LAPPEENRANTA-LAHTI UNIVERSITY OF TECHNOLOGY LUT
School of Engineering Science
Degree Program in Computational Engineering and Analytics
Bachelor's Thesis

Marcus Palmu

Investigating the impact of Brexit on the exchange rate volatility of the pound sterling with respect to the Euro and the US dollar

Supervisor: Christoph Lohrmann, PhD

ABSTRACT

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This thesis investigates did Brexit affect on the exchange rate volatility of the British pound sterling towards the Euro (GBP/EUR) and towards the U.S. dollar (GBP/USD). The observed time frame is from January 2011 to December 2019. The investigation is implemented using a decision tree classifier for predicting if the monthly exchange rate volatility is above or below its historic average. From which the predictor importance of Brexit related variables is measured. In addition, this thesis investigates are the Brexit related variables more important than other variables in predicting the exchange rate volatility and how did Brexit affect the prediction. The results of this research show that the most important variable in the prediction of the both models was the monthly percentage change of the last month's exchange rate. According to the model used in this thesis, Brexit had no importance in predicting the exchange rate volatility of the GBP/EUR and the GBP/USD. However, interpreting the time series data with support of an earlier research Brexit had indirect influence to the exchange rate volatilities through the other explanatory variables. The referendum on Brexit affected on the exchange rate volatility for both the GBP/EUR and the GBP/USD during the month the referendum was held.

TIIVISTELMÄ

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Marcus Palmu

Tutkimusta Brexitin vaikutuksesta Englannin punnan vaihtokurssin volatiliteettiin suhteessa euroon ja Yhdysvaltain dollariin

Kandidaatintyö

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Tässä opinnäytetyössä tutkitaan, että vaikuttiko Brexit vaihtokurssien volatiliteetteihin puntaa euroa kohden (GBP/EUR) ja Yhdysvaltain dollaria kohden (GBP/USD). Tarkasteltava aikaväli on vuoden 2011 tammikuusta vuoden 2019 joulukuuhun. Tutkimus toteutettiin käyttäen päätöspuuluokittelijaa ennustamaan oliko kuukausittainen vaihtokurssien volatiliteetti yli vai alle niiden historiallisen keskiarvon. Brexit-aiheisten ennustajamuuttujien tärkeys mitataan tätä arvoa käyttäen. Lisäksi, tässä työssä tutkitaan ovatko Brexit-aiheiset muuttujat tärkeämpiä kuin muut muuttujat vaihtokurssien volatiliteetin ennustamisessa, sekä miten Brexit vaikutti ennustamiseen. Tutkimuksen tulokset osoittivat, että tärkein muuttuja ennustamiseen molemmille malleille oli viime kuukauden vaihtokurssien kuukausittainen prosentuaalinen muutos. Tässä opinnäytetyössä käytetyn mallin mukaan, Brexitillä ei ollut vaikutusta GBP/EUR:n ja GBP/USD:n vaihtokurssien volatiliteettien ennustamisessa. Kuitenkin tulkitsemalla aikasarjadataa Brexitillä oli epäsuoraa vaikutusta muiden muuttujien kautta vaihtokurssien volatiliteetteihin. Lisäksi, aikaisempi tutkimus aiheesta tuki tätä havaintoa. Kansanäänestys Brexitistä vaikutti sekä GBP/EUR:n, että GBP/USD:n vaihtokurssien volatiliteetteihin sinä kuukautena, kun kansanäänestys pidettiin.

Contents

LIST OF ABBREVIATIONS **6**

1 INTRODUCTION **7**

1.1 Background 7

1.2 Research questions and objectives 9

1.3 Research methods and structure 10

2 LITERATURE REVIEW **11**

3 METHODS **13**

3.1 Data pre-processing 13

3.2 Decision tree classifier 14

4 DATA **18**

4.1 Software 18

4.2 Explanatory and dependent variables 18

4.3 Training Procedure 22

5 ANALYSIS AND RESULTS **23**

5.1 Data analysis 23

5.1.1 Results of the pound sterling towards the Euro 34

5.1.2 Results of the pound sterling towards the U.S. dollar 36

6 DISCUSSION **38**

7 CONCLUSION **39**

References **41**

List of Tables **46**

List of Figures **47**

List of abbreviations

Brexit	The United Kingdom's leave from the European Union ("Britain exit")
GBP	British pound sterling
EU	European Union
EUR	Euro (European Monetary Unit)
UK	United Kingdom
USD	United States dollar

1 INTRODUCTION

1.1 Background

On the 25th of June 2015 the current Prime Minister of the UK, David Cameron, proposed an in/out referendum for the continuation of the United Kingdom's membership in the European Union (European Union 2020a). This measure is commonly known as *"Brexit"*, which is an amalgamation of *"Britain"* and *"exit"* referring to the United Kingdom's leave from the European Union (Lawrence 2019). Brexit originates from the idea of the UK getting control of its own political decisions. The hypothetical reason for Brexit is that the UK government was worried about increasing immigration and incoming foreign culture induced by the EU membership. The UK government had stated that the United Kingdom's economy cannot perform investments in infrastructure and public services to manage with the growth of population. (Gietel-Basten 2016) This statement might have concerned the increasing immigration ensued of the EU membership.

The European Council agreed to find solutions for the UK's competitiveness, sovereignty, economic governance, social benefits and free movement. The leaders of the European Union negotiated and agreed to reinforce the UK's special status in the European Union. All of the 28 leaders agreed on this agreement making it a *"legally binding and irreversible decision"*. (European Union 2020a) According to the agreement whether Brexit is conducted, the arrangements for the special status of the United Kingdom do not apply anymore after the referendum (European Council 2016).

The referendum was held on the 23rd of June 2016 followed by the decision on if the UK would stay or to leave the EU (European Union 2020a). The citizens of the United Kingdom voted to leave the EU of which 51.9% of the votes were for *leave* and 48.1% for *remain*. The collective number of accepted votes were 33,551,983 votes. Three out of twelve of the majority in the regions in the UK voted for *remain*. Brexit opposing regions were London, Scotland and Northern Ireland. The rest of the regions voted for *leave*. (The Electoral Commission 2019)

A study by Shaw et al. (2017) states that the possible reason for voters being in favour with Brexit was that the campaign for *leave* was more justified than the opposing campaign. Brexit favouring campaign had more coherent message throughout the debates. The favouring side of Brexit brought up themes that viewed grievances of the membership in the EU of their concern, such as immigration, trading policy and expenses in the EU. They stated that with Brexit the UK would have their own decisions on trading policy and immigration, the quality

of living and employment would increase and that the UK is wealthy enough to manage without the EU. (Shaw et al. 2017)

After the results of the referendum David Cameron instantaneously resigned from the role of the Prime Minister. Additionally, when the results came out the value of pound sterling against the Euro decreased over 9 percent. (Exchange Rates UK 2020) The British pound sterling's exchange rate has not dropped so low since 1985 (Broad 2016), whereas the value of the United States dollar was higher against other currencies at the time (The Scotsman 2019).

Since Brexit is implemented, there is a possibility that Scotland will separate itself from the United Kingdom. In 2014 Scotland had a referendum whether it should be independent, with a result of remaining in the UK. The majority of Scotland wanted to remain in the EU, therefore there might be another referendum regarding Scotland's independence. (Begg 2016) Additionally, Britain may start paying customs tariffs and operate with trade barriers while trading with the EU, which means that the UK will mislay access to the world's largest trading union, unless the UK and the EU can agree on a trading deal (Abboushi 2018).

In Figure 1 is a detailed timeline depicting some of the events mentioned on the website of the *Council of the European Union* which are later on referred as *main events*. The time of the events are from the beginning of 2015 until the end of 2019. The events are presented as Brexit deal events which support the acts of leaving the EU with a deal and as Brexit no-deal events which support the acts of leaving the EU without a deal.

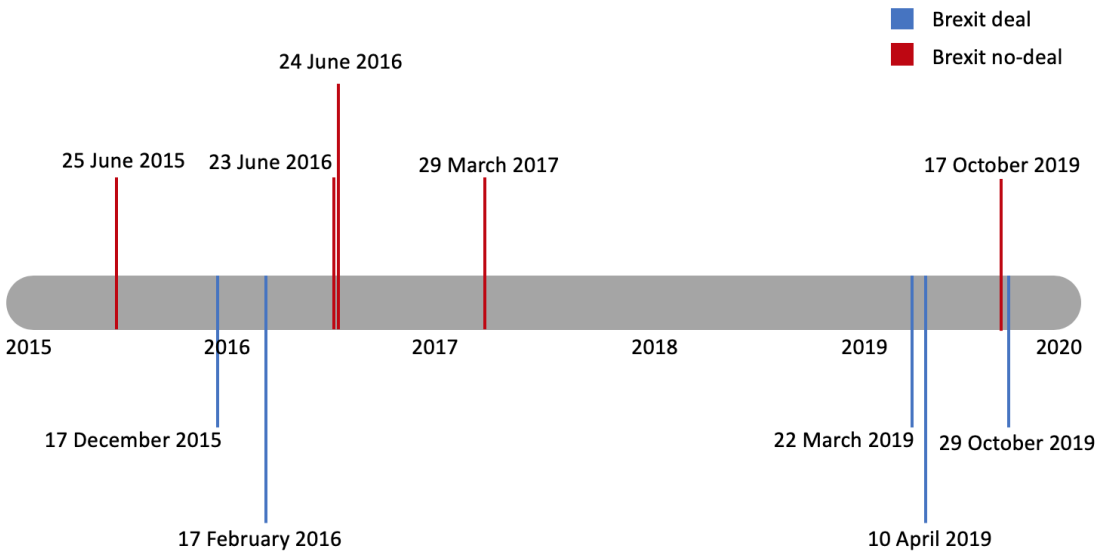

Figure 1. Timeline of the main events during Brexit.

Events in timeline:

- 25 June 2015 - The UK Prime Minister proposes for an in/out referendum for the European Council.
- 17 December 2015 - The European Council agreed to find solutions for the UK's areas of concern at the February meeting.
- 17 February 2016 - Leaders of the EU agreed to improve the UK's special status in the EU.
- 23 June 2016 - The UK referendum
- 24 June 2016 - The results of the referendum (European Union 2020a)
- 29 March 2017 - The UK informs the European Council of its intention of leaving the EU by actuating the Article 50.
- 22 March 2019 - The European Council accepts the UK's request of Brexit extension.
- 10 April 2019 - Leaders of the EU agreed upon delaying Brexit until 31 October.
- 17 October 2019 - The European Council signs the agreements which promotes the UK's resignation of the EU.
- 29 October 2019 - The European Council accepts another request of Brexit extension from the UK. (European Union 2020b)

This thesis evaluates Brexit's impact on the exchange rate volatility of the GBP (British pound sterling). The exchange rate volatility is explained using macroeconomic variables, Brexit related news and events which are assorted in its deal and no-deal factors and Brexit as a time period, dividing it to before and during Brexit. The monthly exchange rate volatility of the GBP with respect to the USD (the United States dollar) and the EUR (Euro) are classified using a decision tree whether the volatility is above or below the historic average volatility.

1.2 Research questions and objectives

This research on the exchange rate volatility with consideration of Brexit and Brexit related news is implemented, since only few research works focused on the recent Brexit decision and development. The objective is to investigate did Brexit have an influence on the volatility of the GBP towards two major global currencies (EUR, USD) and how it affected. The

intention is to answer the research questions, which are presented next. The main research question is

- *Does Brexit contribute to the exchange rate volatility of the GBP to the USD and the GBP to the EUR?*

The sub-questions can be derived from the main research question which are

- *Which variables are important in classifying the volatility of the exchange rate of the GBP to the USD and the GBP to the EUR?*
- *Are Brexit related variables more important for the classification than the other macroeconomic variables considered in this study during the time period of investigation?*

The final outcome of this thesis is to see whether Brexit and Brexit related events are important factors in the classification model in predicting whether the exchange rate volatility is above or below the historic average. Additionally, the outcome is to see were any of the factors more important than others and how they affected the model's prediction. On the basis of the current information, there are not many conducted researches so far investigating the possible impact of Brexit on the exchange rate volatility of the GBP towards the EUR and USD.

