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BACHELOR THESIS

Forecasting Exchange Rates: A VAR Analysis

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Declaration of Authorship

The author hereby declares that he compiled this thesis independently, using only the listed resources and literature.

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Abstract

This thesis aims to out-of-sample forecast the USD/EUR exchange rate using four macroeconomic variables, namely inflation, interest rate, unemployment rate and industrial production index. The model applied is the vector autoregressive model. We use monthly data for a period of 2002-2011 and use the data from 2012 in order to compare the forecast accuracy with the random walk, which is believed to outperform many models when forecasting for a short-time horizon, such as one year. We found out that the vector autogressive model beat the random walk in the period of one and three months, which was surprising. In the longer horizon of six, nine and twelve months, random walk, as expected, heavily outperformed vector autogressive model. The reasoning behind this could be that there was no clear trend in the USD/EUR exchange rate during this period.

JEL Classification	C5, E24, E31, E43, F31
Keywords	exchange rates, foreign exchange market, inflation, interest rate, unemployment rate, industrial production index, vector autoregressive model, random walk

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Abstrakt

Táto práca si kladie za cieľ predpovedať vývoj výmenného kurzu USD/EUR použitím štyroch makroekonomických premenných, menovite inflácie, úrokovej miery, miery nezamestnanosti a indexu priemyselnej produkcie. Použitou metódou je vektorová autoregresia. Pri analýze boli využité mesačné dáta z obdobia 2002-2011 a dáta z roku 2012 boli uchované, aby bolo možné porovnať presnosť predpovede s náhodnou prechádzkou, ktorá zvyčajne produkuje lepšie výsledky v krátkodobom horizonte, ako napríklad jeden rok. Zistili sme, že vektorová autoregresia prekvapujúco porazila náhodnú prechádzku v horizonte jedného až troch mesiacov. V dlhodobejšom období šiestich, deviatich a dvanástich mesiacov očakávane náhodná prechádzka poskytla lepšiu predpoveď ako vektorová autoregresia. Dôvodom mohol byť fakt, že v tomto období nevykazoval kurz žiadny jasný trend.

Klasifikace JEL	C5, E24, E31, E43, F31
Klíčová slova	výmenné kurzy, devízový trh, inflácia, úroková miera, miera nezamestnanosti, index priemyslenej produkcie, vektorová autoregresia, náhodná prechádzka

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Acronyms

RER Real Exchange Rate

IMF International Monetary Fund

ERM Exchange Rate Mechanism

IT Inflation Targeting

CEEC Central and Eastern Europe Countries

GDP Gross Domestic Product

FOREX Foreign Exchange Market

OTC Over-The-Counter

PPP Purchasing Power Parity

VAR Vector Autoregression

RW Random Walk

BVAR Bayesian Vector Autoregression

RMSE Root Mean Squared Error

MAE Mean Absolute Error

UTS Univariate Time Series

SEM Simultaneous Equations Model

OLS Ordinary Least Squares

HICP Harmonised Index of Consumer Prices

IPI Industrial Production Index

IC Information Criteria

Bachelor Thesis Proposal

Author	Jaroslav Mida
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Proposed topic	Forecasting Exchange Rates: A VAR Analysis

Topic characteristics Forecasting exchange rates is a very interesting concept. The exchange rates are influenced by a lof of factors, not only economical, but also by market psychology or political conditions. Firstly, i would like to look at the determinants of exchange rates, divide them into three categories and closely examine them. Secondly, as currencies are traded in the foreign exchange market, i would spend some time describing how it works, its financial instruments, participants, its size. For the practical part of the thesis i would choose four fundamental economic variables, namely inflation rate, interest rate, unemployment rate and industrial production index and examine their effect on fluctuations of exchange rates using the vector autoregressive model, which is a tool to analyse multivariate time series and is often used for forecasting as well as describing dynamic behavior of economic and financial series. Afterwards, i will forecast the USD/EUR exchange rate for 2012 using vector autoregressive model and compare it with the Random Walk to see, which model produced better results.

Hypotheses The main hypothesis is: Random Walk produces better and more accurate forecast of USD/EUR exchange rate than the vector autoregressive model.

Methodology Two main models will be used in this thesis. The first one is the vector autoregressive model and the second one is the Random Walk, which is believed to outperform VAR in most cases. The forecasts will be compared using Root Mean Squared Error and the one with less error outperforms the other one.

Outline

1. Introduction
2. Exchange rate and its main determinants
3. Foreign exchange market
4. Vector autoregressive model
5. Conclusion

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Chapter 1

Introduction

Exchange rate is a very interesting and important asset in today's world, which can be considered as one of the determinants of the relative economic welfare in a country. It is being influenced by a lot of factors, not just economical, and, therefore, changes its value frequently in reaction to the shocks to these factors. There are many market participants, whose possible gain or loss from a transaction depends on the movement of the exchange rate. As a result, it is being monitored and analysed every day.

Our first goal in this thesis is to have a look at the concept of the exchange rate. Firstly, we present the main differences between real and nominal exchange rate. Secondly, we have a look at the exchange rate regimes. We show, how the fixed and free float regime differ from each other as well as explain the difference between de iure and de facto regimes. In the largest part of the Chapter 2, we divide the main exchange rate determinants into three groups, namely economic variables, market psychology and political situation, and study their effect on the exchange rate. It is really important to understand, how they influence the exchange rate, because later we choose some of them and apply an econometric method in order to forecast the USD/EUR exchange rate.

In the third Chapter we are going to look more closely at the foreing exchange market, which is nowadays the biggest financial market and where foreign exchange transactions are conducted and exchange rates determined. FOREX has come a long way before becoming, what we know today and we will briefly discuss its history. We can recognize a lot of different market participants, who enter this market with different goals and motivation and try to accomplish

them, usually by trading and cooperating with others. When trading with other participants, they have a variety of financial instruments they can use for conducting the transactions depending on what their needs and goals are. Therefore, in this chapter we will analyse some of the major market participants as well as major financial instruments. In addition, foreign exchange market fullfils three functions: transfer, credit and hedging, which are also described in this part of the thesis.

The purpose of this thesis is to forecast the USD/EUR exchange rate for 2012 using short-term interest rate, inflation rate, unemployment rate and industrial production index as variables, which interact with this exchange rate. Even more intriguing question is, if the applied method, vector autoregressive model, will be able to outperform Random Walk, which is considered to be more accurate. The superiority of the RW was showed by Meese & Rogoff (1983). They came to the conclusion that RW did better than several other structural models in out-of-sample forecast. There were other papers and studies, showing that the exchange rate is basically unpredictable on shorter horizons, such as one year. To those belonged, for example Cuaresma & Hlouskova (2005) or Kilian & Taylor (2003).

After the paper by Meese & Rogoff (1983) had been published, there existed less interest in using empirical models for exchange rates forecasting. This was changed by Mark (1995), who showed that exchange rates can be forecasted on longer horizons. Afterwards, more and more researchers were trying to beat RW and some of them succeeded fully or at least partially. Rossi (2006) rejected for some countries the hypothesis of exchange rate following RW, whereas Carriero *et al.* (2009) were able to outperform RW with large Bayersian VAR in most of the analysed countries.

The motivation of this thesis is to determine, which one of the two models, VAR and RW, produces better forecast of USD/EUR exchange rate. We use monthly data for Euro area(EU17) countries from 2002 to 2011 and use data from 2012 for the purpose of comparison. After estimating, running tests and forecasting using the VAR and RW model, which are nicely described in Brooks (2008) and Wooldridge (2009) respectively, we use the measure called Root Mean Squared Error in order to compare two forecasts. The results are then presented at the end of the Chapter 4 as well as in the conclusion.

The thesis is structured as follows: Chapter 1 is the Introduction; Chapter 2 describes basic notions connected with the exchange rate; Chapter 3 focuses on the foreign exchange market; Chapter 4 provides empirical analysis, forecast and comparison of two models as well as presents the results. Chapter 5 is the conclusion.

Chapter 2

Exchange rate and its main determinants

Currency exchange rate is one of the most important economic factor, which determines the relative economic welfare of a country. It is the rate, at which the domestic currency can be exchanged for a foreign currency, put another way, it is the price of a foreign currency compared to the domestic one. Its biggest importance lays in the fact that it is one of the most important factors affecting the level of exports and imports of a country. If a currency appreciates compared to another currency, the imported goods will be cheaper and as a result, foreign goods will be more attractive for domestic consumers. A negative consequence will be the decline of exports, because they will be more expensive compared to other goods in the foreign market. The exact opposite happens in case of a deppreciation. In addition, not only they are critical for a country or a company as a whole, they are also very important for smaller investors, because they can largely affect the real return on their investments. For all these reasons, the exchange rates are very closely monitored and analysed on a daily basis, and in some cases, even a government interferes in order to hold the value of a currency at particular level so that it is neither too strong, nor too weak.

In the following sections, we will have a look at the difference between nominal and real values of a exchange rate, between fixed and floating rate and the macroeconomic determinants of exchange rates, which affect the movement of the value of a currency.

2.1 Real versus Nominal exchange rate

The nominal exchange rate simply states how many units of a foreign currency we are able to purchase using one unit of our domestic currency. This is also the reason, why in the foreign exchange market, FOREX, the quoted rate is usually the nominal one.

On the other hand, real exchange rate (RER) is a more complex measure. It is the rate adjusted for inflation and it states how many goods and services in a domestic country can be traded for one unit of the same good or service in a foreign country. Usually, it is not calculated for each good or service separatelly, but rather for all goods and services using aggregate price levels for domestic and foreign country. We can define the equation as:

$$real exchange rate = \frac{nominal\ exchange\ rate * domestic\ aggregate\ price\ level}{foreign\ aggregate\ price\ level}_1$$

In theory, the calculation of RER looks to be pretty straightforward, but in reality, there is a variety of choices, which can be made. Firstly, it is important to choose the right base year. According to Kıpıcı & Kesriyeli (1997), it should be the specific year, in which the economy maintains both internal and external equilibirum. The logic behind it is that RER changes can be interpreted differently for different base years. Then, we have to choose, how many countries we are going to compare, which bilateral rates and price measures to use (usually Consumer Price Index is conducted and used) or what weights we will include.[2]
Moreover, the RER possess one more significant difference compared to the nominal exchange rate. Even if there is a fixed nominal exchange rate regime, the RER can fluctuate due to changes in price levels in countries, so it is pernamently floating.

[1]Economics.about.com - http://economics.about.com/od/Exchange-Rates/ss/Real-Exchange-Rates_4.htm

[2]Reserve Bank of Australia Bulletin - http://www.rba.gov.au/publications/bulletin/2001/nov/pdf/bu-1101-2.pdf

2.2 Fixed versus Free floating exchange rate

We can distinguish between two main exchange rate regimes: Free floating exchange rate and Fixed exchange rate. In today's world, the more preferable one is the free float, but fixed regime also has its advantages over free float. In addition, in this section we will look at the de iure and de facto exchange rate regimes to examine the difference as well as present de facto IMF classification[3]of exchange rate regimes in member countries.

2.2.1 Free floating exchange rate

Free floating exchange rate is determined solely by the market forces, namely supply and demand, and is allowed to fluctuate freely according to them. Usually there is no government intervention at all, but in case of managed floating, there is a possibility for a government interference in case of large instability, inflation or drastic appreciation or depreciation. In today's world, the free float is preferred to fixed regime because of several reasons.

According to Latter (1996), the free float is often called auto-correcting, because of its nature of automatically adjusting to the equilibrium of demand and supply in case of shocks or business cycles without the need of government interference. Secondly, it discharges of the disequilibrium in the balance of payments. If there is a deficit, the value of currency will fall encouraging exports and discouraging imports, and as a result returning to the equilibrium, and vice versa. Thirdly, according to the Mundell-Fleming model, the country can maintain only two out of three features of so called Impossible trinity. Those features are fixed exchange rate, free capital movement and independent monetary policy. In case of free float, the country is able to use its monetary policy for achieving other important goals, and not just for keeping the exchange rate fixed. In addition, a country has to hold much less reserves of foreign currency necessary for keeping the rate fixed. Therefore, the opportunity cost of holding those reserves is much smaller.

On the other hand, free float is not as perfect as it might seem. In contrast to the fixed regime, as Kenen (2000) suggested, because of changes on daily

[3]IMF - http://www.imf.org/external/np/mfd/er/2006/eng/0706.htm

basis, there occurs instability and uncertainty, which affects in negative way the amount of foreign investment and international trade, as the market players are not sure, how much they should buy or sell in case of uncertainty. Another negative aspects are larger amount of speculations which may distort the economy and possible inflationary pressures.

2.2.2 Fixed exchange rate

Fixed exchange regime or pegged regime differs from free float, because the value of a particular currency is tied against the currency of another country, usually U.S. dollar, or against the price of gold. This peg is maintained by the actions of government or, more often, of central bank of a country. These institutions have to hold large reserves of foreign currency in order to buy or sell its own currency at the market so that they are able to fullfil the target level of value of the currency.

As Flood & Rose (1995) suggested, the fixed regime offers less volatily than the free float. The currency is pegged against another one in order to stabilise it and as a consequence, minimise the risk of instability and uncertainty. The mutual trade and investment between these two countries is more stable, because buyers and sellers are sure, at what price they will sell or buy goods. Moreover the speculations should vanish, as it should not be very profitable for speculators to buy or sell pegged currency. But the reality is often different, because speculators often see an opportunity to earn profits by speculating with fixed exchange rates. In addition, the inflationary pressures, which might occur for free float, are less likely to happen. In general, this regime is more suitable for developing or smaller economies, in which the fluctuations in exchange rate, might significantly disturb the trade with their partners and as a result, undermine the economic growth.

The disadvantages of this regime are basically the advantages of the free float. First of all, a country is not able to use its monetary policy for anything, but keeping its exchange rate fixed. Central bank has to hold a very large amount of foreign exchange reserves in order to protect its peg. A good example is China before 2010, where the reserves grew rapidly each year and it was said that in 2011, China held around $2.85 trillion in reserves.[4]One more disadvantage

is that the balance of trade is unable to automatically adjust back to the equilibrium.

