MARKET EXPECTATIONS IN OPTION IMPLIED VOLATILITIES: THE CASE OF BREXIT

by

Artem Bielykh

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Thesis Supervisors: Professor Olesia Verchenko, Dr. Sergiy Pysarenko

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Date ______________________________

Kyiv School of Economics

Abstract

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Did the UK move closer to the US as a result of Brexit referendum? This thesis examines the change in connection between the UK stock market expectations and the US stock market before and after Brexit referendum, which was held on May 23, 2016. Using OLS regression, we found that the US and UK stock market became somewhat less integrated for four-month period after the Brexit referendum than for five-month period before it. S&P500 Index returns had a statistically significant impact on implied volatilities of FTSE 100 only before the Brexit referendum. However, British risk-free rate (LIBOR) became a statistically significant factor affecting FTSE 100 implied volatilities only after the Brexit referendum.

TABLE OF CONTENTS

INTRODUCTION 1
LITERATURE REVIEW 5
2.1. Options and implied volatilities definitions 5
2.2 Academia world papers 7
METHODOLOGY 12
3.1 Data filtering 12
3.2. Implied volatility extraction 13
3.3. Regression estimation 14
3.4 Variables explanations 15
DATA DESCRIPTION 19
ESTIMATION RESULTS 23
CONCLUSIONS 29
WORKS CITED 31
APPENDIX A VECTOR AUTOREGRESSIVE MODEL RESULTS 33
APPENDIX B DICKEY-FULLER TESTS 36
APPENDIX C RISK-FREE RATE (LIBOR) 38

LIST OF FIGURES

Number *Page*

Figure 1. S&P500 Index prices and Volatility Index (VIX) 22
Figure 2 Implied Volatility (IV) values in February-October 2016 22
Figure 3 Risk-free rate (LIBOR) in February-October 2016. 38

LIST OF TABLES

Number *Page*

Table 1 Expected signs of the variables used for the model 18
Table 2. Descriptive statistics of the variables 20
Table 3 Granger causality Wald test 24
Table 4. Estimation results of the model.. 26
Table 5. Correlation among model variables 28
Table 6 Vector Autoregressive model results 33
Table 7 Dickey-Fuller tests... 36

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GLOSSARY

FTSE 100 Index. The Financial Times Stock Exchange 100 Index is a British stock market index based on the 100 largest companies listed on the London Stock Exchange.

IV. Implied volatility

LIBOR. London Inter-bank Offered Rate is benchmark interest rate at which banks borrow from one another

RF. Risk free rate

SP. Strike option price

S&P 500 Index. Standard & Poor's 500 Index is an American stock market index based on the 500 largest companies listed on the NYSE, NASDAQ, and the CBOE BZX Exchange.

VIX. The CBOE Volatility Index is a measure of the stock market's expectation of implied volatility by S&P 500 index option

Chapter 1

INTRODUCTION

This thesis studies the change in connection of option-implied volatilities (IVs) of the UK stock exchange FTSE 100 Index and the US stock exchange S&P 500 Index before and after the Brexit referendum. The first our goal is to generate the option-implied volatilities, which characterize the market expectations before and after Brexit referendum on June 23, 2016. The secondary goal of this study is to compare option-implied volatilities of the FTSE 100 Index before and after Brexit referendum. A few authors have (Konstantinidi 2006; Gemmill & Kamiyama 2000; Mixon 2002; Glatzer & Scheicher 2003) studied the relationship among asset prices and macroeconomic events using option-implied volatilities. Change in implied volatilities could give us an idea of the market expectations of the asset in the future.

Investors always wonder to know the future asset price and potential of its movement to make a profit on it. The investors spend own capital, so they expect that each investment would provide them a profit. Each decision should be made with the appropriate financial tools which can provide the information to make an investment in which investor can trust. Nowadays, there are a lot financial instruments: options, futures, and other financial derivatives are valued based on could give the possibility to see a more likely market movement in the future. Option prices are based on the market expectations in a following manner: If optimistic expectation are prevalent (market is bullish) and the asset price is expected to grow up, then call option a valued higher while put options are valued cheaper. In an opposite situation, when pessimistic expectations are prevalent (market is bearish) and the asset price is expected to decline, call options drop in price, while put options a valued higher. Moreover, the unexpected event may change predominant market anticipations. In our research, we take such event as British Brexit referendum, which was held on 23 June 2016. Brexit referendum may be associated with a significant financial shock. Thus it is interested for investors to understand the market expectation about what can be happen after Brexit.

Knowing a time of the future event, as British Brexit referendum, knowing current option prices, which represent the market anticipations about the future, and assuming that there is a connection between the UK and US market, we ask an interesting question: how does the connection change between the UK and US markets before and after Brexit referendum? It is our main research question. We can answer this question using options price distributions, which give us the possibility to extract the expectation as implied volatility (IV), and do a regression to estimate the changes in connection between two markets. Using Implied volatility, as a dependent variable, we can answer the question whether there is a change in connection between two markets and see how the can influence on each other.

It is known that such a great event, as the referendum, may have an impact on the economy. This will lead to movements in the financial markets. The uncertainty associated with leaving of the United Kingdom from the European Union. It may causes an increase in volatility in the financial markets. Brexit could have a disastrous effect either on global and internal markets. An escape from the British pound would strengthen the other currencies, one of them is US dollar which is the main international currency in the world. That is why it is a mistake to believe that the consequences of Brexit will be limited only to Great Britain and Europe, and will bypass the US. Since the US stock market is the largest in the world, Brexit may have a significant effect on it. In our thesis we assume that there is a connection between the UK and US markets. If the change will have statistically significant values, it means there is a strong effect. In order to be clear the "connection" is the statistically significant effect of the US stock market on the UK stock market. We consider that FTSE 100 Index represents the UK stock market, and S&P 500 represents the US stock market. This change in connection between two markets can be interested for investors who do expect the future changes in the market associated with the great event, which is expected to exist in the future. Knowing market expectations about the connection of two markets, investors may use this information in their investment decisions to make a profit on market movements. Since Brexit referendum is an unusual global event and global economy is becoming more and more integrated to each other, this research may shed light on the change in connection between two markets.