1.3 Research methods and structure

The theoretical background research is implemented utilising qualitative methodologies. The analytical structure is done with quantitative empirical research using time series data. More detailed depiction of the research methods is viewed in the methods chapter.

This report is divided into seven main chapters. The following chapter is the literature review, which provides an understanding of what macroeconomic factors have influence on the exchange rate volatility and how has Brexit generally affected Great Britain's economy. In the methods section the data pre-processing, the decision tree and the confusion matrix are introduced. The data in this study, including the dependent variable, the selected explanatory variables and the computational application are described in the fourth chapter. The computation using decision trees and the analysis of the results are introduced in the fifth chapter. The sixth chapter includes the assessment of the results and the discussion with respect to the research questions. The conclusions of the research are presented in the last chapter.

2 LITERATURE REVIEW

The existing Brexit related scientific studies investigate the impact of Brexit on social contributions (Hill and Bradley 2019) and health services (Griffiths and Norman 2018), border crossing between the UK and the EU (International Financial Law Review 2017), European security policy (Naumescu and Nicolescu 2018), financial services and trading between the UK and the EU (Rehman and Della Posta 2018) and the macroeconomic impact of Brexit on Ireland (Bergin et al. 2017). The researches that investigate the effect of Brexit on the financial and economic sectors mainly focuses on trading and stock markets (Breinlich et al. 2018).

According to a recent report by Driffield and Karoglou (2019), Brexit affects the exchange rate of the UK giving it predicament, resulting in uncertainty and depreciation of currency. Therefore, devaluation of currency should be implemented for allowing inexpensive investments. (Driffield and Karoglou 2019) Currency devaluation is a deliberate reduction of the exchange rate, thereby decreasing the value of the home country's currency against other currencies (Statt 1999). Interest rates are used for capital control and by increasing interest rates will more likely reduce investments, which influences to long-term growth (El-Shagi 2010). Ibarra (2011) states that foreign direct investment (FDI) and portfolio investment have significant increasing influence on the recipient country's currency (Ibarra 2011). This could be interpreted that Brexit has influence indirectly to the exchange rate volatility affecting the explaining variables of the volatility in this research.

It is uncertain to determine unilaterally the effects of Brexit, since different resources have various interpretations. The UK's stock market's reaction to Brexit affected the banking sectors severely (Ramiah et al. 2017). However, a scientific article from early 2018 states that the UK banking sector is capable of managing Brexit related incidents providing that there will be no restrictions in immigration law and human capital mobility (Samitas et al. 2018). However, it must be taken into account that Brexit had not yet been completed during the time period that is examined in this research. Therefore, the statement of the article by Samitas et al. (2018) cannot be entirely verified.

A recent research by Korus and Celebi (2019) on the influence of Brexit news on the exchange rate volatility of the GBP towards the EUR and USD states that the referendum and other Brexit events had a significant impact on the exchange rate volatility of the GBP towards the EUR. The research has separated the Brexit events into *good* and *bad* news with a total of 17 events. (Korus and Celebi 2019) Interpreting the justification of the separation of the Brexit news is that the good news are events where the Brexit implementation seems simple and the bad news are the events where the implementation seems arduous.

The research was implemented using regression analysis including data for a bit over 5-year time range. The explanatory variables included with the Brexit news variables, three-month overnight index swap (OIS) rates, 10-year government benchmark bond yields, Citigroup economic surprise indices (CESI), stock market indices and monetary surprise rates. (Korus and Celebi 2019)

The results of the research indicated that Brexit had an impact on the exchange rate volatility of the GBP towards both the EUR and the USD. The Brexit news affected only the exchange rate volatility of the GBP against the EUR. The good Brexit news had higher influence on the exchange rate volatility than the bad Brexit news. (Korus and Celebi 2019)

Besides Brexit, predicting exchange rates is difficult to implement with absolute precision. The nature of the factors that influence on exchange rate regime, may change over time. One factor may have more significance in predicting the exchange rate in a finite time period than the other factors. (Russell 2012) According to Flood and Rose (1999), macroeconomic fundamentals are insignificant in explaining the volatility of the exchange rate, except in long-term review or in countries with high inflation rates (Flood and Rose 1999).

According to a research by Hnatkovska et al. (2013), domestic interest rates have a varied effect on the exchange rate. While the interest rate increases between minor and moderate amounts the exchange rate increases as well. However, when the interest rate increases with large rates it has an opposite effect on the exchange rate. (Hnatkovska et al. 2013) These results indicate that the interest rate has influence on the exchange rate.

When inflation greatly influences on money, bonds and the domestic interest rate relative to foreign and domestic currency bonds, the macroeconomic variables have low explanatory importance. While on the contrary, postulating that the inflation rate variation is not substantial during the finite time period, the variation of the nominal variables is stable. Therefore, the variables would not explain the volatility of the exchange rate. (Flood and Rose 1999) The time period of the inflation rate in this research is finite, meaning that it may give explanation of how other variables act when explaining the exchange rate volatility.

The United Kingdom has a floating exchange rate which means that its exchange rate is determined by the market (Zhang et al. 2007). It is difficult to determine the absolute correct method in examining the volatility of the floating exchange rate, since various researches lead to contradicting results. One research states that it is difficult to explain the floating exchange rate with macroeconomic factors such as money supply and interest rates. This has been a problem without any absolute solutions for a longer time in international economics. (Engel and West 2005) A different research states that countries with a floating exchange

rate are more volatile than with fixed rates considering when using macroeconomic variables in explanation of the volatility (Flood and Rose 1999).

3 METHODS

3.1 Data pre-processing

The data used in this report is financial time series data. The values in the time series data utilised in the classification and calculation are converted into daily percentage changes from the daily data using Equation 1 where $\%\Delta x$ is the percentage change, x is the current value and x_p is the previous value.

$$\%\Delta x = \frac{x - x_p}{|x_p|} \cdot 100 \tag{1}$$

Then the standard deviation is calculated for every month starting from the current's month 16th date to the next month's 15th date, which is then marked as the current month's value. This is implemented for the data of the explanatory variables end on the 15th date of a month.

The monthly data of the macroeconomic variables are converted into monthly percentage changes using the same methods as for the daily values mentioned above. If the data of the daily percentage changes has any missing values, they are interpreted as *no-daily change* in the calculation. In other words, the missing current value of the percentage change is set as the percentage change of the previous value, giving it a change of zero percent.

The Brexit related events are manually separated into different classes based on their subject contents. The variable for mentioning if the Brexit is ongoing or not are valued as *0* for before Brexit and *1* for during Brexit. The values of the Brexit related events are the amount of the events occurred during the month. The number of events supporting the deal and no-deal events are separated into their own columns.

Once the data is converted into a form, where the time labels of each variable match and the monthly percentage changes are calculated, the data is aggregated into one matrix including all explanatory variables. Thereafter, the data is pre-processed for fitting the decision tree model and for predicting the exchange rate volatility. The decision tree is viewed in more detail in the next section.

3.2 Decision tree classifier

The model used in this research for the investigation of the exchange rate volatility is a binary decision tree for classification. Classification is supervised learning that allocates objects into classes exploiting labelled data (Runkler 2016). In supervised learning the model is trained with a training set of data providing it with a class label or a cost for each pattern (Duda et al. 2001). The model profiles and charts the patterns that are hidden in the data. The known values of input attributes are used to make a model that predict the values of the target attributes. (García et al. 2015)

A decision tree in classification is a directed acyclic graph which has one node with no incoming arcs and the rest of the nodes have exactly one incoming arc. The node with no incoming arcs is called a *root node* or *root* for short and the nodes with no outgoing arcs are called *leaves*. The solution represents the path of the arcs from the root to one of the leaf nodes. (Poole and Mackworth 2010) The pattern of the classification model with nominal data is commonly formed in a method where the dividing branches can be presented as questions. In other words, the alternatives of the division can be implemented as *true/false* or *yes/no*, which represents the answers of the question. The next phase in the decision tree depends on results of the previous question. (Dougherty 2013)

A binary tree is a decision tree which has only two outgoing arcs of its nodes, where the nominal attributes are implemented while utilising two subsets. However, if the nominal attributes are in many categories they are aggregated into two classes to enable binary decision making. For numeric attributes the binary splitting requires always a restricted amount of two subsets, which are represented by tests of $att \leq \Delta$ and $att > \Delta$. (Barros et al. 2015)

Figure 2 shows an example of a binary decision tree. The node a_0 represents the root node, nodes a_2, a_3, a_5 and a_6 represent the internal nodes, and the rectangular nodes represent the leaves. Each leaf represents one of the classes, and all observations following the rules set by the decision tree are then assigned to that class. (Barros et al. 2015)

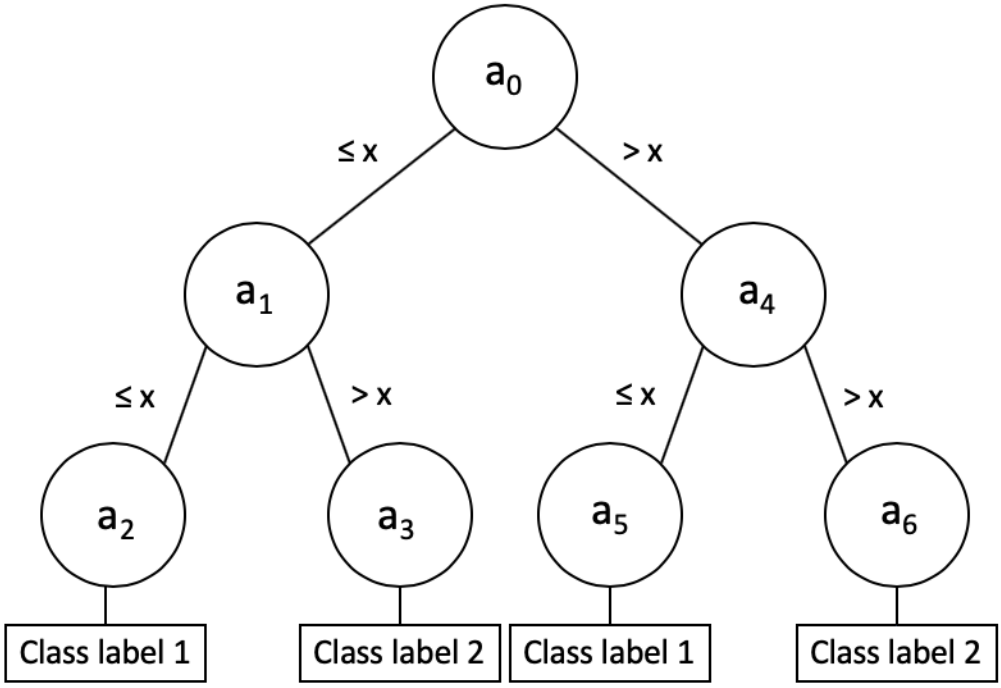

Figure 2. Example of a binary decision tree.

Supervised learning is used to fit a model which can be utilised for future predictions (Poole and Mackworth 2010). A simplified algorithm of decision tree induction is presented below.

- Input: Dataset
- Output: Classification model
- 1: Create a split for the current node.
- 2: Evaluate the split with an evaluation measure of purity.
- 3: If current split is better than the best split, set it as a candidate split.
- 4: Repeat steps 1 - 3 until *Dataset* has no more attributes.
- 5: If stop criteria is met, create a leaf node and add it to the tree Else split the dataset by the best split and recursively return to step 1 for each arc of the node.