2.2.3 De iure versus de facto exchange rate regimes

Previous two subsections showed the main differences between two main regimes, free float and fixed, but in reality there exists other regimes, which are not a perfect float or a perfect fixed regime, but are close to one of them or somewhere in between. Nowadays, some governments pursue a practice, when they officially present and support in public one exchange rate regime , so called de iure ExRate regime, but in practice they actually use other system, so called de facto ExRate regime. This is usually connected with the phenomenon called Fear of floating. It was first studied by Calvo & Reinhart (2002) in their paper called Fear of Floating, where they studied countries, usually those, who have suffered from financial crisis, and examined, if after the announcement of the free float the countries' exchange rate was actually floating. The conclusion was that countries, which claimed that they had allowed the exchange rate to float, acutally didn't fully allow free float. To those belonged the Philippines, Bolivia, Korea or Thailand. This whole paper showed that this phenomenon is very pervasive and mostly emerging countries feared the floating, in other words large fluctuations.

Let's now move on to the classification of the members' de facto regimes as identified by the IMF staff and it may be different from what the members publicly announced. It consists of 8 different ExRate regimes[5]:

- **Exchange arrangements with no separate legal tender** - the currency circulates as the sole legal tender (formal dollarization) or this country belongs to a monetary or currency union, in which the same legal tender is shared by the members of the union. This regime causes complete loss of control over domestic monetary policy.[5]

- **Currency board arrangements** - legislative commitment to exchange domestic currency for a specified foreign currency at a fixed exchange

[4]English.peopledaily.com - http://english.peopledaily.com.cn/90001/90778/7258242.html

rate, meaning that the domestic currency will be issued only against foreign exchange and is backed by foreign assets.[5]

- **Conventional fixed peg arrangements** - country's currency is pegged within bands of ± 1% or less vis-a-vis another currency or a cooperative arrangement, such as ERM II, or vis-a-vis a basket of currencies, where the basket includes currencies of major trading and financial partners and weights reflect the geographical distribution of trade, servis and capital flows.[5]

- **Pegged exchange rates within horizontal bands** - the currency value is held within certain bands of more than ±1% around a fixed central rate or the margin between minimum and maximum value of the ExRate exceeds 2%.[5]

- **Crawling pegs** - currency adjusted periodically at a fixed rate or in response to selective quantitative indicators (past inflation vis-a-vis major trading partner, differentials between inflation target and expected inflation in major trading partner).[5]

- **Exchange rates within crawling bands** - currency kept within certain fluctuations bands of at least ±1% around a central rate, or the margin between minimum and maximum value of the ExRate exceeds 2%, and the central rate and bands are adjusted periodically or in response to changes in quantitative indicators.[5]

- **Managed floating with no predetermined path for the exchange rate** - monetary authority tries to affect the exchange rate without setting a specific target or path for the exchange rate. Intervention may be direct or indirect and indicators for managing are judgmental.[5]

- **Independently floating** - ExRate is market-determined with foreign exchange market intervention aimed at moderating the rate of change

and preventing undue fluctuations.[5]

Different regimes are then associated with different monetary policies, which are again described in the IMF de facto classification of the ExRate regimes. It distinguishes between these Monetary policy frameworks: Exchange rate anchor, Monetary aggregare anchor, Inflation targeting framework, Fund-supported or other monetary program plus others.

2.3 The main determinants of the exchange rate

We already know that the values of currencies in the foreign exchange market are determined by the interaction of demand and supply of those currencies. There exists a variety of factors, which influence demand and supply, and therefore, are the reasons, why exchange rates fluctuate. We can divide them into three categories, namely economic factors, market psychology and political situation. The most important ones are the economic variables, but the other two groups of determinants might affect the currency prices as well. In this section we will discuss the most influential determinants of the exchange rate.

2.3.1 Interest rate

As was suggested for example by Hakkio (1986b) or Sanchez (2008), the differentials in the interest rates of two countries have a significant effect on the value of a currency of one country compared to the other one. The interest rate is a very powerful tool for central banks to influence the levels of inflation and exchange rates, as all of them are highly correlated with the interest rate. The relationship is usually positive, in other words, both variables move in the same direction, but there exists other factors, for example inflation, which can at the same time heavily affect the interest rate-exchange rate relation, causing the overall negative correlation.

The logic behind the interest rate being one of the most important determinants is that the changes in interest rates affect significantly the level of capital

[5]IMF - http://www.imf.org/external/np/mfd/er/2006/eng/0706.htm

flows. In case of an increase, there is an inflow of the foreign capital, as investment in a country is more attractive. As a result, there is a rising demand for domestic currency, which will then be valued at a higher price against foreing currencies. The same would happen, if the interest rates of foreign countries would be decreased, because there would be less demand for investment in these countries, making investment in domestic country again more attractive. So, there is an already mentioned positive correlation between these two variables. But this relationship can be mitigated in case of a very high inflation differentials between these countries. In this scenario, the inflation, alone or with help of other determinants, could force the exchange rate to depreciate.

There is a way to define the relationship between interest rate and exchange rate. It is called the uncovered interest rate parity and it states that the difference between interest rates of two countries is equal to the expected change in exchange rate between them. The approximated formula is:

$$i_1 - i_2 = E(\Delta e),$$

where i_1 and i_2 are the nominal interest rates and $E(\Delta e)$ is the expected change in exchange rate. As Bekaert *et al.* (2007) state, it is an economic concept, which is important for economic theories on exchange rate determination, such as Dornbusch (1976) overshooting model or Krugman (1991) target zone model. However, there exists a mixture of evidence for and against this parity. There are number of studies, such as Mark & Wu (1998) or Froot & Thaler (1990), which have rejected the uncovered interest rate parity concept, especially for short-run horizons, where they found significant deviations. On the other hand, when studying the parity for long-run horizons, the results of studies, for example Meredith & Chinn (1998) or Lothian & Wu (2005), were more consistent with the uncovered interest rate parity. It is difficult to say, who is right, because both sides have conducted research and came up with different results.

2.3.2 Inflation rate

The inflation rate is one of the most important economic determinant of the economic state of a country. The relationship between interest rate and exchange rate has been discussed in many studies, for example by Albuquerque

& Portugal (2005), with the result that they influence each other.

The changes in inflation rate have the opposite effect on the exchange rate. In case of a rising inflation, the purchasing power parity against other countries, decreases, causing the exchange rate to depreciate, because the rising prices of products of a country discourages foreign countries to import them. As a consequence, the exports of domestic country will fall, resulting in the decrease in demand for domestic currency, which in turn results in depreciation. A very similar scenario happens, if a foreign country experiences declining inflation rate. In an opposite situation, i.e. declining domestic inflation or rising foreing inflation, the domestic currency will appreciate.

Some countries have adopted the policy of inflation targeting (IT), which means that the central bank aims at a particular level of inflation and uses monetary tools, mainly the interest rate, to achieve this level. There have been numerous studies examining the relationship between the inflation targeting and exchange rates. The study by Pontines (2012), using a treatment effect regression approach, came with the results that the nominal and real effective exchange rates are less volatile in case of inflation-targeting countries. This was particularly true for developing countries, the industrial ones experienced higher volatility. On the contrary, Sek *et al.* (2012) study on Asian economies shows using GARCH model that the IT leads to a higher volatility in exchange rate fluctuations in most of the studied countries and there is a significant correlation between IT and exchange rate movements.

2.3.3 Unemployment rate

The unemployment rate of a country is another indicator of relative economic health. Low unemployment rates are associated with good economic health, meaning that bigger portion of population is helping the economy to grow. That in return boosts the consumer spending, investment and demand for currency. As a result, the exchange rate is likely to appreciate. In case of high unemployment, the effect is opposite, leading to depreciation.

This negative correlation between unemployment rates and exchange rates is pretty logical, higher unemployment means that a country is not performing

very well and the strenght of its currency is lower. Belke (2005) studied this relationship on the sample consisting of Central and Eastern European Countries (CEECs), trying to assess, to what extent can the exchange rate variability be responsible for unemployment levels and vice versa. The results were as expected, confirming the negative relationship in a number of CEECs. Another research, Feldmann (2011), examining 17 industrial countries, came up with the same conclusion of higher exchange rate volatility causing higher unemployment levels.

2.3.4 Balance of payments

The balance of payments is another indicator of how well an economy is doing. It consists of current account, on which transactions, such as exports and imports, are recorded and capital account, where we record for instance inflow or outflow of foreign investment. Both of them significantly affect the exchange rate of a country. In addition, some institutions, such as International Monetary Fund, recognises not only capital account, but also financial account[6], but for our analysis we will stick to the division of current and capital account used by most of the institutions.

The balance of trade, which falls under current account, is the difference between country's exports and imports. As Branson (1981) suggested, current account has an effect on the exchange rate. When a country is exporting more than importing, it experiences positive balance of trade, meaning that the demand for domestic currency is larger among foreign countries, which may, as a result, cause the exchange rate of the domestic country to appreciate. The opposite process happens, when a country is running trade deficit. It imports more goods than it exports and has to borrow in order to pay for them. Therefore, there is an increasing demand for foreign currency, but a surplus of domestic one. Eventually, the domestic exchange rate will depreciate.

We can look at this relationship from the other side as well, because if the movements in exchange rates are not caused by balance of trade, but by other factors, these fluctuations will influence exports and imports as well. In case of appreciation, the country has a bigger purchasing strenght, but they sell less

[6]IMF - http://www.imf.org/external/pubs/ft/bopman/bopman.pdf

goods in foreign markets, because they are too expensive, causing the trade balance to become negative. However, the depreciation will boost the exports and eventually the trade balance will become positive.

The second part of the balance of payments is the capital account, which records the movements of capital and international loans in and out of the country. When there is a higher inflow of capital than outflow, the excessive supply of foreign currency will be created, leading to the depreciation of foreign exchange rate and appreciation of the domestic one. In the opposite case, there will be larger demand for a foreign currency, the value of it will increase and the value of domestic exchange rate will decrease. The special scenario could be a really huge inflow of short-term capital, known as hot money. Hot money, as shown for example by Martin & Morrison (2008) for China or Maitra (2011) for India, cause an excessive money supply, leading to high inflation. The problem is that as a result of these inflationary pressures, the exchange rate value will depreciate.

2.3.5 Gross Domestic Product

Gross Domestic Product (GDP) is the total market value of all final goods and services produced in a country in a given year[7]. It consists of investment, government purchases, consumption and net exports. It is a very important indicator, of how well an economy has done within a given period. It might not be the most influential determinant of the exchange rate, but it definitely can affect its value.

To understand the logic behind the effect of GDP, we should have a look at its components. In previous section we have already discussed the effect of balance of trade, which is net exports, because net exports are equal to exports minus imports. Another component, consumption, has been basically discussed as well in the part Employment level. When there is a higher employment rate, which is likely to increase the exchange rate, people are willing and have more resources to spend, boosting the consumption. So higher consumption might affect the exchange rate in a positive way, and vice versa. Investment is an economic variable dependent on the interest rate. Increases in investment are associated with increases in interest rates, because it is more attractive and

profitable for people to invest. As pointed out before, higher interest rates are likely to boost the value of the exchange rate, although the phenomenon of hot money might occur.

The last component, goverment purchases, create a little bit of a puzzle. As Kollmann (2010) stated, standard macroeconomic models predict that a rise in government purchases will cause the real exchange rate appreciation, because they will decrease the amount of national savings, shifting the S-I(Savings minus Investment) curve to the left, lowering the amount of currency to be invested in foreign countries and decreasing the net exports as well. But in this study, together with another study of Basu & Kollmann (2012) or Ravn *et al.* (2007), it was shown that an increase in government purchases, in case of Kollman's studies an exogenous rise, will cause the exchange rate to depreciate. One offered explanation was that the purchases of government aren't productive.

2.4 Market psychology

Market psychology includes factors, which influence the mood and feelings of people, especially investors, in the market, their perception of the market, their decisions on where they should put their money, how the prices, demand and supply of goods, services, currencies, etc., will change. These all and many more can strongly influence what will happen in the market and as a result, might, in a process, have an affect on the value of exchange rates. In the following paragraphs we will have a closer look at some of these factors, namely flights to quality, buy the rumour...sell the fact and currency speculations.

Let's first have a look at flights to quality. This type of event usually happens, when something negative occurs in the markets. Investors believe that it is too risky to hold their capital in those markets and want to move them to safe destinations, so known safe havens. Other reason for this movement might be the mood of investors to diversify their portfolio with less risky assets. In both cases, the effect is that there is a high inflow of capital into the country which is believed to have a "safe haven currency". Therefore, as previously discussed,

[7]Stirling University Business Club - http://www.su-bc.org

it will cause the appreciation of this currency and its exchange rates compared to more risky currencies. Viewpoint by Bailey (2012) indicated that currently the most preferable safe havens in terms of currencies are U.S. dollar, Swiss franc and Japanese yen.

Another psychological factor is a phenomenon known as buy the rumour, sell the fact. It means that when some rumours or unofficial announcements about a future event leak out, the stock prices or prices of currencies will react to these rumours in a positive or negative way. But, when this event actually happens and the expectations, which occured via rumours or announcements, are not met, prices are likely to move in the exact opposite direction. Sometimes, even though the expectations are met, the prices will move in the opposite way, because investors with knowledge of the rumour, will use the official announcement as an opportunity to sell the stocks or currencies, which they have previously bought based on rumours.

Lastly, we will examine the effect of currency speculations. Currency speculators are nowadays an essential part of foreign exchange markets. They are people, who want to make profit, usually by short-term transactions of buying or selling one or more foreign currencies. When they believe that a particular currency will rise in future, or they just want to increase its exchange rate to earn profits, they will have to buy a significant amount of this currency. By doing this, they will boost the demand for this currency, likely leading to its appreciation. In a scenario other way around, their action will decrease the demand for a particular currency and its exchange rate compared to other currencies.