Our null hypothesis (H_0) of the research is that there is no a change in connection between two markets after Brexit referendum. The alternative hypothesis (H_1) is that there is a change in connection between two markets after Brexit referendum. It means that the US market does have a statistically significant effect on the UK stock market after Brexit referendum. The regression is shown in Methodology part (Chapter 3). To perform our analysis, we use daily data (181 observation days) on options for the period from February 2016 to October 2016, use S&P 500 Index daily returns, exchange rates between Great British Pound and United States Dollar (GBP/USD), LIBOR as risk-free rate, VIX is the Volatility Index of the US stock market, the difference of 10-Y and 1-Y yields of the US Treasury government bonds. We take 4 months before Brexit and 4 months after Brexit. This period represents the time of uncertainty of the British economy due to the result Brexit referendum, and it ends before the shock associated with the results of the US presidential elections on 8 November 2016.

The structure of this paper is the following: Chapter 2 describes the literature both theoretical and empirical papers about option-implied volatilities; Chapter 3 provides the methodology of the generating option-implied volatilities and model specifications; data description statistics is reviewed in Chapter 4; results are presented in Chapter 5; Chapter 6 provides thesis conclusions.

Chapter 2

LITERATURE REVIEW

This chapter starts with the theoretical literature review about the fundamental aspects of the option IVs, and ends with the most influential empirical results of the papers in academia world.

2.1. Options and implied volatilities definitions

Investors and policymakers study derivatives because they contain rich information on markets' movement expectations. In addition, each of the derivatives can be exposed to primary instruments, called base ones. In the role of base instruments may be various financial instruments or indices. The most well-known are: securities, interest rates, exchange rates, stock indices, commodities, credit risks and etc. In this thesis we use the base one is FTSE 100 Index, which has kind of such derivatives as options. Options give the holder the right to buy or sell the asset for a certain time by a certain price (Hull 2003). The option is a derivative instrument that enables hedging against possible losses resulting of fluctuations in the price of the subject of the transaction. There is a division between US options and European options. US options are exercised to acquire or sell the underlying instrument, at a predetermined price, at any time during the option period, before its expiration. European options are exercised only on expiration day (maturity). Between the exercise price and price, when the option is brought, there is a range of many possible prices of the underlying asset. In our thesis, we use European style options of FTSE 100.

Recently, many techniques have been developed to use option prices for estimation of future financial asset prices and extract the distribution of market expectations. Several authors (Mixon 2002; Neuhaus 1995) paid attention to the determinants of market movements. In general, volatility is a measure of uncertainty about future changes in the price of a financial instrument. If volatility increases, the probability that a given financial instrument will significantly change its price in the future increases too. This can be both advantageous and unfavorable change from the point of view of the holder of such an instrument. The implied volatility is an indicator of market participants' expectations regarding changes of the share price over the year. The IVs are able to incorporate an extensive variety of future scenarios that are not captured by the usage of other historical data. Option IVs are much more sensitive and respond more accurately to changing in market expectations (Hull 2003). Any shift in beliefs, caused by political declaration or new financial information can be captured in the option-implied volatilities. The option prices of assets allow us to extract the IVs using daily data for a constant time horizon. It helps to estimate the period of time which takes into account the past reactions and predict the future market movement expectations. Also, using a short period of time, IVs make it possible to investigate a day-to-day market expectation and help to make the decisions faster compared to models that are more complicated. The IVs embody an information set that includes many important features, which describe the distribution or data. Expected variance (asset volatility) shows whether the distribution is spread out or concentrated near the mean. Bigger variance means lower certainty of asset stability. Using IV of the distribution, we may investigate the impact of macroeconomic and financial events on densities of stock market expectations.

2.2 Academia world papers

There is a rich literature on the estimation the option values. Many investigators - statisticians, econometrics, theoreticians and practitioners of financial management dealt with the problem of option pricing. In order to understand the option implied volatilities, we need to understand the theory, which is a fundament for the options. One of the first pioneers in option pricing theory were Black and Scholes in 1973. They are the first who estimated the fair value of European-style option. They use six variables for option pricing: type of option, underlying stock price, time, volatility, strike price and risk-free rate. In practice, in addition to listed variables, the great importance in shaping the option price has expectations regarding their future levels. Variability is a parameter, which could affect positively on the option value. This can be explained by the fact that it is a measure of the risk of the underlying instrument price and therefore the option risk (Czech 2019). The higher the risk, the more the option buyer has to pay for the option. Hence the value of options goes up as volatility increases. This model (option pricing theory) assumes the underlying asset price evolve due to stochastic process, known as geometric Brownian motion (GBM), in which instantaneous drift and volatility are constant (Bahra 1997) . It means the implied volatility should be the same for all instruments of the underlying asset, however, there should be different expires and strikes. This technique assumes lognormal risk neutral density function. Using all these variables, we estimate option values of the UK stock exchange FTSE 100 Index.

$$C_t = S_0 e^{-\delta(T-t)}\Phi(d_1) - K e^{-r_f(T-t)}\Phi(d_2) \qquad (1)$$

$$P_t = K e^{-r_f(T-t)}\Phi(-d_2) - S_0 e^{-\delta(T-t)}\Phi(-d_1)$$

$$d_1 = \frac{\ln\left(\frac{S_0}{K}\right) + \left(r + \frac{\sigma^2}{2}\right)T}{\sigma\sqrt{T}}$$

$$d_2 = \frac{ln\left(\frac{S_0}{K}\right) + \left(r - \frac{\sigma^2}{2}\right)T}{\sigma\sqrt{T}} = d_1 - \sigma\sqrt{T}$$

Where,

C_t − call option price at time t ϵ [0, T]

P_t − put option price at time t ϵ [0, T]

T − exercise time of the option

t − observed time

K − strike price

Φ(x) − cumulative probability density function for a standardized normal distribution

S_0 − underlying asset price at time zero,

r − risk-free interest rate

σ – expected volatility of underlying asset

The authors (Cox, Ross and Rubinstein 1976) continue to develop Black-Scholes model, and show that the price of an option is the discounted risk-neutral expected value of the payoffs. This parameter approximating method assumes the risk-neutral probability density function of a particular function form.

Parameter values may be found by minimizing a function of the fitted price errors. According to the option pricing concept proposed by Cox and Ross and Rubinstein, the option price can be determined as the cash flow value of the option for assets with the same volatility as the assets to which the option is valued and a rate of return equal to the risk-free rate. If the option is valued in accordance with this rule, it is not possible to obtain arbitrage profits. Both approaches lead to the same option price, assuming that the logarithmic rate of return on assets has a normal probability distribution. It should be noted that the option price does not depend on the rate of return on assets for which it is issued, but on the risk-free rate and the volatility of the return on assets.

