Charles University in Prague

Faculty of Social Sciences
Institute of Economic Studies

MASTER THESIS

The Effects of Foreign Exchange Interventions in a Small Open Economy: The Case of the Czech Republic in a World Context

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Declaration of Authorship

The author hereby declares that he compiled this thesis independently, using only the listed resources and literature. This thesis was not used to obtain another academic degree.

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Prague, August 5 , 2015

Signature

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Abstract

In this thesis we examine the effect of foreign exchange interventions in small open economy, focusing on the Czech experience. In the first part we model volatility development before and after the intervention using GARCH model. In the second part we estimate relationship between macroeconomical variables using vector autoregressive model. In this part we estimate impulse response function of exchange rate and inflation. In second part of VAR modeling we provide counterfactual analysis, which compare actual development of variables with alternative scenario in which the interventions would not happen .

Our results suggest that the interventions is associated with few months delayed decrease in volatility. Base on scenario analysis the interventions increased inflation by approximately 1.5 % and without the intervention the economy would in deflation around -1% nowadays.

Keywords	Vector Autoregression, Monetary Policy, Volatility Modeling, Intervention
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Master Thesis Proposal

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Proposed Topic:

The Effects of Foreign Exchange Interventions in a Small Open Economy: The Case of the Czech Republic in a World Context.

Motivation:

Inflation targeting as a central bank policy framework has been widely adopted in both developed and emerging economies. In period before the Great recession, central banks were mostly successful to achieve the inflation target using only conventional monetary policy tools. However, under some circumstances conventional monetary policy tools may prove insufficient to achieve the central bank's objective.

Unconventional monetary policy tools in form of foreign exchange interventions have been used by several countries in recent years: Switzerland, Israel and the Czech Republic. The core part of this thesis will analyze impacts of the Czech interventions from 2013.

There was strong discussion regarding justification of the interventions. Defenders of the interventions claimed that deflation was a serious threat and thus there was a need for this kind of intervention. It should also promote economic growth and employment, by boasting consumer spending. On the other side the unexpected depreciation could harm Czech industry and consumers and increase price of imports. On top of that, foreign exchange interventions can be risky in that they can undermine a central bank's credibility.

However, in the public debate there was lack of quantitative analysis and whole discussion was mostly ideological. For this reason, I will perform rigorous empirical study to evaluate effect of the FX interventions in the Czech Republic to evaluate effects of this policy on the volatility and key macroeconomic variables.

Research Questions:

1. Is effect of the FX interventions in small open economies on the FX rate volatility significant?
2. Do the Czech interventions have similar effects as Swiss and Israeli interventions?
3. Is there significant impact of the interventions on the key macroeconomic variables (GDP, price level, unemployment)?

Methodology:

The research will be conducted as follows. In the first part, I will undertake literature review focusing on the foreign exchange interventions in small open economies. Aim of this part is to summarize result of previous research and provide a comparison of empirical studies.

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Chapter 1

Introduction

Inflation targeting as a central bank policy framework has been widely adopted in both developed and emerging economies. In period before the Great recession, central banks was mostly successful to achieve the inflation target using only conventional monetary policy tools. However, under some circumstances conventional monetary policy tools may prove insufficient to achieve the central bank's objective. Unconventional monetary policy tools, in form of foreign exchange interventions have been used by several countries in recent years: Switzerland, Israel and the Czech Republic. The core part of this paper will analyze impacts of the Czech interventions from 2013.

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The thesis is structured as follows:

The second chapter provides introduction to the Monetary Policy During Crisis. In this chapter we will go briefly through conventional monetary policies and than proceed to the Zero lower bound problem. The solution of the ZLB are unconventional measures which are extensively discussed in this chapter, including literature review and some thoughts on their effectiveness.

Next chapter go directly to introduction of foreign exchange intervention in the Czech Republic. This chapter provides important insight on economical background prior the intervention and review first empirical studies on this topic.

The following chapter theoretical introduce volatility modeling area. In this chapter we describe and compare the most prominent volatility models and discuss some empirical studies, which use this models in practice. In the last chapter, there is define step by step solution of the volatility estimation.

The fourth chapter is one of the core part of this thesis as it includes volatility modeling on Czech and Swiss data. The chapter begins with data description continuing with GARCH modeling and partial conclusion after this part.

The next part of our research estimate effect of intervention of macroeconomic variables using vector autoregressive models. Aim if this part is to estimate impulse response function of exchange rate and inflation. In this part we will also conduct couterfactual analysis to capture impact of the intervention.

The last chapter concludes and provides final thoughts and main results.

Chapter 2

Monetary Policy During Crisis

2.1 Conventional measures

Inflation targeting has been increasingly popular monetary policy regime used by central banks for maintain price level increases in certain level or a specific range. Usually mentioned advantages of this policy are price stability, transparency of central bank decisions and tendency to have lower and more stable inflation compared to other monetary policy regimes. (Williams 2014)

This approach, firstly adopted by New Zealand in 1989, has been mostly successful and soon accepted by many other countries. Nowadays more than 20 central bank's target inflation around 2% level, along with most important economies including Eurozone, UK and US FED which finally officially joined 2% inflation target in early 2012. (Reuters 2012)

The most important conventional instruments of monetary policies are manipulations with the short-term interest rate, which are implemented by open market operations. Central banks buy or sell government securities on the market to manipulated short term interest rate and thus indirectly control money supply and inflation in economy.

Taylor rule is overall accepted policy guideline, that recommends optimal target interest rate based on inflation and unemployment gap. Simple backward looking version of this rule looks like this: (SF FED 2011)

$$Targetrate = 1 + 1.5 * Inflation - 1 * Unemploymentgap$$

However in practice banks are forced to use so called forward-looking Taylor rule. This rule use rather prediction of inflation and unemployment gap, instead their current values, which are not as relevant for monetary policy.

These conventional measures have worked well up until the Great Recession in late 2000s. Afterwards, target interest rate recommended by Taylor rule get into negative numbers for several countries. These policy rules could not been met because there is a lower bound for interest rate, which limited further power of central banks and thus new unconventional measures were needed to fulfill the inflation target and boost economy.

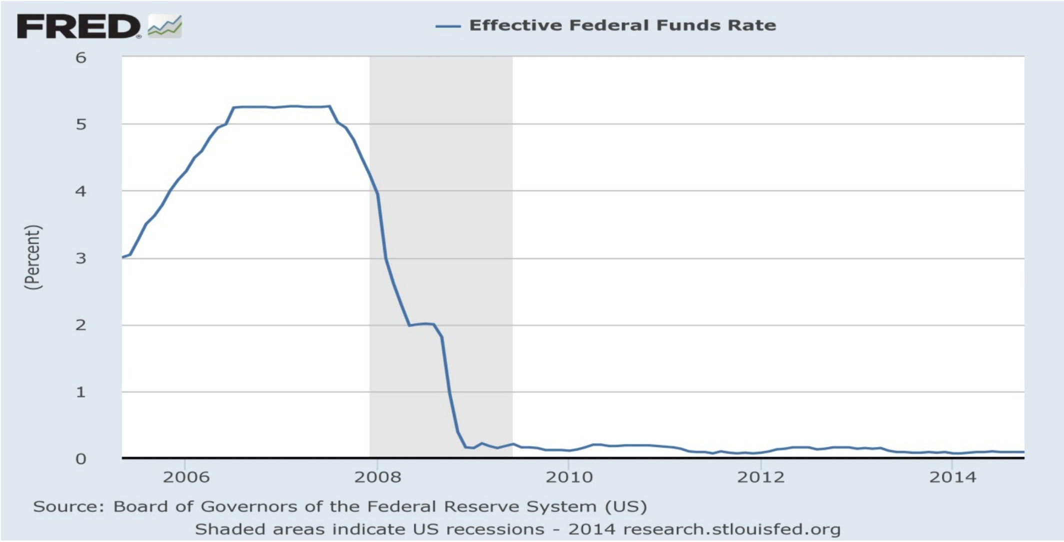
2.2 Zero lower bound problem

The Zero lower bound problem occurs when banks are below inflation target and aim to lower the short-term nominal interest rates, but faces a hindrance when the interest rate reaches or nears zero, and cannot lower it further. The central bank would prefer to lower the interest rate even more to stabilize the economy, but cannot do so not only because the interest cannot get significantly lower than zero. Recently, in several European countries central banks interest rates moved slightly below zero. However, this is limited by the fact, that from some point it became for banks more advantageous to hold cash then to deposit in CB accounts.

US were one of the first countries that hit zero lower bound. Soon after eruption of the Financial crisis Federal funds rate dropped close to zero and since then in has remained on the zero lower bound. (FRED)

Shortly after US, also Bank of England and ECB‘s key interest rates dropped close to zero. Nowadays ECB maintain record low interest rates at 0.05% level and deposit interest rate in negative numbers - currently at - 0.20% as of September 2014 (ECB 2015)

Figure 2.1: Federal Fed Rate



2.3 Literature on Zero Lower Bound

First modern literature on ZLB occurred in late 1990s after Japan deflation in early 1990s, which accelerated academic discussion of the topic. Since the key overnight interest rates have been very close to the zero lower bound since the financial crisis of 2008, economists have taken nowadays a renewed interest in studying how economies function when interest rates are zero.

One of the first mention of this problem appeared in famous Krugman‘s article 'It‘s Baaack: Japan's Slump and the Return of the Liquidity trap' (1998). He emphasizes the problem of liquidity trap —by his prediction it can happen not only in Japan but also in Europe (mentioning record low interest rates in Germany). Krugman strongly criticize Japan government for lack of effort and stated there is a conceptual problem in their policy decision making.

That academics discussion is soon followed by couple of authors —McCallum and Svensson, who firstly suggest depreciation and currency intervention as a cure for liquidity trap.

McCallum (2000) discussed theoretical issues regarding the possibility of the zero lower bound. From the perspective of policy makers there is still a route for monetary action even if short run interest rates are close to zero. The way is to open and boost foreign trade of goods and securities, by adjusting depreciation of exchange rate.

Svensson (2001) firstly theoretically discuss problem of liquidity trap and deflation —negative interest rate is needed to stimulate the economy, whereas nominal interest rate cannot fall below zero. In next parts of the article he suggests several possibilities how to deal with the deflation and then states 'the Foolproof Way' of escaping from a liquidity trap. The main part of plan is a currency depreciation with crawling peg of the currency —it is unique in providing central bank with concrete action demonstrating the central bank's commitment and stimulates the economy by reducing the real interest rate.

Blinder (2000) summarize panel discussion from the Annual Fall Conference, organized the Boston Federal Reserve. The main topics of the conference were prevention of liquidity trap (in other words proposition of measures to not even get there) and cure (several measures how to escape from the liquidity trap. Based on their discussion, the menu of choices is as follows.

For prevention they suggest firstly set a positive inflation target. The inflation target has to be sufficiently high to make probability of zero inflation extremely small (some of conference attendants suggest target of two percent). The second idea is to use a nonlinear reaction function. Coefficients a and b of Taylor function should be higher when inflation is very low, thus reaction would be stronger and provide more insurance against getting stuck in a liquidity trap. The last two ideas are Integral stabilization â€"– instead of inflation and unemployment gap we should use a sums of these gaps over some time period. And the very last measure is to target price level instead of the inflation rate.

He states there is no perfect choice how to escape from liquidity trap for central banks whose stuck in there. However he compiles catalog of some policy alternatives for central bank that already hit zero lower bound and still needs to stimulate its economy. First logical choice is again, similarly as in another paper, to depreciate the exchange rate —unsterilized intervention (aggressive purchases of foreign currency) should lead to depreciation. As alternative policy measure he points out open market operations on private assets â€" trading with private bonds or other private assets such as stocks, real estate and bank loans. The other suggesting, more theoretical, is idea of Stamped money or

Carry tax, which is equivalent of negative interest rate. From obvious reason this policy is also somehow impractical and hard to implement.

One of the more recent studies of the ZLB was published by Borio and Dysiatat (2009). This paper discusses various forms of unconventional monetary policies, characteristic optimal responses of central banks to the crisis and identifies key policy challenges.

Based on previous academically discussion and research it seems, that currency depreciation is the most convenient policy action to use for escaping the liquidity trap at zero lower bound for small open economies. On the other hand for large economies, like US or Euro area, a quantitative easing can be convenient and effective solution. Alternative policies are mostly theoretical or impractical with limited effect or its implementation face serious barriers.

2.4 Unconventional measures

As mentioned in papers before, conventional measures became ineffective in case of the zero lower bound. To overcome the problem of lower interests and deflation, central banks are recommended to use so called unconventional measures.

There are two main measures which have been used in period around the current Great Recession. The first one — apparently more suitable for large economies — is quantitative easing, which has been used mainly in the United States and also by the United Kingdom and Euro area. And the second one — suggested by McCallum and Svensson — currency (foreign exchange) intervention. This measure has been mostly popular among several small open economies with inflation targeting. For completion I will also briefly discuss other unconventional measures used at zero lower bound. The first of these is purchase of covered bonds or other private assets, and the last important measure which I introduce is a forward guidance.