2.5 Political situation

The last effect we haven't discussed yet, is the influence of political situation in a country. Political situation is very important, because it shows how stable an economy is, as are the decisions made by reigning politicall parties, because they influence the way the economy will be taking. Investors are unlikely to invest their capital into currencies of countries, which are unstable. Therefore events, such as wars, elections with uncertain and unexpected outcome or other political turmoils leading to instability, are very likely to have a negative im-

pact on the strenght of the exchange rate, for example study by Odhuno (2009) shows that the Uganda currency depreciated in times of rebellious attacks during the civil war, or during Iraq war, according to Warburton (2009), the U.S. dollar experienced short-term depreciation. Another paper by Garfinkel *et al.* (1999) confirms that unexpected election results explain some of the variation in exchange rates. One more study by Aisen & Veiga (2010) came to conclusion that political instability negatively affects the growth rate of GDP, and as discussed in subsection about GDP, lower GDP usually means weaker currency. On the other hand, when a country is believed to be a stable trading partner with strong currency, investors are more likely put their money into it, because it is less risky than to invest in unstable countries, leading to capital inflow, higher demand for currency and most likely to the increase of the exchange rate.

Chapter 3

Foreign exchange market

The foreign exchange market, or FOREX, is the biggest financial market in the world, with, according to the report in 2010 by the Bank for International Settlements, estimated average daily trading volume of $3.98 trillion. As stated by Ickes (2006), it is the place, where foreign exchange transactions, i.e. purchasing or selling of national currencies, are carried out and exchange rates between countries are determined. In addition, he pointed out that if there was only one common currency in the whole world, there would be no reason for FOREX to operate.

Moreover, FOREX is considered to be the most liquid market in the world thanks to the huge amount of participants as well as operating over-the-counter, or OTC, meaning there is no central exchange, where the currencies would be traded, but instead, it is a global market and participants negotiate deals with each other, which opens some more opportunities than stock market, such as deciding with whom to trade and for what price. Although FOREX is a very liquid market, it experienced large decreases in liquidity, for example, as showed by Mancini *et al.* (2010), during financial crisis in 2007-2009.

FOREX is a global financial market, which is open for 24 hours a day from Monday to Friday. Therefore it creates an opportunity for people from different time zones to trade with each other. As we can see from Figure 3.1, it opens differently in London, New York, Sydney and Tokyo, which are believed to be some of the biggest financial centres in the world. In addition, there are some periods of a day, when it is open for two markets at the same time and, as a result, there are higher volumes of currencies being traded, which offer an

opportunity for a buyer or seller to get a better deal. As a consequence, these time periods are considered to be one of the best for trading.

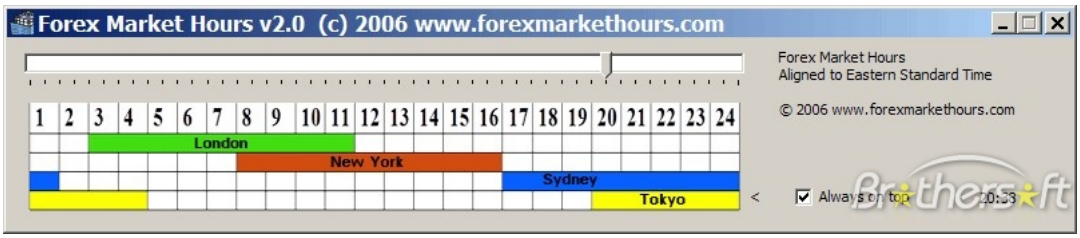

Figure 3.1: FOREX opening hours

The determinants of exchange rates have already been analysed in the first chapter, so in the next few following sections we will have a look at a brief history of FOREX, market participants, its functions and the most frequent financial instruments.

3.1 History of FOREX

Although the creation of FOREX as we know it could be dated back only to 1973, when major economies abandoned the dollar parity and free float became officially a suitable and popular exchange rate regime, first exchanges of currencies occured long time ago. Egyptians[8] were first to use money in different forms, while Babylonians[8] discovered paper bills and receipts. Later on, merchants from Middle East[9] started to trade currencies of different regions and civilisations being the first ones to do so. The trading of coins and paper bills occured with larger frequency and gained higher importance in Middle Ages[9]. The wider use of paper bills made life of traders easier and economies began to grow thanks to the increased trading.

Throughout the history, the problem with the exchanges was that kings, traders or merchants were basically able to change the value of the paper bills and coins whenever they wanted, because there were no official "exchange rates". This changed with gold standard, which was firstly introduced in Great Britain in 1816. According to the book The Gold Standard: Causes and Consequenes by

[8]History of the Stock Market - http://www.mhaven.net/Docs/StockMarketHistory.pdf
[9]Global-view.com - http://www.global-view.com/forex-education/forex-learning/gftfxhist.html

Thompson (1995), we can define gold standard as an obligation of government to convert a unit of its circulating paper money into an intertemporally constant amount of a real commodity, in this case gold. The United States joined the standard in 1879, as stated by Elwell (2011), and later replaced British pound as leading currency in gold standard after the World War I had started, because European nations decided to withdraw from this standard due to the disastrous state of the economies after WWI as well as insufficient gold reserves, according to report by Friend *et al.* (2011). The gold standard was eventually abandoned by the United States in 1933.

After the WWI and abandonement of gold standard, the volatility of FOREX increased significantly and there was a larger amount of currency speculations. This was not the ideal scenario and in order to stabilise the economies, prevent from even more speculations and replace the gold standard, the Bretton Woods Agreement was introduced in 1944. Currencies were pegged against the U.S. dollar, because at that time it was the strongest and most stable currency and were permitted to fluctuate within 1% bounds. In addition, U.S. dollar became the only currency backed by gold. The problems started to occur later. According to Dammasch (2001), significant weaknesses included capital movement restrictions, adjustment of parities only after the speculative and financial crises and pilling pressure on the United states to supply a huge amount of gold. The unwillingness to further intervene in the gold market and the declining gold reserves were further problems, as reported by Bordo & Eichengreen (1993). Eventually it collapsed in 1971. Nevertheless, the Bretton Woods achieved what it was meant for. Dammasch (2001) pointed out that it boosted the international trade and economic performance of economies as well as stabilising them, which was its most important objective at time of its creation.

After the collapse, there were two agreements signed, namely the Smithsonian agreement and the European Joint Flat agreement, which allowed currency movements within wider range than the Bretton Woods, but they included similar errors as were in the Bretton Woods and at the end, both of them were abandoned in 1973, leading to the shift to free-floating system., so the currency could independently move according to demand and supply, but some governments chose to peg their currency to increase its stability or use managed float. Since this moment, the volatility of exchange rates increased significantly, be-

cause of the loss of control over their values. In 1994, another important event happened. It was the year, when currencies were for the first time traded online. Internet and modern technologies heavily boosted the size of FOREX, which was growing larger by each day, attracting more and more new participants to enter the market. Although FOREX has experienced a lot of problems and hard times throughout the history, after all it has become the biggest financial market in the world.

3.2 Market participants

As FOREX grows larger, it attracts more and more new participants, who come to the market with different goals and motivation. They cooperate and trade with each other, exchange knowledge, if it is beneficial for them, take care of their clients' wishes and objectives or, in case of central banks, intervene in order to stabilise the value of currency. There is no unanimous division of market participants into groups. Therefore, we will have a look at probably the most important ones, which conduct the largest and most influential transactions in the market.

3.2.1 Central bank

Central bank is one of the most important and powerful institution not only within a country or area it operates, but also outside, for example on the FOREX market. According to MEJSTŘÍK *et al.* (2008), its main roles include conducting monetary policy, issuing money, controlling the amount of money circulating in the economy or surveillance of other banks. Central bank is a crucial participant of the FOREX. Because most of the participants are trying to make profit by buying, selling and speculating, the goals of central bank differentiates it from them. Its main objectives are to control the money supply, the inflation and interest rate in order to prevent the exchange rate of a country from rapid increasing or decreasing, which could cause economic problems, such as negative balance of trade or crisis and negatively affect the economic state of a country.

Central banks often have an idea at what price level they want to hold the

exchange rate. They have two options to use in order to influence it. The first one is the direct intervention. The logic behind it is that when a central bank wants to boost the exchange rate, it intervenes in the market by buying a huge volume of its currency. As a result, the supply will decrease, leading to an appreciation. In the opposite case, the central bank sells its reserves of domestic currency in order to increase the supply in the FOREX, and by conducting this, eventually depreciating the domestic exchange rate. Another possibility is to buy or sell the foreign currency, to which its currency is pegged or against which the central bank wants to manipulate the exchange rate. A perfect example is China, which set its objective to keep its currency weak against U.S. dollar by buying U.S. Treasury so that it can maintain the positive balance of trade with the United States. But in order for these transactions to achieve what they are aimed for, central banks have to buy or sell very large amounts of currencies. They are able to do this, because they usually hold significant foreign exchange reserves, which are the main instrument for direct intervention.

The second option central banks possess is to affect the exchange rate indirectly by manipulating the money supply and interest rate. The effect of increasing or decreasing the interest rate has been already discussed in the first chapter. So let's examine the changes in money supply. Central banks use different monetary policies to influence it. They can decide to adjust the minimum reserve requirements, which are held by banks. By decreasing it, the money supply will rise as banks now have more money to lend and vice versa. Another option is to use open market operations of buying, which enlarges money supply, or selling government bonds, which lowers money supply. These are the effects of some monetary policies. But what happens to the exchange rate? In case of increasing the money supply, there is a high possibility of rising inflation, which, as discussed in chapter one, has a negative effect on the value of exchange rate. The opposite situation is likely to decrease the inflation, which will cause the appreciation of the currency.

It is hard to choose, which one to use. It often depends on the situation and the goal central banks want to achieve. In addition, central banks have to decide, how quickly they want to influence the exchange rate, because it takes indirect intervention more time to have an affect on the exchange rate. Moreover, manipulating money supply usually forces central bank to manipulate the interest

rate as well in order to compensate for the changes in the money supply. To sum up, central bank is a powerful force, which differentiates from other market participants in its objectives, which are not to make profit, but to stabilise the currency.

3.2.2 Hedgers

Trading in FOREX brings about a substantial risk because of the volatility of the exchange rates. As dicussed before, they are affected by a lot of factors and are changing on daily basis. Investors can't be sure, what the movement of a particular exchange rate will be in the future. Those, who are more risk-averse and don't want to deal with such a high uncertainty want to protect themselves from these unwanted changes in the exchange rates, which could cause a significant losses for them. They wish to hedge against the risk and we can call them hedgers.

Who can be a hedger ? Basically it can be any individual investor, international firm, fund or even a bank that share a common goal of hedging themselves against future uncertain development of the market, and trade in the futures market. The strategy is to make an agreement about the trade that will go through in the future, but the price for goods or services buyers will pay and sellers will receive is the price at the time the deal has been struck. As a result, buyers and sellers don't have to worry so much about price and exchange rate movements, because the contract already states the trading price. Some of the most popular futures contracts are forwards and options. We will examine them more closely in another section, but for now, to have a basic idea, the forward contract sets the exchange rate at which the trade will go through some time later. The option is similar, but traders are not obliged, they only have the option, to finish the trade in the future, meaning that if there is a favourable movement of the exchange rate, then whoever has this option, might want to cancel the trade and try to strike a better deal.

In the upcoming part, we will have a look at speculators and arbitrageurs, who basically employ exactly opposite strategy than the hedgers.

3.2.3 Speculators & Arbitrageurs

As already mentioned, speculators and arbitrageurs is a class of market participants, which can be characterised as the opposite of hedgers, who are risk-averse. These market participants are risk-seeking and in order to make profit they often have to take on a huge risk. They are using the fluctuations in exchange rates to achieve their goals, contrary to hedgers. Let's first look at speculators.

Currency speculators are people, usually individual investors with enough capital, who try to predict the future movement of the value of the currency. They attempt to buy currencies for the lowest price and, of course, sell them for as high as possible. Speculators often buy or sell futures contracts, and depending on how correct their anticipation was, they incur profit or loss. By employing this strategy, they undergo a huge risk, because the exchange rates are affected by many factors and can change rapidly within days. They differ from arbitrageurs, because they conduct the transactions only in one market, whereas arbitrageurs operate in two markets simultaneously.

Moving on to the arbitrageurs, we should first describe what they actually do to earn profit. They look for differentials in prices in different markets, then they buy the currency in a market, where its exchange rate is lower and resell it in the other one, where its exchange rate is higher. These transactions bear much less risk than the operations made by speculators, but it is hard for arbitrageurs to make profit, because nowadays different foreign exchange markets are closely connected, so the opportunity window for an arbitrage is really small. Therefore only a small amount of the best and quickest arbitrageurs is likely to make profit, or, in worse case, incur loss. In addition, the exchange rates don't differ by huge amount, so they have to invest a substantial amount of capital, if they want to make a significant profit.

3.2.4 Market makers & Brokers

A market maker is a firm that stands ready to buy and sell a particular stock on a regular and continuous basis at a publicly quoted price.[10] In our studied case, market makers are dealing with currencies, which they have in their own inventory. They earn profit via the bid-ask spread, meaning that they attempt

to buy currencies from their clients for bid price, which is a little bit lower than listed price, and sell for higher ask price. The advantage for buyers or sellers is that if they are content with the offered bid/ask price, the market makers will immediatetly purchase or sell currencies at those prices. By doing this, market makers are contributing to the creation of more liquid and efficient foreign exchange markets. This was analysed for options trading by Eldor *et al.* (2006). They came to the conclusion of increased liquidity and improved efficiency, confirming the usefulness of market makers.

FOREX brokers or brokerage firms are intermediaries between the buyers and sellers of currencies. Their clients gave them the right to act on their behalf, i.e. they buy or sell currencies according to the clients' wishes. In order to achieve the best results possible, brokers should have profound knowledge of FOREX and they should analyse and monitor it very closely. In addition, they might provide trading platforms or offer services, such as advisory service or consultations. Brokers earn money by agreeing on a fixed price for their services or on a percentage commission from the whole trade. In some cases, a market maker is a broker as well, which might be counterproductive for clients, as broker may advise clients to strike a deal, which is beneficial for the broker, but not so much for the client.

