	***Index***	***Currency***	***Estimation Window Length***	***Pointer to end of Estimation Window***	***End of Estimation Window***	***STEYX***	***Actual Return***	***Estimated Return***	***Abnormal Return***	***t-values***
	-5	17-Jun-16							0.978		1.052	1.361
	-4	20-Jun-16							3.444		3.517	4.549
	-3	21-Jun-16							0.608		0.682	0.882
	-2	22-Jun-16							0.292		0.366	0.474
	-1	23-Jun-16							1.942		2.015	2.607
1	0	24-Jun-16	CAC 40	Euro	200	21	25-May-16	0.773	-8.384	-0.074	-8.310	-10.748
	1	27-Jun-16							-3.016		-2.942	-3.805
	2	28-Jun-16							2.580		2.654	3.432
	3	29-Jun-16							2.571		2.644	3.42
	4	30-Jun-16							1.000		1.074	1.389
	5	1-Jul-16							0.857		0.931	1.204

Appendix E. Estimating GARCH (1, 1) for FTSE100 and FTSE EUROTOP100

Dependent Variable: FTSE
Method: ML ARCH - Normal distribution (BFGS / Marquardt steps)
Date: 02/26/18 Time: 20:36
Sample: 6/24/2015 6/23/2017
Included observations: 507
Convergence achieved after 22 iterations
Coefficient covariance computed using outer product of gradients
Presample variance: backcast (parameter = 0.7)
GARCH = C(3) + C(4)*RESID(-1)^2 + C(5)*GARCH(-1)

Variable	Coefficient	Std. Error	z-Statistic	Prob.
C	0.029838	0.034877	0.855507	0.3923
GLOBAL_DOW	0.079445	0.041124	1.931822	0.0534
		Variance Equation		
C	0.067477	0.018635	3.620982	0.0003
RESID(-1)^2	0.186196	0.038971	4.777835	0.0000
GARCH(-1)	0.744318	0.049893	14.91840	0.0000

R-squared	0.004758	Mean dependent var	0.020027
Adjusted R-squared	0.002787	S.D. dependent var	1.012202
S.E. of regression	1.010791	Akaike info criterion	2.584575
Sum squared resid	515.9573	Schwarz criterion	2.626277
Log likelihood	-650.1899	Hannan-Quinn criter.	2.600929
Durbin-Watson stat	1.962920		

Dependent Variable: FTSE_EUROTOP
Method: ML ARCH - Normal distribution (BFGS / Marquardt steps)
Date: 02/26/18 Time: 20:38
Sample: 6/24/2015 6/23/2017
Included observations: 507
Convergence achieved after 24 iterations
Coefficient covariance computed using outer product of gradients
Presample variance: backcast (parameter = 0.7)
GARCH = C(3) + C(4)*RESID(-1)^2 + C(5)*GARCH(-1)

Variable	Coefficient	Std. Error	z-Statistic	Prob.
C	-0.001820	0.033386	-0.054502	0.9565
GLOBAL_DOW	0.634192	0.032628	19.43684	0.0000
		Variance Equation		
C	0.015021	0.008259	1.818674	0.0690
RESID(-1)^2	0.131344	0.020957	6.267217	0.0000
GARCH(-1)	0.861503	0.024638	34.96714	0.0000

R-squared	0.335759	Mean dependent var	-0.011012
Adjusted R-squared	0.334444	S.D. dependent var	1.205982
S.E. of regression	0.983860	Akaike info criterion	2.562371
Sum squared resid	488.8298	Schwarz criterion	2.604072
Log likelihood	-644.5611	Hannan-Quinn criter.	2.578725
Durbin-Watson stat	2.069700		

Appendix F. Estimating IGARCH for FTSE EUROTOP100

Dependent Variable: FTSE_EUROTOP
Method: ML ARCH - Normal distribution (BFGS / Marquardt steps)
Date: 02/26/18 Time: 20:41
Sample: 6/24/2015 6/23/2017
Included observations: 507
Convergence achieved after 18 iterations
Coefficient covariance computed using outer product of gradients
Presample variance: backcast (parameter = 0.7)
GARCH = C(3)*RESID(-1)^2 + (1 - C(3))*GARCH(-1)

Variable	Coefficient	Std. Error	z-Statistic	Prob.
C	0.001916	0.028271	0.067777	0.9460
GLOBAL_DOW	0.616457	0.024573	25.08716	0.0000
		Variance Equation		
RESID(-1)^2	0.085681	0.008702	9.845877	0.0000
GARCH(-1)	0.914319	0.008702	105.0667	0.0000

R-squared	0.332421	Mean dependent var	-0.011012
Adjusted R-squared	0.331099	S.D. dependent var	1.205982
S.E. of regression	0.986329	Akaike info criterion	2.570993
Sum squared resid	491.2862	Schwarz criterion	2.596014
Log likelihood	-648.7468	Hannan-Quinn criter.	2.580806
Durbin-Watson stat	2.066149		