Quantitative easing

Quantitative easing (QE) is an unconventional form of monetary policy where a Central Bank creates new money electronically to buy financial assets, like government bonds. This process aims to directly increase private sector spending in the economy and return inflation to target.(Bank of England, 2015)

In this chapter I will go through major examples of practical use of Quantittative easing: the United States,the United Kingdom and Euro area

Quantitative easing in the United States

In period since the financial crisis in 2007 US Federal Reserve has been confronted with complex set of challenges. The early phases of the crisis were marked by threats to liquidity and solvency of dominant financial institutions as Bear Stearns or Lehman Brothers. These threats impacted functionality of financial markets as key market participants lost their credibility. Participants in the market were less willing to deposit money so bank started to have problems with liquidity. As a response adoption of new unconventional measures was needed, and central bank started to act as a lender-of-last resort (Bowdler and Radia 2012)

In response to the sharp decline in employment and inflation, FED cuts the federal funds rate — their main conventional policy tool — close to zero. Federal Open Market Committee introduced several rounds of so called Quantitative Easing — the assets have been bought in large quantities — \$45 billion of Treasury securities and \$40 billion of agency mortgage backed securities each month. In late 2013 it owned \$3.5 trillion of these assets. (Bowdler and Radia 2012)

First part of Quantitative easing — QE1 began on November 2008 and continued till March 2010. The QE1 took place at the peak of the economic crisis. Both GDP and SP500 stock market hit bottom in 2009 and the economy was in deep deflation (more then 1%). To overcome this problem FED was forced to pumped billions of dollars into economy in order to boost inflation and growth of the economy. The amount of assets purchased by US Federal Reserve in this period is \$1.75 trillion, which makes QE1 the most powerful out of the thre phases of Quantitative easing in the United States of America. (FRED)
The second part of Quantitative easing started in November 2010 and it was rather short finishing as early as June 2011. The amount of government bonds acquired in this period equals only \$600 million.

The third and final part of Quantitative easing started on September 2009 and the total amount of assets purchased in this period was \$1.7 trillion. The US Federal Reserve Bank, confirmed cessation of buying bonds in October 2014 after five years of quantitative easing program . (Guardian, 2014) The balance sheet has increased form around \$700 billion at the beginning of the financial crisis to more then \$4 trillion.

Most notable effect of the Quantitative easing in the United States was the increase of the inflation close to the 2% target level. Some economists warned that the excessive easing might cause future acceleration of inflation over 2%. However this warnings never fulfill, as inflation remains still below 2%.

Quantitative easing in the United Kingdom

The Bank of England launched its quantitative easing programme in March 2009 with an initial spending target of 75 billion Pounds over three months. At the same time it cut interest rates to a record low of 0.5%. (Guardian, 2015)

The first part of their QE took place between March 2009 and January 2010. The Bank bought around 200 billion Pounds of assets, equivalent to about 14% of GDP to boost the UK economy following the credit crunch. Then the programme was resumed in October 2011, when British economy face warnings of a double-dip rescission, so as reaction is was decided to put another 75 billion Pounds into the financial system. 'Martin Weale, a member of the Bank's Monetary Policy Committee said the QE programme added about 3% or 50bn Pounds to the overall level of GDP since it was first introduced. He also suggested QE had a bigger impact on inflation than first thought and that it had a role to play in dampening stock market volatility by reducing uncertainty.' (Guardian, 2015)

Quantitative easing in Euro area

Euro area was the latest economic player who introduced Quantitative easing. After cutting one of its main interest rates below zero last year the ECB decided to enhance the stimulus plan. It began its Quantitative easing in March 2015 — almost six years after the United States.

President Mario Draghi pledged asset-purchase program worth about 1.1 trillion euros ($1.2 trillion), accounting mohtly private bonds purchases at around 60 billion euros at least until September 2016. One of the main arguments for the QE was to prevent governments from overspending and make European economies more competitive (Bloomberg 2015)

Foreign Exchange Intervention

Foreign exchange intervention is an unconventional monetary policy tool in which central bank takes an active participatory role in influencing the value of the domestic currency. Central bank intervenes in the foreign exchange market in order to stabilize o shift the exchange rate.

The provide examples of the foreign exchange intervention, we can mention the Czech interventions in 1998, Swiss case from 2011 and Israeli intervention in 2008 and of course core of my empirical study — current Czech case from November 2013.

Holub (2004) discusses the role of foreign exchange interventions in the inflation targeting regime, focusing on the Czech experience since 1998. The situations in Czech Republic in late 90‘s had some specifics. The inflation targeting was adopted in late 1997, which ceased the period of fixed exchange rate which has been monetary policy regime for many years before. At the time economy faced destabilization caused by economic overheating, currency depreciation and deregulation of prices. Main aim of the inflation targeting was to stabilize and decrease inflation after turbulent times. The role of interventions was to slow down CZK‘s appreciation. In last part he also questions consistency of exchange rate intervention with inflation targeting, which can be judged by several criterions.

Group of economists from the Czech National Bank — Franta Holub et al.(2014) publish research and policy notes on the current Czech intervention from 2013. They describe the CNB experience with using the exchange rate as a monetary policy instrument. In order to determine optimal level of currency floor, the CNB used scenario simulation conducted by their core DSGE model, which gives the best solution in case od 4% - 5% weakening of Koruna. They also extensively describe consequent public debate and their communication strategy.

Malovana (2014) constructs DSGE model to estimate effectiveness of unconventional monetary policy tools at zero lower bound. She concludes that volatility of prices decreases significantly if the central bank adopts the price-level or exchange rate targeting rule and points out the importance of agents inflation exceptions in case of price-level targeting.

Forward Guidance

Forward guidance is the term used for tool based on central bank communication of their future monetary policy. Aim of central bank is to calm uncertainty in markets and corporations. If a central bank is able to send transparent signal of their intention to keep interest rates low, the market response will be appropriate to its overall policy.

We can distinguish between two types of the guidance. First of them is the Delphic forward guidance, where central banks state its economic outlook without any further commitment. This form of forward guidance tends to affect short term interest rates. In case we are in the zero lower bound we usually need a stronger signal from central banks, if we want stimulate the economy. The more powerful type of forward guidance is the Odyssean forward guidance which publicly commits central bank to a future action. (Financial Times 2014)

This measure was firstly used by Federal Reserve in 2012. The Fed promised that it will not increase interest rates until United States‘ unemployment decrease below 6.5 %, as long as inflation remained under 2.5 %. In middle of 2013 the Bank of England followed them. Its governor declared to keep rates low until unemployment drop down to at least 7% level. In both USA and UK, unemployment fell sharply toward the thresholds, however the rates still have remained low. (Economist 2012)

Purchase of Covered Bonds or Other Private Assets

'One notable feature of a covered bond is that it offers investors dual protection against default. On the one hand, liability for a covered bond rests with the financial institution that issues it (usually a bank); on the other hand, creditors are protected by a pool of collateral in respect of which they have preferential rights should the issuer become insolvent. This collateral often comprises first-class mortgages or public-sector bonds. This distinguishes covered bonds from senior, but unsecured, debt instruments and from asset-backed securities (ABS), for which the issuer cannot be held liable.' (Bundesbank, 2015)

'The ECB Governing Council adopted a Covered Bond Purchase Programme (CBPP) in 2009 to stabilise the market for these securities and thus help resolve banks' refinancing problems. As part of CBPP, the Eurosystem purchased covered bonds, such as Pfandbriefe, in an aggregate volume of 60 billion Euros over a period of one year. In November 2011 the ECB Governing Council launched a second Covered Bond Purchase Programme (CBPP2) with a total volume of 40 billion Euros. By the time this second programme came to an end in October 2012, securities had been purchased with a total volume of 16.4 billion Euros. The third CBPP (CBPP3) was rolled out in the second half of October 2014, with a term of two years. This programme is intended to improve the transmission of monetary policy, for example by easing the provision of credit, and return inflation rates to levels closer to 2%. An Asset-Backed Securities Purchase Programme (ABSPP) was also adopted in conjunction with CBPP3.' (Bundesbank, 2015)

Chapter 3

The Czech Case

3.1 Czech economy overview

The Czech Republic is a stable and prosperous market economy closely integrated with the European Union, which was also supported the country's European Union accession in 2004. The Czech Republic is export driven economy, sensitive to economical development in main export markets in Eurozone, especially Germany. The car industry is the largest industry in the country and together with its suppliers, accounts for nearly 24% of Czech manufacturing. The Czech Republic produce more then million cars a year, over 80% of which are exported. This reflect strong dependence of Czech Republic on the exports and foreign markets. (World Factbook, 2015)

Including some macroeconomical statistic, Czech GDP in purchasing power parity in 20014 was almost $300 billion dollars, which makes the country 52nd largest economy on the world. The GDP per capita (in purchasing power parity] was $28 400 in 2014. Composition of GDP is as follows — 48.2 % is crated by consumption, government consumption accounts for 19.2 % of gross domestic product and next 25 % is investment in fixed capital. Regarding the trade balance, export is equal about 84.5 % of GDP and imports made 77.5 % of gross domestic product. From this number it is easily to compute that the country is a net exporter. (World Factbook, 2015)

The composition of Czech gross domestic product by sectors is following: Agriculture accounts for 2.6 % of GDP, share of industry 37.4 % and remaining 60

% falls on services. Comparing to other developed countries, the Czech Republic has on of the biggest shares of industry on GDP. To make a comparison in whole European Union the industry accounts only for 25 % of GDP and 73 % is made by services. Even lower share of industry is in the United States, when it accounts only 20.6 % of GDP and 77.7 % falls on services. (World Factbook, 2015)

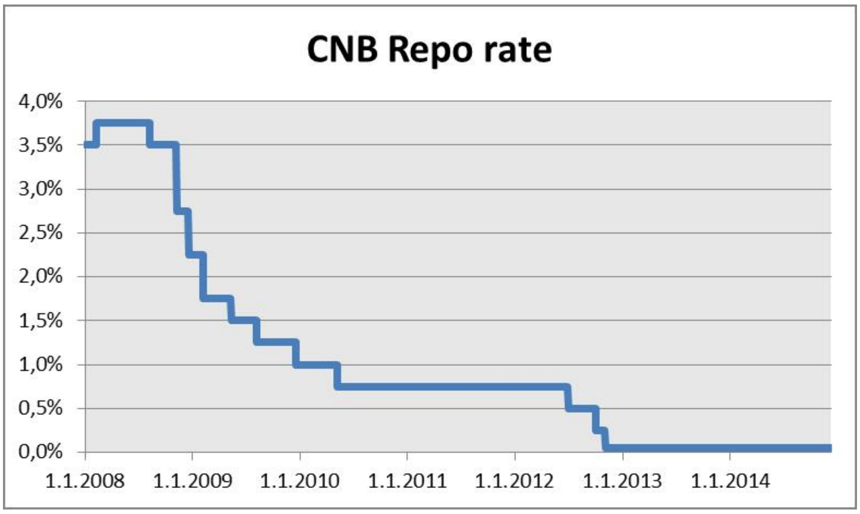
Regarding labour force statistics, the total size of Czech labour force was 5.416 million people in 2014. Unemployment rate in the same year was 7.9 %

3.2 Economical Background

Czech economy enjoyed stable economic growth over whole period from 2000 till 2008. As small open economy it is highly dependent on key economic powers, so the Great Recession spilled from these countries into the Czech Republic. The GDP growth dropped sharply in one year from 3.1% growth (year 2008) to 4.5% loss (year 2009). In 2010 economy started recover, GDP growth return to positive numbers, however the negative effect of recession, most notably higher unemployment remains. Moreover this recession was so called double dip shape — after initial recovery economy dropped again to negative GDP growth in 2012 and 2013, which was caused mainly by restrictive fiscal policy and economical situation in the Eurozone.

As a direct effect of recession, inflation starts slowing down. In 2008 Czech inflation was on its local maximum of 4 %, reverting to deflation of 0.3 % in 2009. Czech National Bank introduced several monetary expansion measures in order to fulfill inflation target. The Bank was gradually decreasing their repo rate since middle of 2008, when the rate remained on level 3.75 %. Since then CNB adjusted the repo rate regularly in downward direction until hit a zero lower bound in the November of 2012. From this moment conventional policies become ineffective and central bank lose one of their main monetary policy tools, so since then it has onlu limited possibilities to increase inflation to fulfill the 2% target.

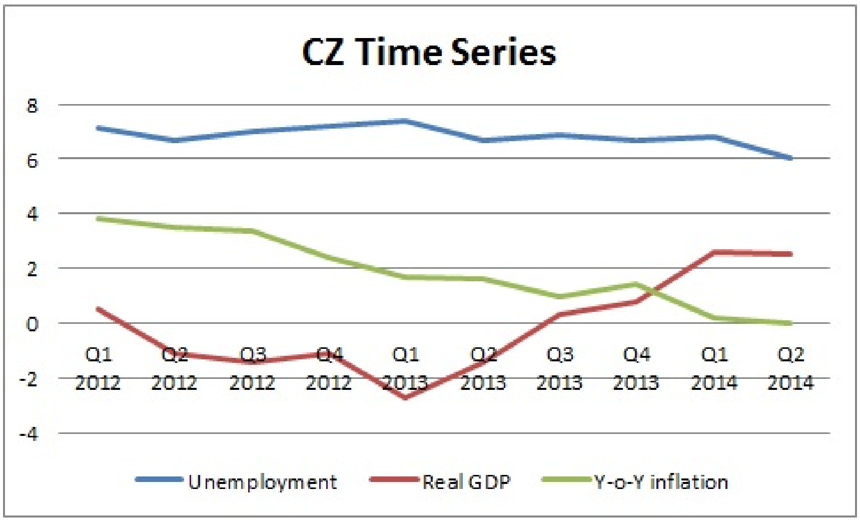
Figure 3.1: CNB repo rate



Macroeconomic development since 2012

In this section, I will investigate macroeconomic development before the intervention which was introduced in November 7, 2013. The key variables I examine are unemployment rate, real GDP and inflation.

