Charles University in Prague

Faculty of Social Sciences
Institute of Economic Studies

MASTER'S THESIS

(How) Does low inflation in euro area affect inflation in the Czech Republic?

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Declaration of Authorship

I hereby declare that I compiled this thesis independently, using only the listed resources and literature.

I also declare that the thesis has not been used to obtain a different or the same degree.

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Prague, July 31, 2016

Vladimír Veselý

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Abstract

The goal of this thesis is to identify domestic and foreign shocks that mostly explain variation in the Czech price level. This goal is accomplished by the use of structural vector autoregression. As the Czech Republic is considered to be a small open economy, it is crucial to include foreign variables into the model which are represented by shocks in euro zone. Furthermore, a block exogeneity restriction is imposed because it is unlikely that shocks in the Czech economy can influence macroeconomic development in euro zone. The results of the thesis indicate that foreign shocks explain 70% variability in Czech price level out of which 50% is explained by euro zone's price level shocks. It is likely that in near future Czech economy will experience deflation for a while. Nevertheless, by 2018 Czech inflation rate should be in 1-3% band.

JEL Classification	F41, E3, E52
Keywords	Structural vector autoregression, block restriction, small open economy, monetary transmission mechanism, external shocks

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Abstrakt

Cílem diplomové práce je identifikovat domácí a zahraniční šoky, které nejvíce ovlivňují fluktuaci české cenové hladiny. Tohoto cíle je dosaženo za pomoci strukturální vektorové autoregrese. Jelikož je Česká republika považována za malou otevřenou ekonomiku je nutné do modelu zahrnout zahraniční šoky, které jsou reprezentovány šoky v eurozóně. Protože je zároveň nepravděpodobné, že by šoky v domácí ekonomice mohly ovlivnit makroekonomický vývoj v eurozóně, je do modelu zahrnuta bloková restrikce. Tato práce indikuje, že zahraniční šoky vysvětlují ze 70% pohyb české cenové hladiny, z čehož 50% je vysvětleno šoky cenové hladiny v eurozóně. V blízké budoucnosti lze očekávat, že se česká ekonomika dostane do deflace, avšak od roku 2018 by se měla inflace pohybovat v pásmu 1-3%.

Klasifikace	F41, E3, E52
Klíčová slova	Strukturální vektorová autoregrese, bloková restrikce, malá otevřená ekonomika, monetární transmisivní mechanism, externí šoky

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Acronyms

AIC	Akaike information criterion
ACF	Autocorrelation function
ADF	Augmented Dicky-Fuller
BVAR	Bayesian vector autoregression
CEE	Central and Eastern Europe
CEE	Central and Eastern Europe
CNB	Czech National Bank
CPI	Consumer price index
CZE	Czech Republic
EA	Euro area
EMU	Economic and Monetary Union
EONIA	Euro OverNight Index Average
ERPT	Exchange rate pass-through
EURIBOR	Euro InterBank Offered Rate
FAVAR	Factor-augmented vector autoregression
FRA	Forward rate agreement
GDP	Gross domestic product
HICP	Harmonised index of consumer prices
HQC	Hannah-Quinn Criterion
IS/AD	Investment and Savings/Aggregate Demand
LDC	Least developed countries
MTM	Monetary transmission mechanism
nid	Normally and independently distributed
OECD	Organiyation for Economic Co-operation and Development
PACF	Partial autocorrelation function
PRIBOR	Prague InterBank Offered Rate
SC	Schwarz criterion
SVAR	Structural vector autoregression

US	United States
VAR	Vector autoregression

Master's Thesis Proposal

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Proposed Topic:

(How) Does low inflation in euro area affect inflation in the Czech Republic?

Topic Characteristics:

Inflation is defined as a sustained increase in the general price level of goods and services in the economy over a certain period. Although high inflation has a negative effect on the economy as money loses their fair value, negative inflation (deflation) is also not welcome as people tend to hold cash balances and the economy slows down. In the situation when nominal interest rate is very low and deflation occurs central bank can lose its opportunity to influence its real output and inflation. In this manner it may be even less acceptable than high inflation (e.g. Japan) because central bank can lose its main tool for influencing inflation. Moderate and stable inflation is considered as an optimal inflation.

There is much evidence that usually inflation in developed countries is currently moderate and stable. And it is not surprising that inflation in recent decades shifts from country specific phenomenon to global specific phenomenon due to globalization. For instance Neely C. J. and D.E. Rapach (2011) point out that international influences together explain just over half of inflation variability.

Currently, in the aftermath of the financial crisis, moderate inflation in the euro area has been approaching zero boundary and several times it has appeared under this threshold. Consequently, even in the Czech Republic, inflation has declined. Therefore, this study will focus on the factors influencing Czech inflation and whether low inflation in the euro area spills over to the Czech Republic.

Hypotheses:

Hypothesis #1: Is inflation in the Czech Republic influenced particularly by shocks from abroad?

Hypothesis #2: Does low inflation in euro area affect Czech inflation and do we face a deflationary trap?

Hypothesis #3: How long does it take for inflation shock in the eurozone to spread in the Czech Republic?

Methodology:

In order to assess whether there exists a co-movement in inflation between the Czech Republic and euro area, a structural VAR model will be performed. The model will be based on New-Keynesian model of a small open economy and will include variables such as Czech and euro area price level, short-term interest rates, GDP and exchange rate. All variables and model selection will be tested according to standard statistical tests. Moreover, as intuition and other researches on the similar subject suggest Czech Republic is a small economy and it is unlikely that a shock in the Czech economy would have a significant effect on euro area. That is why a block exogeneity restriction will be performed. The model estimation results will be summarized according to impulse responses and variance decomposition.

Expected Contribution:

The primary monetary objective of the Czech National Bank is price stability and this is achieved by pursuing inflation target. In order to set monetary instruments correctly, the central bank has to know what impact they will have on inflation. However, some factors that have impact on inflation cannot be controlled by central bank and that is why it is crucial to estimate how big influence they will have. In this study these factors will try to be revealed.

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Author **Supervisor**

1 Introduction

Inflation is defined as a sustained increase in the general price level of goods and services in the economy over a certain period. Although high inflation has a negative effect on the economy as money loses their fair value, negative inflation (deflation) is also not welcome as people tend to hold cash balances and the economy slows down. In the situation when nominal interest rate is very low and deflation occurs central bank can lose its opportunity to influence its real output and inflation. In this manner it may be even less acceptable than high inflation (e.g. Japan at the beginning of 21st century) because central bank can lose its main tool for influencing inflation. Moderate and stable inflation is considered as an optimal inflation. The following quote summarize it all.

"Thus inflation is unjust and deflation is inexpedient. Of the two perhaps deflation is, if we rule out exaggerated inflations such as that of Germany, the worse; because it is worse, in an impoverished world, to provoke unemployment than to disappoint the rentier. But it is necessary that we should weigh one evil against the other. It is easier to agree that both are evils to be shunned." John Maynard Keynes (1923)

Even though second half of 20th century worldwide was more linked with periods of high inflation, current situation is the case of rather low inflation or even deflation in euro zone and the Czech Republic. Deflation itself is not a big threat for economy when it lasts for a while. The problem arises when the monetary policy is not adjusted by central bankers when the economy starts to show signs of deflation and the deflation settles in the economy. That is why it is of utmost importance for central banks to correctly assess inflation development to know what influences domestic inflation and how they can change inflation rate through the monetary transmission mechanism.

In assessing monetary transmission mechanism, vector autoregressive (VAR) models turned out to be very helpful and broadly used in the empirical papers. For small open economies, taking into account foreign variables seems to be crucial and thus a block exogeneity restriction is usually imposed. This appears to be the case of the Czech Republic as it stands at 14th place in the world openness and its exports and imports constitute 83.8% of GDP, 77.1% respectively. As the main trading partner is euro area, the foreign variables are represented by euro area's variables.