We have analysed some of the biggest market participants, which come to the market with different intentions. Of course, there exist more FOREX important players, such as banks or investment management firms, but they often fall under the categories, which we have discussed. In the upcoming section, we will try to analyse functions of foreign exchange market.

3.3 Market functions

Every market in the world has some specific functions, and foreign exchange market is no exception. To be exact, it serves three main functions:

- **Transfer function** - it is the main and most important function of the FOREX. It was mainly created so that economic agents and institutions

[10]U.S. Securities and Exchange Commission - http://www.sec.gov/answers/mktmaker.htm

are able to convert different currencies, invest in foreign countries or conduct other international transactions with relative ease. When the conversion of the exchange rates happens, then there occurs the transfer function, because the purchasing power parity (PPP) between two countries is being transferred. This transfer of PPP usually happens via a number of credit instruments of the market. To those belong cheques and bank drafts, mail transfers, bills of exchange and telegraphic transfers.

- **Credit function** - this function is really useful, because it largely contributes to the growth of the market and international trade. FOREX provides credit for exporters and importers so that they are able to conduct transactions. It is sometimes necessary for them, because of the delay between the time, when the deal is actually made and the time, when the goods are delivered and money transferred. During this time, the importer doesn't dispose of goods and the exporter doesn't have money from the trade. Nevertheless, importer needs resources to pay for goods and the exporter needs money to, for example, buy some goods for production or finance the delivery of sold goods. This is the moment the credit facilities come to play. Since the euro introduction, the euro-dollar credit market has been growing and has become the major one in recent years.

- **Hedging function** - the logic behind hedging has been already described in the section about market participants. Businesses want to protect themselves from foreign exchange risk, which occurs because of the fluctuations in the exchange rates. As discussed, they try to fix the price of the deal by using futures contracts so that they don't have to worry about changes in the exchange rates, which could cause them significant losses.

3.4 Financial instruments

Financial instrument in general has a lot of definitions, because it includes a wide range of financial terms. One way to define it is as a contract that

gives rise to a financial asset of one entity and a financial liability or equity instrument of another entity.[11] It can be an asset, which possesses a monetary value, e.g. cash or cheque or it can be a legal agreement between two parties about a monetary transaction, e.g. swap. Financial instruments are very often used by currency traders in the FOREX market and these traders have a wide range, from which they can choose. Therefore it is important that they fully understand the meaning and the function of each instrument so that they are able to choose the most suitable instrument for the purpose the traders want to achieve. Let's now have a look at the most common foreign exchange market financial intruments:

- **Spot transactions** - have one of the highest average daily trading volume of all FOREX transactions. This volume amounted to over 37% of all transactions[12]. It is a simple agreement between two parties, where one party is purchasing a particular amount of currency and the other one is selling this specific amount. The price of the currency is the current, also known as spot, exchange rate. The spot transaction has a delay between the date of signing the agreement and the date the transactions is finalised and currency bought/sold. Usually, this delay is 2 business days, but there are exceptions for some currency pairs, such as U.S. and Canadian dollar. Looking at other characteristics of spot transactions, they are most commonly conducted in cash, not in form of contracts and do not include interest in the signed agreement. Because of the usage of current exchange rate, they are risky, because they are not protected against unfavourable changes in the exchange rate.

- **Swap** - is a type of transaction useful for traders or even countries with knowledge that they will be needing a foreign currency in the future and want to protect themselves from large unexpected changes in exchange rates. Two partners agree to exchange a specific amount of the currency at the agreed exchange rate, usually current/spot rate, and conduct the opposite transaction at the pre-agreed date in the future at the pre-agreed exchange rate, which differs from the spot rate and is usually calculated

[11] International Accounting Standards, IAS, 32 or 39 - http://www.iasplus.com/en/standards/standard31

[12] Bank of International Settlements report 2010 - http://www.bis.org/publ/rpfxf10t.pdf

as spot rate plus additional price depending on the lenght of swap transaction. Therefore, the swap price is the difference between these two exchange rates. Swap transactions are the most common type of FOREX instruments with average daily volume accounting for over 56 %[12].

- **Forward** - is a non-standardised financial instrument, mostly used as a hedging tool, which is not traded on any exchange. Two parties strike a deal to buy and sell a certain amount of currency at a specified date in the future at the set exchange rate, which is based on the spot rate and the interest rates of both countries. By conducting forward transaction they are protecting themselves from unfavourable fluctuations in the exchange rate. Forward is similar to the spot transaction, but the period between the date of agreeing to the terms of trade and the actual trade could be much longer, such as a week, a month or even a year (in general 3 or more days), whereas by spot transactions it is only a short interval of 1 or 2 days.

- **Futures** - is a standardised forward financial instrument, which is traded on exchanges, such as Chicago Mercantile Exchange. It is a contract between two parties to trade a specified volume of currencies at the predetermined exchange rate at the agreed future date and, in most cases, it includes the interest amount as well. Similarly to forward, they are used for hedging purposes, but they are also popular among speculators, who use them to speculate about movements of the exchange rate and make profit. As a result, unlike with forwards, futures contracts are sometimes closed out before maturity, because speculators want to take advantage of the favourable fluctuations. One more significant difference is that the risk of default is much higher by forwards, because they don't have clearing houses, which would offer a guarantee. The futures contract usually matures in 3 months and one of the currencies in the transaction is most often the U.S. Dollar.

- **Option** - is another financial derivative used by traders to hedge against exchange rate volatility. The holder of an option is provided with right, but not obligation, to buy or sell a set quantity of currency at pre-agreed

exchange rate at the exact predetermined future point in time (European-style options) or at any point within a specified time period (American-style options). These options are usually called traditional options. In addition, we know also Spot options. They can be bought even for a very short time interval, such as a few minutes, usually have smaller premium, which is the option price paid by option holder to the option seller, but also smaller payoffs than traditional options. Spot options offer a large variety of situations, on which a trader can buy an option, e.g. exchange rate will reach a particular value in 5/10/15 minutes etc. or it will not achieve this value, and many more.

Chapter 4

Vector Autoregressive Model

Vector autoregressive model (VAR) is, according to Brooks (2008), a systems regression model (there is more than one dependent variable), which is a hybrid between univariate time series models and simultaneous equations models. The model became known thanks to Sims (1980), who has stated that VAR is a very suitable tool for the analysis of the behavior of economic/financial time series, for forecasting the future values, data description, policy analysis as well as structural inference. VAR is also considered to be a very flexible model, because we can include as many endogenous variables as we want, resulting in as many equations.

In this chapter we will first study the basic bivariate VAR and then we will examine the general advantages and disadvantages of this model. Afterwards, we will move on to the actual model we have used in our estimation and forecast, explain the choice of variables, conduct tests and look at the results of the estimation and forecast. In the final part of this chapter, we will forecast the USD/EUR exchange rate using two models, VAR and RW, which is also described in one of the sections, and compare them using tool called Root Mean Squared Error.

4.1 Bivariate Vector Autoregressive Model

As already mentioned, VAR is flexible and can consist of many endogenous variables being affected by their lagged values and, in some cases, also by current values of the rest of endogenous variables. The simplest kind of VAR is

the bivariate vector autoregressive model, which contains only two variables y_{1t}, y_{2t} (meaning only 2 equations) and their current values are affected by k lagged values of both variables. Brooks (2008) defined the model:

$$y_{1t} = \beta_{10} + \beta_{11}y_{1t-1} + ... + \beta_{1k}y_{1t-k} + \alpha_{11}y_{2t-1} + ... + \alpha_{1k}y_{2t-k} + u_{1t} \quad (4.1)$$

$$y_{2t} = \beta_{20} + \beta_{21}y_{2t-1} + ... + \beta_{2k}y_{2t-k} + \alpha_{21}y_{1t-1} + ... + \alpha_{2k}y_{1t-k} + u_{2t} \quad (4.2)$$

where the term u_{it} is called the white noise disturbance term, which has two specific characterisitics. Firstly, its expected value is equal to zero:

$$E(u_{it}) = 0, i = 1, 2 \quad (4.3)$$

Secondly, the variance-covariance matrix is also equal to zero:

$$E(u_{1t}u_{2t}) = 0 \quad (4.4)$$

The two equations, 4.1 and 4.2, show us only one way, how a model could be written. Brooks (2008) considered for simplicity a case with $k = 1$, so the two equations take form:

$$y_{1t} = \beta_{10} + \beta_{11}y_{1t-1} + \alpha_{11}y_{2t-1} + u_{1t} \quad (4.5)$$

$$y_{2t} = \beta_{20} + \beta_{21}y_{2t-1} + \alpha_{21}y_{1t-1} + u_{2t} \quad (4.6)$$

This system can be written in matrix form:

$$\begin{pmatrix} y_{1t} \\ y_{2t} \end{pmatrix} = \begin{pmatrix} \beta_{10} \\ \beta_{20} \end{pmatrix} + \begin{pmatrix} \beta_{11} & \alpha_{11} \\ \alpha_{21} & \beta_{21} \end{pmatrix} \begin{pmatrix} y_{1t-1} \\ y_{2t-1} \end{pmatrix} + \begin{pmatrix} u_{1t} \\ u_{2t} \end{pmatrix} \quad (4.7)$$

Or as:

$$y_t(g \times 1) = \beta_0(g \times 1) + \beta_1(g \times g)y_{t-1}(g \times 1) + u_t(g \times 1) \quad (4.8)$$

where g is the number of variables. If we want to extend the model to n-variables and p-lags, we arrive to the model in form of, as in Zivot & Wang

(2003):

$$Y_t = c + \Pi_1 Y_{t-1} + \Pi_2 Y_{t-2} + ... + \Pi_p Y_{t-p} + \varepsilon_t, t = 1, ..., T \tag{4.9}$$

where $Y_t = (y_{1t}, y_{2t}, ..., y_{nt})'$ is a $(n \times 1)$ vector of time series variables, Π_i are $(n \times n)$ coefficient matrices and ε_t is an $(n \times 1)$ unobservable white noise vector process with zero mean and time invariant covariance matrix Σ. There are some cases, where we would like to use other deterministic terms, not just intercept, such as seasonal dummies or trends, or even use exogenous variables. Then a more general VAR(p) model would take form of, as in Zivot & Wang (2003):

$$Y_t = \Pi_1 Y_{t-1} + \Pi_2 Y_{t-2} + ... + \Pi_p Y_{t-p} + \Phi D_t + G X_t + \varepsilon_t, t = 1, ..., T \tag{4.10}$$

where G and Φ are parameter matrices, D_t is an $(l \times 1)$ matrix of deterministic components and X_t is an $(m \times 1)$ matrix of exogenous variables.

4.2 Advantages of Vector Autoregressive Models

As any other model, VAR also has its pros and cons compared to other models, especially univariate time series (UTS) and simultaneous equations models (SEM). The most important advantages and disadvantages are examined in Brooks (2008). Therefore, I will usually refer to his book in this and the following section.

One of the biggest benefits of VAR is that all the variables in the model are treated as endogenous (the exception are so called VARX models, which contain variables considered to be exogenous). In SEMs, the problem with identification often arises, because it is difficult to decide, which variables should be treated as exogenous. But in VAR, the right hand sides of the equations are always the same, consisting of lagged endogenous variables, resulting in no such problem. In addition, in UTS models (AR(p) models), the variable depends only on its own lagged variables and white noise terms. VAR is more flexible and the endogenous variable is able to be affected by not only its own

lagged values, but also lagged values of other endogenous variables in the system. Moreover, when there are no contemporaneous terms in the equations, each equation can simply be estimated by the Ordinary Least Squared (OLS) method.

Important feature of VAR is its usefulness in terms of forecasting. It often produces more accurate results than other models. Brooks (2008) referred to McNees (1986), who showed that forecasting some U.S. macroeconomic variables with VAR produced more accurate estimates than using other models. Furthermore, Taiwo & Olatayo (2013) forecasted some Nigerian economic time series data and showed that VAR did better than time series regression with lagged explanatory variables.

4.3 Disadvantages of Vector Autoregressive Models

First major drawback, as suggested by Schlegel (1985), is a very high number of parameteres to be estimated. With each variable, we have to add a separate equation for this variable (k-variables result in k-equations). When we consider q-lags of each variable, then, according to Brooks (2008), we have to estimate $k + qk^2$ parameters, which might be a huge number.

Another problem is the choice of optimal lag lenght for VAR as well as choosing the appropriate ordering of our variables. For deciding on optimal lag lenght, we have several options, but usually we use 4 types of information criteria: Akaike Info Criterion, Final Prediction Error, Hannan-Quinn Criterion and Schwarz Criterion. The issue arises, when they don't produce the same result, and we are forced to choose one of them we believe, produced in our specific case the most appropriate answer. Regarding the most suitable ordering of our variables, we usually put the variable we want to forecast in the last place, because we believe, it is influeced by the others. But the ordering of the rest of variables is the issue and we have to rely on economic theory and common sense.

Schlegel (1985) also pointed out another problem, multicollinearity. A lot of economic time series are correlated with their own past values as well as with

present and past values of other economic time series. Therefore, increasing the number of variables and lags might cause multicollinearity in the model. Moreover, it can result in inability to determine the significance of the variables because of higher standard errors of coefficients. Brooks (2008) emphasized another drawback. VARs are $a - theoretical$, because there is little theoretical background behind the relationship among variables and often the coefficient estimates can't be interpreted straightforwardly.

4.4 Description of the Dataset

In the first chapter we have already seen that the exchange rate has a lot of determinants. But not all of them can be easily implemented into the model. It is not so easy to capture the effect of market psychology or political situation on the exchange rate. In addition, we have to use data with the same time period, but not all of the variables are available with the same time basis, e.g. some are published quarterly, others monthly or annually.