Figure 3.2: Key macro variables since 2012



We can see slow economic recovery from recession since mid-2013. The GDP growth in the second half of 2013 was in black numbers, also unemployment is slowly sliding down. We can notice decrease of inflation and even after the intervention, inflation is still falling down. It could mean that deflation pressures were really strong, and without CNB action we would be in deflation nowadays. On the other hand we could observe positive trend in GDP and unemployment development so the economic stimulus, performed by expansionary monetary policy wasn‘t necessary in that point of time.

Threat of Deflation

Based on CNB announcements and macroeconomic development, the most important reason of intervention was to prevent deflation. The questions is what are effect of deflation and how severe are its impact if some of these exist. Although the majority of economists believe that deflation threat is very strong, we still miss consensus in this area as there in not enough historical experience with deflation. In this part I will review some of the most important papers and studies on deflation threat.

Baba et Al. (2005) analyze two decades of Japanese monetary policy and the deflation problem. The Japanese economy was stagnant for more than ten years. The average growth rate from 1993 to 2003 was just above 1 percent. Due to virtually zero growth and deflation, the Japanese nominal GDP had shrunk by 4 percent from 1997 to 2002, while during the same period, nominal GDP of the United States has increased by 25 percent. This experience show the real threat of deflation and in this paper authors pointed out problematic monetary policy of Bank of Japan from 1998 to 2003, was not helpful in fighting deflation

3.3 Exchange rate interventions from November 2013

In November 2013 the Czech National Bank (CNB) decided to intervene against Czech koruna appreciation and introduce an exchange rate commitment. This intervention, which started on November, 7 was the largest intervention in Czech history. The CNB announced in would not allow the exchange rate below 27 CZK per euro and purchased foreign currencies in equivalent of 200 billion korunas to fulfill that commitment . Koruna weakened sharply after the decision — by 4 % during single trading day (from 25.785 CZK/EUR to 26.850 CZK/EUR).

This unprecedented Czech National Bank action was followed by strong media reaction. Many journalists pointed out the most visible short-term impact of these interventions — drop in koruna's purchasing power, which was considered mainly negatively. Moreover according to some journalist the bank's board was not very clear in explaining the benefits and reasons for intervention. So the public acceptance was firstly mostly negative, with intense public debate following.

However, in the public debate there were very few empirical studies — two of them were mentioned in the previous chapter : Franta, Holub et al. (2014) and Malovana (2014). Otherwise the most of the discussion was only ideological. For this reason, I will perform a new quantitative analysis to measure effect of the FX interventions in the Czech Republic in order to evaluate effects of this policy on the volatility and key macroeconomic variables.

The main reason for the currency depreciation — presented by the board — was to fulfill inflation target. In first part of my empirical study I will measure efficacy of this action to increase inflation. Weaker exchange rate and lower real interest rates (due to higher inflation expectations) typically indirectly affects other macroeconomic variables. My hypothesis is, we can expect it has caused increase of GDP, prices and export, while decrease of unemployment and households savings.

Also these types of interventions inevitably cause side effects. As there was set lower bound for exchange rate, my hypothesis is, we can expect more stable exchange rate - i.e. lower volatility. Measuring this effect will be the first part of my empirical study.

Chapter 4

Volatility Modeling

Foreign exchange intervention is one of the unconventional monetary policies recently used in several small open economies. We can identify two main effect of the intervention. The first one is effect on volatility —we can expect that such a shock affect variance of exchange rate returns. In this part I will perform review of methods used by previous researches and state some expectation based on their result.

The second effect is on macroeconomic variables, especially output and prices, through monetary policy transmission mechanism, which will be covered in subsequent chapter. I will review most popular methods notably standard VAR models and more advanced modifications as well.

4.1 Volatility Definition and Measurement

Volatility refers to the spread of observations in our sample. Statistically volatility is identical to sample standard deviation, which is estimated by this formula:

$$\hat{\sigma} = \sqrt{\frac{1}{T-1}\sum_{t=1}^{T}(r_t - \mu)^2} \tag{4.1}$$

, where r_t is exchange rate return at time and μ is a mean exchange rate return over the T-day period. The daily volatility is not directly observable, because we have only one observation for a trading day using daily data. We can estimate the conditional volatility, which is conditional on current return and previous information. It is denoted as σ_t. The realizations of σ_t have some typical patterns. We can usually observe more volatile periods —volatility clusters, and calmer times. Realizations of σ_t are mostly auto-correlated, it means sigma evolves gradually over time, thus we are able to perform out of sample predictions.

Historical volatility can be measured by several approaches from simple one to more sophisticated. The most straightforward estimation of volatility over some period is average of squares of returns. By this approach we are not able to capture volatility development over time and we are not very accure.

The more sophisticated models are family of conditional heteroscedastic models. These models allow heteroscedasticity of returns size (variance) and are able to capture that dependence. The most notable models of this family are Auto-regressive conditional heteroscedasticity model (ARCH) and enhanced Generalized autoregressive conditional heteroscedasticity model (GARCH).

4.2 Linear Volatility Models

ARCH is autoregressive conditional heteroscedastidy model using for time series volatility modelling, firstly introduced by Engle(1992). He supposed residual variance σ^2as a function of residual squares from past observations

4.2.1 ARCH Models

In simple linear regression model:

$$Y_t = \beta_1 + x_i^T \beta + u_i$$

where u_t is vector of residuals with mean value $E[u_t] = 0$ and variance σ^2. Then we can express conditional variance at time t as

$$\sigma_t^2 = a_0 + a_1 u_{t-1}^2$$

which is simple ARCH(1) process, because conditional variance σ_t^2 depends only on one lagged residual u_{t-1}

4.2.2 Testing for ARCH Effect

A very first step of the estimation is to test whether there we can observe ARCH effect among the time series residuals.

Under the ARCH we observe autocorrelation in volatility. Thus the significance of this effect might be test by conducting following steps. (Brooks 2008)

1. Run a postulated linear regression of the form given by the following equation, e.g.:

$$Y_t = \beta_1 + \beta_2 x_{2t} + \beta_3 x_{3t} + \beta_4 x_{4t} + u_t$$

   and save the residuals, $\hat{u}_t$.

2. Square the residuals and regress them on q own lags to test for ARCH effect of order q, i.e. run the regression:

$$\hat{u}_t^2 = \gamma_0 + \gamma_1 \hat{u}_{t-1}^2 + \gamma_2 \hat{u}_{t-2}^2 + ... \gamma_q \hat{u}_{t-q}^2 + v_t$$

   where v_t is an error term. Obtain R^2 from this regression.

3. The test statistics is defined as TR^2 (the number of observations multiplied by the coefficient of multiple correlation) from the last regression, and is distributed as $\chi^2(q)$.

4. The null and alternative hypotheses are:

$$H_0 : \gamma_1 = 0 \wedge \gamma_2 = 0 \wedge \gamma_3 = 0 \wedge \gamma_4 = 0$$

$$H_1 : \gamma_1 \neq 0 \vee \gamma_2 \neq 0 \vee \gamma_3 \neq 0 \vee \gamma_4 \neq 0$$

4.2.3 GARCH(p,q) Models

The GARCH model was firstly introduced by Bollerslev and Taylor in 1986. The difference from ARCH model is that the GARCH models allows the conditional variance to be dependent on own previous lags, so that the conditional variance equation in the simplest case GARCH(1,1) is as follows: (Brooks 2008)

$$\sigma_t^2 = \alpha_0 + \alpha_1 u_{t-1}^2 + \beta \sigma_{t-1}^2$$

We can denote GARCH(p,q) model generally:

$$\sigma_t^2 = \alpha_0 + \alpha_1 u_{t-1}^2 + ... + \alpha_q u_{t-q}^2 + \beta_1 \sigma_{t-1}^2 + ... + \beta_p \sigma_{t-p}^2 = \alpha_0 + \sum_{i=1}^{q} \alpha_i u_{t-i}^2 + \sum_{i=1}^{p} \beta_i \sigma_{p-i}^2$$

where p is the order of the GARCH terms σ^2 and q is the order of the ARCH terms u^2

4.3 Nonlinear Volatility Models

Nonlinear models suppose that the effect of positive news is not same as the effect of negative news. In most cases negative news causes stronger impact on the stock volatility.

The two most prominent representatives of non-linear models are an Exponential GARCH model (EGARCH) and a Threshold GARCH (TGARCH).

4.4 Literature Review

There is a numerous literature on volatility estimation. The most widely recognized model used for conditional standard deviation estimate are simple GARCH (1, 1) and nonlinear model EGARCH (1, 1) which is able to capture the asymmetric effect of news on returns.

Both of these models are very popular so in this subsection I will review some important empirical studies to provide basic overview and experiences with these approaches.

Many studies indicate some connection between exchange rate volatility and news or information. Engle (1993) presented a concept of asymmetric volatility response to the news. He also suggests that EGARCH is the best parametric model and can capture the most of asymmetry; however there is evidence that EGARCH overestimates conditional variance.

Egert and Kocenda (2012) analyzed the impact of macroeconomic news and central bank communication on the exchange rates of three Central and Eastern European currencies against the Euro. They uses GARCH type models on high-frequency data to estimate the effects of macroeconomic announcements and central bank communication. According their research there was a lack of responsiveness on verbal central bank interventions in pre-crisis period. However, currencies reacted to central bank communication during the crisis period. Surprisingly they did not find any significant non-linearity in their dataset.

Hansen (2001) in his famous paper Doses anything beat a GARCH (1, 1) performed comparison of models and he concludes that simple GARCH (1, 1) is the best estimator of volatility. This is reason I will use this model as core part of my volatility estimation.

Fidrmuc and Horvath (2007) examined the daily exchange rate dynamics in selected new EU member states (Czech Republic, Hungary, Poland, Romania, and Slovakia) using GARCH and TARCH models between 1999 and 2006. Contrary to Egert and Kocenda (2007) they find significant nonlinearities. Their TARCH results point to systematic asymmetries in the exchange rate volatility among the new member states. The volatility of exchange rate is significantly more pronounced especially during the periods of exchange rate appreciation in all analyzed countries.

Abdalla (2012) in his paper applies generalized autoregressive conditional heteroscedastic modeling on a panel of nineteen of the Arab countries using daily observations from Jan 1st, 2000 to Nov 19th, 2011. The paper applies both symmetric GARCH and asymmetric EGARCH models. The asymmetric EGARCH (1, 1) results provide evidence of non-linearity for all of the countries except one – implying a higher next period conditional variance for negative shocks compared to the positive shock with the same magnitude.

Goyal and Arrora (2012) also uses GARCH models to analyze effectiveness of central bank actions. The difference from previous papers is they stress importance of communication on exchange rate volatility. The empirical study, performed on Indian data from November 2005 to December 2008, found that Reserve Bank of India policy announcements and public speeches has outperformed in their volatility effect conventional monetary tools. Based on their results, I can expect similar strong effect of communication also in the Czech Republic. Thus I will focus not only to effect of foreign intervention, but I will also focus on CNB communication effect on volatility, especially impacts of the

Bank's monetary board meeting.