We are going to use implied volatilities, we should take a look how implied volatilities are occurred and then discuss the literature for the IVs. The formula which is used to estimate the implied volatility is the standard Black-Scholes formula, which was shown earlier. The method which is used to derive IV is to determine a value such that the squared loss function between observed price and calculated Black-Scholes price is zero. In order to do this, we can use the Newton-Raphson method (Hull 2003).

(Shimko 1993) proposes a method to smooth the implied volatilities, which can be extracted directly from the exercise price without estimating the option price. He argues the quadratic function of exercise price is an implied volatility (volatility smile curve).

In this thesis we are going to investigate stock market expectations before and after the Brexit referendum. In order to understand the expectations, we extract implied volatilities from the options.

(Konstantinidi 2006) determines the implied volatility (IV) as an instrument to measure a market risk in order to maximize the expected returns. Understanding the variation of the IV, we can form the market anticipations on how the expected returns change over time. In other words, when the market participants assume the direction of change in implied volatility, they can improve their strategies in the stock market. That is why IVs are often used in trading strategies and taken into account in managing investment portfolio.

Konstantinidi studies the determinants, which have a significant impact on IV's prediction. ARIMA, AR(1), VAR, ARFIMA were used as the models to forecast the IV.

$$\Delta IV_t = const + \beta_1^+ R_{t-1}^+ + \beta_2^- R_{t-1}^- + \beta_3 i_{t-1} + \beta_4 fx_{t-1} + \beta_5 oil_{t-1} + \beta_6 \Delta HV_{t-1} + \beta_7 \Delta IV_{t-1} + \beta_8 ys_{t-1} + \beta_9 vol_{t-1} + \varepsilon_t \quad (2)$$

He uses several indices (S&P 500, DJIA, CAC40, DAX, STOXX), their positive and negative daily returns (R^+ and R^- respectively), i-one-month interbank interest rate, fx - exchange rate, oil - price of oil (West Texas Intermediate crude oil). The log-differences are used for the last three variables. ys - the change of yield curve (10-Year US Treasury bond minus 1-Year US Treasury note), IV_{t-1} - 30-day change volatility, and vol - the log-difference of volume of underlying asset. We are going to use FTSE 100 Index and S&P500 Index in this thesis.

(Gemmill and Kamiyama 2000) found that the changes in IVs in one market are caused by lagged change in another market. Their research is focused on stock exchange option FTSE1000, Nikkei 225, and S&P 500 indices.

The authors (Glatzer, Scheicher 2003) analyze the 2^{nd}, 3^{rd}, and 4^{th} moments of the German DAX Index. They investigate the relationship of the options with macroeconomic news, and information from the US stock market. They estimate the relationship of US stock market on German stock market in 1995-2002 horizon time. We use an idea to estimate the change in connection between the US and UK markets before and after the significant expectation of macroeconomic news, in our case it is Brexit referendum.

(Mixon 2002) studies determinants which explain the change in the implied volatility. The keys finds explain the short rates increase leads to decrease the volatility and vice versa. The volatility of options with 2-3-month maturity increases if the index price decreases. In our case, if the volatility increase, and the uncertainty also increases, after the FTSE 100 Index becomes more risky and investors would invest less in the nearest future. Since we assume that the US market is the dominant in the stock market, it means that the largest share of the US investors would abstain from investment in the UK market.

Chapter 3

METHODOLOGY

Our methodology can be summarized by the four stages: first, we get the data from Bloomber Terminal which gives an access to the database from the London Stock Exchange and the CBOE. We clean the data in order to have a clear data for our estimations. Second, we estimate the implied volatilities from the options of the FTSE100 Index. We estimate the market expectations about future stock market movements before and after Brexit referendum. Third, we estimate the change in connection of two markets before and after Brexit referendum by estimating the regression using a dummy variable. Dummy variable is a key indicator, which shows this change.

3.1 Data filtering

We get the daily database from Bloomber Terminal. We use two databases. The first we use to estimate option-implied volatilities. The second data consists of variables which are used for the regression.

We begin with the first data. The whole database includes: FTSE 100 Index close price, call options premiums, option strike prices, days to maturity, and risk-free rate (LIBOR). We filter our database in order to have a clear data with no omitted values. The data consist of 181 trading days from February till October in 2016. Weekends and holidays days are discarded from the sample. The set of all available call options prices are chosen with a horizon up to 9 months - the period of our research. Every option contract expired every third Friday of the each month. The same criteria was used by (Glatzer E., Scheicher M. 2003).

3.2. Implied volatility extraction

When the all sample is ready, we take "at-the-money" strike prices which are the most close to underlying asset price for each day. "At-the-money" is the situation when the current strike options price is the same as underlying asset price. The major part of the investors are concentrated in this value, thus there is the lowest volatility at this price. It is important because there is no intrinsic value and may have time value (amount of time which is remained until the expiration of the option contract). So when we take "at-the-money" option strike price, we have only one strike price for one correspond day.

The formula which is used to estimate the implied volatility is based on the standard Black-Scholes formula (1), which was shown earlier. The method which is used to derive IV is to determine a value such that the squared loss function between observed price and calculated Black-Scholes price is zero. In order to do this, we can use the Newton-Raphson method.

The software, that is used to estimate IVs, is MATLAB, Financial Toolbox. The variables that are used to estimate IVs are next:

- Strike option price
- Underlying asset price (FTSE 100 Index price)
- Risk-free interest rate (LIBOR)
- Time to maturity expressed in annual basis
- Call European option price

For now we get implied volatilities for each trading days with correspond variables.