The split can be evaluated for example using the *Gini index*, which is an evaluation measure of purity. (Suknovic et al. 2012) The formula of the Gini-index is shown in Equation 2, where Sigma is the sum over total classes i at the node and p_i is the probability of an attribute being classified to a particular class.

$$Gini = 1 - \Sigma_{i=0}^{n} p_i^2 \tag{2}$$

A node with only one class is called a *pure node* which has a Gini index of 0, otherwise the Gini index is positive. Or the split can be evaluated using *node error* where p_j is the probability of the class with the largest number of training samples at a node. The node error is the portion of falsely labelled nodes. (MathWorks 2020a)

$$NodeError = 1 - p_j \tag{3}$$

The basic steps executed using the trained decision tree are described below.

- Step 1: Check is the numeric attribute larger or smaller than the comparison value in the node.
- Step 2: Choose the outgoing arc appropriate to the result.
- Step 3: Repeat the above steps until a leaf node is reached.
- Step 4: If the current node is a leaf node set the class label of the node as the result.

The algorithm starts from the root node and ends when the leaf nodes are reached. The values of the leaves are the class labels. (Quinlan 1986)

The reliability of the decision tree classifier can be tested with a confusion matrix. Figure 3 visualises a confusion matrix, where the rows are the class label predictions made by the classifier model and the columns are the actual class labels. *TP* stands for true positive, which depicts correctly predicted positive labels, *FP* stands for false positive, which depicts falsely predicted positive labels, *FN* stands for false negative, which depicts falsely predicted negative labels, and *TN* stands for true negative, which depicts correctly predicted negative labels. (Ruuska et al. 2018).

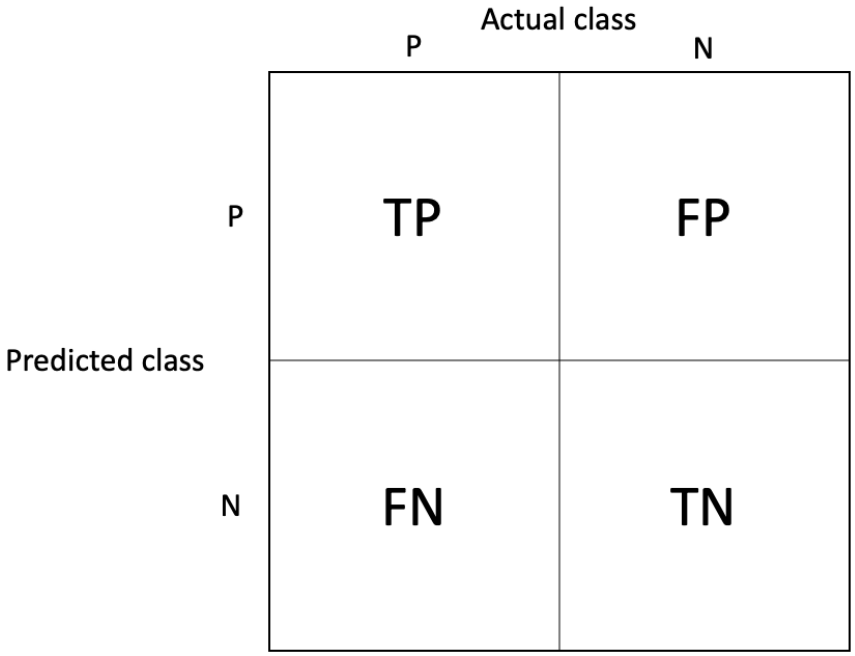

Figure 3. Example of a confusion matrix (CF).

After forming a confusion matrix, the accuracy of the classification tree model can be calculated with Equation 4, the precision is calculated with Equation 5 and the recall is calculated with Equation 6, where P is the total amount of positive labels and N is the total amount of negative labels. Accuracy depicts the correctly predicted labels from all predictions. Precision depicts the correctly predicted positive labels of all positive predictions (true positive and false positive), while recall depicts the correctly predicted positive labels of the actual true positive labels and false negative labels. (Ruuska et al. 2018).

$$accuracy = \frac{TP+TN}{P+N} = \frac{TP+TN}{TP+FP+TN+FN} \tag{4}$$

$$precision = \frac{TP}{TP+FP} \tag{5}$$

$$recall = \frac{TP}{TP+FN} \tag{6}$$

4 DATA

4.1 Software

The software used in this research is MATLAB R2019b version 9.7.0 by MathWorks, Inc. MATLAB can be used for data analysis and for creating data prediction and machine learning models. MATLAB has built-in applications and algorithm for creating and enhancing machine learning and deep learning models. MATLAB automatically converts written scripts and machine learning models to C and C++ programming languages. In addition, MATLAB creates graphical figures of the implemented data analysis. (MathWorks 2020b)

The calculations with the decision tree classifier are done using integrated functions of the *Statistics and Machine Learning Toolbox* in MATLAB. The function *fitctree* fits a binary classification decision tree based on the variables inputted. The explanatory variables and the class labels are given as parameters to the function with $'OptimizeHyperparameters'$ and $'auto'$, where the first function determiner attempts to minimise the cross-validation error for the function *fitctree* by varying the parameter, and the second determiner automatically selects the minimum number of leaf node observations controlling the depth of a tree. The tree splits the nodes using *Gini index* or *node error*.

4.2 Explanatory and dependent variables

This research is based on the investigation of the exchange rate volatility in a time period from the 1st of January 2011 to the 31st of December 2019. The time period includes the time before the 24 June 2016 Brexit referendum and approximately four and half years after that. The time period before the Brexit implementation covers 60 percent of the data and the time during Brexit implementation covers 40 percent of the data. The monthly exchange rate volatility is investigated whether it is above or below the historic average of the volatility separately for each model, the GBP to the EUR and the GBP to the USD.

The raw macroeconomic data is collected from *Thompson Reuters Datastream*. The data utilised for the GBP/EUR model includes the daily exchange rate of the GBP to the EUR, monthly exchange rate of the GBP to the EUR, inflation rates, interest rates (1 year deposit), M1 money supply and M3 money supply each for the UK/GBP and the EU/EUR. The data utilised for the second model (GBP/USD) includes the daily exchange rate of the GBP to the USD, monthly exchange rate of the GBP to the USD, inflation rates, interest rates (1 year deposit), M1 money supply and M3 money supply each for the UK/GBP and the US/USD. The money supply refers to the circulating money within an economy including the information of circulating cash and bank deposits (Statt 1999).

The above variables are selected to predict the exchange rate volatility. According to the previous researches mentioned in the literature review these variables apply well for the prediction. For example, Hnatkovska et al. (2013) stated that interest rates have varied effect on the exchange rate, from which the volatility is calculated. Therefore, this is interesting to examine for the prediction of the exchange rate volatility.

The inflation rate data are measured for the UK and the US by the consumer price index (CPI) and for the EU by the harmonised index of consumer prices (HICP). The difference between HICP and CPI is that HICP includes the rural population (% of total population), and it excludes owner-occupied housing, since the measuring of it is complex. Despite the differences, a research on inflation and the comparison of the CPI and HICP by Lane and Schmidt (2006) showed that the two measures acted similarly when applied on to the United States inflation measuring. Neither did the inflation highly differ between the inflation of the US and the EU. (Lane and Schmidt 2006)

The daily exchange rate of both GBP/EUR and GBP/USD are converted into monthly volatility by calculating the standard deviation for each month. The monthly exchange rates, inflation rates, interest rates and M1 and M3 money supply values are converted to monthly percentage changes. A simpler view of the data of the macroeconomic variables used for the prediction of the exchange rate volatility of the GBP towards the EUR is presented in Table 1 and for the GBP towards the USD in Table 2.

The monthly percentage change of the exchange rate volatility is calculated with date shifting by starting from 16.1.2011, since the dates of the explanatory variables start from the 16th date of the current month and end on the 15th date of the next month. The time period of the daily percentage change data of the exchange rate volatility used in the calculation is started from 1.1.1970 to 15.1.2011, allowing to calculate a long-term historic average, which is less affected by possible higher volatility during Brexit. The daily data includes only the trading days, meaning that one year includes approximately 252 days.

The model uses the previous month's percentage change of the exchange rate. The time period of the monthly exchange rate that is used in predicting the model is shifted to the previous month. In other words, the actual time period of the data is from December 2010 to November 2019, however it is defined as from January 2011 to December 2019.

Table 1. Data of the macroeconomic variables for the GBP/EUR model

Index	Variable	Periodicity	Time period
1	Exchange rate volatility	1 Month	Jan 2011 - Dec 2019
2	Historic avg. of the exchange rate volatility	1 Month	Jan 1970 - Dec 2010
3	Inflation rate UK (%) (CPI) (All items)	1 Month	Jan 2011 - Dec 2019
4	Inflation rate EU (%) (HICP)	1 Month	Jan 2011 - Dec 2019
6	Interest rate UK (%) (1Y Deposit)	1 Month	Jan 2011 - Dec 2019
7	Interest rate EU (%) (1Y Deposit)	1 Month	Jan 2011 - Dec 2019
9	M1 Money supply GBP (%) (UK)	1 Month	Jan 2011 - Dec 2019
11	M1 Money supply EUR (%) (EU)	1 Month	Jan 2011 - Dec 2019
12	M3 Money supply GBP (%) (UK)	1 Month	Jan 2011 - Dec 2019
13	M3 Money supply EUR (%) (EU)	1 Month	Jan 2011 - Dec 2019
14	Prev. month Exchange rate GBP/EUR (%)	1 Month	Jan 2011 - Dec 2019

Once the macroeconomic data is in a form of monthly percentage change the Brexit related variables are processed. The timeline split of before and during Brexit for the monthly data is done between May 2016 and June 2016, defining the time period for before Brexit from January 2011 to May 2016 and for during Brexit from June 2016 to December 2019. The value of the Brexit variable for before Brexit is set as *0* and during Brexit as *1*. The number of the Brexit no-deal and deal events are set according to the Brexit events timeline introduced in the section 1.1, considering the date shifting from the 1st date of month to the 16th. The Brexit related variables are shown in Table 3.

Table 2. Data of the macroeconomic variables for the GBP/USD model

Index	Variable	Periodicity	Time period
1	Exchange rate volatility	1 Month	Jan 2011 - Dec 2019
2	Historic avg. of the exchange rate volatility	1 Month	Jan 1970 - Dec 2010
3	Inflation rate UK (%) (CPI) (All items)	1 Month	Jan 2011 - Dec 2019
4	Inflation rate US (%) (CPI)	1 Month	Jan 2011 - Dec 2019
6	Interest rate UK (%) (1Y Deposit)	1 Month	Jan 2011 - Dec 2019
7	Interest rate US (%) (1Y Deposit)	1 Month	Jan 2011 - Dec 2019
9	M1 Money supply GBP (%) (UK)	1 Month	Jan 2011 - Dec 2019
11	M1 Money supply USD (%) (US)	1 Month	Jan 2011 - Dec 2019
12	M3 Money supply GBP (%) (UK)	1 Month	Jan 2011 - Dec 2019
13	M3 Money supply USD (%) (US)	1 Month	Jan 2011 - Dec 2019
14	Prev. month Exchange rate GBP/USD (%)	1 Month	Jan 2011 - Dec 2019

Table 3. Data of Brexit related variables for both models

Index	Variable	Value	Periodicity	Time period
1	Brexit	0	1 Month	Jan 2011 - May 2016
2	Brexit	1	1 Month	Jun 2016 - Dec 2019
3	Brexit no-deal	1	1 Month	June 2015
4	Brexit no-deal	2	1 Month	June 2016
5	Brexit no-deal	1	1 Month	March 2017
6	Brexit no-deal	1	1 Month	October 2019
7	Brexit deal	1	1 Month	December 2015
8	Brexit deal	1	1 Month	February 2016
9	Brexit deal	1	1 Month	March 2019
10	Brexit deal	1	1 Month	April 2019
11	Brexit deal	1	1 Month	October 2015

The dependent variable is the set of class labels for the decision tree modelling. In order to obtain the class labels, one must first calculate the placement of the standard deviation for each month comparing to the historic average of the exchange rate volatility. Meaning, whether its comparable value is above or below the historic average of the exchange rate volatility for each model, GBP/EUR and GBP/USD. The class labels are *'1'* for below the historic average and *'2'* for equal or above.