Before moving to the justification of the chosen macroeconomic variables, we should have a closer look at our dataset. As we want to predict the exchange rate of USD/EUR, our data are based on the Eurozone (EU17), countries, which have already adopted euro as their currency. In our analysis, we will be using monthly data from January 2002 till December 2011, meaning 10-year period and 120 observations for each variable. Right now, we have also data available for the whole year 2012, but we will not use them for the estimation. The reasoning behind this is that we would like to compare the forecasted values generated by VAR and Random Walk for 2012 with the actual values, and decide, which one of the models produced better forecast. For the purpose of comparison, there are several tools available. The most often used ones are Root Mean Squared Error (RMSE), which we will later explain and use in our analysis, or Mean Absolute Error (MAE). Of course, there is also a small benefit of using data for 2012, which would give us 12 more values for each variable, but this benefit would not be greater than the drawback of being unable to compare the models, because we couldn't compare forecasted and actual values. The approach of not using all the data available, but leaving a part of them for the comparison of our forecast with actual values, is called the Out-of-Sample forecast. The other method, where we take all of the data and

then produce the forecast, is the In-Sample forecast. As described above, we will use the first approach.

Schlegel (1985) emphasized the problem of multicollinearity and a large number of parameters to be estimated in case of large number of endogenous variables. Therefore, it was important not to use too many variables to try to avoid this issue. In the end, we have chosen for our VAR model five macroeconomic variables, which are all available with monthly intervals. We believe that 4 of them, Harmonised Consumer Price Index, Unemployment rate, short-term interest rate Euribor and Industrial Production Index have strong effect on our fifth, dependent variable, the bilateral exchange rate. Let's now have a brief look at each variable:

- **Exchange rate (ExRate)** - the bilateral exchange rate USD/EUR is the variable we want to forecast and examine the effect of the rest of the variables on ExRate. The data were downloaded from the Statistical Data Warehouse (SDW)[13] of the European Central Bank.

- **Euro Interbank Offered Rate (Euribor)** - short-term (1 year) interest rate, at which banks can lend or borrow funds with other banks within the interbank market. The data are available from the SDW[14].

- **Harmonised Index of Consumer Prices (HICP)** - it is the measure of the monthly inflation within Eurozone. It is neither seasonally nor working day adjusted. It is calculated with the base year 2005=100 and the data were again downloaded from SDW[15].

- **Unemployment rate (UnemRate)** - it is the standardised unemployment rate including all ages anf both genders (male and female). It is seasonally, but not working day adjusted and is calculated as percentage of civilian workforce. The source of the data is SDW[16].

[13] http://sdw.ecb.europa.eu/quickview.do?SERIES_KEY=120.EXR.M.USD.EUR.SP00.E
[14] http://sdw.ecb.europa.eu/quickview.do?SERIES_KEY=143.FM.M.U2.EUR.RT.MM.EURIBOR1YD_.HSTA
[15] http://sdw.ecb.europa.eu/quickview.do?SERIES_KEY=122.ICP.M.U2.N.000000.4.INX
[16] http://sdw.ecb.europa.eu/quickview.do?SERIES_KEY=132.STS.M.I6.S.UNEH.RTT000.4.000

- **Industrial Production Index (IPI)** - according to the OECD glossary, it is the index covering production in mining, manufacturing and public utilities (electricity, gas and water), but excluding construction[17]. It is working day and seasonally adjusted with the base year 2010=100. Once again, data are available at SDW[18].

For our analysis we will do transformation of variables ExRate, HICP and IPI and we will use logarithms of these variables. This approach was used in many papers and studies, such as Chinn (2006) or Mark (1995) - log of ExRate, Ercolani & Dutta (2006) or a study by the Consumer Prices Unit(2008)[19] - log of HICP and Jamil *et al.* (2012) - log of IPI. In the Table 4.1 we can see summary statistics (number of observations, mean value, standard deviation, minimum and maximum) for all the data as well as for logarithms of exchange rate, HICP and IPI. The summary was produced by the statistical software Stata.

Variable	Obs	Mean	Std. Dev.	Min	Max
ExRate	120	1.23	0.19	0.85	1.58
UnemRate	120	8.76	0.82	7.29	10.21
HICP	120	101.16	6.08	90.36	111.29
Euribor	120	3.02	1.20	1.22	5.39
IPI	120	102.97	5.69	90.23	114.92
ExRate_log	120	0.20	0.16	-0.16	0.46
HICP_log	120	4.61	0.06	4.50	4.71
IPI_log	120	4.63	0.06	4.50	4.74

Table 4.1: Summary statistics for all endogenous variables and the logarithms of ExRate, HICP and IPI

We should now discuss another problem, which arises with VAR modelling. It is very important to try to find the most suitable ordering of our variables. Ordering is very important for impulse responses and forecast error variance decompositions. When analysing possible options, we should think about the movements of variables. Most of them change its value in reaction to changes in other variables. The variable we want to forecast should obviously be the

[17]OECD glossary - http://stats.oecd.org/glossary/detail.asp?ID=1339
[18]http://sdw.ecb.europa.eu/quickview.do?SERIES_KEY=132.STS.M.I6.Y.PROD.NS0020.4.000
[19]Consumer Prices Unit - http://www.nso.gov.mt/docs/RPI&HICP-Manual.pdf

last one, because we suppose that other variables influence it. In our case, the last variable will be ExRate. For ordering of the rest of the variables, we should have a look at Kim & Roubini (2000), who studied monetary policy shocks on exchange rates and other macroeconomic variables. They included some of the variables, which are used in this thesis in this order: short-term interest rate, consumer price index, industrial production and exchange rate (in addition, there were also used other variables, which are not used in this thesis). Therefore, we will apply this ordering. We have one more variable, which was not included in their model, unemployment rate. We know that UnemRate and HICP have a negative relationship (Phillips curve) and influence each other. It is not so easy to decide, which should be used after the interest rate, but in the end, we decided to use this ordering: Euribor, UnemRate, HICP, IPI, ExRate (more accurately, logarithms of ExRate, HICP and IPI).

In the figures 4.1 to 4.5 we can see the charts, which capture movements of values of our endogenous variables. All charts were downloaded from the Statistical Data Warehouse of the European Central Bank.

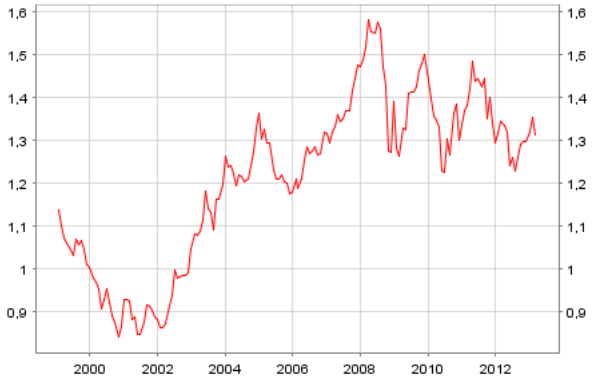

Figure 4.1: Graph of developments in the USD/EUR exchange rate

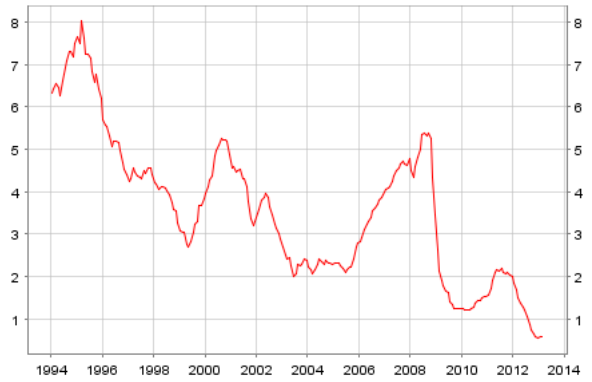

Figure 4.2: Graph of developments in short-term interest rate - Euribor

Figure 4.3: Graph of developments in Industrial Production Index

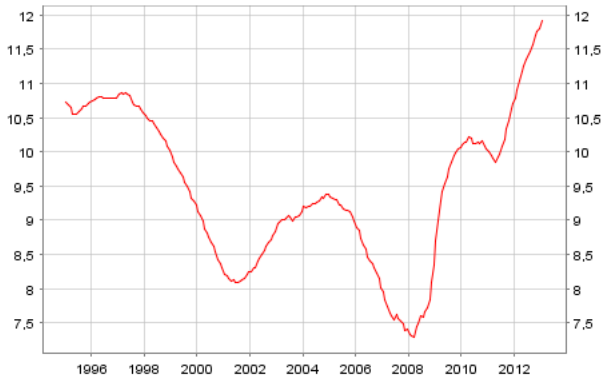

Figure 4.4: Graph of developments in Unemployment rate

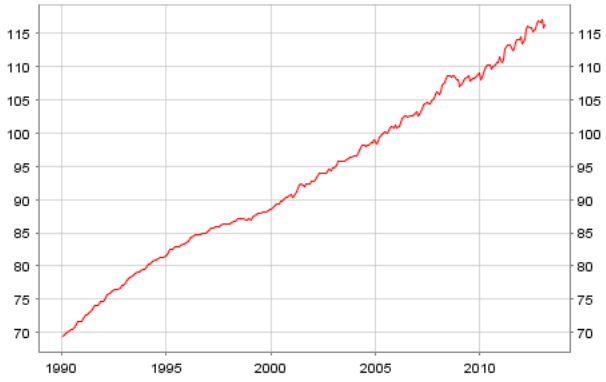

Figure 4.5: Graph of developments in the Harmonised Index of Consumer Prices

4.5 Specification of Vector Autoregressive Model and the Estimation

It is time for us to define the model we will be using in the analysis and forecast. As discussed above, we have chosen five endogenous variables, resulting in five separate equations. It is important now to decide on the optimal number of lags of the variables. There exist several methods how to find the optimal answer and in our analysis we will use the multivariate information criteria (IC). The goal is to minimise the value of this criteria. Before computing the actual IC, we have to set the maximum number of endogenous lags. We chose to set the value to 10, because we don't want too many possible lags in our model, because it brings the danger of multicollinearity. Among the most popular criteria belong, according to Brooks (2008), Akaike IC (AIC), Hannah-Quinn IC (HQIC), Schwarz IC (SIC). In addition, statistical software computes automatically Final Prediction Error (FPE) as well. Unfortunatelly for us, the criteria produced different answers. AIC and FPE suggested optimal lag lenght of 4 lags, whereas HQIC and SIC went for 2 lags. Every criterion has its pros and cons compared to others, but as Brooks (2008) stated, no criterion is in all cases better than the others. After conducting more tests connected with the VAR approach, which we will discuss later, we found out that the VAR with 4 lags produced more desirable test results. Therefore, we have decided to continue our analysis with 4 lags.

In our case, as previously discussed, our vector of endogenous variables takes form of $Y_t = (Euribor, UnemRate, log\_HICP, log\_IPI, log\_ExRate)'$ and this ordering must be applied to all the coefficients as well. We apply $p = 4$ lags of endogenous variables on the formula (4.9) and come up with the following model:

$$Y_t = c + \Pi_1 Y_{t-1} + \Pi_2 Y_{t-2} + \Pi_3 Y_{t-3} + \Pi_4 Y_{t-4} + \varepsilon_t, t = 1, ..., T \tag{4.11}$$

where:

$$Y_t = \begin{pmatrix} y_{1t} \\ y_{2t} \\ y_{3t} \\ y_{4t} \\ y_{5t} \end{pmatrix} \quad ; \quad Y_{t-p} = \begin{pmatrix} y_{1t-p} \\ y_{2t-p} \\ y_{3t-p} \\ y_{4t-p} \\ y_{5t-p} \end{pmatrix} \quad ; \quad c = \begin{pmatrix} c_1 \\ c_2 \\ c_3 \\ c_4 \\ c_5 \end{pmatrix} \quad ; \quad \varepsilon_t = \begin{pmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \\ \varepsilon_{3t} \\ \varepsilon_{4t} \\ \varepsilon_{5t} \end{pmatrix}$$

$$\Pi_p = \begin{pmatrix} \beta_{11}^p & \beta_{12}^p & \beta_{13}^p & \beta_{14}^p & \beta_{15}^p \\ \beta_{21}^p & \beta_{22}^p & \beta_{23}^p & \beta_{24}^p & \beta_{25}^p \\ \beta_{31}^p & \beta_{32}^p & \beta_{33}^p & \beta_{34}^p & \beta_{35}^p \\ \beta_{41}^p & \beta_{42}^p & \beta_{43}^p & \beta_{44}^p & \beta_{45}^p \\ \beta_{51}^p & \beta_{52}^p & \beta_{53}^p & \beta_{54}^p & \beta_{55}^p \end{pmatrix}$$

We can write the model in a more simple way as:

$$Y_t = c + \sum_{p=1}^{4} \Pi_p Y_{t-p} + \varepsilon_t, t = 1, ..., T \tag{4.12}$$

Now we have a certain ordering as well as optimal lag length. Each equation has the same number of lags of all endogenous variables, meaning that our VAR is unrestricted. We can apply OLS method on the each equation separately. The tables 4.3-4.6 with estimated coefficients can be found at the end of this chapter. For the whole analysis, the estimation and forecast, we will use statistical software JMulti, some parts of the analysis can be conducted in the software Gretl.

4.6 Tests

After we have done the estimation of the parameters, we should now move on to the part, where we want to conduct necessary tests to check for suitability of our model. Our first test is the test about the stability of the model. There are several ways to test it and we started with CUSUM test. Brown *et al.* (1975) showed that if the cumulative sums of recursive residuals of our variables go beyond the two bands(confidence intervals) based on our chosen significance level, then it is the evidence against the stability of our model. We have chosen 5% significance level and from 5 charts we can see that all the curves wander in between the bands, meaning the stability of the model. In addition to this

test, we wanted to confirm the joint stationarity of our model by looking at the eigenvalues of the coefficient matrices and if all of them have modulus less than 1, then the VAR model is stable, as defined by Lütkepohl (2005). Statistical software JMulTi produces modulus of the eigenvalues of the reverse characteristic polynomial, where all the eigenvalues are supposed to be greater than 1 in order for model to be jointly stationary. In our case:

$$|z| = (1.3628\ 1.4708\ 1.4708\ 1.8311\ 1.4915\ 1.4915\ 1.5485\ 1.5485\ 16.3838\ 1.5753$$
$$1.5753\ 1.1499\ 1.1499\ 1.3784\ 1.3784\ 1.6959\ 1.0115\ 1.0115\ 1.1030\ 1.0035)$$

where as we can see, all of the values are greater than 1, confirming the joint stationarity. Moreover, we also conducted the Chow test for parameter constancy, which is again described in Lütkepohl (2005). We set the break date to the seventh month of 2004 and the test resulted in $p - value = 0.2100$ for the break point Chow test. As a consequence, we do not reject the null hypothesis of parameter constancy. However, as we all know, our dataset includes data from the time of financial crisis, when the values of our variables fluctuated a lot. Therefore setting the date at a later time would cause the rejection of the null hypothesis because the crisis caused the parameter inconstancy.