Although, some studies have been already coping with Czech monetary transmission mechanism with the help of VAR models in the past, recent literature is rather scarce. Vast majority of empirical papers on Czech economy have focused on data up to global financial crisis and the most recent studies have covered only data up to 2012, to my knowledge. Statistically, a larger and newer dataset is always welcome as it yields more reliable outcomes. Moreover, most studies disregard the fact that global financial crisis could have changed functioning of monetary transmission mechanism and therefore, their results could be biased in this matter. Our findings indeed prove so and thus, the dataset is split into two sub-samples that cover pre-crisis and post-crisis period. According to models, Czech price level seems to be much more affected by foreign shock in post-crisis period and the monetary transmission mechanism appears to be less significant in this period. Our prediction goes in line with Czech National Bank's prediction where the inflation rate is at first expected to drop into negative numbers for few months but by 2018 it should be back in 1-3% band.

The thesis is structured as follows. Second section presents the literature regarding at first VAR modelling, literature that covers Central and Eastern Europe (CEE) economies and lastly the Czech Republic. In third and fourth chapter, theoretical model is derived which will further be used as a basis for determination of variables for VAR models. Next section focuses on derivation of structural vector autoregressive (SVAR) model based on which final outcomes are estimated. Sixth and seventh chapter reveals information about the dataset and models' outcomes. In chapters eight and nine outcomes are discussed and compared with relevant literature and policy implications are derived. In the last chapter concluding remarks are formed.

2 Literature review

In this chapter a literature overview is provided about macroeconomic comovements mostly in Central and Eastern Europe (CEE) and about econometric concept that is used for the purpose of this thesis. The focus will be particularly on a vector autoregressive (VAR) modelling, small economies and the assessment.

2.1. VAR model

Sims (1980) pointed out in his paper Macroeconomics and Reality the shortcomings of the macroeconomic models that study business cycles (multivariate simultaneous models were very popular) at that time. He mainly referred to the identification problem which in his thoughts was too complex. In his work, he mentions that another drawback of sophisticated multivariate simultaneous models is including too many variables. As empirical evidence shows including too many variables usually does not improve the forecasting power of the model. Another explanation can be that large multivariate simultaneous models do not allow for dynamic interactions among variables. Hence, he comes with VAR models that treat variables only as endogenous variables and recommends the use of its impulse responses for policy analysis.

One of the earliest studies that deals with the impact of large economies on small economies was published by Dornbusch (1985). The motivation behind the research was a puzzle that arose in 1984 as least developed countries (LDC) across the world recorded significantly different economic developments. While Asian LDCs recorded positive economic development, LDCs in Latin America were dipped in negative figures. These facts led him to investigate how different combinations of interest rate, inflation, and OECD growth had impacted on a particular LDC.

VAR modelling became widely popular mainly in late 1990s when most of the studies were focused on macroeconomic comovements between countries regarding United States, OECD countries and least developed countries. Soon, but rather already in new millennium, this useful methodology was spread into Europe. Among the earliest and most known studies that deal with macroeconomic comovements in small open economies using VAR modelling belong following papers.

Cushman and Zha (1997) study the monetary policy in Canada with the help of vector autoregressive (VAR) models. In their paper they emphasize that previous studies do

not assess monetary policy impacts precisely as they do not account for external factors explicitly. As monetary policy in Canada is most likely to be influenced by foreign factors as well as by domestic ones they include both foreign and home factors into the model. Furthermore, they study impact of the US economy, which is represented in this study as "the rest of the world", on Canadian economy. As they argue that shock in Canadian economy has little effect on US economy, they treat Canada as a small open economy and US macroeconomic variables as exogenous from Canadian's perspective. This is known as block exogeneity restriction. Among home variables they consider exchange rate, money supply, short term Treasury bill rate, consumer price index (CPI), industrial production and net export with the US. US industrial production, US CPI, US federal fund rate and world commodity price index then represent foreign variables. They conclude the reaction of monetary policy to external shocks is in most cases in line with economic theory. The overall conclusion is that the exchange rate plays a very significant role for the transmission of foreign shocks and domestic monetary policy and that external factors are key drivers of the economic activity variance in Canada.

Stock and Watson (2001) remind us of the key four tasks that true macro econometricians have to carry out. They name: *"description and summary of macroeconomic data, macroeconomic forecasts, quantification of what we do or do not know about the true structure of the macroeconomy, and to advise (and sometimes become) macroeconomic policymaker."* Consequently, they assess how VAR models help econometricians to carry out their roles. The general answer would be it depends. With respect to the first two mentioned tasks, data description and forecasting, VAR model proves to be reliable and powerful method that is more or less in everyday use. Speaking of structural inference and policy analysis, a straight conclusion as in previous cases cannot be derived. Rather institutional knowledge and economic theory should be used over pure econometric analysis as the identification issue is present here.

Paper from Negro and Homs (2000) follow Cushman's and Zha's econometric concept from 1997 as structural VAR (SVAR) is conducted in order to identify impact of domestic and foreign shocks on Mexican economy, which represents the home economy. They find that exogenous shocks have little impact on prices and real activity and that business cycles in the US economy significantly influence Mexican economy.

Canova (2005) questions which transmission mechanisms are present in the least developed countries regarding the business fluctuation in US economy. Knowing these features would be helpful in determining, for instance, whether shortage in monetary

interdependence would cause disparities leading to abandonment of the currency board regime. For his study, he chooses 8 Latin American countries with relatively different features and investigates the transmissions of US shocks to these countries. He concludes that monetary shocks in the US reveal high variation in Latin America, on the other hand supply demand shocks do not seem to cause any fluctuation. Also financial transmission channel seems to be of a big importance and US disturbances describe a significant part of variability in Latin American variables.

Kim and Roubini (2000) come with macroeconomic anomalies that had been found in numerous studies where researchers were using VAR models for either closed or open economies. Therefore, the performance of VAR models was in doubt. Among the most known and discussed puzzles that have been discussed by Kim and Roubini belong:

- The liquidity puzzle – according to regular economic theories in the short run there should be a negative relationship between nominal interest rate and monetary aggregates. Nevertheless, the liquidity puzzle is associated with an increase in nominal interest rate after the occurrence of a shock in monetary aggregate. This puzzle was noted for example by Leeper and Gordon (1991). In reaction, Sims (1992) finds the liquidity puzzle when there is a sign of money demand shock. If this is the case, he suggests using rather short term interest rates as a proxy for monetary policy in modelling. On the other hand, later on there were responses (see for instance Eichenbaum and Evans (1995)) that this solution causes the prize puzzle and propose solution of using narrow monetary aggregates as a representant of a monetary policy.

- The price puzzle – similarly, a monetary tightening should be accompanied by decrease in output and price level. But for instance Sims (1992) found an evidence of opposite relationship which indicated the presence of the price puzzle. In addition to the solution proposed by Eichenbaum and Evans under the liquidity puzzle, Sims says that some part of interest rate increase may be due to using nominal interest rate where some movements are explained by inflation itself. This explanation can also be used for explaining the exchange rate puzzle. As a solution Sims and Zha (1995) suggest using structural VAR models and instead of employing recursive identification scheme they come with contemporaneous restriction that adds proxies for expected inflation.

- The exchange rate puzzle – Eichenbaum and Evans (1995) found in their research interesting finding that after an interest rate shock in the US the exchange rate with other G7 currencies will result in appreciation of US dollar. Whereas, according to studies of Grilli and Roubini (1995) and Sims (1992) the

same shock in interest rate in non-US G7 countries leads in depreciation of their currencies with respect to US dollar. Grilli and Roubinin solved the puzzle by unrestricted VAR model with proxy for expected inflation and the model shows promising outcomes in most countries, however, this solution come with some shortcomings. Firstly, attention needs to be paid to VAR ordering and secondly, there are signs of delayed overshooting in the cases when the macroeconomic relationships are in order in the model. Kim and Roubini (2000) follow the ideas of Sims (1992) and Grilli and Roubini (1995) and conclude that once price puzzle is solved, the exchange rate one is as well.