Appendix G. Estimating GARCH model with dummy variable for FTSE EUROTOP100

Dependent Variable: FTSE_EUROTOP
Method: ML ARCH - Normal distribution (BFGS / Marquardt steps)
Date: 02/14/18 Time: 17:08
Sample: 6/24/2015 6/23/2017
Included observations: 507
Convergence achieved after 34 iterations
Coefficient covariance computed using outer product of gradients
Presample variance: backcast (parameter = 0.7)
GARCH = C(3) + C(4)*RESID(-1)^2 + C(5)*GARCH(-1) + C(6)
*@DATE>@DATEVAL("2016/06/23")

Variable	Coefficient	Std. Error	z-Statistic	Prob.
C	-0.007418	0.033941	-0.218551	0.8270
GLOBAL_DOW	0.608774	0.034684	17.55217	0.0000
		Variance Equation		
C	0.150658	0.062318	2.417567	0.0156
RESID(-1)^2	0.096347	0.034421	2.799078	0.0051
GARCH(-1)	0.804309	0.065779	12.22745	0.0000
@DATE>@DATEVAL("2016/06/23")	-0.115684	0.048519	-2.384307	0.0171

R-squared	0.331471	Mean dependent var	-0.011012
Adjusted R-squared	0.330147	S.D. dependent var	1.205982
S.E. of regression	0.987030	Akaike info criterion	2.522711
Sum squared resid	491.9853	Schwarz criterion	2.572753
Log likelihood	-633.5072	Hannan-Quinn criter.	2.542336
Durbin-Watson stat	2.066462		

Dependent Variable: FTSE_EUROTOP
Method: ML ARCH - Normal distribution (BFGS / Marquardt steps)
Date: 02/21/18 Time: 14:38
Sample: 6/24/2015 6/23/2017
Included observations: 507
Convergence achieved after 30 iterations
Coefficient covariance computed using outer product of gradients
Presample variance: backcast (parameter = 0.7)
GARCH = C(3) + C(4)*RESID(-1)^2 + C(5)*GARCH(-1) + C(6)
*@DATE<@DATEVAL("2016/06/23")

Variable	Coefficient	Std. Error	z-Statistic	Prob.
C	-0.007475	0.033940	-0.220251	0.8257
GLOBAL_DOW	0.610883	0.034524	17.69426	0.0000
		Variance Equation		
C	0.032104	0.014260	2.251340	0.0244
RESID(-1)^2	0.099591	0.033920	2.936080	0.0033
GARCH(-1)	0.811504	0.060554	13.40133	0.0000
@DATE<@DATEVAL("2016/06/23")	0.104112	0.042279	2.462488	0.0138

R-squared	0.331883	Mean dependent var	-0.011012
Adjusted R-squared	0.330560	S.D. dependent var	1.205982
S.E. of regression	0.986726	Akaike info criterion	2.525848
Sum squared resid	491.6822	Schwarz criterion	2.575890
Log likelihood	-634.3025	Hannan-Quinn criter.	2.545473
Durbin-Watson stat	2.066825		

Appendix H
Correlogram squared residuals for before and after the Brexit for FTSE100, respectively.

Sample: 6/24/2015 6/23/2017
Included observations: 507

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob*
		1	-0.024	-0.024	0.3024	0.582
		2	-0.021	-0.022	0.5360	0.765
		3	0.032	0.031	1.0482	0.790
		4	0.050	0.052	2.3519	0.671
		5	0.015	0.019	2.4613	0.782
		6	0.028	0.031	2.8763	0.824
		7	-0.034	-0.036	3.4894	0.836
		8	0.009	0.005	3.5313	0.897
		9	0.017	0.013	3.6862	0.931
		10	-0.054	-0.054	5.1914	0.878
		11	-0.022	-0.023	5.4547	0.907
		12	-0.000	-0.005	5.4547	0.941
		13	-0.015	-0.013	5.5723	0.960
		14	-0.003	0.001	5.5784	0.976
		15	-0.018	-0.015	5.7572	0.984
		16	-0.018	-0.013	5.9259	0.989
		17	0.010	0.008	5.9758	0.993
		18	-0.027	-0.026	6.3502	0.995
		19	0.027	0.032	6.7323	0.996
		20	0.016	0.015	6.8701	0.997
		21	0.031	0.034	7.3877	0.997
		22	0.015	0.018	7.5055	0.998
		23	-0.008	-0.012	7.5399	0.999
		24	-0.006	-0.008	7.5565	0.999
		25	0.014	0.003	7.6634	1.000
		26	0.038	0.035	8.4546	1.000
		27	-0.052	-0.050	9.9191	0.999
		28	-0.021	-0.025	10.159	0.999
		29	-0.004	-0.009	10.169	1.000
		30	-0.034	-0.036	10.805	0.999