Next, we want to have a look at residual autocorrelation and conduct two tests. First, we conducted Portmanteau test, which tests for the significance of the residual autocorrelation up to selected number of lags, as stated by Lütkepohl (2005), and can be only applied, if there are no exogenous variables in the model. The null hypothesis states that there is no autocorrelation among the residuals. Our test came up with the $p - value = 0.0895$, meaning that we failed to reject the null hypothesis at the 5% significance level. To confirm this, we have also run Breusch-Godfrey LM test with F-approximation, which again tests the null of no residual autocorrelation against the alternative of residual autocorrelation, and compared to the Portmanteau test, it can be used in case of exogenous variables. We didn't use basic LM test, because our data sample isn't so large and Edgerton & Shukur (1999) showed that this test might be biased in smaller samples. Our $p - value$ is equal to 0.1109 and we again failed to reject the null hypothesis at the 5% significance level. To sum up, there is no autocorrelation in the residuals.

Our last carried test was the Granger-causality test. We wanted to see, if our chosen macroeconomic variables cause changes in our dependent variable, the exchange rate. The logic, as described by Brooks (2008), behind this test is that if our 4 endogenous variables cause the exchange rate, then lags of these variables should be significant in the equation for exchange rate. The null hypothesis is that Euribor, UnRate, HICP_log, IPI_log, "do not Granger-cause " ExRate_log. The resulting $p - value$ is 0.1810, so we can reject the null at the 20% significance level, meaning that those variables Granger-cause the exchange rate. We can see that the rejection of the null happened at quite high significance level. As a result, if we look at the estimated coefficients in tables 4.3-4.6, we can find several coefficients equal to or very close to zero. Moreover, the software produced also test for instantaneous causality with null hypothesis: No instantaneous causality between Euribor, UnRate, HICP_log, IPI_log and ExRate_log. The $p - value = 0.0845$, so we can reject the null hypothesis at 10% significance level. As a consequence, there is instantaneous causality between them.

4.7 Impulse responses

The disadvantage of the VAR models is the large number of estimated parameters, in our case it is 105. It is not so easy and straightforward to interpret the effect of variables on the dependent variable. In order to examine the sign of the effect as well as how long the effect will last, we should examine the VAR's impulse responses (IR), and in the next section also Forecast Error Variance Decompositions (FEVD).

Brooks (2008) defined the function of IR as tracing out the responsiveness of the dependent variables in the VAR model to shocks to each of the variables. The procedure is to apply a unit shock to the error of each variable (additionally, we assume that this error will regain its value of zero in the following period and other errors are equal to zero), and we can see, how the variable responds to this shock and changes in time. IR, as well as FEVD, are dependent on the ordering of our variables. As a consequence, different orderings will most likely bring different results. This shows the importance of the ordering analysis while preparing the model.

We can create n^2 impulse responses, where n stands for number of variables, in our case we have 25 possible IR. In this study, we would like to examine the effect of inflation, interest rate, unemployment rate and production index on the dependent variable, exchange rate. Therefore, we will construct only 4 IR. Each IR function will show the impact of shocks to the 4 variables (Euribor, UnemRate, HICP, IPI) on the exchange rate and we will have a look at the sign of the effect, if it complies with what we expected. We decided to include in the charts the 95% Efron Percentile confidence interval and we set the number of time periods to 50. In addition, especially from the Figures 4.7 and 4.9, we can see that the confidence bands are sometimes quite large. This was also stated by Runkle (1987). Let's now have a look at the impulse responses:

- **Shocks to Euribor** - innovations in the short-term interest rate are supposed to bring positive effect to the exchange rate, because higher interest rates attract inflow of capital. From Figure 4.6 we can deduct that this is here not the case, as the effect is negative for all 50 periods. There is a possible explanation, because there could be a inflow of so called 'hot money", in other words risky short-term capital, which would cause higher level of inflation and mitigate the effect of interest rate, as discussed in the second chapter of this work.

- **Shocks to Unemployment rate** - during first 10 periods, the sign of the effect was fluctuating between positive and negative, Figure 4.7. Afterwards, the response was negative for around 25 periods, as expected, because higher unemployment usually results in weaker currency. But in the end, there was an unexpected change of the sign of the effect.

- **Shocks to HICP** - from the Figure 4.8 we can see that in the first 10 to 15 periods, the effect was once positive and other time negative. Although we had expected the negative effect of the shocks to HICP on the exchange rate, the exchange rate responded in a positive way, which is quite surprising.

- **Shocks to IPI** - when the production increases, the exchange rate is supposed to appreciate. From the Figure 4.9 we can see that the logic

complies completely with the reality, as responses to the shocks to IPI brought positive effect on the exchange rate.

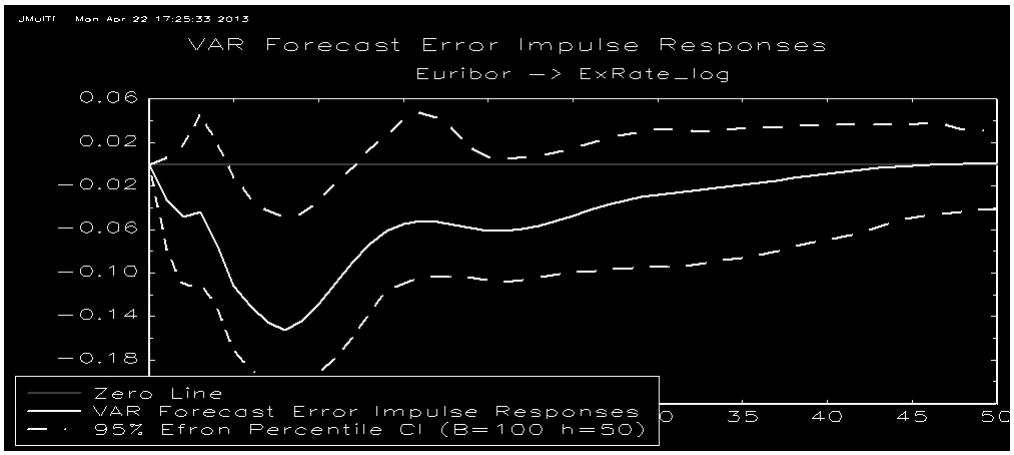

Figure 4.6: Impulse responses for the shocks to short-term interest rate for 50 periods and with included 95% Efron confidence interval

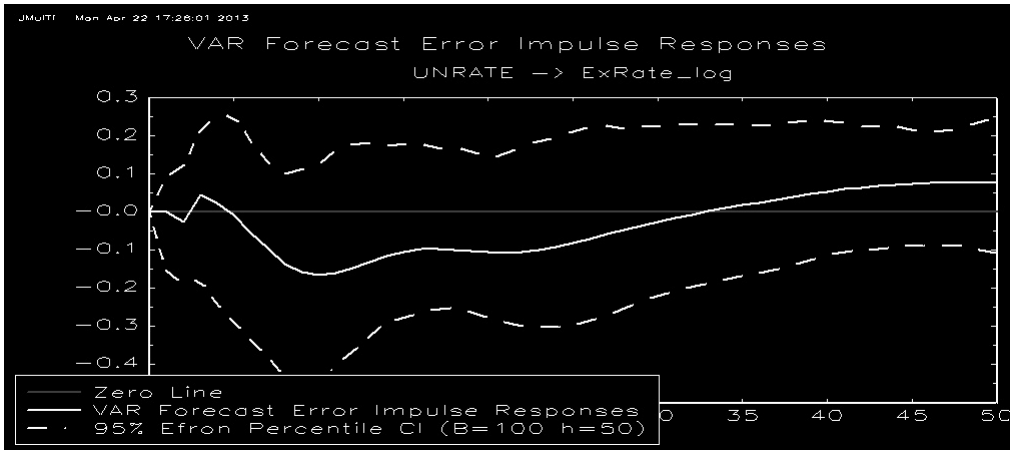

Figure 4.7: Impulse responses for the shocks to the unemployment rate for 50 periods and with included 95% Efron confidence interval

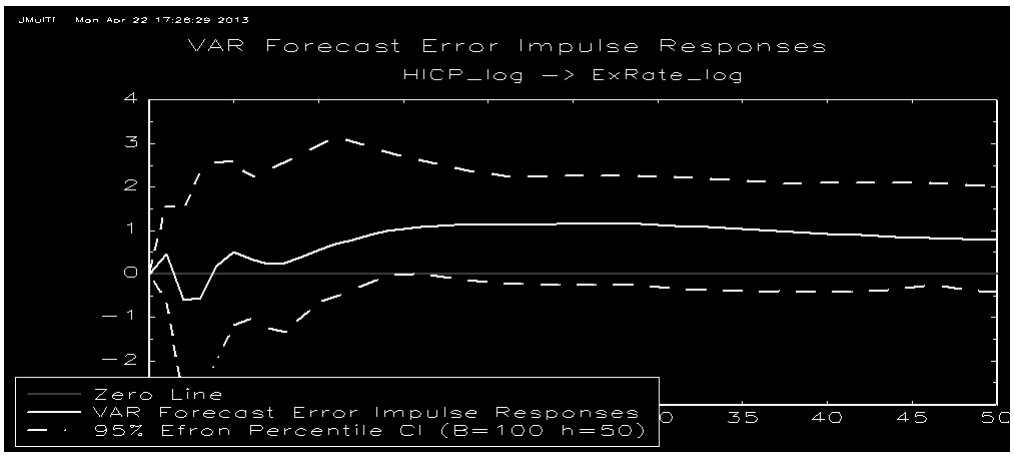

Figure 4.8: Impulse responses for the shocks to the HICP for 50 periods and with included 95% Efron confidence interval

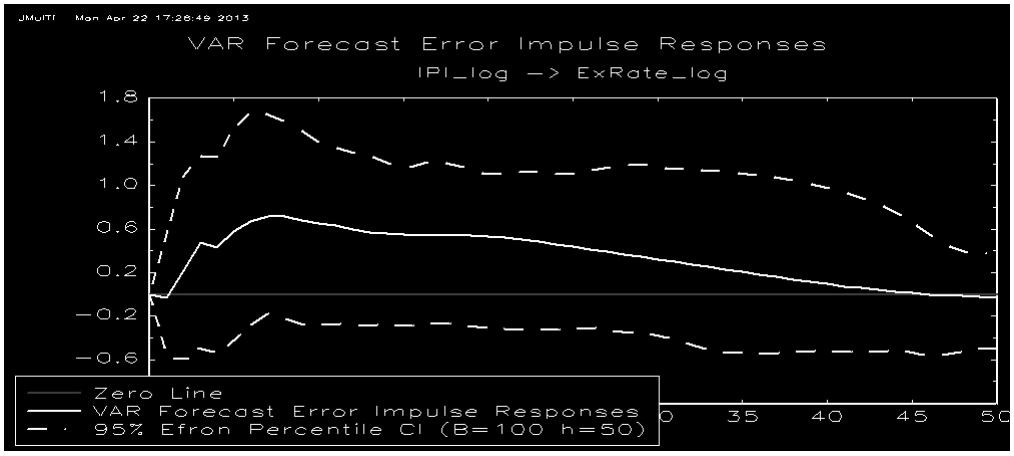

Figure 4.9: Impulse responses for the shocks to the index of industrial production for 50 periods and with included 95% Efron confidence interval

4.8 Forecast Error Variance Decomposition

FEVDs offer a little different analysis of shocks. According to Brooks (2008): "They give proportion of the movements in the dependent variables that are due to their own shocks, versus shocks to the other variables." He also further explains that a shock to the variable will not only have an impact on this variable, but thanks to the dynamic structure of VARs, it will influence other variables as well.

In our case, it also follows economic theory and common sense, because our chosen variables often influence each other, for example negative relationship between inflation and unemployment, positive relation between production and employment etc. Moreover, it has been observed that most of the error variance of the time series is explained by the shocks to its own series.

Figures 4.10 to 4.14 capture the forecast error variance decomposition of our variables and are included at the end of this chapter. Most of the error variance of the unemployment rate and harmonised consumer price index can be explained by the shocks to their own series (Figures 4.11 and 4.12). In case of IPI and Euribor, the shocks to the unemployment rate are also a significant factor explaining the error variance of the these two variables (Figures 4.13 and 4.10). From the last Figure 4.14, the error variance of the exchange rate is also significantly explained by the short-term interest rate Euribor.

4.9 Random Walk

Random Walk is, according to Wooldridge (2009), a highly persistent time series model, which can be characterised as Autoregressive model of order 1 with $\rho_1 = 1$, AR(1). Then we write:

$$y_t = y_{t-1} + \varepsilon_t, t = 1, 2, ..., \tag{4.13}$$

where $\{\varepsilon_t; t = 1, 2, ...\}$ is independent and identically distributed with mean zero and variance σ_e^2 and we assume that y_0 is independent of ε_t for all $t \geq 1$. If we further imply repeated substitution, we can show that the expected value of RW doesn't depend on $t(E(y_t) = E(y_0)$, for all $t \geq 1)$, whereas its variance

does($Var(y_t) = \sigma_e^2 t$), meaning that the process cannot be stationary.