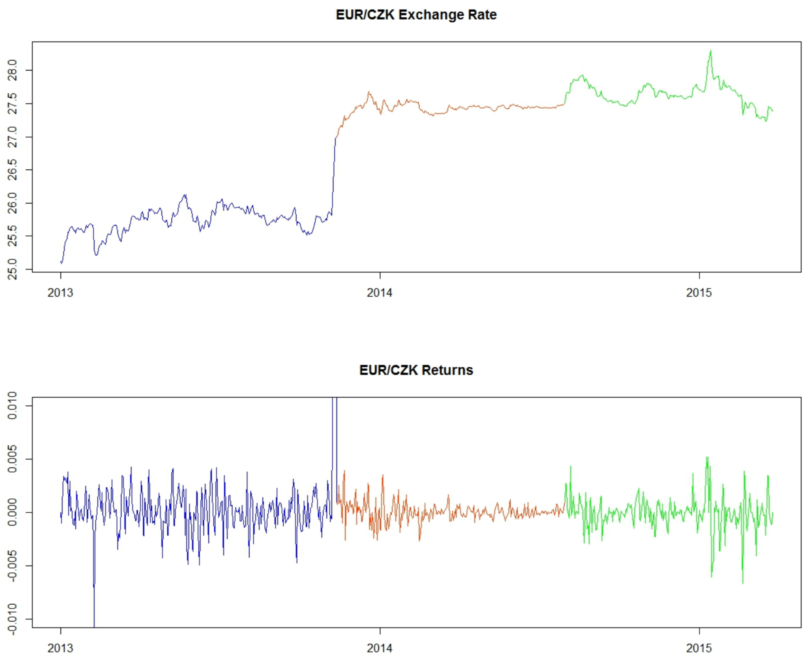
4.5 Empirical modeling

4.5.1 Data

The data used for volatility modeling are EUR/CZK exchange rates from January 1st, 2012 to March 26th, 2015 (ECB, 2015) and exchange returns obtained by my own computations. I compute simple percentage rate of returns by this formula:

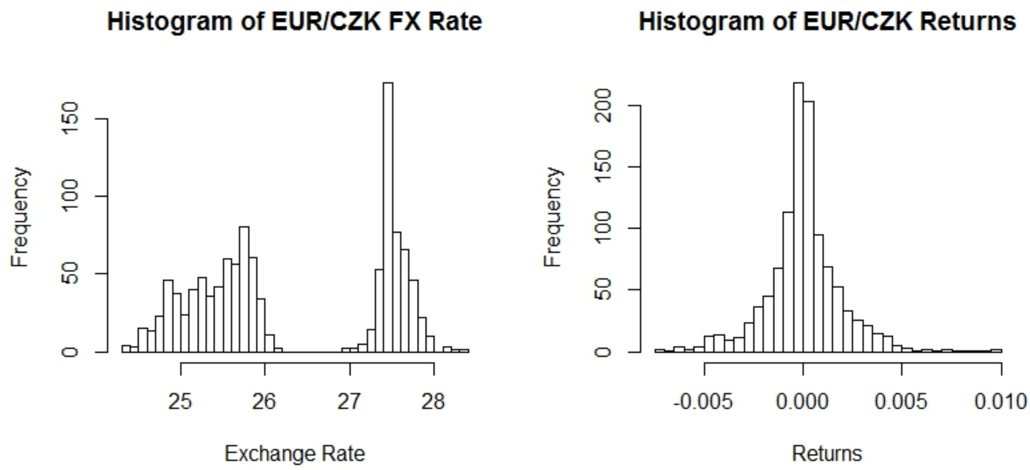
$$R_t = \frac{E_t - E_{t-1}}{E_{t-1}}$$

Figure 4.1: CZK/EUR since 2012



From the first look we can observe several interesting insight from the charts. The fist past of the time series (depicted in blue) is period before the intervention. This period is characteristic by moreless constant volatility and mean value of exchange rate slightly below 26 CZK/EUR. Then later in the second half of 2013, there is visible a quick depreciation of the exchange rate, which is caused, not surprisingly, by the announcement of the exchange rate commitment. After the shift the exchange rate to the new level around 27.5 and the volatility slowly decayed. Finally from mid 2014 volatility began to increase and return to pre-crisis level, while mean exchange rate is still around 27.5 CZK/EUR.

Figure 4.2: CZK/EUR Histograms



Histogram of exchange rate show us interesting fact — this rate was mostly distributed either between 27-28 or 24-24 CZK/EUR but very rarely in the middle between 26 and 27 CZK/EUR. Returns are as expected centered around zero witch very high curtosis.

For my analysis I split time series into three separate periods by two important events. First important event which caused a large structural change is of course the intervention from November 7th, 2013. The intervention caused a large jump in exchange rate but from the first look on the chart the effect on volatility is few months delayed.

Second important event is — maybe little surprisingly â€“- CNB Board monetary policy meeting from August 1st, 2014. After this event volatility increses considerably, but on the other side the impact on long term level of exchange rate is not so strong.

Descriptive statistics

In this part I will provide and compare basic descriptive statistics for all samples (periods).

Time/Statistics	Observations	Mean	St. Dev.	Min	Max
Period 1 (1. 1. 2013 - 6. 11. 2013)	274	25.72	0.19	25.09	26.137
Period 2 (8. 11. 2013 - 31. 7. 2014)	241	27.43	0.09	27	27.69
Period 3 (1. 8. 2014 - 26. 3. 2015)	223	27.65	0.17	27.23	28.3

Table 4.1: Descriptive Statistics of CZK/EUR Exchange Rates

Each periods contains approximately same number of observations — around 250, thus we can make a relevant comparison between periods. In period before intervention there is average exchange rate around 25.52, while after intervention it is about of 27.5. Comparing standard deviation it is similar in first and third period — a 0.17 and 0.19 respectively, but in second period it is only 0.09.

Time/Statistics	Observations	Mean	St. Dev.	Min	Max
Period 1 (1. 1. 2013 - 6. 11. 2013)	274	0.0003	0.0033	-0.11	0.045
Period 2 (8. 11. 2013 - 31. 7. 2014)	241	0.000078	0.0009	-0.0026	0.0039
Period 3 (1. 8. 2014 - 26. 3. 2015)	223	-0.000014	0.0016	-0.0066	0.0052

Table 4.2: Descriptive Statistics of CZK/EUR Returns

4.5.2 Estimation strategy

1. Firstly separate data into the three parts, based on time periods —one pre-intervention and two post-intervention periods. This division is needed to capture and measure effect on volatility.

2. Check whether the returns are white noise (it means $E[r_t] = 0$ and $E[r_t^2] = \sigma^2$)– all lags of autocorrelation and partial ACF function should be insignificant. If not remove any linear structure in data by autoregressive model and then perform the same diagnostics with residuals

   AR model: $r_t = \sum_{i=1}^{l} a_i r_{t-i} + \epsilon_i$ where l is an order of AR process

   Residual equation: $e_t = r_t - \hat{r}_t$ where $\hat{r}_t$ is predicted return from the AR model

3. Engle‘s ARCH test - tests whether the residual series exhibits conditional heteroscedasticity (autocorrelation in squared residuals) â€“ i.e. it has autoregressive conditional heteroscedastic (ARCH) effect.

   ARCH LM - recommended lags for $GARCH(l,q)$ are $l+q$, so I use ARCH test with lag of 2

   Regress $e_t^2 = a_0 + a_1 e_{t-1}^2 + a_2 e_{t-2}^2$
   $H_0 : a_0 = a_1 = a_2 = 0$
   $H_A : nonH_0$

4. Estimate $GARCH(1,1)$ using the filtered residuals

   In case we use ARMA model for estimation of time series relationship and save residuals, the conditional heteroscedasticity of errors is given as follows:

$$\sigma_t^2 = \alpha_0 + \alpha_1 \epsilon_{t-1}^2 + ... + \alpha_q \epsilon_{t-q}^2 + \beta_1 \sigma_{t-1}^2 + ... + \beta_q \sigma_{t-p}^2 = a_0 + \sum_{i=1}^{q} \alpha_i \epsilon_{t-1}^2 + \sum_{i=1}^{p} \beta_i \sigma_{t-1}^2$$

   where p is the order of the GARCH terms σ^2 and q i the order of the ARCH terms ϵ^2

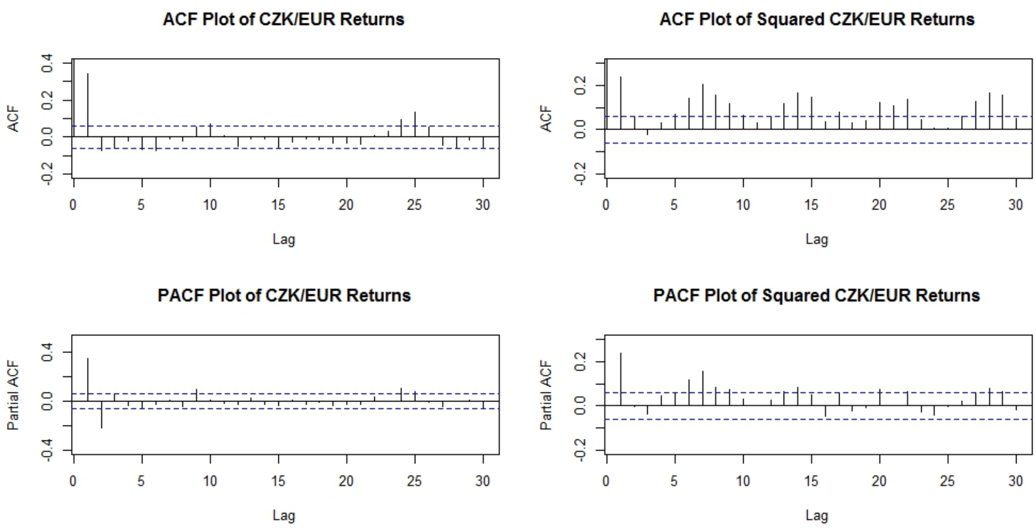
5. Evaluation of models and comparison between periods. Test hypotheses, whether the foreign exchange intervention increase volatility

6. Estimate GARCH with the same procedure for Switzerland. Discuss the differences and state the conclusion

4.5.3 GARCH estimation

Firstly I plot the autocorrelation function (ACF) that provides evidence of serial correlation among the observations. Moreover, the plot of the partial autocorrelation function (PACF) indicates longterm dependence among the observations.

Figure 4.3: ACF and PACF Plots of CZK/EUR Exchange Rate



We can observe some linear dependence in both simple and squared returns. In order to estimate we must filter data by AR(10) process

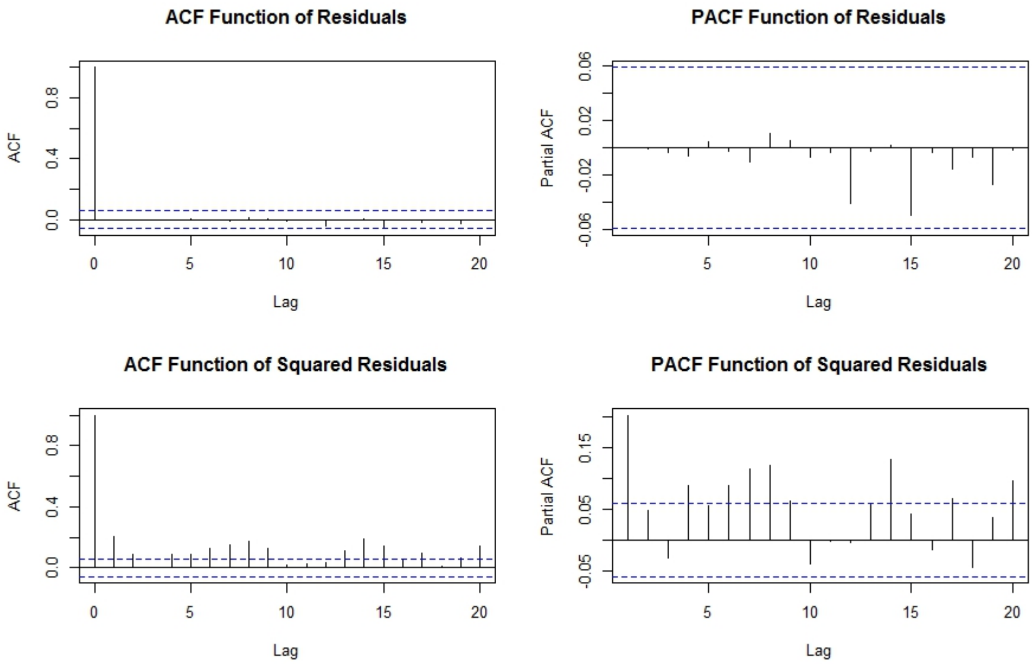
ar1	ar2	ar3	ar4	ar5	ar6
0.423	-0.238	0.054	-0.014	-0.041	-0.045
ar7	ar8	ar9	ar10	intercept	
0.051	−0.079	0.086	0.012	0.0001	

Table 4.3: AR(10) Regression Results

Now we can see ACF and PACF of residuals are not significant, so we have a whit noise series without linear dependence.

On the other hand on case of squared residuals we can observe the linear relationship, thus we suppose ARCH effect among squared results. We can proceed directly to GARCH estimation of volatility.

Figure 4.4: ACF and PACF Plots Residuals after AR(10) Filtering

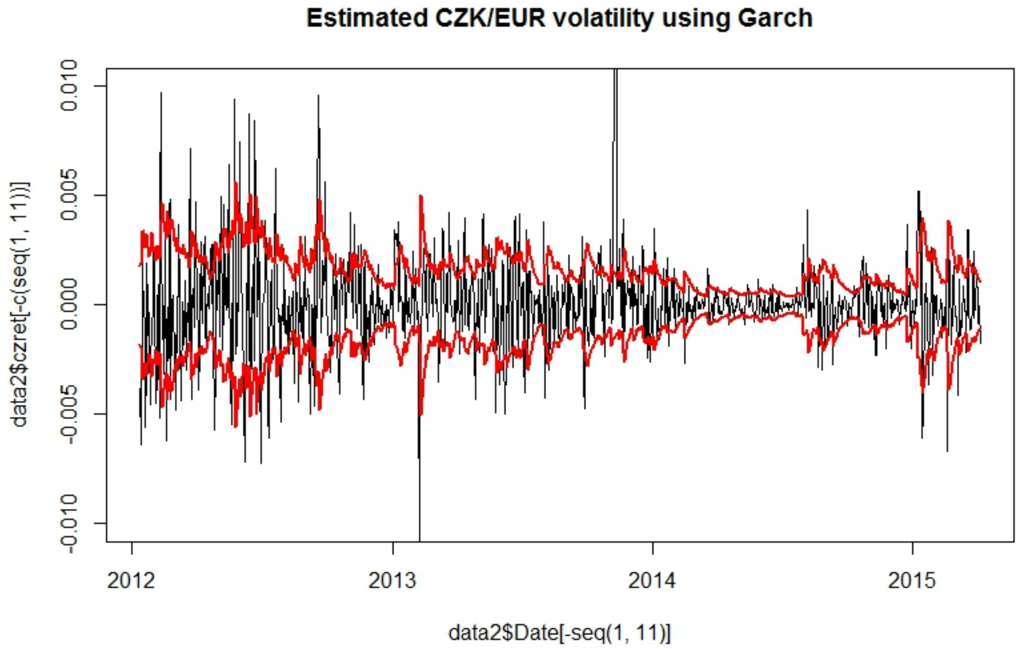


GARCH Model

Firstly we can estimate GARCH for the whole time period from 2012 to March 2015, to get overall view of volatility development. In the next step I will compare volatility between three periods of time to capture effect of intervention to volatility.