- The forward discount rate puzzle – under the conditions of capital mobility and perfect substitutability when uncovered interest rate parity holds, a positive shock in interest rate of domestic country (positive interest rate differential) leads to depreciation of the domestic currency. Although some empirical studies show otherwise in the period of up to 2 years after the monetary impulse. Following the model by Kim and Roubini (2000) where they manage to control for the rest of puzzles, they also achieve to lower significantly the occurrence of the forward discount rate puzzle and the so called delayed overshooting.

2.2. Relevant CEE literature

One of the earlier studies dealing with Central and Eastern Europe countries (CEE) with the VAR model was published by Maćkowiak (2005). More specifically, he brings results from impulse response analysis and error variance decomposition for three CEE transition countries – Czech Republic, Hungary and Poland. At first, he argues whether chosen CEE countries are small and open in order to use exogeneity restriction. He finds out they are and proceeds further. External shocks in this study can be brought from European Union, which is represented by German macroeconomic variables and world. He includes only main macroeconomic variables in the model – real aggregate output and price level for domestic countries; the same ones plus interest rate for Germany, an index of export prices of nonfuel primary commodities and the price of crude oil for the world. In the long run he finds that 60 to 80% of variability in the aggregate price level, respectively 25 - 50% in output, are explained by external shocks. A significant portion of that takes interest rate shock on CEE output (50%).

Jarocinski (2005) further deals with a comparison of monetary transmission mechanism between Western and Eastern European countries. More precisely he studies impact of monetary policy shock in Economic and Monetary Union countries

(EMU) and new member states countries at that time. For the purpose of comparison some countries were omitted from both groups which were not taken as representative.[1] The model includes standard set of domestic variables and three external variables – Federal Funds Rate, oil prices and non-fuel commodity prices. Due to the lack of observations VAR model is estimated by using Bayesian estimation framework and it uses identification schemes that omits instant effect of the output and prices to the interest rate shock and contemporaneously it states the appreciation is immediately followed by interest rate hike. The overall conclusion is that impulse responses to the domestic monetary shock are pretty much similar within each group. More lagged and stronger responses are however found among new member states as it was expected.

Before Slovakia joined euro area (EA) in 2009, it was important for Slovakia to assess how the EA's economy affects Slovak economy. Horvath and Rusnak (2009) come with a study revealing these relations. For this purpose, they run VAR model with block exogeneity restriction and with the use of Cholesky recursive scheme. As Maćkowiak (2005) argues CEE countries are usually small and open which also holds in Slovakia. Therefore, Horvath and Rusnak treat in SVAR model Slovak Republic as a small open economy and look for relation with European economy, which is not represented only by Germany itself as in Maćkowiak (2005). The selection of variables follows a New Keynesian model, which in general is derived from IS-LM model and Phillips curve and as they deal with an open economy they can augment the model for international variables. Hence, the model accounts for domestic and euro area's output gaps, price levels, interest rates and exchange rate. Their results are similar as Maćkowiak's, the price level is mainly influenced by external factors and EA monetary policy has a greater effect on price level than Slovak monetary policy. Slovak interest rate is found to follow EURIBOR. According to variance decomposition, Slovak economic activity is, however, mainly described by domestic factors. In comparison with Borys and Horvath (2008) and therefore Czech economy, the impact of domestic monetary shock on price level shows faster response (minimum in about 6 months). Exchange rate similarly appreciates and bottoms out after 3 months and reaction of GDP gap is very insignificant. Studying European Central Bank's monetary contraction, it leads to a drop in inflation in Slovakia reaching the minimum after 6 months, however, Slovak output gap experiences peaking in year or so that is partly described due to the

[1] EMU countries sample consit of 5 countries – Finland, France, Germany, Italy and Spain. On the other hand, Czech Republic, Hungary, Poland and Slovania form the group of counties that represents new member states.

depreciation of the exchange rate from the Slovak side. Moreover, they mention that using output gap instead of GDP itself helps to minimize price puzzle.

Krznar and Kunovac (2010) examine mainly the importance of foreign shocks in Croatia. Foreign shocks are represented by European Union's output and world's prices. They stress the importance of stationary data and thus, transform data by first differencing. Moreover, they do not consider lag length based on any info criteria but they rather use lag length of 1. Surprisingly, they do not include any interest rates in the model as they claim that for instance EURIBOR and EU's output constitute the same. Foreign external shocks (mainly world prices) describe around 43% variation in Croatia price level. With respect to impulse responses, the responses usually show growing tendency for 9 quarters (the whole observed period) which brings the question of stability of the model.

Andrle et al (2013) deal with the impact of external and domestic shocks on Polish economy with the use of trend cycle VAR model. They treat Poland as a small open economy despite its dimension and euro area as a closed economy. They stress the importance of using stationary data rather than data in log levels. They also argue that differencing data in order to make them stationary is also inconsistent approach as a lot of information is lost this way and results in high frequency dynamics. They conduct models on quarterly data ranging from 1999 till 2012. The dataset contains standard set of variables – interest rates, inflation rates, outputs and exchange rate. They conclude that 50% of variability in Polish GDP and interest rate is explained by external factors and about 25% of inflation variability is explained by external shocks. Furthermore, they find out that inflation and output react negatively to monetary tightening and biggest response is after 3 quarters and 4 quarters respectively. No signs of puzzles are found. Even though, they provide us with impulse responses of monetary transmission mechanism, they do not put much weight on the responses as they argue that impulse of monetary policy to different kinds of shock is what is of interest and not vice versa.

Krusper (2012) studies to what extent common and regional factors influence inflation in CEE countries. Common factors in this sense mean European components and regional – CEE components. According to Krusper variation in Czech inflation is described mainly by common components (45%), then regional (35%) and only 20% is explained by idiosyncratic components. Hungary, Poland and Romania, on contrary, show that for their price level the development of CEE inflation rates is of utmost importance.

Last year Nalban (2015) published study regarding finding optimal number of variables in BVAR model when modelling monetary transmission mechanism. Best set of variables is picked according to its forecasting accuracy and models are run on Romanian dataset with inclusion of EA's variables as external ones. The outcomes vary when different forecasts are performed but in general it seems that set of 7 variables do the best. Monetary shock in that case results in increase of GDP (max after 22 months), decrease in consumer price index (min after 13 months) and depreciation (max after 5 months). He stresses the fact that best predictive model unfortunately does not comply with economic theory (output's positive response to monetary tightening or exchange rate puzzle).

2.3. Relevant Czech literature

Arnostova and Hurnik (2005) discuss the importance of knowing the monetary transmission channel and as they find VAR models as most used ones in the Czech Republic they study the impact of exogenous shock to domestic monetary policy by VAR methodology. Nevertheless, the outcomes have to be interpreted with caution because the data sample is rather small to deduce clear conclusion. They have a quarterly data span covering period of 10 years, although, there was change in a monetary policy regime in 1998. Due to this fact they conduct 2 models, one that covers the whole period and the other one that covers period 1998-2004. In the model domestic variables (real GDP, net inflation price index, the commodity price index, nominal short-term interest rate, exchange rate with Euro and domestic money shock) form a vector of endogenous variables and further there is a vector of exogenous variables that contains only one variable and that is German GDP. In terms of identification, two possibilities arise in their study. One that follows the solution to puzzles under Kim and Roubini (2000) by using non-recursive scheme and where they allow for contemporaneous relationship between interest rate and exchange rate. The second one is using recursive assumption and facing the puzzles. The downturn of using non-recursive is that we get rid of contemporaneous effect of price level and output. This in case of the Czech Republic and in its inflation targeting regime seems problematic. That is why Arnostova and Hurnik go along with the recursive scheme and believe that missing contemporaneous effect to exchange rate does not essentially mean any big mistake. The short sample model yields following results. After a shock in interest rate, output tends to decrease and reaches its peak after 4 periods. Price level exhibits similar outcomes but reaches its minimum after a year and a half. Exchange rate shows instant appreciation and then it gradually depreciates.