3.3. Regression estimation

Once we get the IVs, we can estimate the main regression. The goal of the thesis is to estimate the change of connection between the US and UK stock exchange markets before and after Brexit referendum. It means that there are independent variables which may have a significant impact on implied volatilities. Now we are going to use the second database the components of which we get from Bloomberg Terminal. The following key variables of the regressions are:

- change in Implied volatility (ΔIV) is estimated in 3.2;
- risk-free rate (ΔRF) as LIBOR,
- exchange rate (ΔEX) of GBP/USD, ΔVIX,
- the US slope yield curve (ΔUSSL),
- S&P500 Index returns (ΔSP500)
- implied volatility of one period back ($\Delta\ IV_{t-1}$)

All these variables are must be stationary. Thus we use variables' changes. The delta (Δ) represents the difference between current period and previous period. In addition, in order to represent the change of connections between two markets, we use dummy (D) variable cross-terms with the variables. When the significant coefficients are got from the regression, we may say about the change in connection between two markets. The main regression is used by (Konstatidini 2016) and (Glatzer & Shneider 2003), thus we are going to replicate it using the UK and US markets instruments in our estimation. All these variables were chosen because they are used by the authors who study the predictability of asset returns.

$$\Delta IV_t = const + \beta_1 \Delta RF + \beta_2 \Delta EX + \beta_3 \Delta VIX + \beta_4 \Delta USSL + \beta_5 \Delta SP500 + \beta_6 \Delta IV_{t-1} + \beta_7 \Delta RF * D + \beta_8 \Delta EX * D + \beta_9 \Delta VIX * D + \beta_{10} \Delta USSL * D + \beta_{11} \Delta SP500 * D + \beta_{12} \Delta IV_{t-1} * D + \varepsilon_t \quad (3)$$

Where,

ΔIV – change in the implied volatility (t – (t-1))
ΔRF – change in risk free rate
ΔEX – change in exchange rate of GBP/USD
ΔUSSL – difference between Long-term bond (10-Year) and Short-term note (1-Year) of the US Treasury government bond yield
ΔVIX – change in Volatility Index quoted by CBOE
$\Delta\ IV_{t-1}$ – change of IV in period t-1
D – dummy variable "Change in connection" (0 - before Brexit; 1 - after Brexit)

Dummy variable is needed to show the change in connections between the US and UK markets.

3.4 Variables explanations

Before we begin to explain each variable, we would like to remind that our main goal is to estimate the change in connection between two markets, and not to explain the causality effect of each variable on another. It can be explained by our assumption about the existing of the unaddressed issues of possible endogeneity.

Risk-free rate. We expect the coefficient for the risk free rate will have a negative sign. Risk free rate is a disincentive leverage trading, thus the risk becomes less for the market. When risk free rate increase, it becomes more expensive for investors to invest, so the IV, as an indicator of potential future risk, will decrease.
Exchange rate GBP/USD have a positive relation to the FTSE 100. It is logically that if exchange rate increases, then the British pound becomes stronger, and IV will decrease because investors become more confident about the UK economy.

VIX is the US market volatility index (based on S&P 500 index), and we assume it has a positive effect on IV. If two markets are connected to each other due to market openness, thus any geopolitical or any other news may have a significant effect to the market. We suppose that the UK economy is attractive to the American investors as a stable market, therefore, the market volatility of the US market has the same direction of movement as UK market. On the other side, if the prevalent market anticipations are more pessimistic about Brexit, the VIX may negatively effect on IV. Because investors would like to leave the British market to US stock market, thereby implied volatility of the UK market would be a negative. To summarize, the effect of the VIX is an ambiguous, so the sign is also uncertain.

The US yield curve (USSL) represents future interest rate shapes and market activity – it is a difference between 10-Y US Treasury government bond and 1-Y US Treasury government note. Basically, longer maturity bonds have a higher yield, because investors are confident about market stability. In case when yield curve slope are becoming flatter or inverse, it indicates about the beginning of recession process in the economy. That is why a decreasing or increasing of slope indicates the market growth prospects, which, in turn, can attract or avert investors. If the entire US curve yield decrease, then there is an opportunity for investor to switch to another market for investments. One of such alternative market is the UK stock market. So if the USSL decrease, then investors may turn in the UK market, thereby make volatility to increase. However, if the investors come to the market, the expected volatility about the future should decrease, so IV will also decrease and it means that USSL has a positive effect on IV. To summarize, the effect of the USSL is an ambiguous, so the sign is also uncertain.

The interpretation of the return of S&P500 Index has the same idea as US curve yield. The returns represents the attractiveness for investors. If it becomes bigger, the investors would like to stay in the domestic market.

IV_{t-1} represents a simple logic - tomorrow's volatility will be the same as today's. Moreover, today's volatility has a significant impact on tomorrow's. We suppose it has the same effect on IV. However, when the shock occurs, then the implied volatility increases immediately, however, it should decrease over a time.

The null hypothesis in our research is: there is no a change of connection between the UK and US markets before and after Brexit referendum. We expect that each variable is statistically significant, and then we reject our null hypothesis (H_0) and may say there is a change in connection.

Table 1 represents the expected signs of the variables which were discussed above. The independent variables are listed in the first column. In addition, there are dummies variables which are presented below.

Table 1 Expected signs of the variables used for the model

Variable	Description	Expected effect
Variable represent the effect before Brexit referendum		
ΔRF	Risk-free rate	-
ΔEX	Exchange rate	+
ΔVIX	Volatility Index (US)	ambiguous
ΔUSSL	US Government bonds yield slope (Difference between 10Y and 1Y)	ambiguous
ΔSP500	S&P 500 returns	-
ΔIV_{t-1}	Implied volatility in period t-1	+
Dummies for each variable represent the effect after Brexit referendum		
D_ΔRF	Risk-free rate	-
D_ΔEX	Exchange rate	+
D_ΔVIX	Volatility Index (US)	ambiguous
D_ΔUSSL	US Government bonds yield slope (Difference between 10Y and 1Y)	ambiguous
D_ΔSP500	S&P 500 returns	-
D_ΔIV_{t-1}	Implied volatility in period t-1	+

Chapter 4

DATA DESCRIPTION

The daily option data of FTSE100 are chosen for this study. The data is obtained from Bloomberg Terminal which gives an access to the database from The London Stock Exchange and the Chicago Board Options Exchange (CBOE). The duration of observation is from Feb 1, 2016 to Oct 30, 2016. We do expect the structural break exists on the market after the Brexit referendum on May 23, 2016. It means after a "break point" we are going to estimate the change of connections between two markets. As we said in the Methodology part, we use Dummy variable, as an indicator of the change in connection. Thus, our sample is divided by 92 trading days (92 observations) before Brexit referendum day, and 89 days trading days (89 observations) after Brexit referendum day. The whole sample includes 181 trading days, so there are 181 observations. Every traded day includes contracts with maturities from 2 to 3 months. Options are expired every third Friday of the month. Holidays and weekends days were discard from the sample.