The model is estimated on AR filtered residuals. On the other hand on the plot there are simple returns (non-filtered) in black line and continuous garch volatility depicted in red. I use also mirrored volatility (just estimated volatility multiplied by -1) for better graphical visualization.

Figure 4.5: GARCH Estimation Full Sample



From GARCH estimation we can observe see cluster of high volatility during almost whole year of 2012. Since late 2012 the volatility declines, since Czech National Bank had announced aim to intervene in the market in advance and through 2013 it remains more-less stable.

One could expect volatility decrease after introduction of 27 CZK/EUR floor. However this decrease was slow and gradual, where the lowest volatility period is delayed approximately one quarter after the intervention start.

The volatility remained low till August 1, 2014 —when Czech National Bank after Monetary board meeting announced it will hold the floor longer —at least till 2016. From early 2015 there is another turbulent period, when CNB considered shift of exchange rate floor from 27 to 28 CZK/EUR (or at least some of the key market players excepted it), which was followed by several public announcements from not only bankers but also several key political figures. Thus we can also confirm strong effects of public information on volatility.

Shortly after the intervention volatility slowly decayed,

Estimated coefficient from model are as follows

mu	omega	alpha1	beta1
−0.00000	0.00000	0.232	0.803

Table 4.4: Estimated GARCH(1,1) Parameters

Alpha1 coefficient measures the extent to which a volatility shock today goes through into next period's volatility. In this case aplha1 coefficient equals 0.232

Alpha1 + Beta1 measures the rate at which this effect dies over time, for this model this sum is slightly over 1. This can be interpret in the way, that persistence of volatility in this case is extremely high and the volatility shocks die out only very slowly and gradually

Comparison of Volatility Between Periods (multiplied by 1000)

Statistic	N	Mean	St. Dev.	Min	Max
Period 1 (1. 1. 2013 - 6. 11. 2013)	275	1.829	0.604	0.887	5.012
Period 2 (8. 11. 2013 - 31. 7. 2014)	241	0.890	0.472	0.361	2.602
Period 3 (1. 8. 2014 - 26. 3. 2015)	222	1.432	0.730	0.465	3.971

Table 4.5: Inter-Period Volatility Comparison

Interpretation

Generally we can say the volatility in period two is approximately half of these in period 1. After the first of August the volatility returns almost to pre-interventions volatility levels, though it is still slightly lower. Thus we can say the intervention had only temporary effect on volatility even though the CNB still hold the 27 CZK/EUR floor.

4.6 Volatility of Swiss Franc

The data used for Swiss volatility modeling are EUR/CHF exchange rates from January 1st, 2009 to April 11th, 2015 (ECB, 2015). The data range used for Swiss Franc is much wider compared to Czech Koruna. It is because we need capture two important events.

The first is September 6th, 2011 when the Swiss National Bank pegged the Swiss franc against the euro in an attempt to protect its economy from the European debt crisis. (BIS, 2015). The Bank in effect devalued the Franc, pledging to buy "unlimited quantities" of foreign currency to down this value. This is very similar to promise as a Czech National Bank statement from November 2013. The lower bound to EUR/CHF exchange rate was set to the value of 1.2.

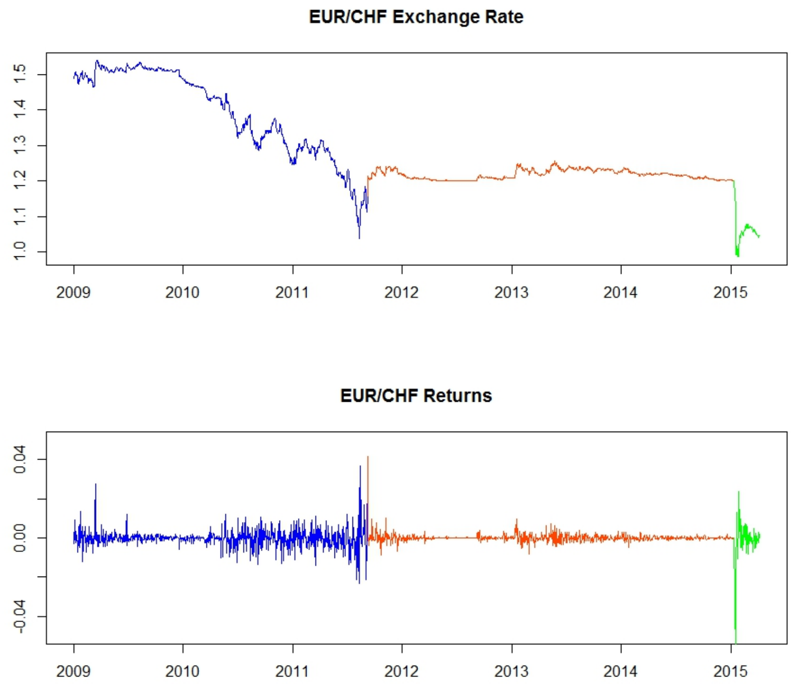
The second crucial date was the 15th of January, 2015 when the Swiss National Bank (SNB) suddenly announced that it would lift the currency peg. (Economist, 2015) The end of the currency peg was followed by chaotic situation and market collapse when Swiss franc soared from 1.2 per Euro to just .0.85 francs per one Euro.

Exchange returns are obtained by my own computations, again by following formula formula:

$$R_t = \frac{E_t - E_{t-1}}{E_{t-1}}$$

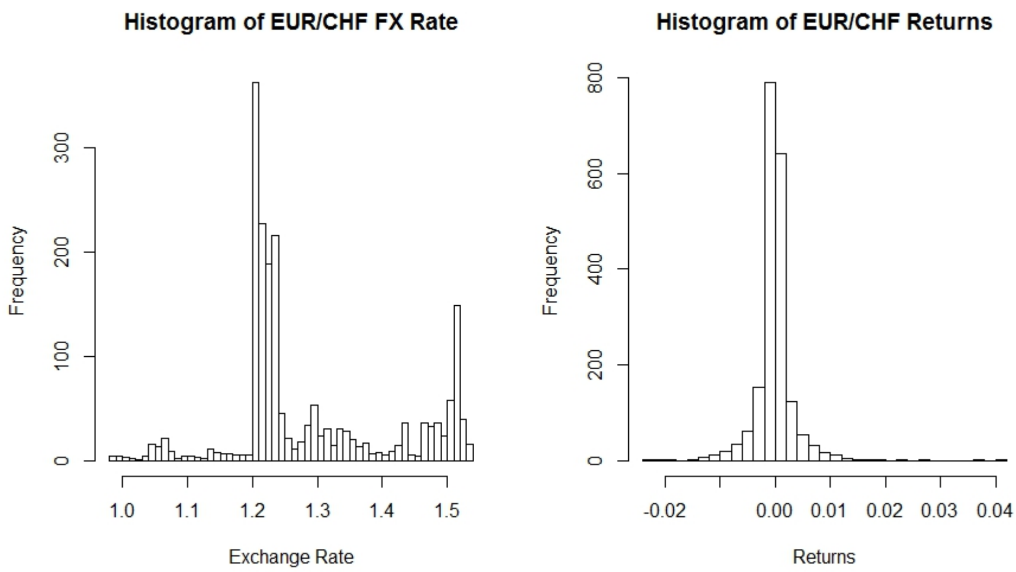
Again I will analyze dataset by three separated periods - before currency peg, currency peg and after currency peg

Figure 4.6: EUR/CHF since 2009



From the chart above we can observe strong appreciation of Swiss Franc from 2010 onwards. Between the 2010 and mid 2011 the Swiss Franc appreciated from 1.5 EUR/CHF to 1 EUR/CHF. In order to stop rapid strengthening of currency, the Swiss National bank pegged Franc against Euro on 6th September, 2011. Since then the Franc stabilized around pegged value of 1.2 EUR/CHF. Finally at the end of period the end of intervention is easily visible from the chart when Swiss currency again strengthen significantly in a few days.

Figure 4.7: EUR/CHF Histograms



Regarding nominal exchange rate histogram we can observe most of values slightly above 1.2 and then another peak is around 1.5, which were the franc values mostly in 2009 and 2010. When we look at the returns histogram there is extremely strong kurtosis - most of values are very close to the zero (much more then normal distribution would suggests).

Descriptive Statistics

Now let us take a look at the descriptive statistics:

Time/Statistics	Observations	Mean	St. Dev.	Min	Max
Period 1 (2. 1. 2009 - 10. 9. 2011)	912	1.388	0.1197	1.038	1.538
Period 2 (11. 9. 2011 - 15. 1. 2015)	996	1.218	0.0163	0.993	1.256
Period 3 (16. 1. 2014 - 11. 4. 2015)	75	1.049	0.0232	0.986	1.078

Table 4.6: Descriptive Statistics of CHF/EUR Exchange Rates

First period between January 2, 2009 and September 9, 2011 is before Swiss intervention. The rapid appreciation is visible from the statistics. Min exchange rate value is only 1.038 and max is 1.538, which is stunning 50% difference during two and half years. Mean value is 1.388 and this period is associated with very high standard deviation (0.1197). The second period is completely different. Mean exchange rate is now 1.218, which is slightly above exchange rate floor. Standard deviation is marginal compared to previous period (only

0.0163). In the last period after the exit form intervention we have only 75 observations. Mean value of exchange rate is 1.049, making Swiss Franc stronger currency then before start of the intervention.

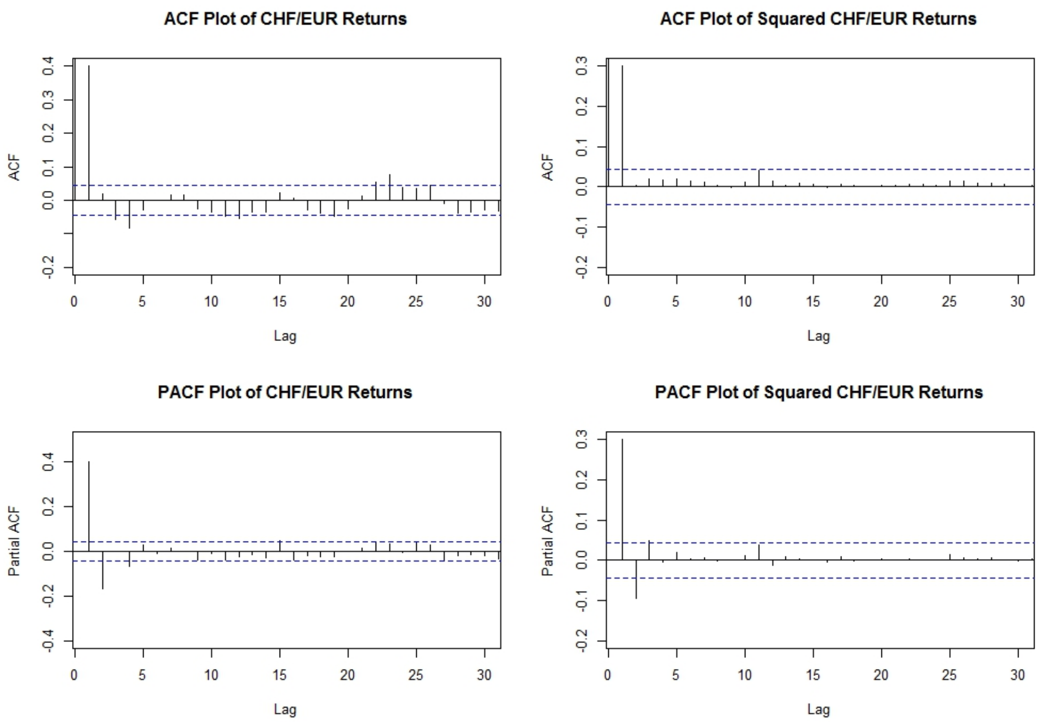
Time/Statistics	Observations	Mean	St. Dev.	Min	Max
Period 1 (2. 1. 2009 - 10. 9. 2011)	912	0.0003	0.0033	-0.11	0.045
Period 2 (11. 9. 2011 - 15. 1. 2015)	996	0.000078	0.0009	-0.0026	0.0039
Period 3 (16. 1. 2014 - 11. 4. 2015)	75	-0.000014	0.0016	-0.0066	0.0052

Table 4.7: Descriptive Statistics of CHF/EUR Returns

4.6.1 GARCH estimation

In this part I plot Autocorrelation function to capture serial dependence in residuals. Moreover, the plot of the partial autocorrelation function (PACF) indicates long term dependence among the observations.