Borys and Horvath (2008) examine the monetary transmission mechanism in the Czech economy by using regular VAR framework, SVAR and factor-augmented VAR (FAVAR) structure. As a set of domestic variables they introduce real output gap, net price index[2], 3 months PRIBOR and nominal exchange rate with Euro. The foreign variables are formed of 3 months EURIBOR, commodity price index, forward rate agreement (9*12 FRA). In both sets, variables are used in order they are given above. Even though most researchers use quarterly data they decide to go for monthly in order to have a bigger sample size which now accounts for a period 1998 - 2006. First, they run regular VAR model on only domestic data as they assume that external shocks have impact on Czech economy only through the exchange rate. By doing so, their results show that after a monetary contraction price level and output seem to drop and bottom out after about a year and 4 months respectively. Exchange rate drops immediately and then there are signs of delayed overshooting as it starts to depreciate. Nevertheless, they do not find any pattern of price puzzle and delayed overshooting can be explained by uncovered interest rate parity. Second model, SVAR, takes rather non-recursive framework when it allows for contemporaneous effect between monetary policy and exchange rate and at the same time they do not consider contemporaneous price. Nevertheless, this model does not seem to bring much of additional information. Rather, it shows more or less similar outcomes with much greater confidence interval and thus, the model is less reliable. In the study they also exchange in the model price level for non-tradable price index and tradeable price index and conclude that tradeable goods adjust their prices faster than nontradeable goods. Moreover, they provide evidence that using GDP gap instead of just GDP yields more precise outcomes even though, GDP gap is unknown and has to be estimated. Furthermore, logarithmic form of used variables are employed.

Babecka-Kucharcukova (2009) re-measures exchange rate pass-through (ERPT) in the Czech Republic by applying VAR model. In the previous studies it was found that in the short run there is not much evidence of ERPT but in long run ERPT accounts up to 40%. Babecka-Kucharcukova comes to the results that ERPT appears in the domestic prices relatively quickly. Most of the ERPT appears in 3 months and the rest in another 3 months. Nevertheless, the impact of ERPT seems to be rather smaller (30%). This is argued that it is due to a change in monetary policy regime. Czech Republic turned to inflation targeting and in general this yields lower ERPT. Data in this study were gathered for a period from January 1991 till September 2009.

[2] Consumer price index excluding regulated prices.

Havranek and Rusnak (2009) do not make their own model but conduct meta-analysis about monetary transmission mechanism functioning in developed and post-transition countries. In order to do so they gather 67 studies regarding this topic and the utmost importance lies in the length of the period during which biggest response of price level to monetary shock is recorded. They claim that developed economies experience in general longer transmission lags and average values should be found in an interval ranging from 25 up to 50 months. Post-transition economies are found to experience lags between 10 and 20 months. The reasoning behind this might be that that economies with more developed financial markets seem to experience longer lags. As for Czech monetary transmission mechanism (MTM), the average is found to be 14.8 months. Moreover, the use of monthly data instead of quarterly show signs of faster MTM, according to the study by 4 months.

Havranek et al (2010) investigates monetary policy transmission mechanism in the Czech Republic by using recursive VAR model with block exogeneity restriction. In their research they investigate two models: one that contains only macroeconomic variables and follows the previous literature and a second one where they add financial variables into the model. Among macroeconomic variables they use economic activity, aggregate price level, interest rate and exchange rate for the Czech Republic and the same ones except for exchange rate for euro area. They apply both models on a monthly data ranging from January 1999 till September 2009. As Czech GDP data are published only once per 3 months, monthly data are determined by quadratic match method interpolation. Firstly, they conduct a model with only macroeconomic variables and then they are compared to models with various financial variables (credit, liquidity, loan loss provisions, and non-performing loans and PX index). The fundamental outcome compares forecasting performance of various models based on in-sample-data on out-sample data. In order to do so, the in-sample-data are bounded by following three possibilities – 8M 2006, 8M 2007, and 8M 2008 and the forecast horizon is one year. With regards to impulse responses, after a monetary tightening, economic activity gradually decreases and bottom out after approximately a year, the same is true for inflation except it bottoms out after 18 months. In addition, the evaluation of comparison between two models is somehow mixed, though. In most period financial variables shows an improvement in forecasting, however, performance of individual financial variables fluctuates in different time periods.

Babecka-Kucharcukova et al (2013) focus on studying three different transmission channels – the monetary policy channel, the exchange rate channel, and moreover, the asset price channel, by using three different types of VAR models – standard VAR model with Cholesky decomposition, Bayesian VAR, and time-varying parameter

VAR. Second goal is to determine whether transmission channels have experienced some structural changes during financial crisis. The data available at the time of the research allow for studying period from mid 1990s till 2010. BVAR is conducted on monthly data while the others use quarterly data. Variables included in VAR model are real GDP for Czech Republic and EA, Czech and world CPI, 3M PRIBOR and EONIA, nominal effective exchange rate and M2 aggregate. Variables beside interest rates are used in logarithmic forms. Their findings conclude that their estimates more or less comply with other studies and confirm good working monetary transmission mechanism. Nevertheless, results show that according to BVAR, monetary tightening has an impact on inflation after a year, whereas in VAR it is after a year and a half. Other outcomes suggest that MTM slowed down during the crisis period but also show signs that it is on its way to pre-crisis functioning.

One of the newest studies dealing with MTM in the Czech Republic is a study published by Koerner (2015). His paper investigates the MTM via three models – VAR, SVAR and SVECM. The dataset spans, however, only until 2011. Variables included are real GDP, CPI, real money supply and PRIBOR. In his models he does not consider any external variables, though. He takes a different attitude when handeling data stationarity. In most studies authors prefer using non-stationary data over the loss of additional data when the data are transformed. Koerner claims that consistency is necessary and transform data by demean-remean method when needed. He finds that output reaches minimum after 9 months after an interest rate shock and inflation bottoms out after 3 months, respectively. Nevertheless, author claims that the fast inflation reaction is due to the high trust of Czech National Bank's inflation expectations. Furthermore, he does not find any price puzzle in the model.

2.4. Czech national bank's forecast

Ultimately, Czech National Bank's stance towards inflation forecast has to be taken into consideration. As CNB's primary target is price stability and one of its ways it can influence inflation is by publicly claiming the inflation forecast, it publishes periodically its forecast. The newest forecast was published in May 2016 by CNB. Generally, this forecast is based on models and experts view especially in short term. Main assumptions taken into account when creating this forecast are that fiscal policy should be rather neutral, the unconvential measures conducted by European Central Bank in the form of quantitative easing are said to remain in place until March next year, and the exchange rate commitment is expected to be released in mid 2017. After the release, it is expected that Czech crown will appreciate but rather continuously to the pre-commitment level than sharply.