In what we are interested the most is the future value generated by RW. We want to find the expected value of y_{t+h} and we know the current value y_t. Wooldridge (2009) explains that RW shows highly persistent behavior so that value of y today influences future value of y significantly. We can write RW for h periods:

$$y_{t+h} = \varepsilon_{t+h} + \varepsilon_{t+h-1} + ... + \varepsilon_{t+1} + y_t \tag{4.14}$$

Because expected value of ε_{t+j}, given, y_t, is zero for all $j \geq 1$, we arrive to:

$$E(y_{t+h}|y_t) = y_t, \text{for all } h \geq 1 \tag{4.15}$$

This formula means that it doesn't matter how far in the future we want to predict a value of y_{t+h}, because the best forecast will be the current value y_t. We have monthly data for 2011, let's say y_1 to y_{12} and we wish to predict their values for $h = 12$. As a result, in our Random Walk forecast we will take monthly values of USD/EUR exchange rate in 2011 and they will be the prediction for the exchange rate in 2012.

We can define RW in a more complicated way, as provided by Grinstead & Snell (1997) in their book Introduction to Probability: Second Revised Edition, chapter 12: "Let $\{X_k\}_{k=1}^{\infty}$ be a sequence of independent, identically distributed discrete random variables. For each positive integer n, we let S_n denote the sum $X_1 + X_2 + ... + X_n$. The sequence $\{S_n\}_{n=1}^{\infty}$ is called a random walk. If the common range of the X_k's is R^m, then we say that $\{S_n\}$ is a random walk in R^m."

4.10 Forecast and the comparison

Our main goal in this work is to forecast the USD/EUR exchange rate for all the months in 2012 and compare the forecast with the actual values. We would also like to compare the forecast accuracy of our model, VAR, with the Random Walk (RW), which is often considered to produce better forecasts than other models. There have been many studies confirming how difficult it is to forecast the exchange rate using macroeconomic variables and consequently difficult to

beat the RW. This basically means that it is very hard to predict the exchange rate and it is more accurate to assume that ExRate is almost unpredictable, i.e. it follows RW. Meese & Rogoff (1983) compared several structural and time series ExRate models on the one to twelve months horizon with the conclusion that RW performed better in out-of-sample forecast than other models and structural models performed poorly even though the forecast was based on the realized values of explanatory variables. Kilian & Taylor (2003) found evidence that ExRate could be predicted at longer horizons, such as 2 or 3 years, but not at shorter ones. Muck & Skrzypczynski (2012) tried to outperform RW for currencies of several Central and Eastern European countries, but found again evidence that it is very hard to do so. Another study by Cuaresma & Hlouskova (2005) compared the accuracy of several multivariate time series models, including VAR, but even the models with low prediction error failed to reject the test of equality of forecasting accuracy against the RW at short-time horizons. Yuan (2011) revealed that fundamentals-based models are not able to beat RW, because they usually fail to capture the persistence of ExRates.

Although RW seems to be superior in most cases to other empirical models, it is not perfect and can be outperformed. Yuan (2011) presented the weakness of RW. In case the ExRate follows some trend, then the RW is usually outperformed by other models, as it is unable to properly capture these trends. Mark (1995) showed evidence that empirical models can predict the ExRate on longer horizons. The same was also showed by already mentioned Kilian & Taylor (2003). In addition, Hakkio (1986a) came up with the confirmaton that the tests for RW have low power and although we can not reject the hypothesis, that ExRate follows RW, we should not make conclusions based just on this due to the low power of tests. Another study, by Rossi (2006), presented evidence that for some countries it was possible to reject the hypothesis that ExRate follows the RW. She also further explained that the rejection of other empirical models could have been caused by the unstability of the relationships between fundamental variables over time, and not because these fundamentals have no effect whatsoever on the ExRate movements. Carriero *et al.* (2009) tried to beat the RW forecast with a large Bayesian VAR (BVAR) model using a panel of 33 exchange rates against U.S.dollar. After producing the forecasts for all 33 countries, they found out that BVAR performed better in most of the countries than RW.

We can now see that there is no consensus about the most suitable model for forecasting the ExRate. The evidence in favour of RW might be stronger, but there are many studies showing that not always RW beats empirical models, such as VAR. In this section we will also have a look at the forecasts produced by VAR and RW. For the comparison it is possible to use several statistics. The most often used ones are Root Mean Squared Error (RMSE), which we will later explain and use in our analysis, or Mean Absolute Error (MAE) and both are more closely examined in Wooldridge (2009). In practice, they were used for example by Taiwo & Olatayo (2013), when comparing VAR and Time series regression, by Lack (2006), when comparing VAR forecast with naive forecast for Swiss inflation, or by Yin *et al.* (2008), when analysing the possibility of structural model beating Random Walk. We expect that RW will produce better forecast than the VAR. One reason might be that there was no clear trend in USD/EUR ExRate. Moreover, we are going to predict values only on 1-year horizon, which can be considered as a short one, and as showed by some of the above mentioned studies, it is very difficult to predict the values of exchange rate on such a short time period. Therefore, RW is poised to outperform VAR.

In the figure 4.15, which is attached at the end of this chapter, we can see the forecasted values by VAR for logarithm of USD/EUR exchange rate for the period of 12 months. What we can deduct from this figure is that the predicted exchange rate is steadily (with exception of February 2012) appreciating, reaching a value of around 1.462 dollars for one euro. The forecast was done in statistical softwares JMulTi and Gretl.

The two most commonly used tools for comparing the accuracy of models are Root Mean Squared Error and Mean Absolute Error. In this analysis, we will focus on the RMSE. For a better understanding and definition of this measure we should have a look in Wooldridge (2009). We have $n+m$ (in our case 120+12) observations and we use n observations to estimate the parameters and keep m of them for the forecast. We define $\hat{f}_{n+h}$ to be the one-step-ahead forecast of y_{n+h+1} for $h = 0, 1, ..., m-1$. The m forecast errors $\hat{e}_{n+h+1} = y_{n+h+1} - \hat{f}_{n+h}$. Then the RMSE is defined as:

$$RMSE = \left(m^{-1} \sum_{h=0}^{m-1} \hat{e}_{n+h+1}^2 \right)^{1/2} \tag{4.16}$$

To put it in other words, we sum the square differences of actual and forecasted values, then we average them and take the square root. When comparing RMSEs of more models we prefer the one with the smallest out-of-sample RMSE, as pointed out by Wooldridge (2009). We can also compute the ratio of RMSEs. In our case, we will compute the ratio of $RMSE_{VAR}/RMSE_{RW}$. If it is greater than 1, the RW outperformed VAR and vice versa. The following statistics were produced using Microsoft Excel.

Time period	$RMSE_{VAR}$	$RMSE_{RW}$	$RMSE_{VAR}/RMSE_{RW}$
1M	0.03997	0.10068	0.39700
3M	0.02728	0.06344	0.43001
6M	0.05507	0.04722	1.16624
9M	0.08317	0.04301	1.93374
12M	0.09126	0.04601	1.98348

Table 4.2: Root Mean Squared Errors for the VAR and RW forecast and the ratio between these two RMSEs

From the Table 4.2 we can clearly see that during the horizon of 1 and 3 months, our VAR produced more accurate forecast than the Random Walk, although not by a huge margin, which is still quite surprising, because RW should perform better at shorter time periods. But if we look at our dataset, we realise that during January-March, the USD/EUR was much stronger in 2011 than in the same months in 2012. That is the reason, why the error is high for RW. However, for the rest of the year, RW heavily outperformed VAR, because as already mentioned, VAR forecasted steadily appreciating exchange rate, whereas in reality, the Euro was depreciating against U.S.dollar for the most of the period between April-December 2012. Therefore, as expected, RW has beaten VAR in this time horizon.

In our setting we can conclude that Random Walk produced better and more desirable forecast. However, if we include more or different variables, the results might be totally different, but in case of USD/EUR it would not be likely. The possible reason behind this is that the exchange rate hasn't experienced a clear trend. Before the crisis, the Euro was appreciating most of the time against U.S.dollar, but when the crisis has started, there was an unexpected appreciation of U.S.dollar against many currencies, including Euro, as pointed out by Fratzscher (2009). It could also be possible to forecast for a longer

horizon, say 2 or 3 years, to see, if RW still outperforms VAR most of the time, because during longer periods VAR model should gain edge over RW.

Equation number	**1**	**2**	**3**	**4**	**5**
Variable	**Euribor**	**UnemRate**	**HICP_log**	**IPI_log**	**ExRate_log**
Intercept	-5.422	2.693	-0.108	0.608	-1.668
Std. Deviation	(4.084)	(1.528)	(0.114)	(0.305)	(0.815)
p-value	0.184	0.078	0.343	0.046	0.041
t-value	[-1.327]	[1.763]	[-0.948]	[1.997]	[-2.047]
Euribor(t-1)	1.380	-0.003	-0.001	0.017	-0.033
Std. Deviation	(0.106)	(0.040)	(0.003)	(0.008)	(0.021)
p-value	0.000	0.948	0.649	0.035	0.119
t-value	[13.030]	[-0.066]	[-0.456]	[2.112]	[-1.558]
UnemRate(t-1)	-0.240	1.265	0.001	-0.049	0.000
Std. Deviation	(0.285)	(0.107)	(0.008)	(0.021)	(0.057)
p-value	0.400	0.000	0.940	0.022	0.995
t-value	[-0.842]	[11.865]	[0.075]	[-2.294]	[0.006]
HICP_log(t-1)	6.751	0.000	1.040	0.743	0.459
Std. Deviation	(3.700)	(1.384)	(0.103)	(0.276)	(0.738)
p-value	0.068	1.000	0.000	0.007	0.535
t-value	[1.825]	[0.000]	[10.082]	[2.693]	[0.621]
IPI_log(t-1)	1.802	-1.842	0.065	0.553	-0.033
Std. Deviation	(1.411)	(0.528)	(0.039)	(0.105)	(0.282)
p-value	0.202	0.000	0.100	0.000	0.906
t-value	[1.277]	[-3.490]	[1.647]	[5.253]	[-0.118]
ExRate_log(t-1)	-1.034	0.222	-0.022	0.040	1.232
Std. Deviation	(0.506)	(0.189)	(0.014)	(0.038)	(0.101)
p-value	0.041	0.240	0.118	0.286	0.000
t-value	[-2.044]	[1.174	[-1.563]]	[1.067]	[12.198]

Table 4.3: Estimated coefficients for the first lag with the values of standard deviation, p-value and t-value

Equation number	**1**	**2**	**3**	**4**	**5**
Variable	**Euribor**	**UnemRate**	**HICP_log**	**IPI_log**	**ExRate_log**
Euribor(t-2)	-0.726	0.010	0.001	-0.024	0.038
Std. Deviation	(0.176)	(0.066)	(0.005)	(0.013)	(0.035)
p-value	0.000	0.878	0.851	0.071	0.276
t-value	[-4.117]	[0.154]	[0.188]	[-1.808]	[1.090]
UnemRate(t-2)	-0.115	0.250	0.000	-0.004	-0.035
Std. Deviation	(0.431)	(0.161)	(0.012)	(0.032)	(0.086)
p-value	0.790	0.121	0.992	0.891	0.681
t-value	[-0.266]	[1.550]	[-0.010]	[-0.138]	[-0.411]
HICP_log(t-2)	-6.073	0.048	-0.221	-0.765	-1.407
Std. Deviation	(5.422)	(2.028)	(0.151)	(0.404)	(1.082)
p-value	0.263	0.981	0.143	0.059	0.193
t-value	[-1.120]	[0.024]	[-1.465]	[-1.891]	[-1.301]
IPI_log(t-2)	-1.634	2.289	-0.007	0.163	0.308
Std. Deviation	(1.595)	(0.597)	(0.044)	(0.119)	(0.318)
p-value	0.306	0.000	0.884	0.170	0.334
t-value	[-1.024]	[3.837]	[-0.146]	[1.371]	[0.967]
ExRate_log(t-2)	1.174	-0.454	0.030	0.025	-0.544
Std. Deviation	(0.796)	(0.298)	(0.022)	(0.059)	(0.159)
p-value	0.141	0.127	0.171	0.670	0.001
t-value	[1.474]	[-1.525]	[1.370]	[0.426]	[-3.420]

Table 4.4: Estimated coefficients for the second lag with the values of standard deviation, p-value and t-value

Equation number	**1**	**2**	**3**	**4**	**5**
Variable	**Euribor**	**UnemRate**	**HICP_log**	**IPI_log**	**ExRate_log**
Euribor(t-3)	0.369	-0.009	-0.004	0.008	-0.021
Std. Deviation	(0.174)	(0.065)	(0.005)	(0.013)	(0.035)
p-value	0.034	0.888	0.387	0.514	0.554
t-value	[2.118]	[-0.141]	[-0.865]	[0.653]	[-0.591]
UnemRate(t-3)	0.192	-0.674	0.004	0.042	0.116
Std. Deviation	(0.409)	(0.153)	(0.011)	(0.030)	(0.082)
p-value	0.639	0.000	0.743	0.163	0.156
t-value	[0.469]	[-4.409]	[0.328]	[1.394]	[1.419]
HICP_log(t-3)	0.714	-1.511	-0.046	0.395	1.392
Std. Deviation	(5.535)	(2.070)	(0.154)	(0.413)	(1.104)
p-value	0.897	0.465	0.765	0.338	0.208
t-value	[0.129]	[-0.730]	[-0.300]	[0.958]	[1.260]
IPI_log(t-3)	-1.232	-0.248	0.005	0.254	0.049
Std. Deviation	(1.656)	(0.619)	(0.046)	(0.124)	(0.330)
p-value	0.457	0.689	0.905	0.039	0.881
t-value	[-0.744]	[-0.400]	[0.119]	[2.060]	[0.150]
ExRate_log(t-3)	0.275	0.117	-0.011	-0.035	0.297
Std. Deviation	(0.840)	(0.314)	(0.023)	(0.063)	(0.168)
p-value	0.743	0.709	0.631	0.582	0.076
t-value	[0.328]	[0.373]	[-0.480]	[-0.551]	[1.775]

Table 4.5: Estimated coefficients for the third lag with the values of standard deviation, p-value and t-value