Figure 4.8: ACF and PACF Plots of CHF/EUR Exchange Rate

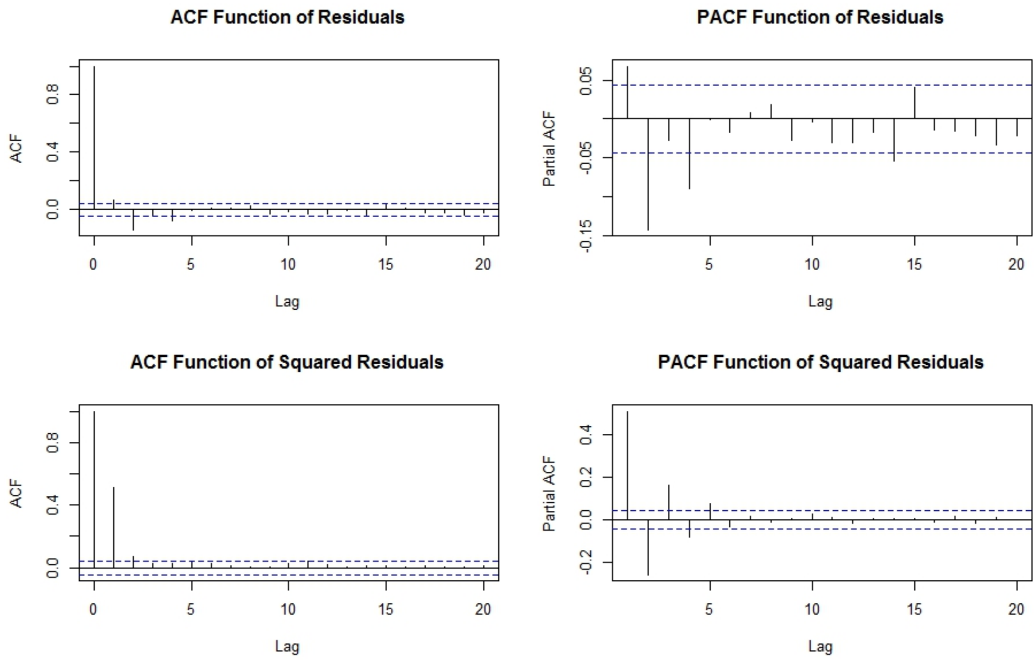


When we look firstly at the autocorrelation function, we can observe significant correlation with one period lagged returns. The same patterns is presented in the partial autocorrelation function. We can observe some linear dependence in both simple and squared returns, but mostly only in first order, so I will proceed with filtering by simple AR(1) model.

ar1	intercept
0.401	−0.0001

Table 4.8: AR(1) Regression Results

Figure 4.9: ACF and PACF Plots Residuals after AR(1) Filtering



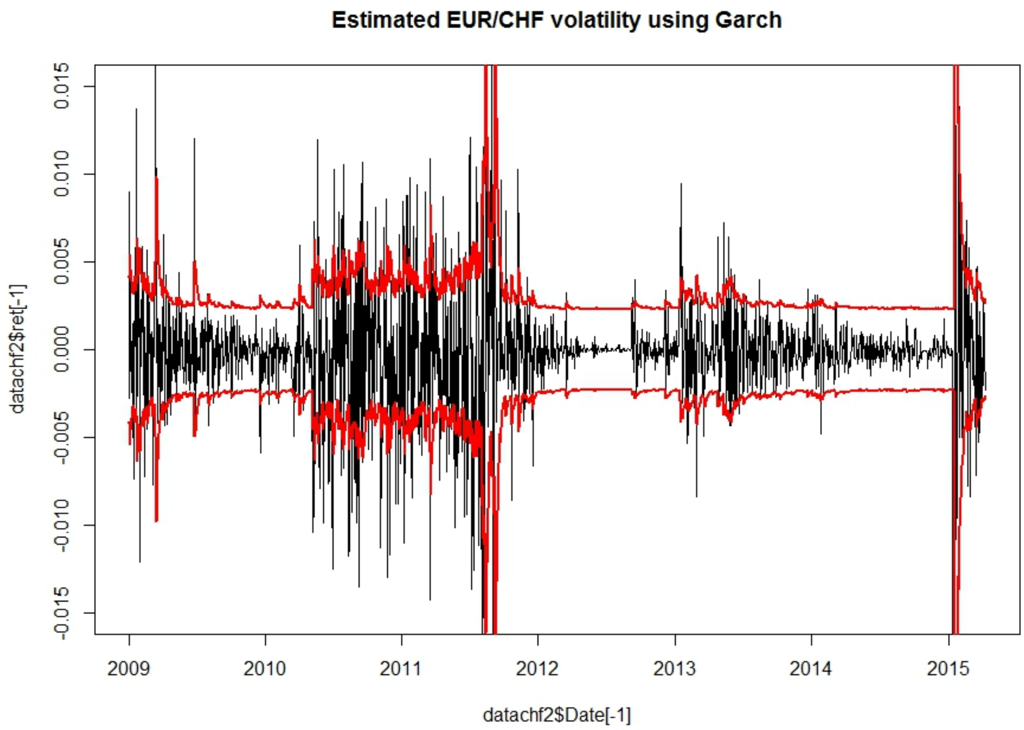
The table above summarize results of AR(1) regression applied on CHF/EUR daily returns. The AR1 coefficient of this estimation is approximately 0.4. The next step is to save residuals from this regression and check whether now we got white noise time series.

From ACF of residuals, we can confirm these are white noise after the filtering. Again if we look at autocorrelation function of squared residuals we can observe some dependence (ARCH effect), which we capture by GARCH model in next section.

GARCH Model

The estimation strategy for this part is as follows. Firstly I will estimate GARCH model for the the whole time series. In the next step I will proceed to comparison of estimated volatility between periods.

Figure 4.10: GARCH Estimation Swiss Franc



Estimated coefficient from model are as follows

mu	omega	alpha1	beta1
0.00000	0.00000	0.145	0.773

Table 4.9: Estimated GARCH(1,1) Parameters

In this case aplha1 coefficient equals 0.145, which is less then in the Czech model.

Alpha1 + Beta1 measures the rate at which this effect dies over time, for this model this sum is 0.918. The persistence on volatility in Switzerland is also quite high but significantly lower then in the Czech republic.

Comparison of Volatility Between Periods (multiplied by 1000)

Statistic	N	Mean	St. Dev.	Min	Max
Period.1	911	3.815	1.776	2.313	18.448
Period.2	996	2.702	1.558	2.300	38.500
Period.3	75	7.040	7.089	2.661	36.414

Table 4.10: Inter-Period Volatility Comparison

4.7 Assessment of Results, Conclusion

Results of the GARCH estimation for Switzerland provides similar results as for the Czech Republic. After beginning of the intervention the volatility decreased sharply. The Swiss Franc exchange rate became less volatile few moths after the intervention, because it hit the lower barrier of 1.2 CHF/EUR few months thereafter, which limited a fluctuation range of the currency. The opposite was true for Czech Republic. In the Czech case the exchange rate never hit the lower barrier of 27 CZK/EUR and almost the whole time remained higher, approximately around 27.5 CZK/EUR. The volatility development in the Czech Republic shows similar patterns as Swiss case — there was also several months delayed volatility decrease after the intervention. However there is a significant difference that volatility on the Czech exchange market is much more persistent then volatility of Swiss Franc returns.

Regarding the end of intervention in Switzerland, we can observe immediate sharp appreciation (approximately 20 % in a single trading day). Moreover the volatility surged very rapidly. The question is whether we can expect similar scenario when Czech National Bank lift the barrier and exit the monetary intervention. There might by several reasons why Swiss Franc reacted so extremely. Firstly, the Franc was much more under-valuated then Czech Koruna and secondly, Franc is one of the most important global reserve currencies, which attracted higher inflow of capital from investors and speculators.

Chapter 5

VAR modeling

5.1 Introduction

To introduce the topic, vector autoregression is a system of equations where endogenous variables are regressed on lagged observations of all the variables. In other words, the future value of each of the processes is a weighted sum of past (or present) values plus some random part. There is also a possibility of the expansion of the model to include deterministic time trend and other exogenous variables.

5.2 Standard VAR

Standard vector autoregression model is multivariate autoregressive model, firstly introduced by Sims in 1980 and now it is widely uses econometric tool, used in case there is mutual dependence among variables.

5.2.1 VAR with exogenous variables

The components of the vector X_t are known as exogenous variables since their values are determined outside of the VAR system – in other words, there are no equations in the VAR with any of the components of X_t as dependent variables. Such a model is sometimes termed a VARX, although it could be viewed as simply a restricted VAR where there are equations for each of the exogenous variables, but with the coefficients on the RHS in those equations restricted to zero. Such a restriction may be considered desirable if theoretical considerations suggest it, although it is clearly not in the true spirit of VAR modeling, which is not to impose any restrictions on the model but rather to 'let the data decide'. (Brooks 2008)

However in case of small open economy, like Czech Republic, is obvious that aggregated macroeconomic variables for whole Eurozone, are almost exogenous on Czech situation and on the other side Czech economy is strongly connected with Eurozone's.

5.3 Literature Review

Bitans (2004) examines the exchange rate pass-through in a set of 13 East European countries during the period of 1993 — 2003. He found the exchange rate pass though is positively related to average inflation rate, import structure and openness to foreign trade of a country. The pass-through estimates are derived from a recursive VAR model in first differences, and the impact of exchange rate changes on both the producer and the consumer prices is studied

Horvath and Borys (2007) examined the effect of Czech monetary policy on economy by VAR models, structural VAR and the Factor-Augmented VAR. They focus on period after 1998, shortly after the CNB structurally changed their policy from fixed exchange rate to inflation targeting regime. They recommend using more advanced models — as SVAR and FAVAR in case of the structural change, to capture the monetary policy transmission affect effect. The main finding from impulse response functions is that prices and output decline after monetary tightening, and that reaction of tradable prices is faster than those of non-tradable.

Similarly we can look at the case of the recent foreign exchange intervention as a structural shift of monetary policy from inflation targeting to partly exchange rate targeting.

Popescu (2012) use simple VAR and SVAR models to estimate effects of monetary policy in Romania. He focus on assessing the extent and persistence of monetary policy effects on GDP, price level, M3 money aggregate and exchange rate. The impulse response analysis observes impacts of an unexpected contractionary monetary policy shock (a sudden increase in short term interest rate). Main result is negative response of CPI, gross domestic product and M3 money aggregate.

5.4 Data

The data sample covers data from 1999 till 2014. I decided to use 4 endogenous and 2 exogenous variables in my model, which I describe later.

- GDP growth of the Czech Republic (y): Czech GDP is included in the model as the key macroeconomic variable. We can expect some connection among GDP and inflation, and we want estimate response to GDP from exchange rate shock. I sourced quarterly year-to-year seasonally adjusted data of real GDP growth, which I simply extrapolated to get monthly values

- Inflation Rate(ϕ): Inflation rate is the most important variable observed by central bank and moreover the low inflation was the main reason of intervention so it is obvious it must be included in model to capture impulse rate from exchange rate. I decided to use year-over-year CPI rate which is more smother compared to month-over-month values. Again I use monthly observations

- 3M Pribor (p): It is the average inter-bank interest rate in economy. Pribor is watch closely because it it used as a base rate (benchmarch) by banks and other financial institutions

- Exchange Rate (x): I include exchange rate in the model because it serve as a main instrument of Czech national bank policy during intervention. In order to capture shift in exchange rate from October to November 2013 I use monthly data observed as CZK/EUR nominal exchange rate value corresponding to the last trading day of a particular months. The values are in levels.

- Commodity Price Index (C): Commodity price index combining prices of all commodities, provided by IMF (2015). Commodity price strongly affect economic growth and inflation so is reasonable to include it in the model. Moreover the sharp decline of commodity and especially fuel prices causing decline in inflation and the question of further intervention is being discussed again.

- Eurozone GDP growth in y/y quotation(Y): The Czech Republic is a small open economy and its economic growth is strongly connected with the Eurozone countries, especially with Germany.

Statistic	N	Mean	St. Dev.	Min	Max
gdp	190	2.557	2.987	−5.700	7.300
cpi	190	2.402	1.716	−0.400	7.500
Pribor	190	2.661	1.756	0.340	7.580
fxrate	190	29.099	3.795	23.893	38.393
commodity	190	4.617	0.581	3.251	5.519
EurGdp	190	1.188	2.011	−5.570	4.480

Table 5.1: Descriptive Statistics

5.5 Model Specification

Our estimated VAR model has the following specification

$$Y_t = C_t + \sum_{i=1}^{p} A_i Y_{t-i} + BX_t + e_t$$

where Y_t is the endogenous variables vector, C_t is the vector of constants (intercepts), e_t is a vector of residual terms (should be white noise), $A_i, ..., A_{i-p}$ are matrices that contains all the coefficients reflecting relationships between endogenous and exogenous variables, t is time and $i = 1, ..., p$ shows number of lags.

$$Y_t = [gdp_t, cpi_t, pribor_t, fx_t]$$

$$X_t = [gdpEur_t, CommodIndex_t]$$

For identification of shocks is used Choleski identification with the same ordering as in vector of endogenous variables Y_t above.