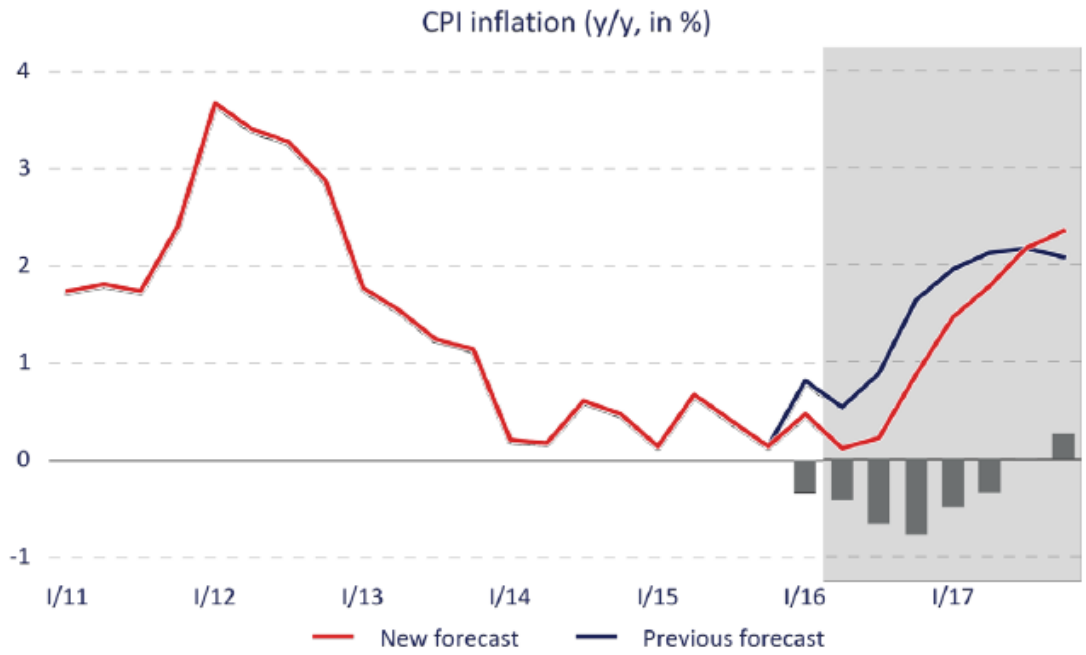


Figure 1: Czech CPI forecast
Source: CNB's inflation report/II 2016

In figure 1 CNB's CPI forecast is present together with their old one. From the first view it is clear that CNB struggles more to achieve or to get close to their inflation target than they have thought. This is particularly due to the fact that foreign price level remains low and output growth has slowed down even though it is still experiencing a good pace.

3 Small open economy

Czech Republic can be generally characterized by relatively small internal market, high level of industrial development and its possession of non-complex wealth of natural resources. Taking into account mainly these features plus its location in the center of Europe, it has all prerequisites to show high degree of openness to the outside world.

"As it is the power of exchanging that gives occasion to the division of labour, so the extent of this division must always be limited by the extent of that power, or, in other words, by the extent of the market. When the market is very small, no person can have any encouragement to dedicate himself entirely to one employment, for want of the power to exchange all that surplus part of the produce of his own labour, which is over and above his own consumption, for such parts of the produce of other men's labour as he has occasion for." Adam Smith (1776)

Economic openness is usually measured by the so called openness index. Openness index is composed of sum of export and import divided by gross domestic product of individual economies. Hence, index can be very easily obtained by knowing basic economic indicators and trade balance or the index itself is usually published by national authorities. Worldbank keeps such statistics of 197 countries or other politico-economic unions in their database. According to the database Czech Republic ranks at 14th place and therefore belongs to the most open economies in the world.

Table 1: Openness index (2014)

Ranking	Country Name	Openness index (%)
1	Hong Kong	439.2
2	Luxembourg	374.1
3	Singapore	350.9
4	Ireland	209.1
5	Maldives	197.6
6	Seychelles	181.3
7	Slovak Republic	180.1
8	United Arab Emirates	175.9
9	Hungary	171.2
10	Vietnam	169.5
11	Belgium	167.0
12	Estonia	164.4
13	Equatorial Guinea	162.8

14	Czech Republic	160.9
87	Germany	84.7
90	Euro area	83.4
134	Canada	64.1
145	France	59.2
183	Australia	42.3
184	China	41.5
188	Japan	38.6
194	United States	29.9

Source: Worldbank database

In table 1 top 14 open economies are presented according to the openness index and additionally other economies that are of interest and subject of this thesis are included. Even though in general this index shows a good measurement of the openness it has some drawbacks as it can be noted from table 1. Based on the theoretical and empirical knowledge there exists a positive correlation between economic openness and degree of economic development and a negative correlation between economic openness and size of the economic territory. However, both correlations do not always hold. For instance, Maldives is very small economy but the degree of economic openness is rather low. Nevertheless, their economy is based on tourism and due to this fact, it trades goods and services with foreign economies. On the other hand, United States that is widely known for their open economy ranks very low in the standings. This is a good example how the openness index does not provide us with an accurate measure of true economic openness. This is mostly because United States' economy is large and well diversified. In the Czech Republic case, common sense indicates that both correlation holds and for the purpose of the further research it reliably shows that Czech Republic is a small open economy and that world events can have significant impact on Czech economy stance.

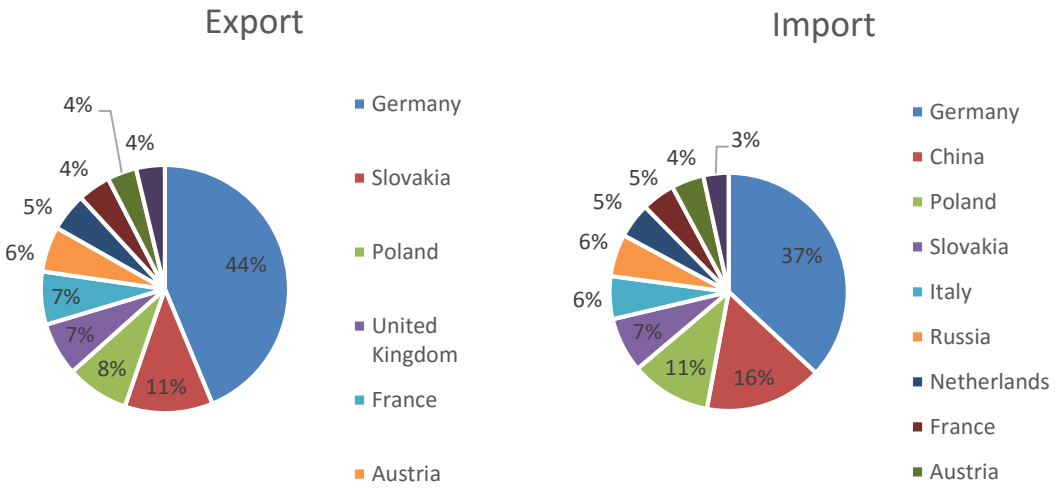


Figure 2: Distribution of exports and imports – Czech Republic
Source: UN Comtrade database

Moreover, attention will be turned into finding main trading partners of the Czech Republic. Until 2004, Czech Republic constantly showed trading deficit but since that time balance of trade has plunged into positive numbers meaning export exceeds import. According to UN Comtrade database, exports formed 83.8% of GDP whereas imports 77.1% in 2014. The biggest portion in export and imports take industrial machinery. Concerning the trading partners, biggest partner is Germany where 44% of all exports head into Germany and 37% of all imported goods and services come from Germany. Taking a closer look it can be noted that in general Czech Republic trades with countries that surround the Czech Republic. In fact, all major countries besides some exceptions such as China and Russia are part of European Union and most of them of euro area.

4 Theoretical model

Model used in this thesis is based on New-Keynesian model of a small open economy which was modified into the form below by Giordani (2004). First of, it starts with a partially forward looking rule (Phillip's curve):

$$\pi_{t+1} = \alpha_\pi \bar{\pi}_t + (1-\alpha_\pi)E_t(\pi_{t+2}) + \alpha_x x_{t+1} + \alpha_q(q_t - q_{t-1}) + \epsilon_{t+1}^{CP} \quad (4.1)$$

where $\bar{\pi}_t$ denotes annual inflation that was calculated as a simple average of last four quarters inflation, π_t is annualized quarterly CPI inflation, x_t stands for output gap which is defined as a difference between actual and potential real output, q is the exchange rate and ϵ_{t+1}^{CP} is the cost push shock with following attributes $\epsilon_{t+1}^{CP} \sim nid(0, \sigma_{CP}^2)$. When the exchange rate is set in the form that higher exchange rate signals depreciation of domestic currency then all variables should have a positive impact on inflation in this equation. From equation 4.1 it can be noticed that inflation in the next period π_{t+1} is defined by current expectation of inflation two periods ahead rather than one period. This brings a lag into the model.

Moreover, the output gap in the next period is determined by the IS/AD model:

$$x_{t+1} = \beta_x x_t + (1-\beta_x)E_t(x_{t+2}) + \beta_i\big(i_t - E_t(\pi_{t+1})\big) + \beta_{x^*} x_{t+1}^* + \beta_q E_t(q_{t+1}) + \epsilon_{t+1}^{AD} \quad (4.2)$$

where *i* is the short term interest rate which works as an instrument of monetary policy, x^* is foreign output gap, ϵ_{t+1}^{AD} is aggregate demand shock and fulfills $\epsilon_{t+1}^{AD} \sim nid(0, \sigma_{AD}^2)$. According to economic theory, all beta coefficients should be positive except β_i which is expected to be negative. Note that interest rate movement affects output gap with a lag.