Finally, each model will have a matrix of the monthly percentage changes of the inflation rates, interest rates, M1 and M3 money supplies, the previous month percentage change of the exchange rate, Brexit, Brexit no-deal and Brexit deal as its explanatory variables, and the calculated array of class labels describing if the exchange rate volatility was above or below the historic average as its dependent variable. The explanatory variables include the macroeconomic variables and the Brexit related variables.

4.3 Training Procedure

The matrix of the explanatory variables and the array of the class labels constructed during data pre-processing, are divided randomly into an amount of sets using automated *hyperparameter optimisation* of the calculation software used in this research. The hyperparameter optimisation automatically finds the optimal value for minimising the holdout cross-validation loss. The sets are then divided into automatically into training and testing data. The size of the training and testing datasets are divided subject to the automatic hyperparameter optimisation. (MathWorks 2020a)

The decision tree classifier is modelled using the MATLAB's built-in function *fitctree* with the table of the explanatory variables, the vector of class labels given as features for the model and the feature for automatic optimising to the used function. Then the function command *view* is used for viewing the optimised tree classifier. After the tree is modelled, then the class labels for the exchange rate volatility is predicted using the function command *predict* which uses the optimised model and the explanatory variables as parameters. For the next step, the importance of the predictors can be displayed with the function *predictorImportance* which takes the modelled tree as its parameter.

The confusion matrix takes the class labels and the predicted results as its inputs. The confusion matrix function can be called with the command *confusionmat* and it can be graphically visualised with the command *confusionchart* with the confusion matrix as its parameter. Lastly the accuracy, precision and recall are calculated for the classification model to measure its reliability.

The entire process is implemented separately for both the GBP compared to the EUR and the GBP compared to the USD, resulting in with two cross-validation models which are compared to each other in the end. The objective of using a binary classification decision tree in this research is to investigate the exchange rate volatility above or below the historic average of the exchange rate volatility, to observe which variables are most meaningful and does Brexit have important functions in predicting the volatility of the exchange rate. Analysis of the data is implemented in the next chapter.

5 ANALYSIS AND RESULTS

5.1 Data analysis

The data used in the analysis is shown in the following graphs. Figures from 4 to 19. For each graph the solid blue line describes the values before Brexit, the blue dashed line describes values during Brexit and the black solid line describes the historic average for Figures 4 and 5 and means for figures from 6 to 17. The placements of the standard deviations for both volatility calculations can be seen from Figures 4 and 5.

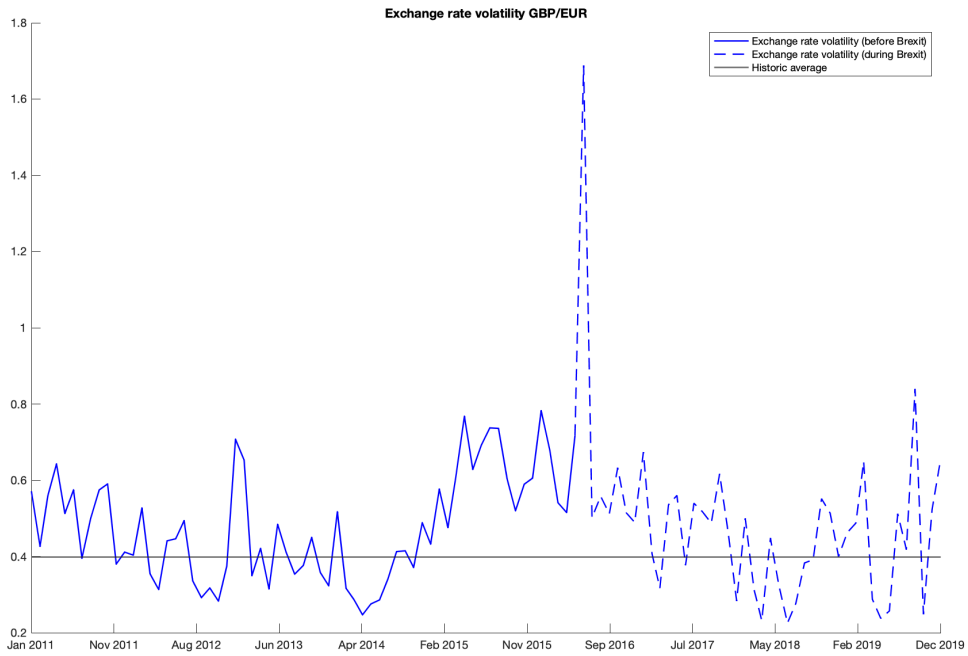

Figure 4. The exchange rate volatility of the GBP towards the EUR and the historic average.

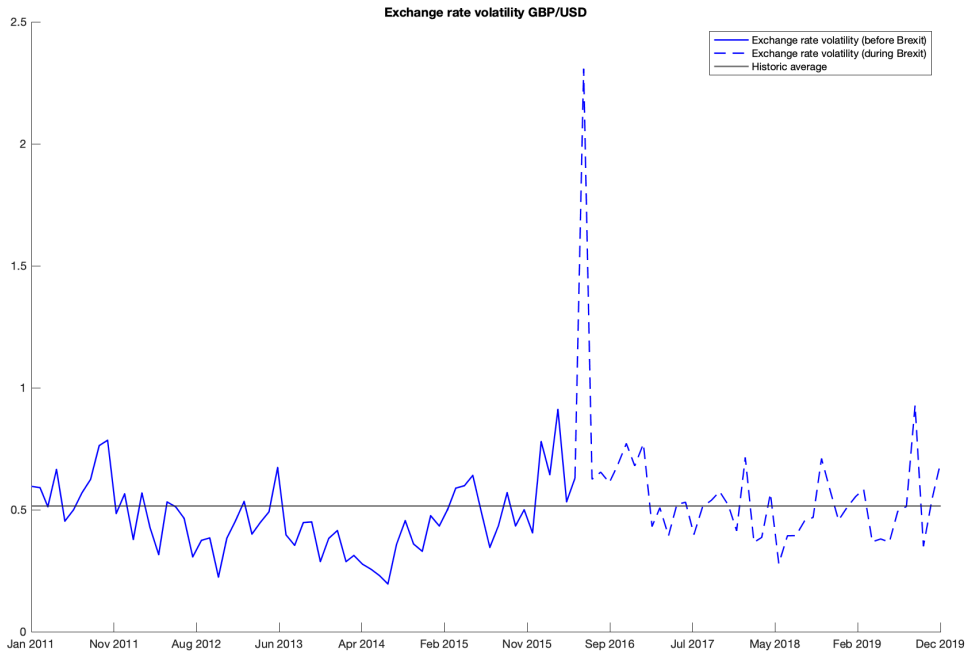

Figure 5. The exchange rate volatility of the GBP towards the USD and the historic average.

The prominent spikes in Figures 4 and 5 are placed between May 2016 and July 2016, what occur simultaneously with the Brexit referendum. However, after this event the curves in the GBP/EUR and the GBP/USD models return to level of the historic average in both graphs. The maximum value of the spike in Figure 4 is 1.6880, which is the standard deviation of June 2016. There was a 0.5754 or in other words 57.54 % increase in the volatility of the exchange rate of the GBP towards the EUR from the last month during June 2016. Likewise, the maximum value of the volatility of the exchange rate of the GBP towards the USD is 2.3075 making the increase 0.7271 or 72.71 % in percentages. More variation in the standard deviation can be seen in Figure 4 before June 2016 and after compared to the same time of Figure 5. The historical average of the exchange rate volatility of the GBP towards the EUR is 0.3977 and for the GBP towards the USD is 0.5161.

The monthly percentage change for the inflation for the UK, the EU and the US can be seen from Figures 6, 7 and 8. The inflation rates increased for both the UK and the EU during the month of the Brexit referendum on June 2016. The inflation rates increased 66.67 % in the UK and 200 % in the EU. However, none of these where the peak values of the percentage changes, unlike in the graphs for the exchange rate volatilities where the peaks were on June 2016. The inflation rates of the US decreased 1.96 % on June 2016. The mean of the inflation rate's percentage change in the calculated time period for the UK is 2.59 %, for the EU the mean is 6.63 % and for the US it is 9.47 %.

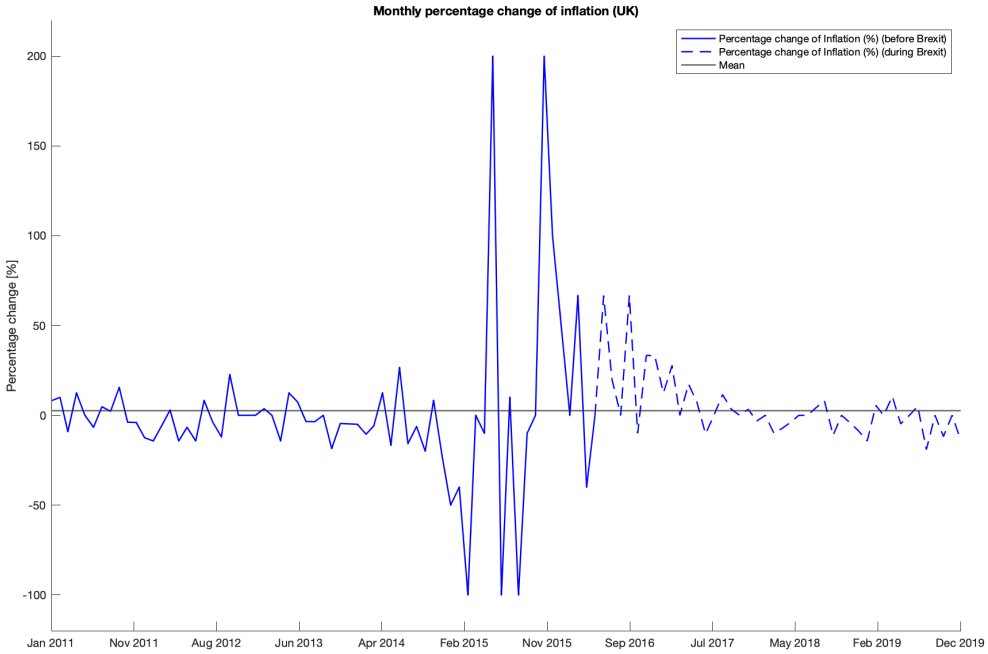

Figure 6. Percentage changes of inflation of the UK.

Figure 7. Percentage changes of inflation of the EU.