5.6 Lag Length Selection

Vector autorression optimal number of lags is selected based on information criterions. The most common criterion are as follows (Ivanov, Kilian 2005):

- Schwarz information criterion: $SC(p) = \log|\bar{\sum}(p)| + \frac{\log N}{N}(K^2p)$
- Hannah-Quinn information criterion: $HC(p) = \log|\bar{\sum}(p)| + \frac{2\log N}{N}(K^2p)$
- Akaike information criterion: $AIC(p) = \log|\bar{\sum}(p)| + \frac{2}{N}(K^2p)$

Where N is the sample size, $\bar{\sum}$ is the quasi-maximum likelihood estimate of the covariance matrix $\sum$. Then the lag value p is chosen to minimize the value of the criterion function.

Following table sums up optimal number of lags by each of this criterion.

AIC(n)	HQ(n)	SC(n)	FPE(n)
14	2	2	2

Table 5.2: Inforamtion Criteria

According to the Hannah-Quinn, Schwarz and FPE criterion the optimal number of the lags is 2. Only Akaike crterion shows different value (14). The problem is that this criterion asymptotically overestimates the order of VAR with positive probability. Thus I will consider only the three other criterions and choose the maximum number lags of 2.

5.7 Model Estimation

Now we can proceed to the estimation of specified model. All estimated relationship, including coefficients and standard errors are included in following table.

	Dependent variable:			
	gdp	mcpi	mPribor	mfxrate
gdp.l1	1.686^{***}	-0.239^{*}	-0.054	-0.039
	(0.050)	(0.130)	(0.034)	(0.145)
mcpi.l1	-0.009	1.045^{***}	0.073^{***}	-0.219^{***}
	(0.029)	(0.074)	(0.019)	(0.083)
mPribor.l1	0.044	0.007	1.259^{***}	0.633^{**}
	(0.100)	(0.260)	(0.067)	(0.291)
mfxrate.l1	-0.010	0.122^{*}	-0.020	0.961^{***}
	(0.026)	(0.066)	(0.017)	(0.074)
gdp.l2	-0.737^{***}	0.211^{*}	0.045	0.051
	(0.045)	(0.116)	(0.030)	(0.129)
mcpi.l2	-0.010	-0.166^{**}	-0.060^{***}	0.168^{**}
	(0.028)	(0.073)	(0.019)	(0.082)
mPribor.l2	-0.101	-0.003	-0.314^{***}	-0.573^{**}
	(0.096)	(0.248)	(0.064)	(0.278)
mfxrate.l2	0.026	-0.067	0.033^{*}	-0.021
	(0.026)	(0.066)	(0.017)	(0.074)
const	-0.798	-5.571^{***}	-0.808^{**}	3.321^{**}
	(0.534)	(1.383)	(0.358)	(1.546)
trend	-0.003^{***}	-0.008^{***}	-0.002^{**}	0.003
	(0.001)	(0.003)	(0.001)	(0.003)
mcommodity	0.207^{**}	1.092^{***}	0.153^{**}	-0.418
	(0.088)	(0.228)	(0.059)	(0.255)
mEurGdp	0.035^{**}	0.052	0.019^{**}	0.00001
	(0.014)	(0.036)	(0.009)	(0.040)
Observations	190	190	190	190
R^2	0.997	0.943	0.996	0.985
Adjusted R^2	0.997	0.940	0.996	0.985
Residual Std. Error (df = 178)	0.163	0.421	0.109	0.471
F Statistic (df = 11; 178)	$5{,}776.596^{***}$	268.911^{***}	$4{,}443.127^{***}$	$1{,}099.253^{***}$

Table 5.3: VAR Model Estimated Coefficients

From the table above we can distinguish which explanatory variables and lags are significant in determination of explained variable. We can write down relationships including all variables, while the significant variables are marked with stars:

$$\begin{aligned} GDP_t = &-0.798 - 0.003 * t^{***} + 1.686 * GDP^{***}_{t-1} - 0.009 * CPI_{t-1} \\ &+0.044 * PRIBOR_{t-1} - 0.01 * FxRate_{t-1} - 0.737 * GDP^{***}_{t-2} \\ &-0.010 * CPI_{t-2} - 0.101 * PRIBOR_{t-2} + 0.026 * FxRate_{t-2} \\ &+0.207 * CommodityIndex^{**}_t + 0.035 * EuroGDP^{**}_t \end{aligned}$$

The most significant determinants of current GDP are lagged GDP values. What is interesting is that one period lagged GDP has coefficient higher than one (one unit increase of lagged GDP would cause approximately 1.686 increase of current GDP). The opposite is true for two periods lagged GDP, that coefficient is negative (-0.737). When we combine these two coefficients we get value 0.946. Thus we can say that current GDP is from 95% explained by own lagged values.

The next important variable explaining current GDP is exogenous variable of Commodity price index. The coefficient is positive, which is quite contraintuitive, because one would expect that the higher prices of commodities diminishes GDP growth. The explanation can be there is causality from opposite direction. Stronger GDP growth stimulates demand for commodities and boost their price increase. Thus GDP can by positively correlated with prices of commodities. The last variable which is associated with GDP growth is GDP growth in Eurozone. However the size of coefficient is rather small. One unit increase of Eurozone GDP growth is associate only with 0.035 unit increase of Czech GDP growth.

$$\begin{aligned} CPI_t = &-5.571^{***} - 0.008 * t^{***} - 0.239 * GDP^{*}_{t-1} + 1.045 * CPI^{***}_{t-1} \\ &+0.007 * PRIBOR_{t-1} + 0.122 * FxRate^{*}_{t-1} + 0.211 * GDP^{*}_{t-2} \\ &-0.166 * CPI^{**}_{t-2} - 0.003 * PRIBOR_{t-2} - 0.067 * FxRate_{t-2} \\ &+1.092 * CommodityIndex^{***}_t + 0.052 * EuroGDP_t \end{aligned}$$

Current value of the Consumer price index is significantly associated with lagged values of inflation, when much more important is the one period lagged inflation, which has a coefficient 1.045 meaning extraordinary strong dependence. The other important variables are lagged GDP, while one of them is negative (first lag, coefficient -0.239) and second (second lag, coefficient 0.211 is positive. If we combine them, we get slightly negative correlation between lagged GDP and current inflation. This is again in line with economic theory and intuition. Last but not leas, the increase in Commodity price index is, not surprisingly, associated with higher inflation.

$$
\begin{aligned}
PRIBOR_t = -0.808^{**} - 0.002 * t^{**} - 0.054 * GDP_{t-1} + 0.073 * CPI^{***}_{t-1} \\
+1.259 * PRIBOR^{***}_{t-1} - 0.02 * FxRate_{t-1} + 0.045 * GDP_{t-2} \\
-0.060 * CPI^{***}_{t-2} - 0.314 * PRIBOR^{***}_{t-2} + 0.033 * FxRate^{*}_{t-2} \\
+0.153 * CommodityIndex^{**}_t + 0.019 * EuroGDP^{**}_t
\end{aligned}
$$

PIROBOR value can be explained using lagged values of Consumer price index inflation, lagged PRIBOR and both external variables — European Commodity price index and GDP growth. We can also observe some relationship between foreign exchange rate and PRIBOR, however the only at lower significance level.

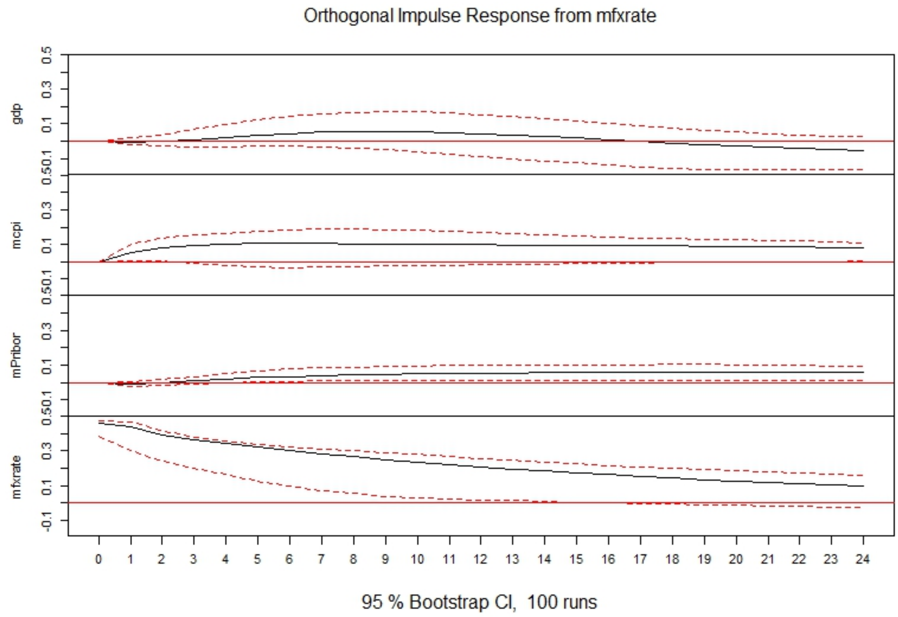
$$
\begin{aligned}
FXRate_t = -3.321^{**} + 0.003 * t - 0.039 * GDP_{t-1} - 0.219 * CPI^{***}_{t-1} \\
+0.633 * Pribor^{**}_{t-1} + 0.961 * FxRate^{***}_{t-1} + 0.051 * GDP_{t-2} \\
-0.168 * CPI^{**}_{t-2} - 0.573 * Pribor^{**}_{t-2} - 0.021 * FxRate_{t-2} \\
-0.418 * CommodityIndex_t + 0.00001 * EuroGDP_t
\end{aligned}
$$

Foreign exchange rate can be from 96% explained by own first lagged value. The exchange rate is also negatively correlated with both lags if CPI inflation. FX rate depends also on past observations of PRIBIR rate.

5.7.1 Impulse Response Function

Impulse responses trace out the responsiveness of the dependent variables in the VAR to shocks to each of the variables. So, for each variable from each equation separately, a unit shock is applied to the error, and the effects upon the VAR system over time are noted. (Brooks, 2008)

Figure 5.1: Impulse Response from VAR Model



The plot describes reponse of other variables on one unit shock in exchange rate depreciation. Impulses are modeled 24 periods ahead. Regarding impulse response to GDP we can observe small positive effect, which is in maximum 8 months delayed — observed between 3th and 16th month. Nevertheless, this effect is not statistically significant

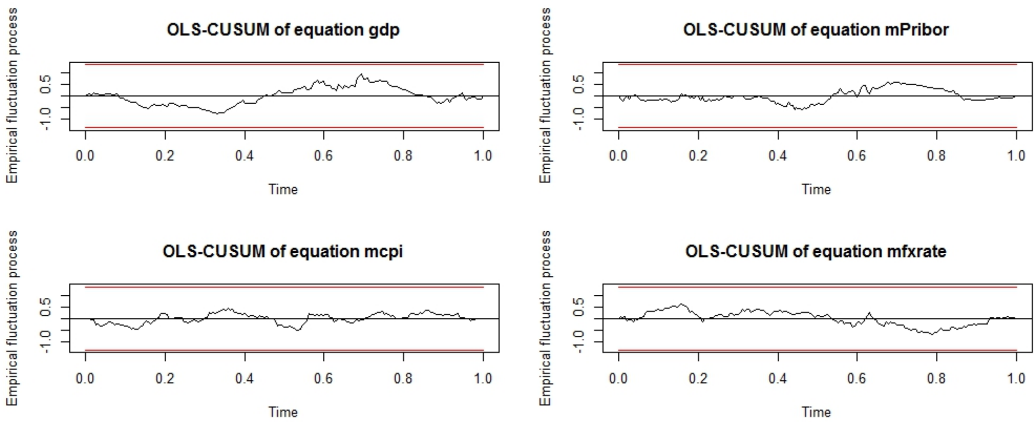
Impulse response of inflation is positive from beginning, reaching maximum after one quarter and then remain persistent. The effect is on the edge of significance on 95% level, however on 90% level it would be definitely significant.

5.8 Model Diagnostics

5.8.1 Stability test

The stability of the model is depicted through the reaction of the endogenous variables onto the exogenous shock. In the case if the process is stable, then shocks have a declining effect, which lasts for a relatively small amount of time, otherwise the process is not stable. If the process is integrated, then the effects of shocks never disappear and, finally, if the process is explosive, then shocks dramatically increase as the time passes.

Figure 5.2: Stability test

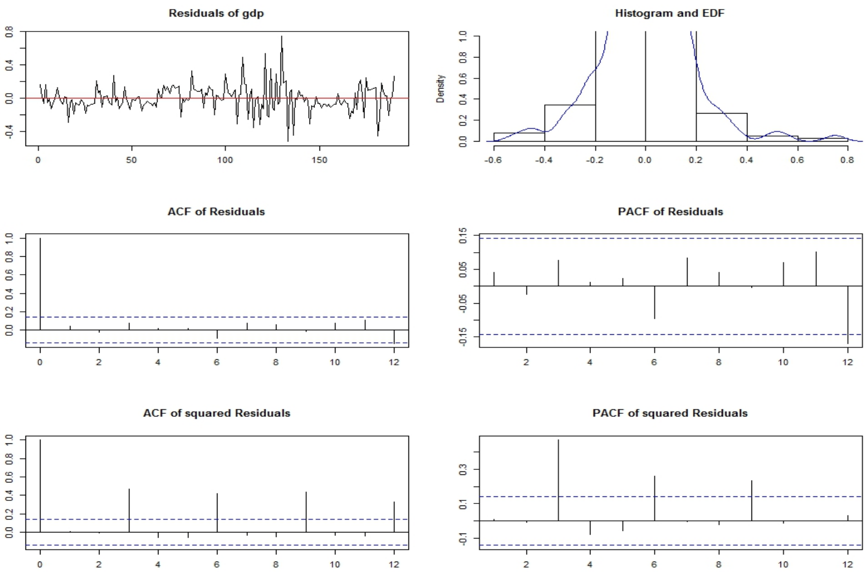


Parameter constancy throughout the sample period is a key assumptions in econometric models. Interpretation of this stability test is straightforward. Whether the depended variable fluctuation remains in the bandwidth (red color lines) we can say the model is stable. As we can see, all the variable lie within the lines, so we can not confirm there is not any instability in our model.