The development of exchange rate is described with respect to uncovered interest rate parity in the following form:

$$\big(i_t - E_t(\pi_{t+1})\big) - \big(i_t^* - E_t(\pi_{t+1}^*)\big) = E_t(q_{t+1}) - q_t \quad (4.3)$$

where π^* and i^* are foreign inflation and interest rate respectively.

By combining and substituting equations 4.1 through 4.3 a final monetary (Taylor type) policy rule for setting interest rate can be derived in the form below:

$$i_{t+1} = \rho_i i_t + (1-\rho_i)(\gamma_x x_{t+1} + \gamma_\pi \bar{\pi}_{t+1} + \gamma_i i^*_{t+1} + \gamma_{x^*} x^*_{t+1} + \gamma_{\pi^*} \bar{\pi}^*_{t+1}) + \epsilon^{MP}_{t+1} \quad (4.4)$$

where ϵ^{MP}_{t+1} is a monetary policy shock and fulfills $\epsilon^{MP}_{t+1} \sim nid(0, \sigma^2_{MP})$.

5 Empirical model

As the purpose of this thesis is to investigate whether and how foreign shocks influence the Czech inflation, the time series of multiple variables will be examined. In this matter either dynamic simultaneous equation models or the vector autoregressive models (VAR) serve best this purpose in empirical studies.

The first mentioned type of models brings some statistical issues such as the underidentification or overidentification issues have to be accounted for and decision which variables will be endogenous and which will be exogenous has to be made.

The latter one is an alternative model which releases these assumptions and therefore, is more suitable for the purpose of this study. Hence, VAR models are employed for the purpose of this thesis.

5.1. VAR model

The VAR model has quite extensive history in macroeconomic modeling. It has been claimed by some economists (for instance by Sims (1980)) that VAR models perform better in macroeconomic forecasting than some simultaneous equation models. The advantage is that it treats all variables as endogenous and includes the same degree of lags. On the other hand, some economists have found these features as a disadvantage as it is nothing else than an overfitted reduced form model of simultaneous equations. These issues result from inclusion of more lags of some variables than it would be needed in just identified model. Nevertheless, it has been argued earlier that in reality it is hard to just identify simultaneous equation models.

The VAR model is an extended simple autoregressive model of one variable:

$$y_t = v + \alpha_1 y_{t-1} + \ldots + \alpha_p y_{t-p} + u_t \tag{5.1}$$

where u_t stands for vector of nonautocorrelated disturbances with zero mean and fulfills $E(u_t u_t') = \Omega$. This is an autoregressive model of order p (p lags are included in the model) or it can also be called a VAR model of 1 variable and p lags. In this way we can extend this model for K (k=1,…,K) variables:

$$\begin{aligned} y_{k,t} = v_k + \alpha_{1,1} y_{1,t-1} + \cdots + \alpha_{K,1} y_{K,t-1} \\ + \alpha_{1,2} y_{1,t-2} + \cdots + \alpha_{K,2} y_{K,t-2} \end{aligned} \tag{5.2}$$

$$\dots + \alpha_{1,p} y_{1,t-p} + \cdots + \alpha_{K,p} y_{K,t-p} + u_{k,t}$$

where a vector y_t can be defined with following characteristics $(y_{1,t},\dots,y_{K,t})$', vector of constants $v = (v_1,\dots,v_k)$',constant matrix of autoregressive coefficients A_i, where $i = 1,\dots,p$ with following attributes:

$$A_i = \begin{pmatrix} \alpha_{1,1,i} & \dots & \alpha_{1,K,i} \\ \vdots & \ddots & \vdots \\ \alpha_{K,1,i} & \cdots & \alpha_{K,K,i} \end{pmatrix} \tag{5.3}$$

and vector of error terms $u_t = (u_{1,t},\dots,u_{K,t})$' satisfying $E(u_t) = 0$, $E(u_t\, u_t') = \Omega$, $E(u_t\, u_{t-i}') = 0$, then the VAR model with order p is rewritten as follows

$$y_t = v + A_1 y_{t-1} + \cdots + A_p y_{t-p} + u_t \tag{5.4}$$

5.2. SVAR model

Even though VAR model has brought some remarkable benefits to macroeconomic forecasting (Litterman (1986)), it is often argued that including the same number of lags of all variables is atheoretical. Regarding this issue imposing restrictions (matrix B_0) on the VAR model according to the economic theory could lead to theoretically justified results. This way we create a structural VAR model with form:

$$B_0 y_t = c + B_1 y_{t-1} + \cdots + B_p y_{t-p} + e_t \tag{5.5}$$

where c is a vector of constants, B_i are coefficients matrices (K x K), B_0 is a matrix with ones on the diagonal and e_t is an error term fulfilling the same properties as the error term in the VAR model.

However, in the structural VAR model parameter identification issue might occur when we have multiple equation models that have some variables in common. This problem can be overcome by transforming it to reduced form model.

By premultiplying equation 5.5 by B_0^{-1} we yield a reduced form of a model:

$$y_t = c^* + A_1^* y_{t-1} + \cdots + A_p^* y_{t-p} + e_t^* \tag{5.6}$$

which can further create a new matrix x of all variables on the right hand side and new matrix of coefficients A^* that fulfills following equation:

$$y_t = c^* + A^* x + e_t^* \tag{5.7}$$

5.3. Model

The goal of this thesis is to estimate economic interaction mainly between Czech inflation and other variables that are included in the model. The data selection process was done according to New Keynesian model of a small open economy described in section 4 theoretical model. Two sets of variables are thus considered: one contains domestic variables and the other foreign variables. Hence, a VAR model with block restriction is considered. In other words, this type of VAR model takes into account that domestic variables cannot affect foreign variables and foreign variables do have an impact on domestic variables. Domestic variables were chosen according to New Keynesian model including Czech output gap (x_{cze}), Czech inflation (π_{cze}), Czech short term interest rate (i_{cze}) and exchange rate (ER). Representants of foreign variables are foreign output gap (x_f), foreign inflation (π_f) and foreign short term interest rate (i_f).

Two sets of variables can be interpreted as two vectors of variables:

$y_{1,t}' = (x_{cze,t}, \pi_{cze,t}, i_{cze,t}, ER_t)$

$y_{2,t}' = (x_{f,t}, \pi_{f,t}, i_{f,t})$

Besides having those variables, their structural disturbances or shocks are included in the model**.** They can be called as Czech output gap shock (e_t^{xcze}), Czech inflation shock ($e_t^{\pi\mathrm{cze}}$), Czech interest rate shock (e_t^{icze}), exchange rate shock (e_t^{ER}), foreign output gap shock (e_t^{xf}), foreign inflation shock ($e_t^{\pi\mathrm{f}}$) and foreign interest rate shock (e_t^{if}). The variables can be grouped in two parts again, domestic shocks and foreign shocks according to the same logic as with variables:

$e_{1,t}' = (e_t^{xcze}, e_t^{\pi cze}, e_t^{icze}, e_t^{ER})$

$e_{2,t}' = (e_t^{xf}, e_t^{\pi f}, e_t^{if})$

For our model purposes we can rewrite equation 5.5 in order to fit our domestic and foreign blocks:

$$\begin{pmatrix} B_{0,11} & B_{0,12} \\ B_{0,21} & B_{0,22} \end{pmatrix} \begin{pmatrix} y_{1,t} \\ y_{2,t} \end{pmatrix} = \begin{pmatrix} c_{1,t} \\ c_{2,t} \end{pmatrix} + \begin{pmatrix} B_{1,11} & B_{1,12} \\ B_{1,21} & B_{1,22} \end{pmatrix} \begin{pmatrix} y_{1,t} \\ y_{2,t} \end{pmatrix} + \tag{5.8}$$

$$+\cdots+\begin{pmatrix}B_{p,11} & B_{p,12}\\ B_{p,21} & B_{p,22}\end{pmatrix}\begin{pmatrix}y_{1,t}\\ y_{2,t}\end{pmatrix}+\begin{pmatrix}\varepsilon_{1,t}\\ \varepsilon_{2,t}\end{pmatrix}$$

Since $y_{1,t}$ represents domestic variables and $y_{2,t}$ represents foreign variables and we have declared that small open economy, which is a domestic economy, cannot influence the rest of the world significantly, we impose the restrictions that coefficients in the lower left corner in matrices are equal to zero – domestic variables cannot influence foreign variables in any lags.

$$B_{0,21}=B_{1,21}=\cdots=B_{p,21}=0$$

By imposing such restrictions, the model corresponds more with the economic theory plus the degrees of freedom are released as already 7 variables are present in the model.