The data for the regression consists of changes in implied volatilities of call option prices (ΔIV), change in LIBOR rates for 2 and 3 months for corresponding day (as a risk free rate (ΔRF)), change in exchange rate (Great British Pound/United States Dollar- ΔEX), change in VIX (Volatility Index) - ΔVIX, the United States Slope (the difference between 10Y and 1Y US Treasury government bonds) -$\Delta USSL$, and S&P 500 Index returns ($\Delta SP500$). It was discussed earlier why we do use changes of the variables (Methodology part).

Table 2 represents the data descriptive statistics of the variables. The variables IV, RF, VIX and USSL are presented in pure format – without any changes there. It helps us to understand the nature of our database. The variables ΔEX and ΔSP500 are both presented in changes in order to show stationary data statistics.

Table 2. Descriptive statistics of the variables

	N	mean	sd	min	max	skew	kurt
IV	181	0.200	0.135	0.001	1.301	4.436	30.015
RF	181	0.004	0.0009	0.003	0.005	-0.6	1.636
ΔEX	181	-0.0008	0.010	-0.080	0.028	-2.787	24.219
VIX	181	15.332	3.287	11.340	28.140	1.640	5.774
USSL	181	1.124	0.106	0.890	1.340	-0.008	1.966
ΔSP500	181	0.0007	0.007	-0.035	0.023	-0.437	6.415

The highest implied volatility is depicted with a value 1.301. Figure 2 represents the implied volatility. As you can see, the high volatility is depicted not during the Brexit referendum in June, but during the October. We do assume that it can be explained by the market expectations about Presidential elections in the USA. However, we additionally check the impact of this volatility and do not see any significant changes in our estimations. Since the expectation about Brexit referendum brings the uncertainty in the market, it makes to depreciate British pound against US dollar. Thus the mean of the change in exchange rate (ΔEX) is negative, and, thereby, the skewness is negative (right-handed skewed). In addition, kurtosis represents the tails of the distribution which are quite wide (24.219). It means the uncertainty is huge.

One of the most interesting finding from the data descriptive is the negative skewness of ΔSP500 (-0.437). Usually the VIX and S&P500 are positive correlated, however, now it is an opposite cases. The Brexit referendum can explain this. The S&P 500 Index returns fall due to uncertainty of Brexit. The US and UK economy are the part of open economy, and market players gear up for negativity, thus the US stock market begin fall down even earlier than the referendum has been happened. The volatility (VIX), in turn, rocked up immediately. That is why there is a negative relationship between VIX and S&P500 Index. Figure 1 represents the dynamics of the S&P500 and VIX movements during February – October in 2016. In the beginning of July, the market expectation normalized and kept on moving with positive correlation between S&P500 and VIX.

After Brexit referendum the Risk free rate (RF) falls down, and thus we can observe using skewness with negative value (-0.6). Risk-free falling is represented in APPENDIX C Figure 3. Risk-free rate (LIBOR).

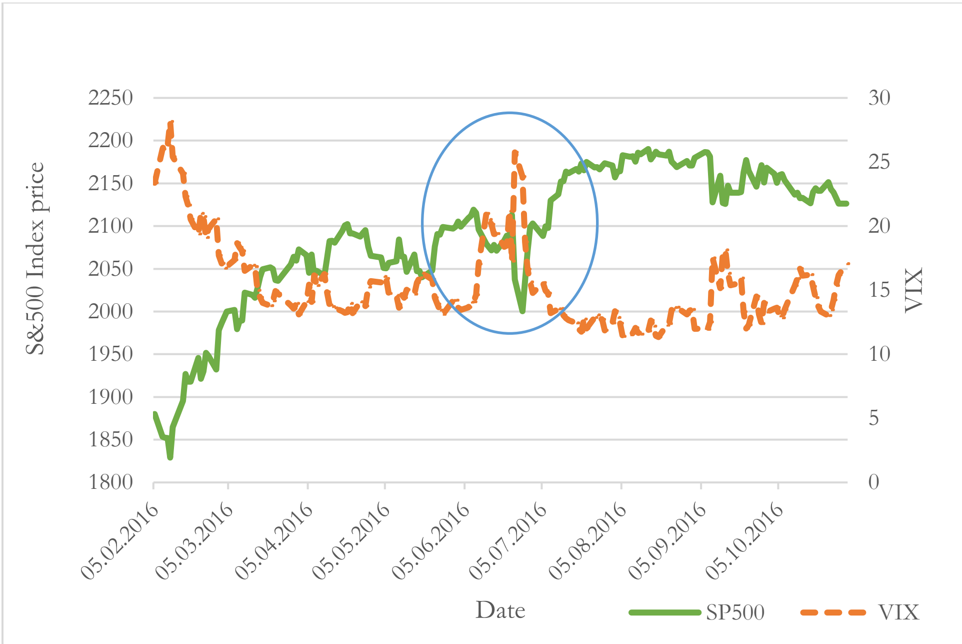

Figure 1. S&P500 Index prices and Volatility Index (VIX)

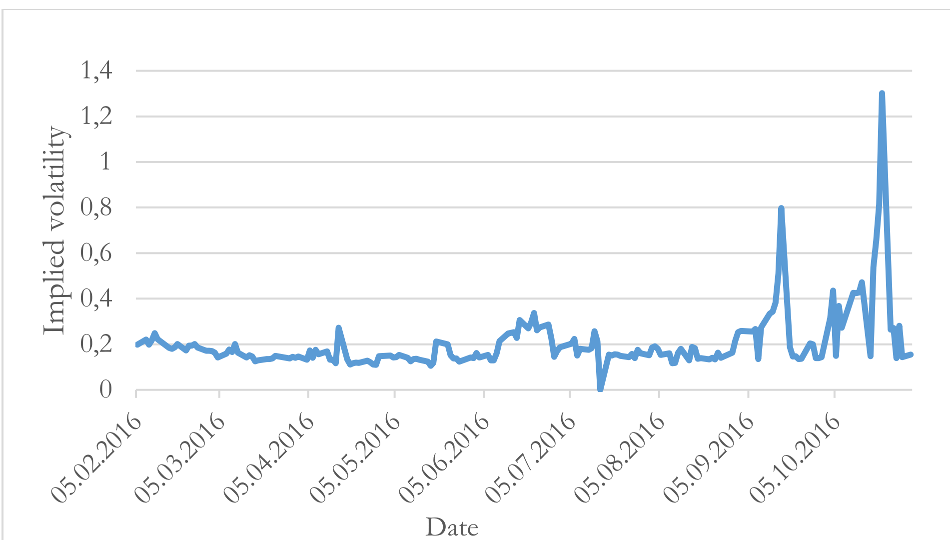

Figure 2 Implied Volatility (IV) values in February-October 2016

Chapter 5

ESTIMATION RESULTS

In this section, we would like to show the results of our thesis. But firstly, we would like to begin with explain some potential risks in our database which may effect on the results' quality, and respective the main conclusions of this thesis.