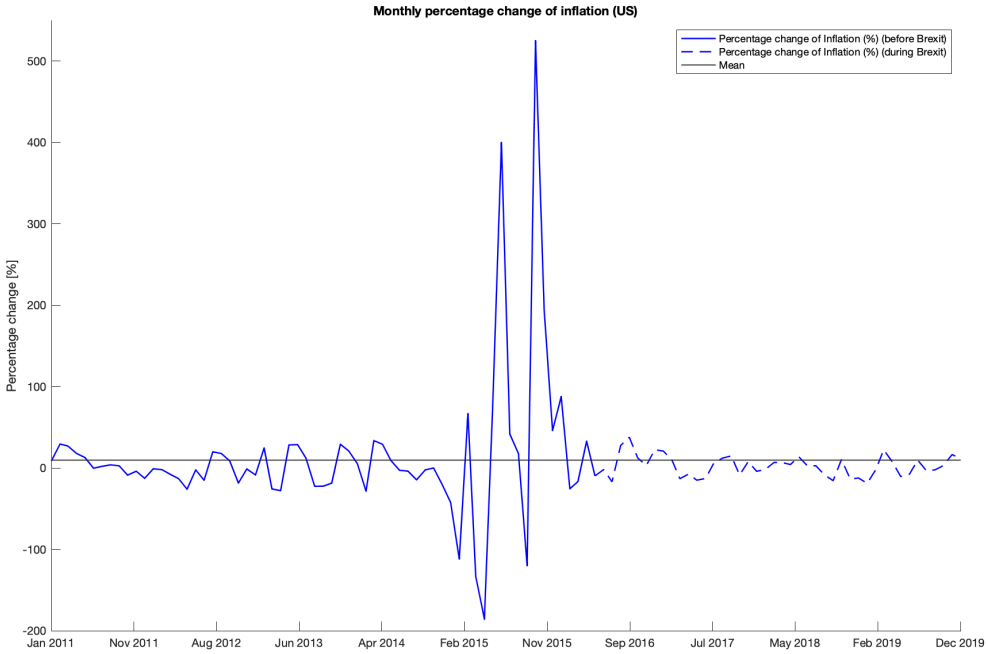

Figure 8. Percentage changes of inflation of the US.

Figures 9, 10 and 11 represent the monthly percentage changes of the interest rates for the UK, the EU and the US. During June 2016 the interest rates increased 4.08 % in the UK, while the interest rates decreased 100 % in the EU and 2.94 % in the US. The monthly percentage change means are 0.40 % for the UK, -7.00 % for the EU and 1.40 % for the US.

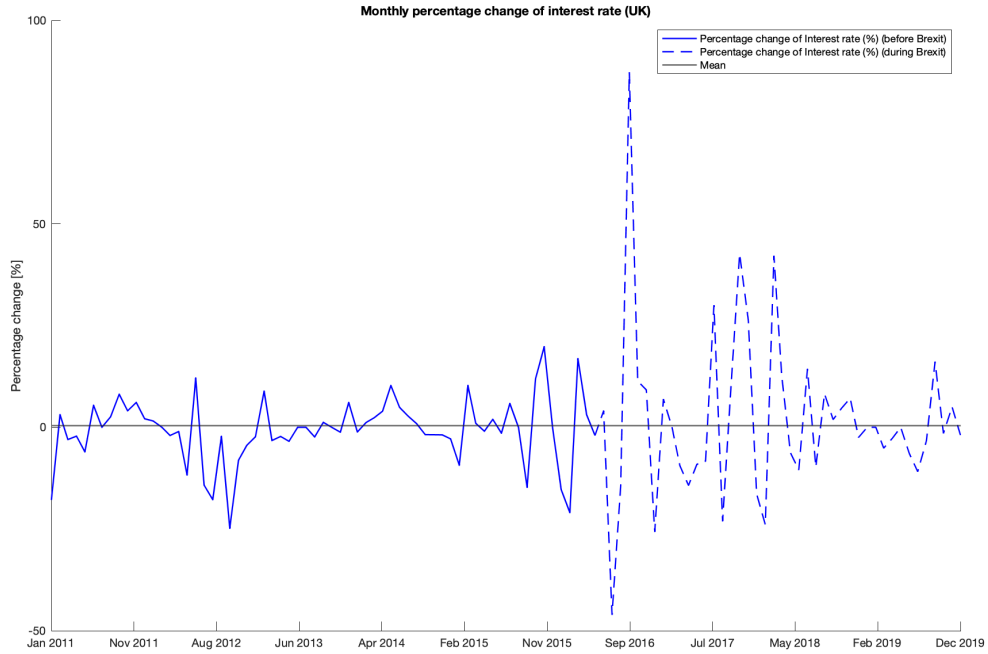

Figure 9. Percentage changes of the interest rates of the UK.

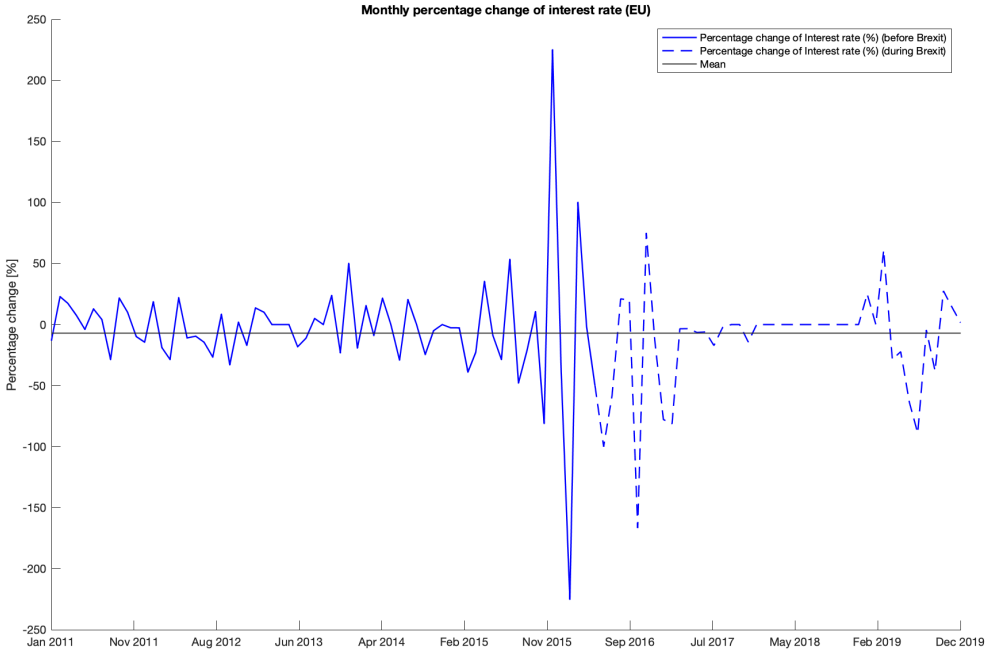

Figure 10. Percentage changes of the interest rates of the EU.

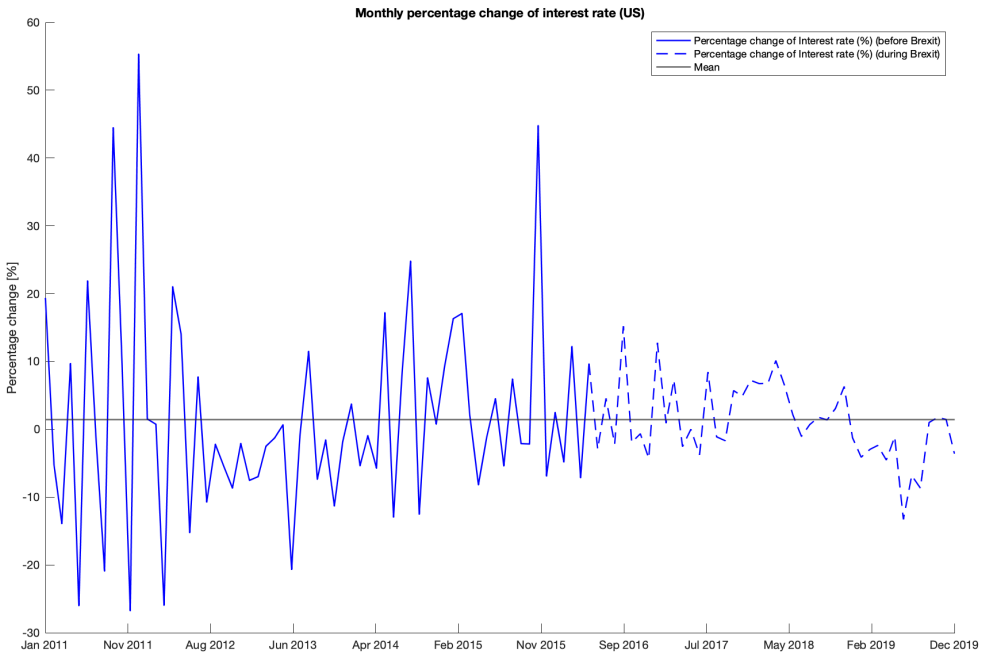

Figure 11. Percentage changes of the interest rates of the US.

The monthly percentage changes of the M1 money supply are represented in Figures 12, 13 and 14. The highest peak in the monthly percentage change graph for the UK is on June 2016 with an increase of 4.04 %. The percentage change on June 2016 in the EU increased 1.59 % and in the US it increased 0.25 %. The percentage variation of the M1 money supply of the EU is uncertain for 2019 due to the missing data. Therefore, there is no percentage change in the graph during the year. The monthly percentage change means are 0.48 % for the UK, 0.76 % for the EU and 0.72 % for the US. The missing data can affect on the actual mean of the EU.

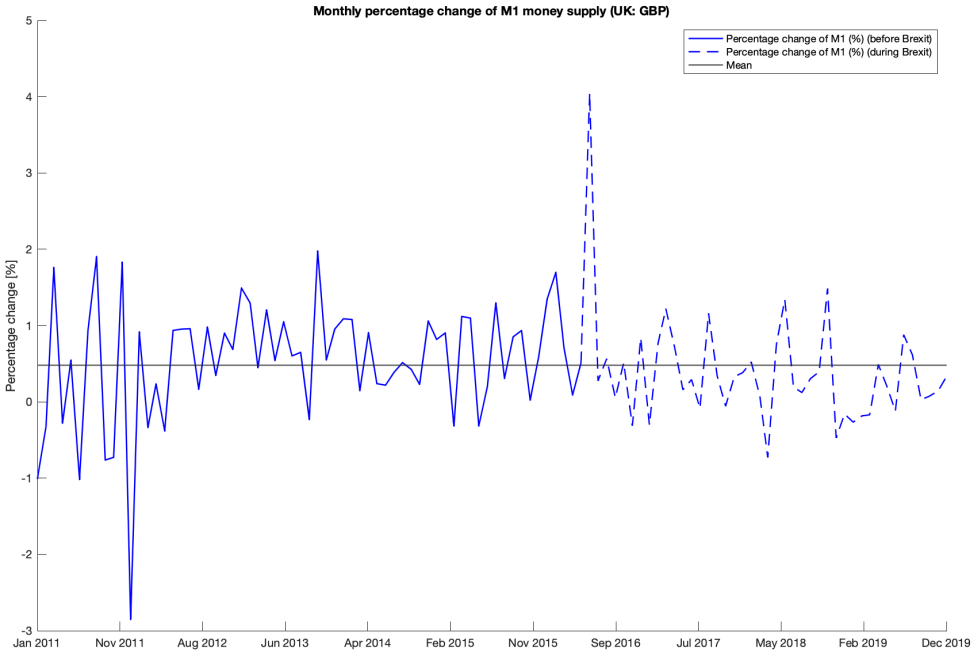

Figure 12. Percentage changes of the M1 money supply of the UK.