In the next step, the model is transformed into the reduced form model in order to overcome difficulties with the identification as it has been discussed earlier. This is done by premultiplying the whole VAR equation by B_0^{-1}:

$$y_t=c^*+A_1^*y_{t-1}+\cdots+A_p^*y_{t-p}+e_t^* \qquad (5.9)$$

where $A_i^*=B_0^{-1}B_i$ and $e_t^*=B_0^{-1}*e_t$

In the final equation (5.9) the error terms in the reduced form model are a linear combination of shocks. Having this form of model, it can be proceeded further to estimating shocks of particular variables. Nevertheless, in order to do so the orthogonality of the innovation in the model has to hold. That is that in a model with *K* variables, *K(1-K)/2* restrictions have to be imposed in order to make the model just identified. In this case, 7 variables are considered hence 21 restrictions have to be set. One option is to follow Cholesky decomposition method where the values above diagonal are set to zero. Ordering of variables in the vector autoregression does matter. The variable that is the most up influences all other variables but none of others influences it back. The second one from top is affected only by the previous one but itself it influences all other variables except the first one. The same logic holds for other variables. In this matter it is clear that foreign variables will be placed above the domestic variables. According to intuition, variables have been ordered gradually – foreign output gap, foreign inflation, foreign interest rate, domestic output gap, domestic inflation, domestic interest rate and exchange rate. Model's identification scheme has a following form:

$$\begin{pmatrix} e^*_{t,xf} \\ e^*_{t,\pi f} \\ e^*_{t,if} \\ e^*_{t,xcze} \\ e^*_{t,\pi cze} \\ e^*_{t,icze} \\ e^*_{t,ER} \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ d_{21} & 1 & 0 & 0 & 0 & 0 & 0 \\ d_{31} & d_{32} & 1 & 0 & 0 & 0 & 0 \\ d_{41} & d_{42} & d_{43} & 1 & 0 & 0 & 0 \\ d_{51} & d_{52} & d_{53} & d_{54} & 1 & 0 & 0 \\ d_{61} & d_{62} & d_{63} & d_{64} & d_{65} & 1 & 0 \\ d_{71} & d_{72} & d_{73} & d_{74} & d_{75} & d_{76} & 1 \end{pmatrix} \begin{pmatrix} e^{xf}_t \\ e^{\pi f}_t \\ e^{if}_t \\ e^{xcze}_t \\ e^{\pi cze}_t \\ e^{icze}_t \\ e^{ER}_t \end{pmatrix} \quad (5.10)$$

6 Data description

First of all, data of some variables included in the model cannot be found in the form that it has been assumed so far and a right proxy or data transformation has to be performed. Domestic block is formed of Czech variables and foreign block is represented by euro zone since it is main trading partner with the Czech Republic. Moreover, there is no source that would provide us with output gap. As it was derived earlier output gap is the difference between actual and potential real output (GDP). Output data are publicly available from CNB but problem appears with potential output. In numerous studies economists (see for instance Ball and Mankiw (2002) or Hájek and Bezděk (2000)) deal with this issue by employing The Hodrick–Prescott filter (HP filter) on the original data. The principle of the filter is to smoothen data and hence, remove cyclical components. In case of output, the data moves around the potential output depending on which part of the business cycle the economy is in. Therefore, removing these cyclical components should yield the potential output. The mathematical theory of the HP filter is to minimize the function:

$$\min\left(\sum_{t=1}^{T}(y_t - y_t^*)^2 + \lambda \sum_{t=2}^{T-1}[(y_{t+1}^* - y_t^*) - (y_t^* - y_{t-1}^*)]^2\right) \qquad (6.1)$$

where y denotes the actual output, y^* is the potential output and λ is a parameter determining the smoothness of a trend. Hence, setting λ equal to zero would imply that actual output is potential output and on the other hand λ limiting to infinity would show a trend line. Thus, setting λ in this function is crucial. In the literature corresponding to HP filter (Canova (1994)) and from the initiators of this method themselves (Hodrick and Prescott (1997)) it is recommended to set λ to 100 when dealing with yearly data, 1600 for quarterly data and 14400 for monthly periodicity. Having both actual and potential output, the output gap can be obtained.

As all exchange rates with Czech Crown cannot be included because that would result in too many variables in the model, only exchange rate with Euro is included as it is found to be the most important. Data are collected from CNB.

Inflation data are usualy a year on year percentage change of price indices and it could be obtained by using equation 6.2:

$$Inflation\ rate_t = \frac{Price\ index_t - Price\ index_{t-12}}{Price\ index_{t-12}} \quad (6.2)$$

Nevertheless, by doing so a complicated structure of residuals would be brought into the model and it would cause issues in estimating models later on. Hence, a price level, consumer price index (CPI), will work as a proxy of inflation for the Czech economy and euro zone's harmonised index of consumer prices (HICP) for euro zone. Both indices could be found in OECD database.

Prague InterBank Offered Rate (PRIBOR) and European InterBank Offered Rate (EURIBOR) are proxy variables for domestic interest rate, foreign interest rate respectively. As we are interested in short term interest rates, 3 months PRIBOR and EURIBOR are used for our purpose. Data were collected from CNB's webpage and European Central Bank's statistical data warehouse.

Data are collected for the period starting in January 1999 and ending in March 2016 on the monthly basis. The theoretical background for the starting period is that in January 1999 the euro zone was formed.

The dataset has a format of panel data and covers 207 observations. In the following subsections, data descriptions of individual variables will be studied more closely.

Czech CPI and euro zone's HICP

In figure 3 Czech CPI and EA's HICP development can be seen. Both indices use year 2010 as a base year (value of indices in 2010 are 100). Indices signal a growing trend for the observed period. Czech price level seems to be lower for the period up until the year 2008. Then it appears more that in both areas the price level overlaps. As changes in the price level are quite hard to interpret from figure 3 inflation rates calculated according to equation 6.2 are also plotted in the figure. Inflation rates show similar tendency in development, especially after 2007 except the fact that Czech inflation rates look more volatile. Czech inflation's mean in the sample is 2.26% and inflation itself has been quite volatile with standard deviation worth 1.771% in the sample. The maximum value was achieved right before the onset of financial crisis peaking at 7.5% while in January 2003 reaching the minimum of -0.5%. The inflation seems to be less volatile in the recent years and also reaching lower values.

On contrary, the average inflation rate of euro zone is 1.85% with the maximum value at the beginning of the crisis 4.1%. Euro zone's inflation rate dropped to the lowest value of -0.61 % in July 2009 but nowadays it is still around the 0% level. The standard deviation is 0.98% which is almost twice as low as opposed to Czech inflation.