In order to have good quality results, the data, which is used, should be stationary. It means that an unconditional joint probability distribution of the stochastic process does not have any changes over a time. Other words, mean and variance of the variables are constant. Dickey-fuller test is applicable to test the data on stationarity. We check the key variables on the stationarity in order to use them in the regression. These variables are: change in implied volatility, change in exchange rate, S&P500 index returns, change in VIX, and change in risk-free rate. The results of stationarity is presented in APPENDIX B Table 7. Dickey-Fuller tests. When the stationarity is checked, we use the autoregressive vector model (VAR). VAR regression give the possibility to regress each dependent variable on lags of other dependent variable and on lags of itself. The results of VAR regression are presented in APPENDIX A Table 6. Vector Autoregressive model. These results are needed to estimate the Granger causality effect (Wald test) in order to understand the causation of each variable. This results will help us to understand the economic insights and check the endogeneity. The results of Granger causality effect are presented in Table 3. The most interesting findings are related to the ΔVIX which has a significant effect on the change in Exchange rate (ΔEX) and on the returns of S&P500 Index (ΔSP500). As we mention above, our key goal is not to describe the cause of relationships, but to understand the change in connection between the UK and the US markets. To summarize, these tests give the sure that we use the stationary data (using Dickey-fuller test) and check the endogeneity (using Granger causality effect).

Table 3 Granger causality Wald test

Equation	Excluded	Chi2	df	Prob>chi2
ΔIV	ΔVIX	1,545	2	0,462
ΔIV	ΔSP500	1,262	2	0,532
ΔIV	ΔRF	3,377	2	0,185
ΔIV	ΔEX	1,258	2	0,533
ΔIV	ALL	6,261	8	0,618
ΔVIX	ΔIV	1,443	2	0,486
ΔVIX	ΔSP500	1,583	2	0,453
ΔVIX	ΔRF	1,552	2	0,460
ΔVIX	ΔEX	0,765	2	0,682
ΔVIX	ALL	7,253	8	0,510
ΔSP500	ΔIV	0,442	2	0,802
ΔSP500	ΔVIX	6,242	2	0,044
ΔSP500	ΔRF	1,132	2	0,568
ΔSP500	ΔEX	0,996	2	0,608
ΔSP500	ALL	9,258	8	0,321
ΔRF	ΔIV	0,0006	2	0,999
ΔRF	ΔVIX	0,021	2	0,989
ΔRF	ΔSP500	0,072	2	0,964
ΔRF	ΔEX	0,308	2	0,857
ΔRF	ALL	0,368	8	0,989
ΔEX	ΔIV	0,017	2	0,991
ΔEX	ΔVIX	7,614	2	0,022
ΔEX	ΔSP500	3,705	2	0,157
ΔEX	ΔRF	1,062	2	0,588
ΔEX	ALL	9,813	8	0,278

When we check our data, we can represents our results.

Table 4 represents estimation results of the model. Independent variables are listed in the first column. The dependent variable is the change in implied volatility which is estimated three times. Estimated coefficients and standard errors (in parentheses) are reported. The significance of p-value is labeled by stars, which indicates the corresponded confidence interval, where * (one star) represents $p < 0.1$, ** (two stars) represent $p < 0.05$, *** (three stars) represents $p < 0.01$. In addition, Adjusted R-squared and number of observations are shown in the bottom.

The first regression represents the time before Brexit referendum May 23, 2016. The results shows that change in IV_{t-1} and the S&P500 Index returns are significant values and have an impact on ΔIV.

The second regression, which is designed in the third column, represents the time after Brexit referendum May 23, 2016. After Brexit referendum the LIBOR rate has been lowered, thus it has a significant effect on implied volatility. The most interesting thing is the effect of S&P500 Index returns become insignificant. We may ask what has happened and what does it mean? In order to answer on this question, we should appeal to investor psychology. The investor tends to invest in stable asset which can give the regular return. The UK economy is stable and related to the developed and progressive market with strong financial institutions. When the uncertainty occurs, investor is going to investigate the market and keep waiting the market reaction.

Table 4. Estimation results of the model

	Before referendum IV	After referendum IV	Full period IV
ΔRF	-0.228	-2.323***	-0.308
	(0.336)	(0.567)	(0.366)
ΔIV_{t-1}	-0.222**	-0.307	-0.197*
	(0.088)	(0.193)	(0.106)
ΔEX	-0.8	-0.582	-0.719
	(2.417)	(3.916)	(2.57)
ΔVIX	0.153	-0.632	0.367
	(0.345)	(0.706)	(0.407)
ΔUSSL	-0.228	1.09	0.414
	(0.2)	(0.867)	(0.418)
ΔSP500	-8.383**	-8.796	-7.609*
	(3.862)	(8.579)	(4.054)
D_ΔRF			-1.951***
			(0.658)
$D\_\Delta IV_{t-1}$			-0.098
			(0.226)
D_ΔEX			0.209
			(4.72)
D_ΔVIX			-0.926
			(0.84)
D_ΔUSSL			0.127
			(0.117)
D_ΔSP500			-1.3
			(9.564)
Constant	0.313	-1.038	-0.465
	(0.239)	(0.857)	(0.505)
Observations	92	89	181
Adjust R-squared	0.139	0.117	0.114

Note: Dependent variable: Implied Volatility (IV) of FTSE 100 Index. Standard errors in parentheses. Significance codes: * p<0.1, ** p<0.05, *** p<0.01

Before Brexit referendum financial markets were more optimistic, the FTSE 100 increased and the returns grew up correspond. Furthermore, the GBP was depreciating since the end of 2015, British goods and services became cheaper, and UK financial market became a dainty piece for investors in spite of potential risk of Brexit. However, when the Brexit referendum exists, the US investors became more pessimistic about British economy and it leads to the disintegration of the UK economy with the US economy. This effect is represented in insignificance of the S&P500 Index returns.