Sample: 6/24/2015 6/23/2017
Included observations: 507

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob*
		1	-0.024	-0.024	0.3040	0.581
		2	-0.021	-0.022	0.5379	0.764
		3	0.032	0.031	1.0500	0.789
		4	0.050	0.051	2.3084	0.679
		5	0.014	0.018	2.4125	0.790
		6	0.029	0.031	2.8312	0.830
		7	-0.035	-0.036	3.4516	0.840
		8	0.009	0.005	3.4943	0.900
		9	0.017	0.013	3.6471	0.933
		10	-0.054	-0.054	5.1522	0.881
		11	-0.023	-0.023	5.4220	0.909
		12	-0.000	-0.005	5.4220	0.942
		13	-0.015	-0.012	5.5370	0.961
		14	-0.003	0.001	5.5420	0.977
		15	-0.019	-0.016	5.7244	0.984
		16	-0.018	-0.013	5.8915	0.989
		17	0.009	0.007	5.9379	0.994
		18	-0.027	-0.026	6.3101	0.995
		19	0.027	0.032	6.7003	0.996
		20	0.017	0.016	6.8475	0.997
		21	0.031	0.034	7.3674	0.997
		22	0.015	0.018	7.4865	0.998
		23	-0.008	-0.012	7.5225	0.999
		24	-0.005	-0.008	7.5371	0.999
		25	0.014	0.004	7.6496	1.000
		26	0.038	0.035	8.4367	1.000
		27	-0.052	-0.050	9.8895	0.999
		28	-0.021	-0.025	10.124	0.999
		29	-0.004	-0.009	10.133	1.000
		30	-0.034	-0.036	10.767	1.000

Correlogram squared residuals for before and after the Brexit for FTSE EUROTOP100, respectively

Sample: 6/24/2015 6/23/2017
Included observations: 507

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob*
		1	0.005	0.005	0.0107	0.917
		2	-0.049	-0.049	1.2457	0.536
		3	-0.053	-0.052	2.6713	0.445
		4	0.132	0.131	11.633	0.020
		5	-0.019	-0.026	11.816	0.037
		6	-0.005	0.005	11.830	0.066
		7	-0.004	0.009	11.836	0.106
		8	0.012	-0.008	11.916	0.155
		9	-0.030	-0.024	12.370	0.193
		10	0.024	0.025	12.671	0.243
		11	-0.014	-0.018	12.771	0.309
		12	0.009	0.009	12.817	0.382
		13	0.002	0.010	12.819	0.462
		14	-0.004	-0.013	12.827	0.540
		15	-0.001	0.006	12.828	0.616
		16	-0.015	-0.018	12.950	0.676
		17	-0.022	-0.025	13.212	0.722
		18	0.029	0.031	13.656	0.751
		19	-0.029	-0.034	14.089	0.778
		20	-0.029	-0.026	14.530	0.803
		21	-0.007	0.001	14.557	0.845
		22	0.061	0.048	16.563	0.787
		23	0.007	0.011	16.587	0.829
		24	0.001	0.013	16.587	0.866
		25	0.013	0.018	16.683	0.893
		26	0.005	-0.009	16.695	0.918
		27	-0.066	-0.063	19.019	0.869
		28	-0.038	-0.041	19.818	0.871
		29	-0.046	-0.056	20.981	0.860
		30	-0.028	-0.038	21.404	0.875

Sample: 6/24/2015 6/23/2017
Included observations: 507

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob*
		1	0.006	0.006	0.0175	0.895
		2	-0.049	-0.049	1.2323	0.540
		3	-0.053	-0.052	2.6436	0.450
		4	0.133	0.132	11.685	0.020
		5	-0.018	-0.026	11.860	0.037
		6	-0.004	0.006	11.867	0.065
		7	-0.001	0.011	11.868	0.105
		8	0.014	-0.006	11.967	0.153
		9	-0.029	-0.024	12.415	0.191
		10	0.025	0.027	12.744	0.238
		11	-0.011	-0.016	12.812	0.306
		12	0.011	0.010	12.872	0.378
		13	0.003	0.012	12.876	0.457
		14	-0.002	-0.011	12.878	0.536
		15	0.001	0.008	12.879	0.612
		16	-0.014	-0.017	12.976	0.675
		17	-0.020	-0.022	13.187	0.724
		18	0.032	0.034	13.727	0.747
		19	-0.028	-0.034	14.152	0.775
		20	-0.029	-0.026	14.609	0.798
		21	-0.006	0.003	14.625	0.841
		22	0.060	0.046	16.550	0.788
		23	0.008	0.012	16.584	0.829
		24	0.004	0.016	16.591	0.866
		25	0.016	0.021	16.732	0.891
		26	0.003	-0.010	16.736	0.917
		27	-0.066	-0.063	19.086	0.867
		28	-0.039	-0.042	19.889	0.868
		29	-0.046	-0.057	21.052	0.857
		30	-0.027	-0.036	21.437	0.874