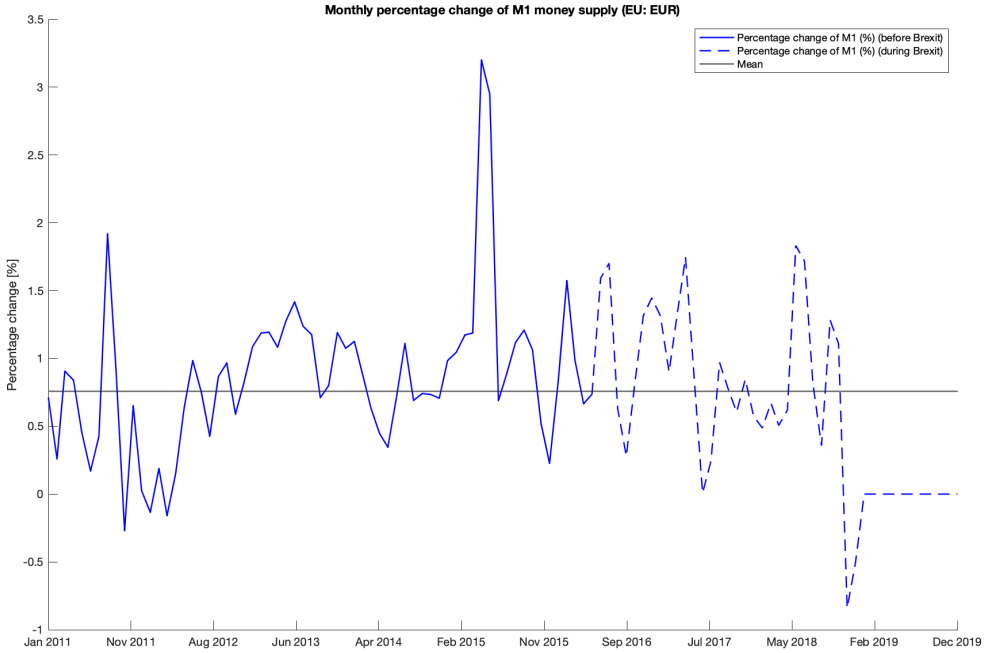

Figure 13. Percentage changes of the M1 money supply of the EU.

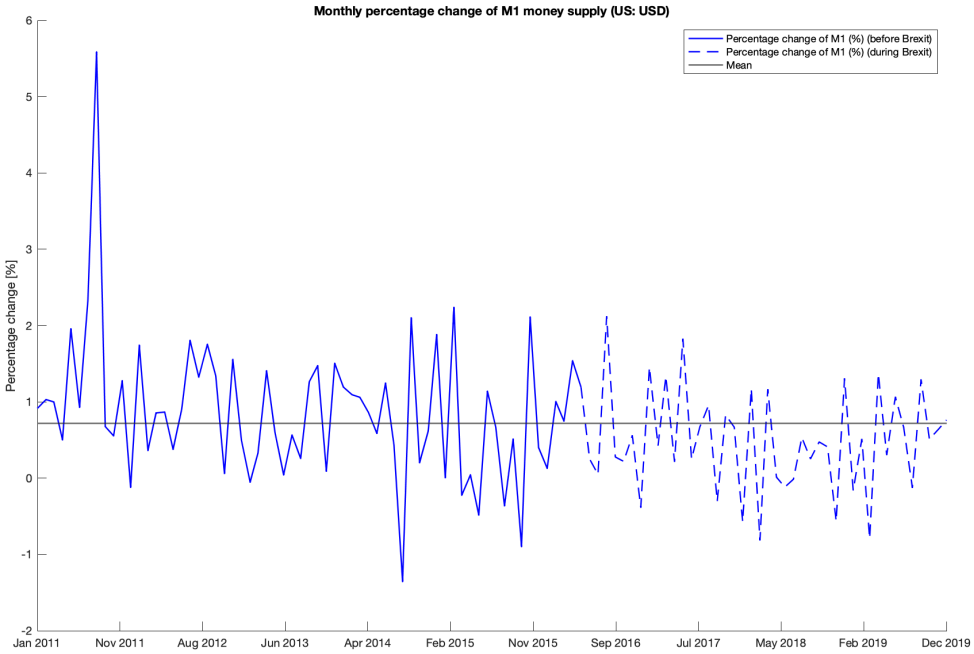

Figure 14. Percentage changes of the M1 money supply of the US.

Figures 15, 16 and 17 show the monthly percentage changes of the M3 money supply for each the UK, the EU and the US. As for M1 money supply of the EU, the percentage change of the Euro M3 money supply is uncertain for the year 2019 due to missing data, affecting the actual mean of the monthly percentage change of the EU as well. The Brexit referendum month June 2016 includes percentage changes of 3.45 % for the UK, 1.24 % for the EU and 0.53 % for the US. The monthly percentage change means are 0.20 % for the UK, 0.51 % for the EU and 0.52 % for the US.

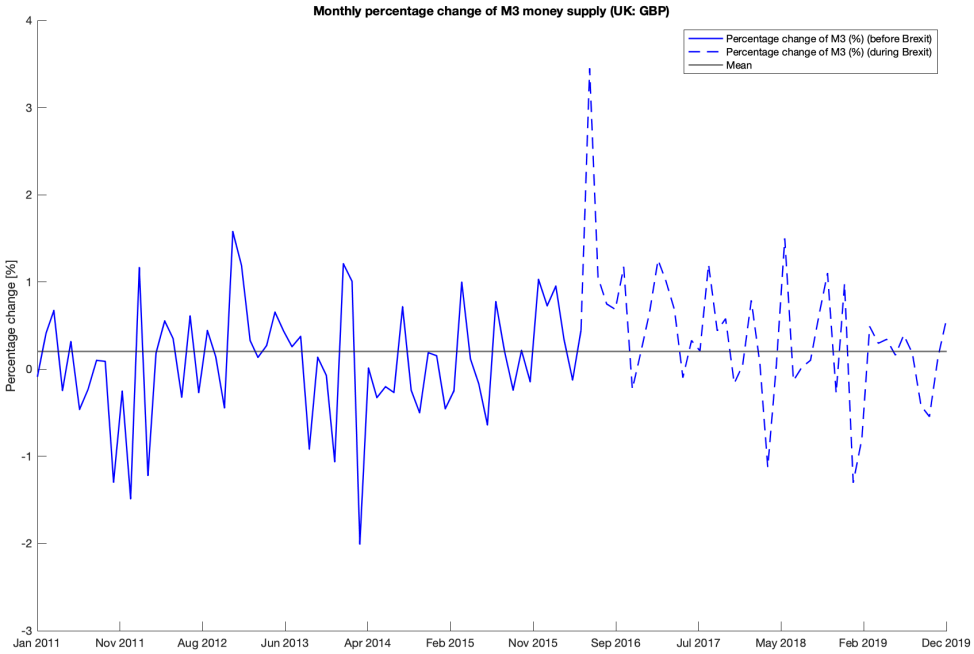

Figure 15. Percentage changes of the M3 money supply of the UK.

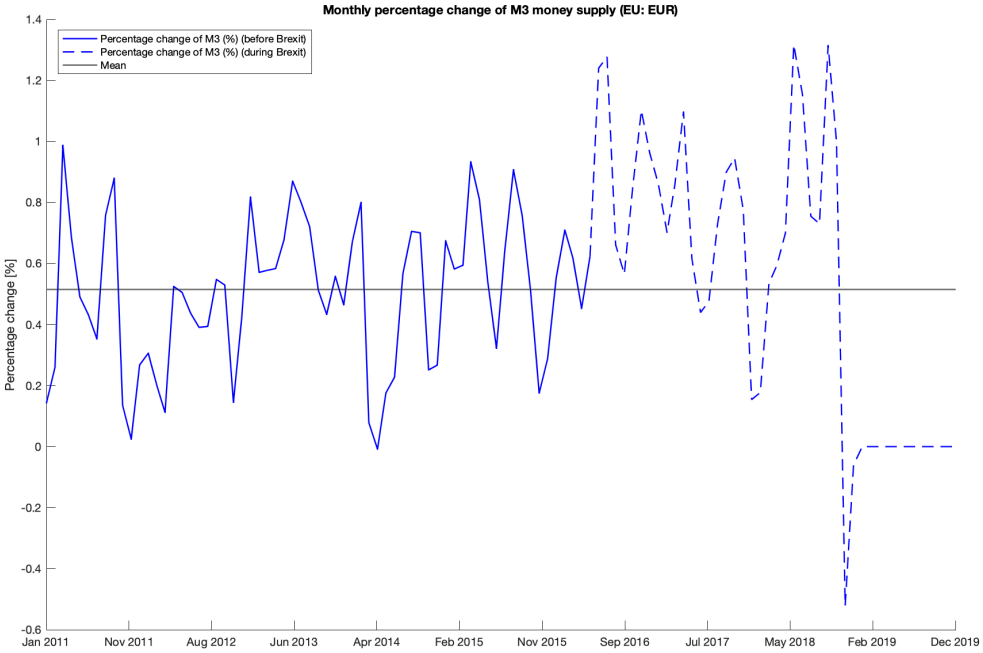

Figure 16. Percentage changes of the M3 money supply of the EU.

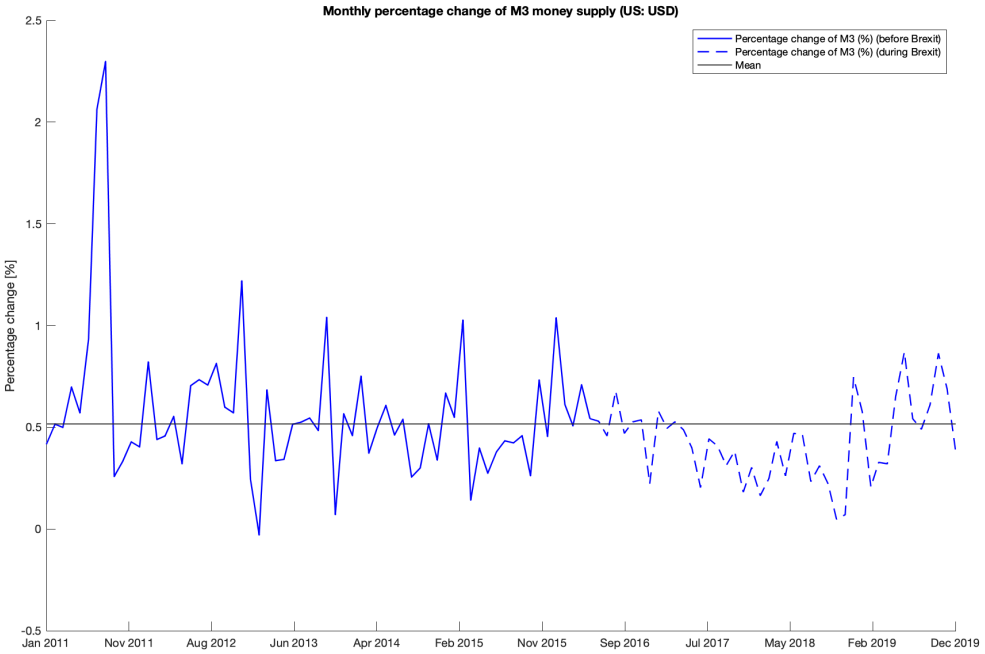

Figure 17. Percentage changes of the M3 money supply of the US.

Figures 18 and 19 show the monthly changes of the exchange rate for the GBP to the EUR and the USD. On June 2016 the value of the EUR increased against the GBP from 0.7884 to 0.85035 weakening the purchase power and value of the GBP. The increase in percentage during the month is 7.86 from the last month. The exchange rate value of the GBP to the EUR has stayed above the mean after the referendum, where the value of the mean is 0.8360.

The value of the exchange rate of the GBP to the USD increased from 0.69767 to 0.76953 and has stayed above the mean after June 2016, where the mean is 0.6913. The percentage increase to June 2016 from its previous month is 10.3, meaning that the value of the GBP against the USD weakened.