Equation number	**1**	**2**	**3**	**4**	**5**
Variable	**Euribor**	**UnemRate**	**HICP_log**	**IPI_log**	**ExRate_log**
Euribor(t-4)	-0.325	0.033	0.003	-0.011	-0.020
Std. Deviation	(0.108)	(0.040)	(0.003)	(0.008)	(0.021)
p-value	0.003	0.415	0.400	0.174	0.359
t-value	[-3.016]	[0.816]	[0.842]	[-1.361]	[-0.917]
UnemRate(t-4)	-0.187	0.167	-0.006	-0.003	-0.121
Std. Deviation	(0.272)	(0.102)	(0.008)	(0.020)	(0.054)
p-value	0.492	0.101	0.397	0.879	0.026
t-value	[-0.687]	[1.639]	[-0.846]	[-0.152]	[-2.233]
HICP_log(t-4)	-0.431	1.364	0.226	-0.321	-0.229
Std. Deviation	(3.753)	(1.404)	(0.105)	(0.280)	(0.749)
p-value	0.909	0.331	0.030	0.251	0.760
t-value	[-0.115]	[0.972]	[2.164]	[-1.148]	[-0.305]
IPI_log(t-4)	2.151	-0.720	-0.033	-0.121	-0.072
Std. Deviation	(1.367)	(0.511)	(0.038)	(0.102)	(0.273)
p-value	0.116	0.159	0.391	0.234	0.792
t-value	[1.574]	[-1.408]	[-0.858]	[-1.190]	[-0.264]
ExRate_log(t-4)	-0.898	0.229	-0.001	-0.038	-0.127
Std. Deviation	(0.547)	(0.204)	(0.015)	(0.041)	(0.109)
p-value	0.101	0.262	0.961	0.349	0.245
t-value	[-1.642]	[1.122]	[-0.049]	[-0.936]	[-1.163]

Table 4.6: Estimated coefficients for the forth lag with the values of standard deviation, p-value and t-value

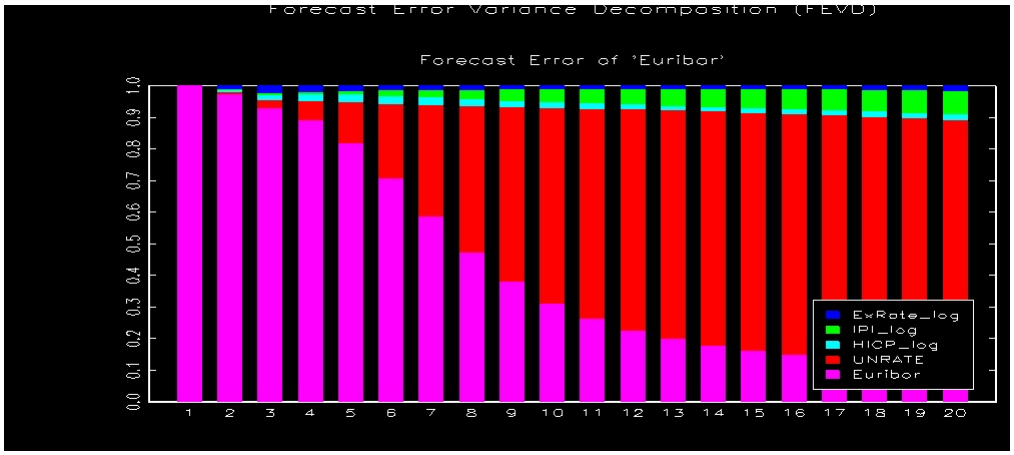

Figure 4.10: Forecast error variance decomposition of the short-term interest rate

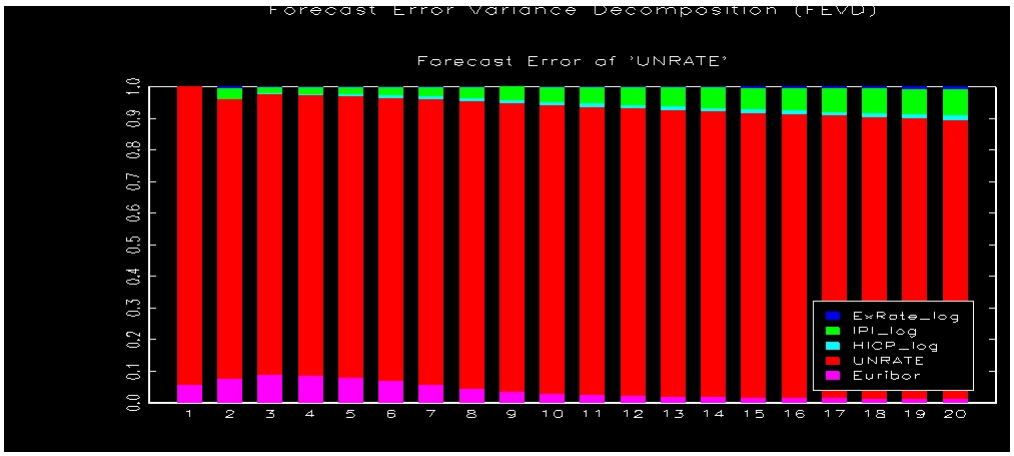

Figure 4.11: Forecast error variance decomposition of the unemployment rate

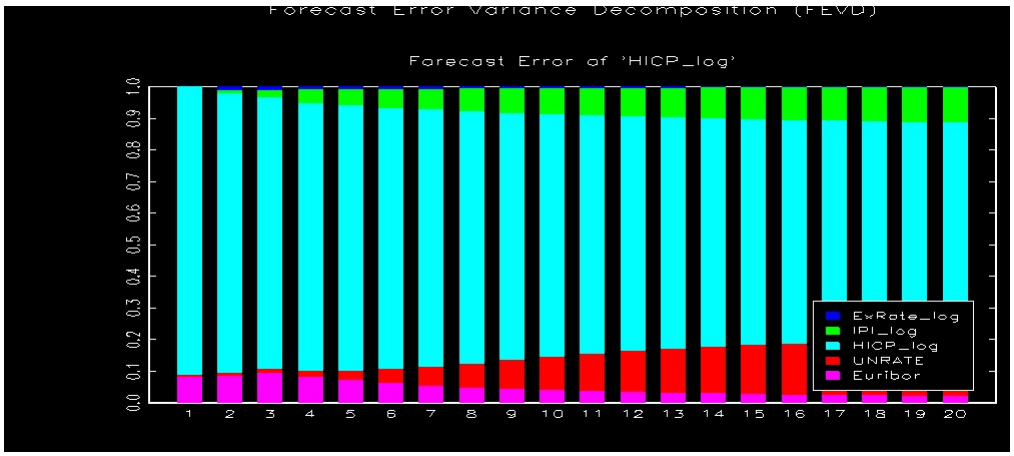

Figure 4.12: Forecast error variance decomposition of the HICP

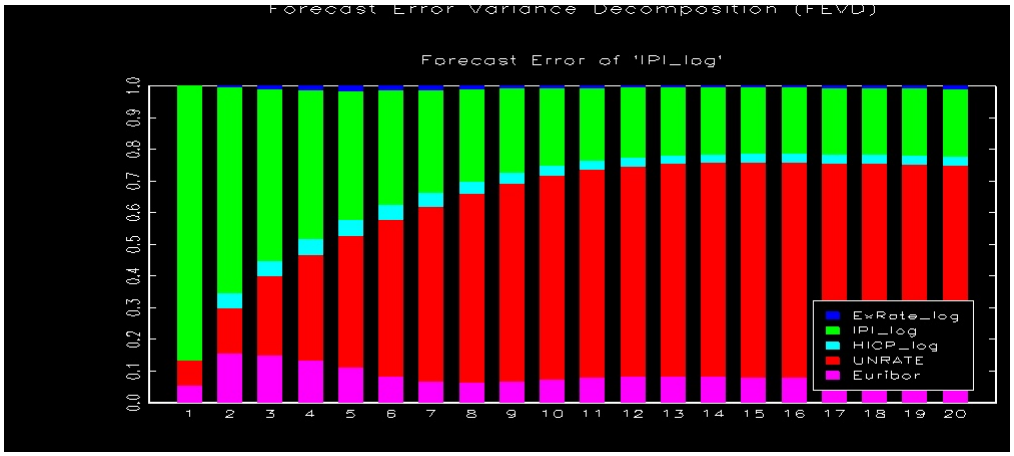

Figure 4.13: Forecast error variance decomposition of the industrial production index

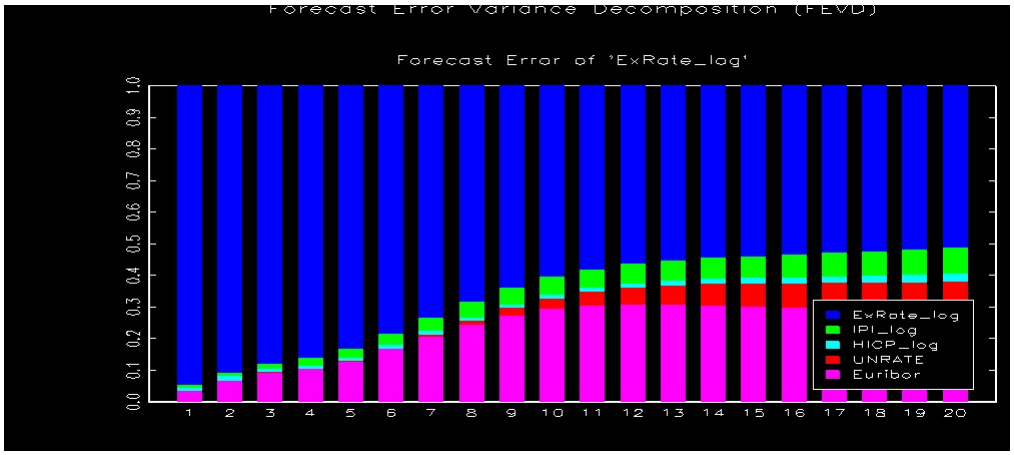

Figure 4.14: Forecast error variance decomposition of the exchange rate

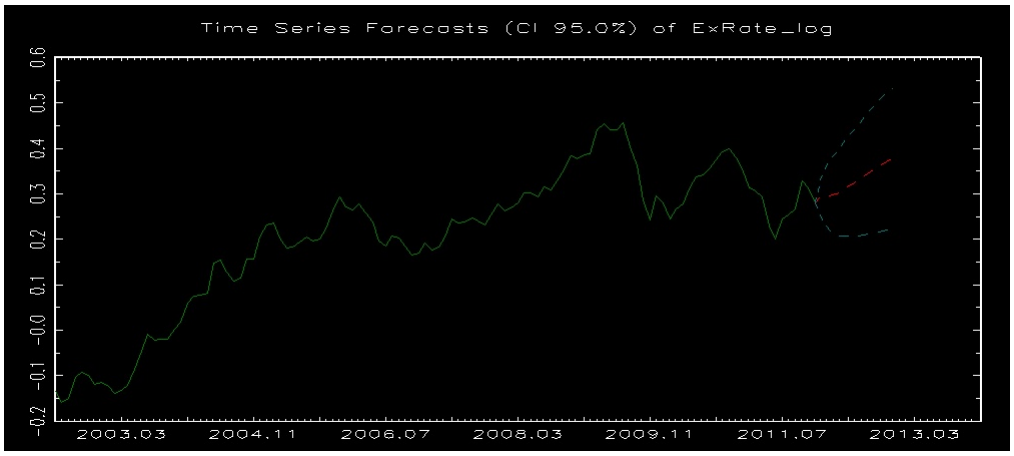

Figure 4.15: Forecasted values for the USD/EUR exchange rate for 12 months in 2012 using VAR model

Chapter 5

Conclusion

The main objective of this thesis was the forecast of the USD/EUR exchange rate using two econometric approaches, vector autoregressive model and random walk. Random walk is believed to have the stronger forecasting power and to be more accurate than other empirical models, especially during shorter horizons. As we were forecasting only for a period of one year, random walk was poised to outperform our VAR model.

We collected and used monthly data for Euro area (EU17) starting in 2002 and ending in 2011. We also prepared data for 2012, which we kept aside in order to use them for the comparison of the two approaches. We created our VAR model with five endogenous variables(inflation rate, short-term interest rate, unemployment rate, industrial production index and exchange rate), estimated the parameters, ran necessary tests to check the suitability of our model, analysed impulse respones and forecast error variance decompositions. Finally, we predicted the USD/EUR exchange rate for twelve months in 2012.

After the forecasts had been done, we calculated Root Mean Squared Errors of VAR and RW method in order to compare the models. Our findings were partially surprising. We expected RW to beat VAR during the whole period. The reasoning behind this was the short period of forecast, no persistent trend and a lot of studies advocating the superiority of RW. The surprising fact we found out was that VAR produced better forecast for one and three months period. It is not so easy to find the reason, why it performed better. During rest of the analysed horizons, six, nine and twelve months, RW was able to heavily beat VAR and as expected produced more accurate forecast.

Furthermore, we studied the concept of exchange rate, looked at the differences between real and nominal exchange rate, between fixed and free floating as well as de iure and de facto regimes. Large part of this thesis was also the overview of the major determinants, which cause the fluctuations in the ExRate. We detected three main groups of factors: economic variables, market psychology and political situation. In addition, we examined the largest financial market in the world, FOREX. We looked at the market participants, their goals and motivation, at the major financial instruments used by them as well as at the functions of FOREX. We also had a brief glimpse of the history of this market.

Although RW usually outperforms other models, such as VAR, we have seen that it is not impossible to beat it, even during shorter horizons. Therefore, we should always try to create new or use already discovered methods when trying to forecast, for example the exchange rate. Moreover, the results could be totally different with other setting. IP and FEVD might differ in case of different orderings. We could have included other macroeconomic variables, such as balance of payments or GDP in form of real GDP growth, or even try to capture political situation, for example by using dummy variables. There was also a small dilemma in choosing the optimal number of lags. Even the number of endogenous variables is important, so including more or less of them can change the situation. As a result of all these reasons, there is an open space for further research.

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