Table 5 indicates the correlation relationship among variables which are used in the regression. The correlation between the returns of ΔVIX and ΔS&P500 are negative. Figure 1 depicts the increase of VIX and decline of S&P500 one week before and after Brexit referendum. Moreover, there is a positive correlation between change in RF and change in EX. When risk free rate increases, the exchange currency pair GBP/USD also grows up, because British pound becomes stronger.

The change in risk-free rate (ΔRF) negatively correlates with the change in implied volatility (ΔIV) of the FTSE 100 Index. Increase of risk-free rate makes it more expensive to invest, so the volatility of the market becomes decline. In turn it decreases the option-implied volatility.

Table 5. Correlation among model variables

	ΔIV	ΔIV_{t-1}	ΔRF	ΔVIX	ΔUSSL	ΔEX	ΔSP500
ΔIV	1						
ΔIV_{t-1}	-0.263	1					
ΔRF	-0.239	0.064	1				
ΔVIX	0.170	-0.138	-0.165	1			
ΔUSSL	-0.034	-0.033	0.066	0.005	1		
ΔEX	-0.097	0.036	0.036	-0.395	0.061	1	
ΔSP500	-0.197	0.068	0.153	-0.823	0.039	0.475	1

Chapter 6

CONCLUSIONS

In this thesis I investigate the change in connection between the UK stock market expectations and the US stock market returns caused by Brexit referendum which was held on June 23, 2016. To the best of my knowledge this question has not been covered in the literature. To gauge the UK stock market expectations, I calculate implied volatility of the FTSE 100 index in the period starting five months before and ending four months after the referendum. To keep my analysis "clean" it stops right before the 2016 US presidential elections. The change in connection is estimated by the OLS regression where the independent variable is the change in option-implied volatility.

My main finding, is that Brexit referendum is associated with the significant change on how the US stock market returns affects UK stock market expectations. Specifically, S&P 500 returns have negative statistically significant effect on implied volatilities before Brexit referendum. However, there is the insignificant effect after the referendum. This change happened because of uncertainty from investors' side about the future of the UK economy, and worries about business reallocations from the UK. Thus the UK and US stock markets became less integrated in June-October period in 2016.

My secondary finding is that British Risk-free rate (LIBOR) started to negatively affect the implied volatility of the FTSE 100 Index after Brexit referendum. Decline of risk-free rate makes it cheaper to invest, increasing Sharpe ratios of equity portfolios, and causing portfolio reallocations. In turn it increases expected volatility (measured by option-implied volatility).

Providing Dickey-Fuller test allows to check the stationarity of data for our estimations. The results show that the variables are stationary for estimations.

However, Granger causality test shows the existing problem of variables endogeneity. Due to data limitations there was no possibility to find appropriate instrumental variables, which is both the limitation of our findings and a motivation for future research.

In addition, we noticed negative correlation between S&P 500 and VIX one week before and one week after the Brexit referendum, which should be studied in future research perhaps with high-frequency data.

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APPENDIX A

VECTOR AUTOREGRESSIVE MODEL RESULTS

Table 6 Vector Autoregressive model results

Equation	Parms	RMSE	R-sq	chi2	P>chi2
IV	11	0,314078	0,1123	13,15594	0,2151
VIX	11	0,089148	0,0803	9,083468	0,5242
SP500	11	0,007444	0,0921	10,5491	0,3937
RF	11	0,043313	0,131	15,67705	0,1093
EX	11	0,010347	0,1184	13,96817	0,1744

		Coef.	Sd.er.	z	P>|z|	95% conf. Interval	
IV	IV						
	L1.	-0,192	0,087	-2,200	0,028	-0,363	-0,021
	L2.	0,074	0,088	0,840	0,400	-0,099	0,248
	VIX						
	L1.	0,933	0,899	1,040	0,299	-0,829	2,695
	L2.	-0,528	0,695	-0,760	0,448	-1,889	0,834
	SP500						
	L1.	4,144	8,961	0,460	0,644	-13,419	21,707
	L2.	-7,449	7,316	-1,020	0,309	-21,787	6,890
	RF						
	L1.	0,452	0,721	0,630	0,531	-0,961	1,864
	L2.	1,465	0,797	1,840	0,066	-0,098	3,028
	EX						
	L1.	4,373	4,196	1,040	0,297	-3,850	12,596
	L2.	1,882	3,886	0,480	0,628	-5,734	9,498
	cons	0,079	0,032	2,420	0,015	0,015	0,142

Table 6 (continued)

VIX							
	IV						
	L1.	-0,030	0,025	-1,200	0,230	-0,078	0,019
	L2.	-0,008	0,025	-0,300	0,761	-0,057	0,042
	VIX						
	L1.	-0,128	0,255	-0,500	0,615	-0,629	0,372
	L2.	0,373	0,197	1,890	0,059	-0,013	0,759
	SP500						
	L1.	0,069	2,544	0,030	0,978	-4,916	5,054
	L2.	2,613	2,076	1,260	0,208	-1,457	6,683
	RF						
	L1.	0,248	0,205	1,210	0,225	-0,153	0,649
	L2.	0,160	0,226	0,710	0,479	-0,283	0,604
	EX						
	L1.	0,578	1,191	0,490	0,627	-1,756	2,913
	L2.	0,837	1,103	0,760	0,448	-1,325	2,998
	cons	-0,009	0,009	-0,990	0,324	-0,027	0,009

SP500							
	IV						
	L1.	0,001	0,002	0,320	0,745	-0,003	0,005
	L2.	-0,001	0,002	-0,490	0,624	-0,005	0,003
	VIX						
	L1.	0,005	0,021	0,210	0,830	-0,037	0,046
	L2.	-0,041	0,016	-2,500	0,012	-0,073	-0,009
	SP500						
	L1.	-0,105	0,212	-0,500	0,620	-0,522	0,311
	L2.	-0,283	0,173	-1,630	0,103	-0,623	0,057
	RF						
	L1.	-0,016	0,017	-0,920	0,358	-0,049	0,018
	L2.	-0,016	0,019	-0,840	0,402	-0,053	0,021
	EX						
	L1.	-0,052	0,099	-0,520	0,600	-0,247	0,143
	L2.	-0,081	0,092	-0,880	0,377	-0,262	0,099
	cons	0,001	0,001	1,690	0,091	0,000	0,003

Table 6 (continued)