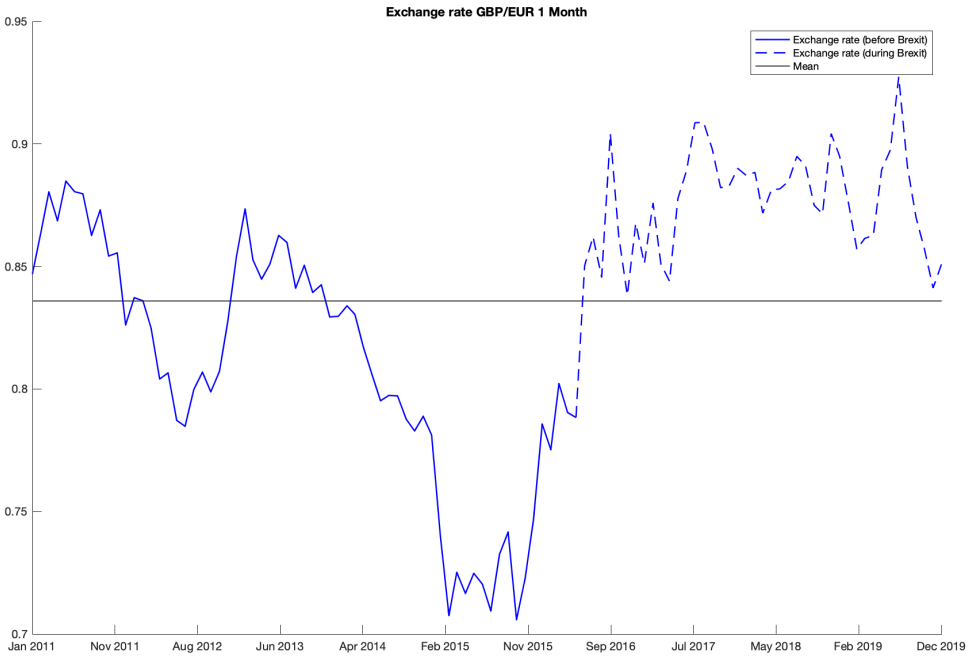

Figure 18. Monthly exchange rates of the GBP to the EUR.

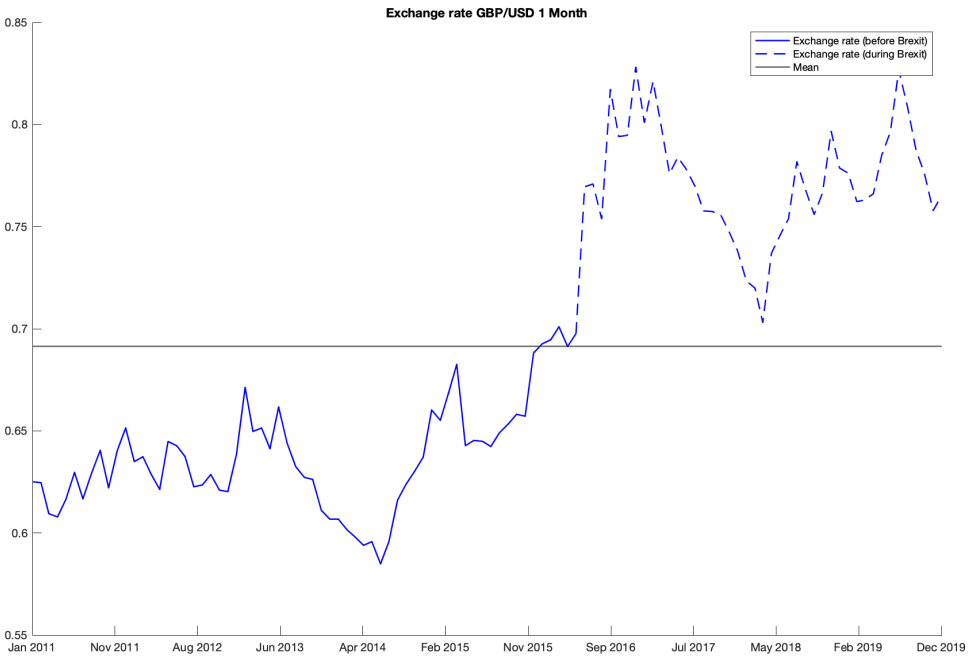

Figure 19. Monthly exchange rates of the GBP to the USD.

5.1.1 Results of the pound sterling towards the Euro

Figure 20 shows the fitted classification tree used for prediction. The importance of the variables used for prediction are presented in Figure 21. The reliability is tested with the confusion matrix, which results are shown in Figure 22.

The predictor importance graph indicates that the most important variable in predicting the model is the exchange rate of the previous month (Prev mon XR) with an estimate value of 0.0058, followed by the interest rate of the EU with an estimate value of 0.0041. Inflation of the UK has an estimate value of 0.0032, M1 money supply of the UK has 0.0028, M1 money supply of the EU has 0.0046, M3 money supply of the UK has 0.0045 and M3 money supply of the EU has the value of 0.0034. Indicated by the results, the inflation of the EU and the interest rate of the UK, Brexit and Brexit related events has no importance in predicting the model with the values of 0.

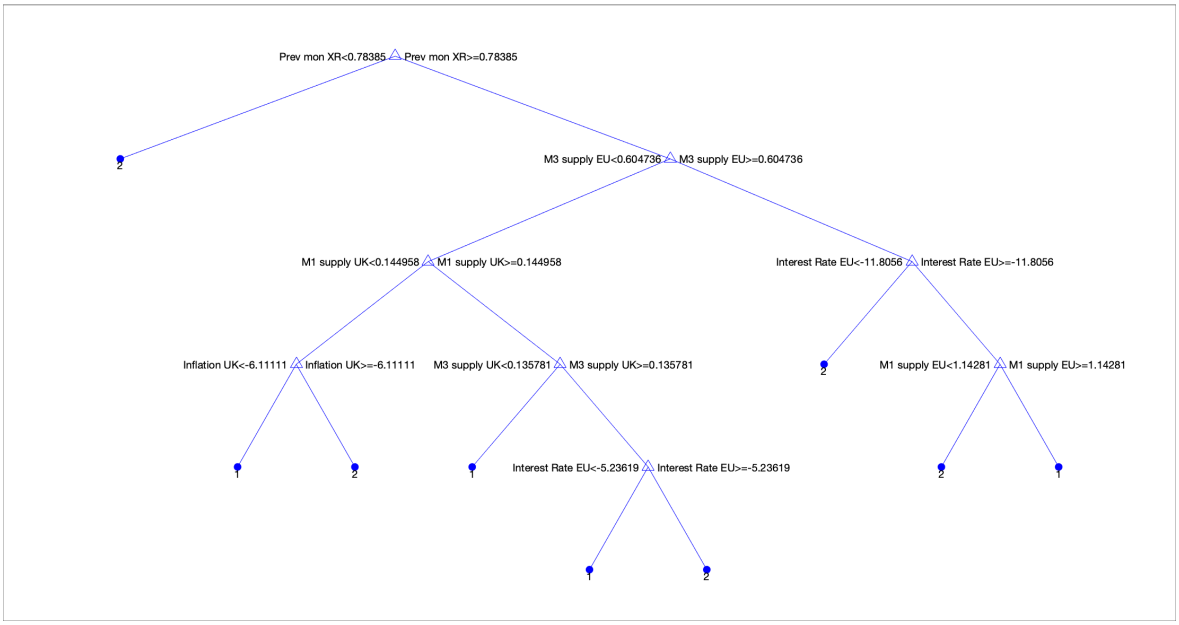

Figure 20. The decision tree classifier of the GBP towards the EUR.

According to the confusion matrix, the classification model predicted correctly 33 times the class label as *1*, which designates as below the historic average of exchange rate volatility, while it got 8 labels wrong predicting them as *2*, which signifies equal or above the historic average of the exchange rate volatility. The model correctly predicted 58 times the class label as *2*, while 9 of the labels were falsely predicted.

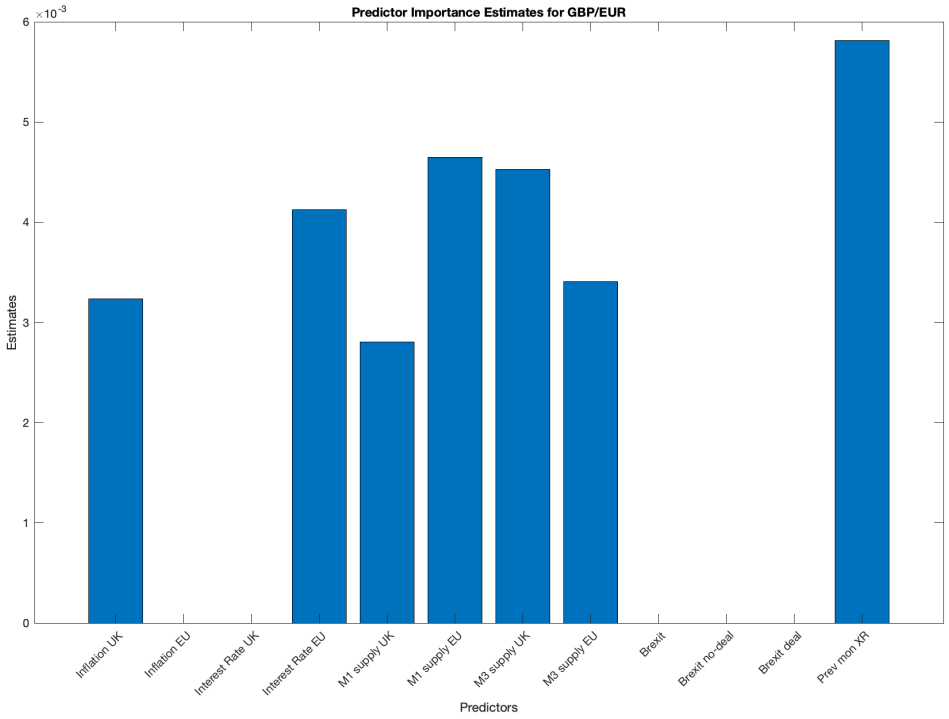

Figure 21. Importance of the predictors in the classifier tree model of the GBP towards the EUR.

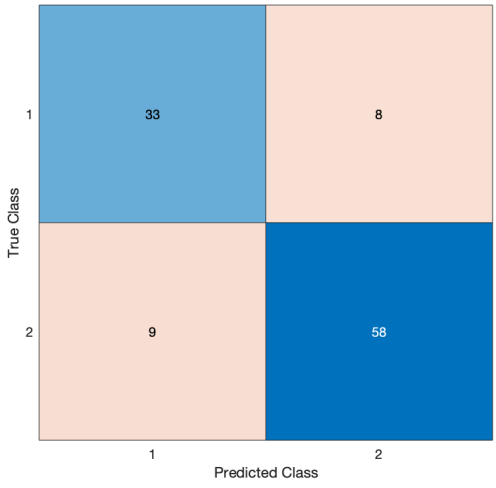

Figure 22. Confusion matrix of the label prediction for the GBP towards the EUR.

Lastly, the accuracy is measured after forming the confusion matrix. The values needed in the calculation can be obtained from the confusion matrix in Figure 22. The value of *TP* is 33, *FP* is 8, *FN* is 9 and *TN* is 58. After obtaining the values, the value of accuracy of the prediction can be calculated giving it the value of 0.8426, for the precision 0.8657 and for the recall 0.8788.

5.1.2 Results of the pound sterling towards the U.S. dollar

Figure 23 shows the fitted classification tree used for prediction. The importance of the variables used for prediction are presented in Figure 24. The reliability is tested with the confusion matrix, which results are shown in Figure 25.

The predictor importance graph indicates that the most important variable in predicting the model is the exchange rate of the previous month (Prev mon XR) with an estimate value of 0.0064, closely followed by the M1 money supply of the UK with an estimate value of 0.0063. Inflation of the UK has an estimate value of 0.0019, inflation of the US has 0.0038, interest rate of the UK has 0.0019, M1 money supply of the US has 0.0036 and M3 money supply of the US has the value of 0.0042. Indicated by the results, the interest rate and the M3 money supply of the UK, Brexit and Brexit related events has no importance in predicting the model with the values of 0.