5.8.2 ARCH test

ARCH test and subsequent residuals analysis are provided within this section.

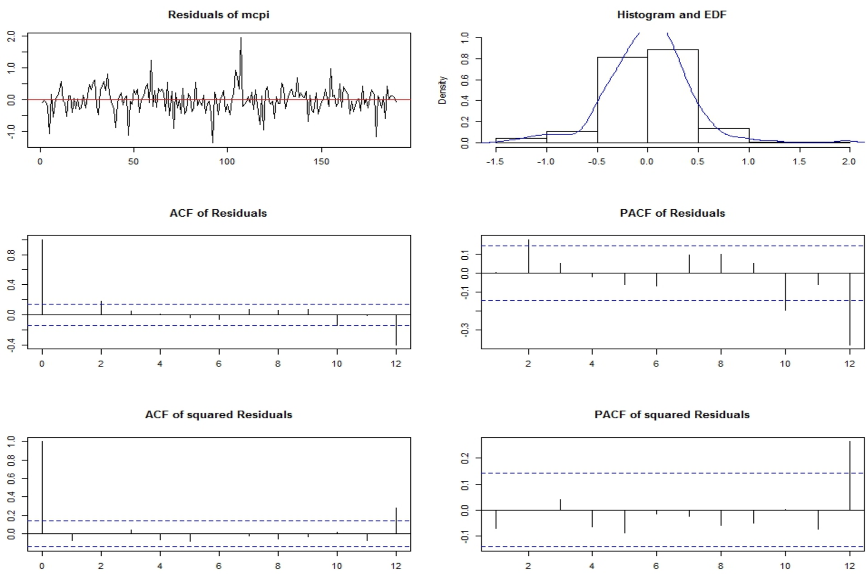
Figure 5.3: ARCH test GDP



In case of GDP our test imply that mean value of its residuals is around zero. On the other hand, standard deviation is not constant as we can observe volatility surge in second half of aour time series.

Regarding autocorrelation and partial autocorrelation function we do not find any linear dependence in the data. Only using square residuals, the lagged values of ACF and PACF are significantly different from zero.

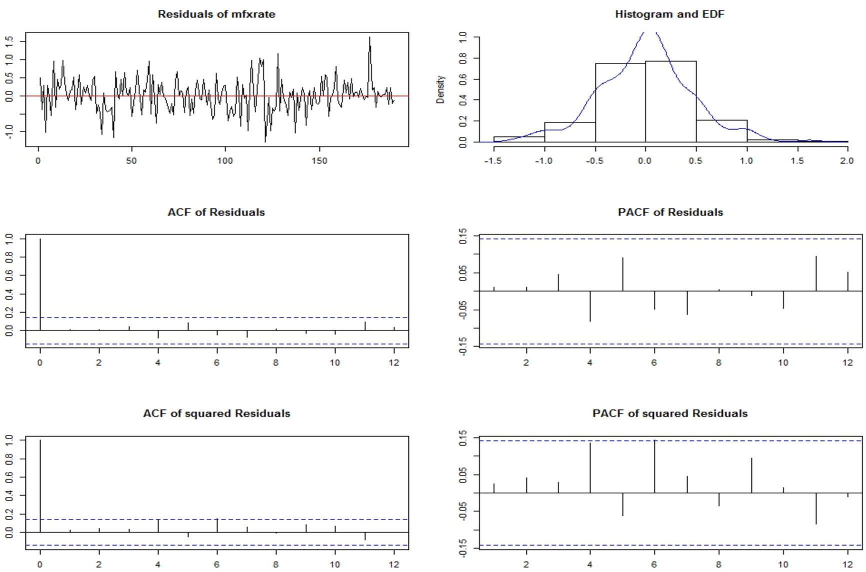
Figure 5.4: ARCH test CPI



Results of second test suggest that standard deviation of CPI residuals is constant over time with mean around zero. Distribution of residuals is similor to normal, but with higher curtosis.

Furthermore both ACF and PCF function for residuals and their squares are insignificant for lags 1-11. Our estimates imply only minor dependence in 12th lag.

Figure 5.5: ARCH test FX rate



For the FX rate our test shows the best result. The residuals are centered around zero with constant volatility. Again the distribuion is close to normal distribution, with higher curtosis. (leptocurtic distribution]

All ACF and PCF between lag 1-12 are absolutely insignificant.

5.9 Counterfactual Analysis

In the second part of VAR modeling we decided to conduct coounterfactual analysis, which could provide use interesting insight about effect of interventions.

Aim of this part is to predict VAR model using pre-intervention data ahead into future and compare with actual development. The trick is we predict from the last data before intervention, so we simulate alternative scenario which would happen in case there would not be any intervention. Then we can compare this prediction with real value of variables after intervention, which can show us the effects of intervention.

5.9.1 Model Specification

For purpose of contractual analysis we use still the same model as before:

Our estimated VAR model has the following specification

$$Y_t = C_t + \sum_{i=1}^{p} A_i Y_{t-i} + BX_t + e_t$$

where Y_t is the endogenous variables vector, C_t is the vector of constants (intercepts), e_t is a vector of residual terms (should be white noise], $A_i, ..., A_{i-p}$ are matrices that contains all the coefficients reflecting relationships between endogenous and exogenous variables, t is time and $i = 1, ..., p$ shows number of lags.

$$Y_t = [gdp_t, cpi_t, fx_t]$$

$$X_t = [gdpEur_t, CommodIndex_t]$$

The difference is, that now we have use only first 176 observations of all endogenous variables with aim to predict them 14 periods ahead (from October 2013 to December 2014). Also we get rid of PRIBOR variable. The reason is following. Including PRIBOR in the model would cause us problem in counterfactual prediction, because is will go below zero in predicted period and if would affect prediction of other variables. From this reason the best solution is not to use PRIBOR in the model.

In order to predict VAR we need the exogenous variables "prediction" - in this case we are able to use their actual value (we conduct ex post prediction for period in past).

5.9.2 Estimation Results

GDP scenario analysis provides surprising results. Actual GDP is actual higher then VAR prediction only few months after intervention. We would expect opposite - based on economics theory, expansionary monetary policy is usually associate with delayed accelerated GDP growth. However the opposite is true by our model. The explanation could be that currency depreciation increased future inflation expectation and this stimulated purchasing of (mainly) imported goods before price increase.

In the long term we are not able to observe effect of the intervention on GDP. One of the possible reasons could be a fact that monetary policy is not the only determinant of GDP growth. Economical power is more strongly affected with fiscal policies - stimulus policies, tax changes etc. And some of these coincide witch the currency intervention and thus it is difficult to separate effect and find some causality. The other determinant which influence GDP are EU subsidiaries, business cycle shift (end of recession and economical boom) and investors expectations. However, these variable are not possible to easily measure and include in our model. On the other hand the model was able to correctly capture future GDP trend. In our model it is explained mainly by external variables, especially GDP growth in the Euro area which strongly influence Czech economy.

Figure 5.6: GDP Scenario Analysis

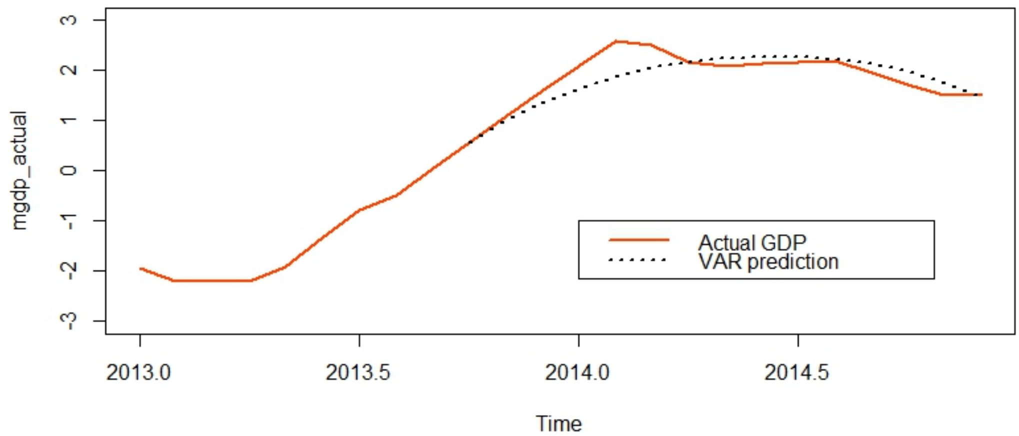
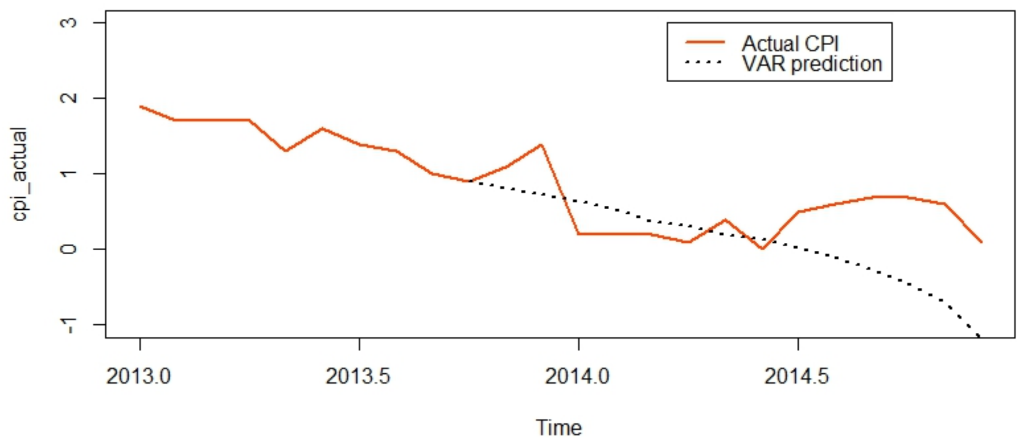


Figure 5.7: CPI Scenario Analysis



Scenario analysis for CPI inflation shows us more interesting insights. The prediction documents that in scenario without intervention the inflation would go below zero to -1 % value. This is in line with our expectations as well as witch CNB estimates.

Thus our result suggest, the intervention was successful in preventing the deflation and keeping inflation levels above zero.

5.9.3 Model Diagnostic

Diagnostic of the models can be conduct by two methods. Firstly we can use confidence intervals of our prediction, to test significance of our results...

5.9.4 Interpretation of Results

After estimating contractual analysis we can conclude that positive effect on GDP was observable shortly after the intervention, which was probably driven by stimulation of consumer goods purchases due expectation of future inflation. Another interesting fact is that due interconnection of Czech and Euro area economies we are able to predict future upsurge of domestic GDP from European macro variables.

Regarding inflation our expectations are supported with the model, and the intervention made approximately one percentage point difference in inflation.

Chapter 6

Conclusion

Based on literature consensus, unconventional measures are needed to overcome a zero lower bound problem. The best tool for large economies is a quantitative easing while for a small open economy the foreign exchange intervention is considered by many economists as the most convenient solution . Aim of this thesis is to comprehensively assess the effects of the intervention mainly in Czech Republic and compare it with Switzerland. This empirical study is composed from two parts — GARCH modeling to capture volatility changes and VAR models to estimate effect on GDP and inflation.

After conducting volatility modeling using GARCH, we can conclude the intervention in both countries resulted in temporary volatility decrease, which was several months delayed after the beginning of intervention. In Czech Republic volatility increased again to pre-intervention level since August 2014, when Czech National Bank inform it will hold their commitment at least till 2016. Generally lower volatility is beneficial for companies involved in international trade. However, this was complicated by the fact, that most of companies were hedged so we can hardly estimate the effect of volatility change on real economy.

The second part of empirical analysis involves vector autoregressive modeling. Simple VAR-X model with 6 variables and provide with some interesting insights. We can prove the intervention had statistically significant effect on inflation. Based on scenario analysis we can conclude that without intervention, we would and up in 1 % deflation in late 2014. This is also the only significant result of VAR modeling. We are not able to prove any significant effect on GDP. The reason is that it is influenced by many other factors, not only monetary policy.

Finally we can say the intervention in Czech Republic fulfilled its main aim — prevent the economy from entering the deflation and help the central bank to get closer to their inflation target. Regarding effect on real economy there are mainly short term effects and at the moment we are not able to find proof of long term positive effects. However there is still place for future research with more recent or different methods, which can provide us with new important insights and results.

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