RF							
	IV						
	L1.	0,000	0,012	0,000	1,000	-0,024	0,024
	L2.	0,000	0,012	-0,030	0,980	-0,024	0,024
	VIX						
	L1.	-0,018	0,124	-0,150	0,884	-0,261	0,225
	L2.	0,001	0,096	0,010	0,994	-0,187	0,188
	SP500						
	L1.	-0,292	1,236	-0,240	0,813	-2,714	2,130
	L2.	0,128	1,009	0,130	0,899	-1,850	2,105
	RF						
	L1.	-0,356	0,099	-3,590	0,000	-0,551	-0,162
	L2.	-0,234	0,110	-2,130	0,033	-0,450	-0,019
	EX						
	L1.	0,321	0,579	0,560	0,579	-0,813	1,455
	L2.	0,010	0,536	0,020	0,986	-1,041	1,060
	cons	-0,002	0,004	-0,360	0,722	-0,010	0,007

EX							
	IV						
	L1.	0,000	0,003	0,100	0,922	-0,005	0,006
	L2.	0,000	0,003	-0,060	0,949	-0,006	0,006
	VIX						
	L1.	0,048	0,030	1,630	0,103	-0,010	0,106
	L2.	-0,054	0,023	-2,340	0,019	-0,098	-0,009
	SP500						
	L1.	0,204	0,295	0,690	0,490	-0,375	0,782
	L2.	-0,431	0,241	-1,790	0,074	-0,903	0,041
	RF						
	L1.	-0,023	0,024	-0,990	0,323	-0,070	0,023
	L2.	-0,017	0,026	-0,630	0,525	-0,068	0,035
	EX						
	L1.	-0,230	0,138	-1,670	0,096	-0,501	0,041
	L2.	-0,086	0,128	-0,670	0,500	-0,337	0,165
	cons	0,000	0,001	-0,160	0,877	-0,002	0,002

APPENDIX B

DICKEY-FULLER TESTS

Table 7 Dickey-Fuller tests

ΔRF Augmented Dickey-Fuller test for unit root

	Test Statistics	1% Critical value	5% Critical value	10% Critical value		
Z(t)	-3,042	-3,73	-2,992	-2,626		
D2.RF	Coef.	Std. Err	t	P>t	[95% Conf.	Interval]
LD.	-1,979	0,650	-3,04	0,006	-3,322	-0,636
LD2.	0,270	0,510	0,53	0,602	-0,783	1,323
L2D2.	0,014	0,231	0,06	0,950	-0,463	0,493
cons	-0,011	0,008	-1,25	0,225	-0,029	0,007

ΔIV Augmented Dickey-Fuller test for unit root

	Test Statistics	1% Critical value	5% Critical value	10% Critical value		
Z(t)	-5,033	-3,73	-2,992	-2,626		
D2.RF	Coef.	Std. Err	t	P>t	[95% Conf.	Interval]
LD.	-2,778	0,552	-5,03	0	-3,918	-1,639
LD2.	0,682	0,409	1,67	0,108	-0,162	1,527
L2D2.	0,274	0,175	1,56	0,132	-0,088	0,636
cons	0,112	0,067	1,66	0,11	-0,027	0,253

Table 7 (continued)

ΔS&P500 Augmented Dickey-Fuller test for unit root

	Test Statistics	1% Critical value	5% Critical value	10% Critical value		
Z(t)	-4,066	-3,73	-2,992	-2,626		
D2.RF	Coef.	Std. Err	t	P>t	[95% Conf. Interval]	
LD.	-3,099	0,762	-4,07	0	-4,672	-1,526
LD2.	0,622	0,534	1,16	0,256	-0,481	1,727
L2D2.	0,242	0,232	1,05	0,306	-0,236	0,722
cons	-0,003	0,001	-1,55	0,134	-0,007	0,0009

ΔVIX Augmented Dickey-Fuller test for unit root

	Test Statistics	1% Critical value	5% Critical value	10% Critical value		
Z(t)	-3,838	-3,73	-2,992	-2,626		
D2.RF	Coef.	Std. Err	t	P>t	[95% Conf. Interval]	
LD.	-2,845	0,741	-3,84	0,001	-4,375	-1,315
LD2.	0,433	0,529	0,82	0,421	-0,659	1,527
L2D2.	0,216	0,253	0,85	0,401	-0,306	0,740
cons	0,020	0,020	1,02	0,316	-0,020	0,061

ΔEX Augmented Dickey-Fuller test for unit root

	Test Statistics	1% Critical value	5% Critical value	10% Critical value		
Z(t)	-2,29	-3,73	-2,992	-2,626		
D2.RF	Coef.	Std. Err	t	P>t	[95% Conf. Interval]	
L1.	-2,394	1,045	-2,29	0,032	-4,558	-0,231
LD.	0,992	0,925	1,07	0,295	-0,922	2,908
L2D.	0,749	0,542	1,38	0,18	-0,372	1,871
_cons	-0,0047	0,003	-1,49	0,15	-0,011	0,001

APPENDIX C

RISK-FREE RATE (LIBOR)

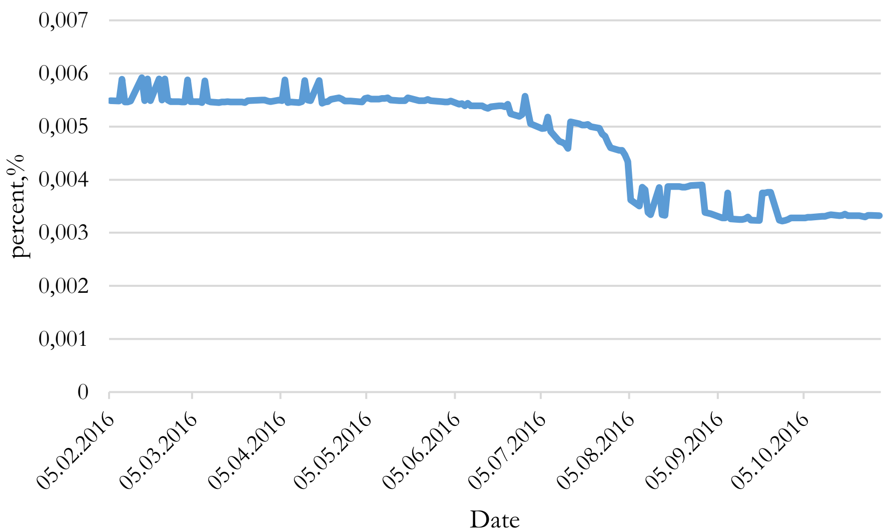

Figure 3 Risk-free rate (LIBOR) in February-October 2016.