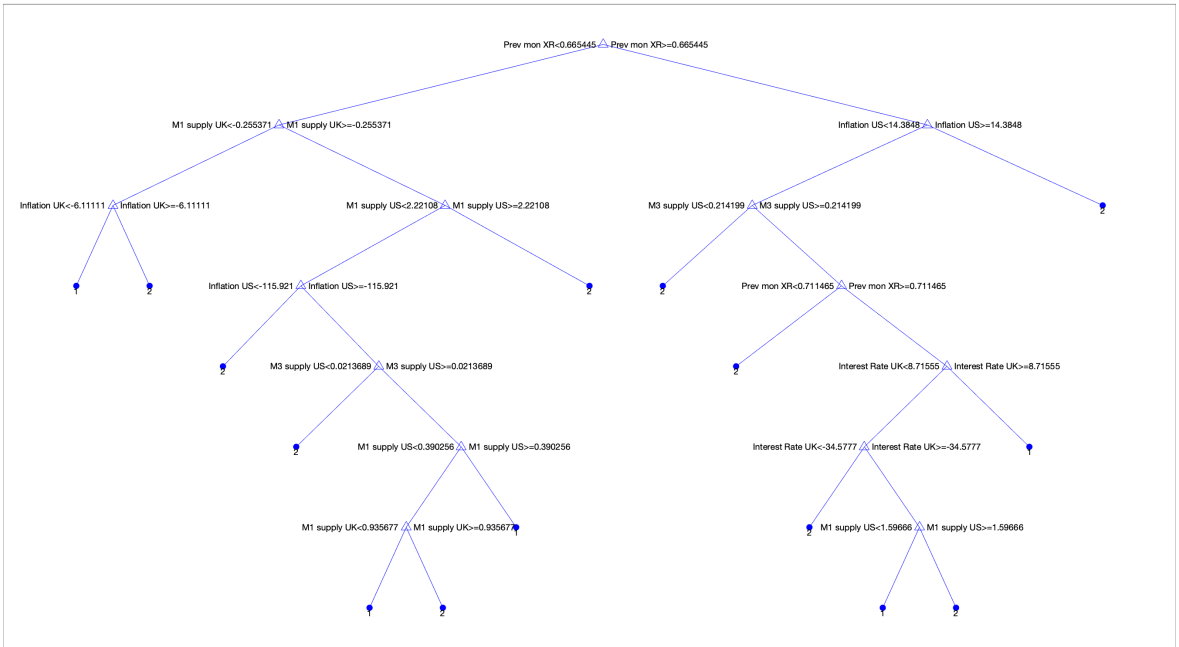

Figure 23. The decision tree classifier of the GBP towards the USD.

According to the confusion matrix, the classification model predicted correctly 64 times the class label as *1*, which designates as below the historic average of exchange rate volatility, while it got one label wrong predicting it as *2*, which signifies equal or above the historic average of the exchange rate volatility. The model correctly predicted 37 times the class label as *2*, while 6 of the labels were falsely predicted.

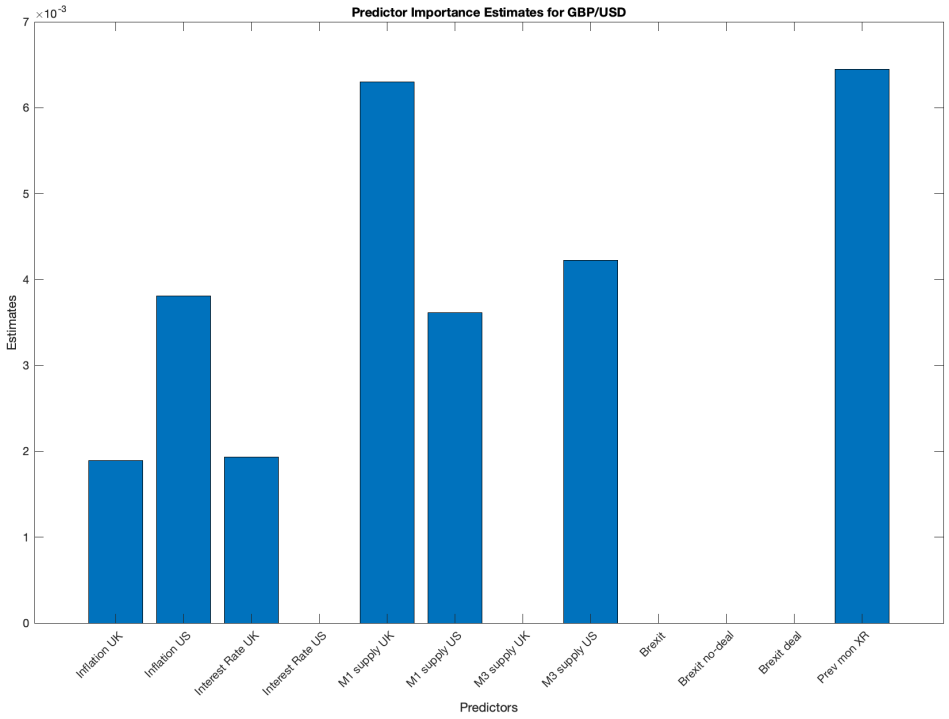

Figure 24. Importance of the predictors in the classifier tree model of the GBP towards the USD.

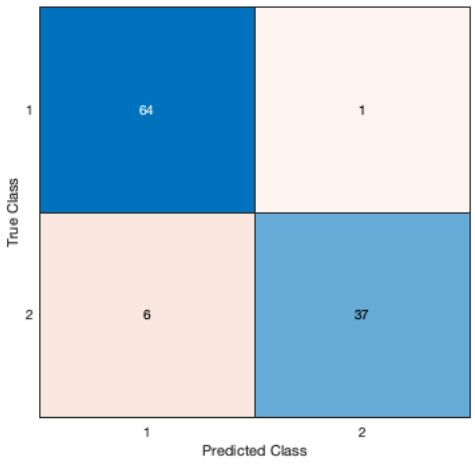

Figure 25. Confusion matrix of the label prediction for the GBP towards the USD.

Lastly, the accuracy is measured after forming the confusion matrix. The values needed in the calculation can be obtained from the confusion matrix in Figure 25. The value of *TP* is 64, *FP* is 1, *FN* is 6 and *TN* is 37. After obtaining the values, the value of accuracy of the prediction can be calculated giving it the value of 0.9352, for the precision 0.8605 and for the recall 0.9737.

6 DISCUSSION

According to the results, the most important explanatory variables for the prediction of the exchange rate volatility of the GBP/EUR are the exchange rate of the previous month and the M1 money supply of the Euro and slightly below this the M3 money supply of the pound sterling. For the prediction of the exchange rate volatility of the GBP/USD the most important variables are the exchange rate of the previous month and the M1 money supply of the pound sterling. The accuracy of the prediction for the models determined by the confusion matrix are quite good, especially for the model of the GBP/USD.

The Brexit related variables do not have any importance in predicting the exchange rate volatility for both of the models. However, as the research by Driffield and Karoglou (2019) indicated that Brexit affects the exchange rate of the UK, while the exchange rate was the most important predictor of the model in this report. This would support the perspective of interpreting that Brexit affects the exchange rate volatility indirectly by affecting it through the exchange rate. The graphs of the exchange rates of GBP/EUR and GBP/USD indicate that the time during Brexit affected the exchange rates in a way that the value of the GBP against the EUR and the USD weakened.

The results of the research by Korus and Celebi (2019) showed that the referendum and Brexit related events had an influence on the exchange rate volatility of the GBP to the EUR, conflicting with the results of this thesis. Even if the Brexit related events have no importance predicting the both models of the exchange rate volatility, the results of the research by Korus and Celebi (2019) and this thesis do support each other by analysing the graphs of the exchange rate volatility, as shown in Figures 4 and 5. For example, the month of the referendum of Brexit and its results on June 2016 the exchange rate volatility peaks for both the GBP to the EUR and the USD, returning back to its original level on the next month. Therefore, this can be interpreted that the referendum had importance for a short-term.

Other observation where Brexit itself or the referendum had influence are that the variation monthly percentage change of the interest rate of the UK became unstable during Brexit, the inflation rate of both the EU and the UK and the M1 money supply of the UK have a upward spike in the monthly percentage change during the month of the referendum, where the spike of the M1 of the UK is the peak. The monthly percentage changes of the US for the inflation rate, interest rate, M1 and M3 money supply, all stabilised to a level close to their mean values, while the changes were more unstable before Brexit or right before the referendum.

As observed in the literature review, the prediction of the exchange rate volatility is uncertain since the macroeconomic variables may have various behaviours in different situations. Furthermore, several researches state various research methods that conflict each other. In addition, the missing data of the M1 money supply of the Euro may have negative influence in the prediction of the exchange rate volatility of the GBP/EUR model. Therefore, the results of this research may indicate accurate or inaccurate outcomes depending on the context.

This research can be improved further by applying more Brexit related data, and more macroeconomic variables. Additionally, the research can be improved by investigating the effect of Brexit related variables on the macroeconomic variables which predict the exchange rate volatility. This way the possible indirect influence of Brexit on the exchange rate volatility can be observed. For the future research, the data until the end of Brexit and after it should be investigated to potentially achieve more accurate results.

7 CONCLUSION

The main objective of this research was to investigate whether Brexit had any influence in the exchange rate volatility of the pound sterling towards the Euro and the pound sterling towards the U.S. dollar. The sub-objectives were derived from the main objective, investigating which variables were the most important in predicting the exchange rate volatility and were the Brexit related variables more important for the classification rather than the macroeconomic variables.

The investigation was done modelling a decision tree classifier which predicted whether the exchange rate volatility of the GBP to the EUR or the GBP to the USD was above or below its historic average. The explanatory variables used for the prediction included monthly percentage changes of the inflation rates, interest rates, exchange rates of the previous month, M1 and M3 money supply values and Brexit and Brexit related events. The data used in this research was obtained from *Thompson Reuters Datastream* and the Brexit related data was collected from *the Council of the European Union's* website. Lastly the accuracy of the predictions for both of the models were calculated using a confusion matrix.

The results showed that the Brexit and Brexit related variables had no importance in predicting the exchange rate volatility, however it appeared to have an effect on the variables that predict the volatility based on the curves in the graphs that describe the monthly percentage changes. The referendum of Brexit did have a short-term influence on the exchange rate volatility during the month it was held, on June 2016. In addition, Brexit had an effect on the exchange rate values of GBP/EUR and GBP/USD during and after the month when the referendum was held.

The results of this research where Brexit related events had no effect on the exchange rate volatility conflict with earlier research. However, the effect of the referendum to the exchange rate volatility was indirect mainly through the monthly percentage change of the previous month's exchange rate. The concise amount of the Brexit related data and the missing values of the M1 money supply of the EU, may have negative affect on the accuracy of the results in this research.

For the future, it would be interesting to investigate the effects of Brexit on the exchange rate volatility of the GBP to the EUR and GBP to the USD including the data until the end of Brexit and after it. In addition, the effect of Brexit could be investigated on the EU for example how Brexit affected the exchange rate volatility of the EUR towards the USD or the Japanese yen.

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List of Tables

1 Data of the macroeconomic variables for the GBP/EUR model 20

2 Data of the macroeconomic variables for the GBP/USD model 21

3 Data of Brexit related variables for both models 21

List of Figures

1 Timeline of Brexit events 8

2 Binary decision tree 15

3 Confusion matrix 17

4 Exchange rate volatility of GBP/EUR 23

5 Exchange rate volatility of GBP/USD 24

6 Inflation of the UK 25

7 Inflation of the EU 25

8 Inflation of the US 26

9 Interest rates of the UK 27

10 Interest rates of the EU 27

11 Interest rates of the US 28

12 M1 money supply of the UK 29

13 M1 money supply of the EU 29

14 M1 money supply of the US 30

15 M3 money supply of the UK 31

16 M3 money supply of the EU 31

17 M3 money supply of the US 32

18 Exchange rate GBP/EUR 1 Month 33

19 Exchange rate GBP/USD 1 Month 33

20 The decision tree classifier of GBP/EUR 34

21 Predictor importance of the GBP/EUR classifier 35

22 Confusion matrix GBP/EUR 35

23 The decision tree classifier of GBP/USD 36

24 Predictor importance of the GBP/USD classifier 37

25 Confusion matrix GBP/USD 37