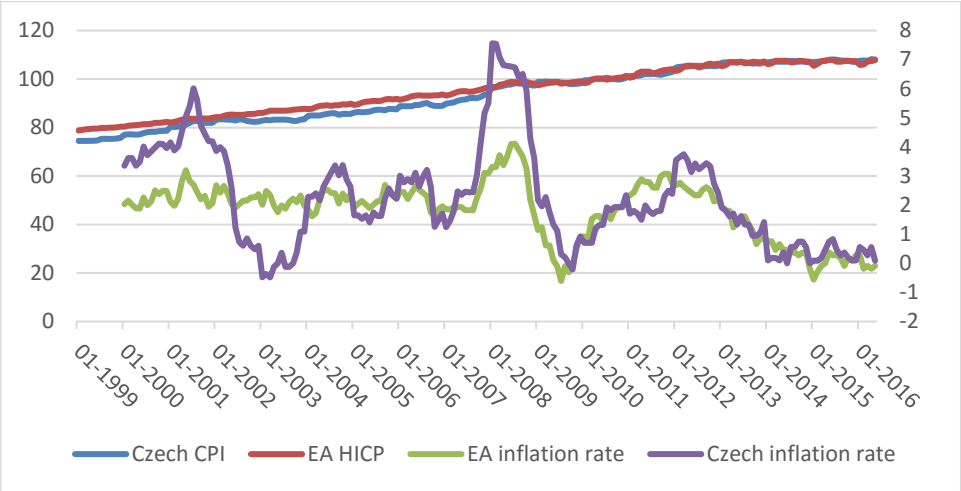


Figure 3: Czech and EA price levels (LHS) and inflation rates (RHS in %)

The autocorrelation function (ACF) and partial autocorrelation function (PACF) are carried out in order to find out whether the series is stationary. The outcomes for Czech price index are depicted in figure 4. The ACF shows persistence and PACF drops sharply for the second lag which indicates that random walk pattern is present.

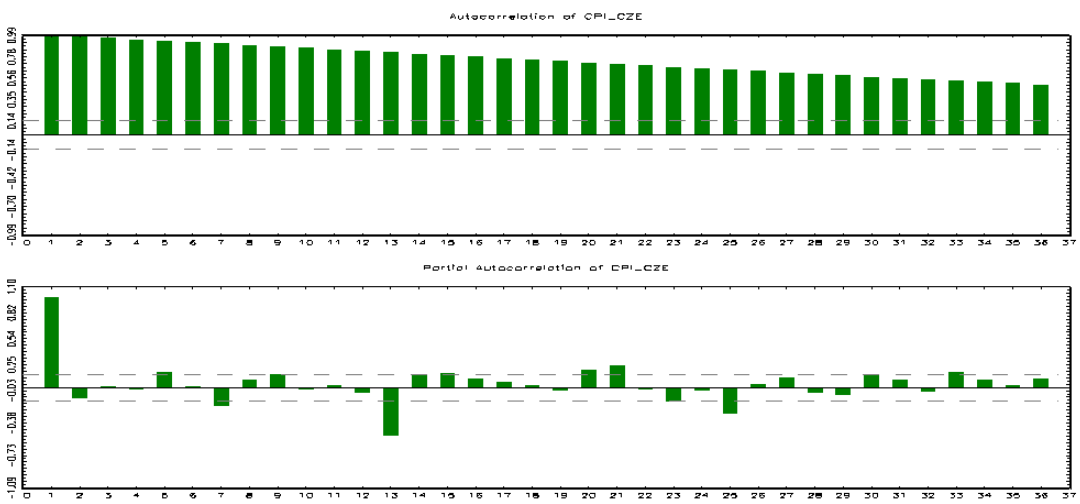


Figure 4: ACF and PACF of Czech CPI

To verify the conclusion, the Augmented Dicky-Fuller (ADF) test for the presence of unit roots is run. The ADF test requires to select the lag length *p*. When choosing too low *p* the lasting serial correlation in the disturbances can bias the test. On contrary, if too high lag length is selected, the test loses its power. Taking into account these facts the predetermined lag length of 2 by the JMulti package is left in the model. As noted there is an upward sloping trend and as it is a macroeconomic variable that usually experiences seasonal trend, constant, trend and seasonal dummies are added into the ADF testing procedure. By running this test, it can be concluded that the null hypothesis of unit root cannot be rejected even at 10% level of significance.

Table 2: ADF test for Czech CPI

ADF Test for series:	CPI_CZ		
Level of significance	1%	5%	10%
Critical values	-3.96	-3.41	-3.13
Value of test statistic	-1.1209		

Even though a textbook approach would advise to transform data by taking first differences or finding cointegrating relationship among variables there are some economists (see Sims et al (1990) or Stock and Watson (1988)) who believe in leaving variables in the form as they are in the model as additional information that are present in levels of variables might be lost by taking first differences. For the purpose of this thesis other variables will be tested similarly and according to their results a final decision about transforming data will be made.

Plotting ACF and PACF for euro zone's harmonised index of consumer prices (HICP) reveals similar patterns (appendix 1) as in Czech price index case and similar outcomes can be expected. The performed ADF test confirms the expectation of non-stationarity. It reaches t-value of 0.1366 which is even higher than in Czech price level case and hence the null hypothesis of stationarity cannot be rejected.

Table 3: ADF test for selected variables

	ADF Test	
Variables	Critival value	Value of test statistics
EA's HICP	-3.41	0.1366
Czech output gap	-1.94	-2.4278**
Czech output	-3.41	-0.9125
EA output gap	-1.94	-2.4919**
EA output	-3.41	-1.9373
PRIBOR	-3.41	-2.3654
EURIBOR	-3.41	-2.4673
Exchange rate	-3.41	-1.1646

Note: Critical value is based on 5% level of significance; ** indicates that a varialbes reject at 5% level of significance null hypothesis of unit root presence

Czech and euro zone's output gap

Czech output, estimated potential output (HP filter CZE GDP) and output gap are plotted in figure 5. Estimated potential output is a smoothened GDP by employing HP filter as it is described in the previous section. GDP gap is then the difference between actual output and potential output. From the first view it is clear that output gap is less volatile than inflation but certainly, interpolation of actual output and the process of creating output gap itself cause output gap to be less volatile. The biggest output gap was measured in August 2008, right before the onset of the crisis. On the contrary, the lowest value was reached when the crisis spread to the Czech Republic in May 2009. By creating an output gap, the trend was removed from the data and it can be expected that there should not be any sign of unit root. According to table 3 the t-value is higher now than some critical values and we find that it does not follow a random walk even at 95% confidence interval. Nevertheless, real output itself has unit root.

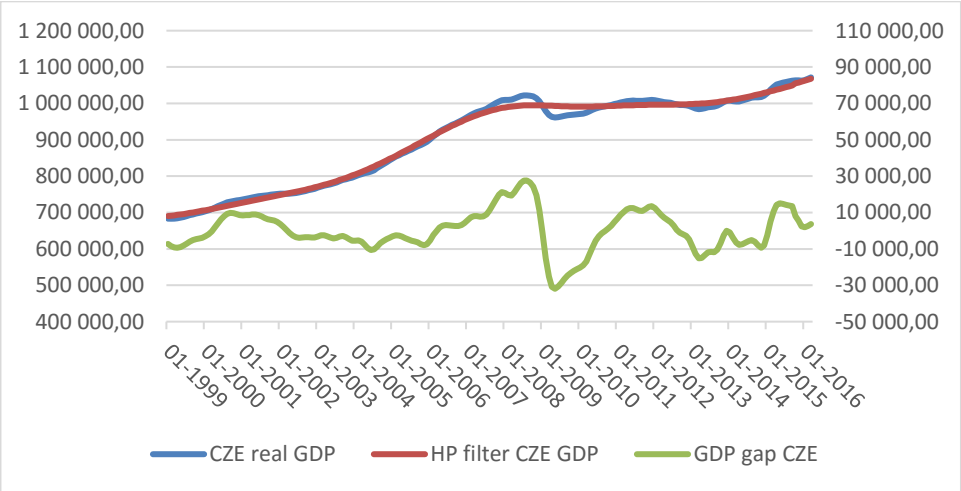


Figure 5: Czech GDP and potential GDP (LHS in mil. CZK) and GDP gap (RHS in mil. CZK)

Figure 6 is a similar to figure 5 except euro zone's data are used. Likewise to price level case, similar patterns can be seen with comparison to Czech output chart. It finds its maximum before the beginning of the crisis, in March 2008 and plunged to its minimum in April 2009.

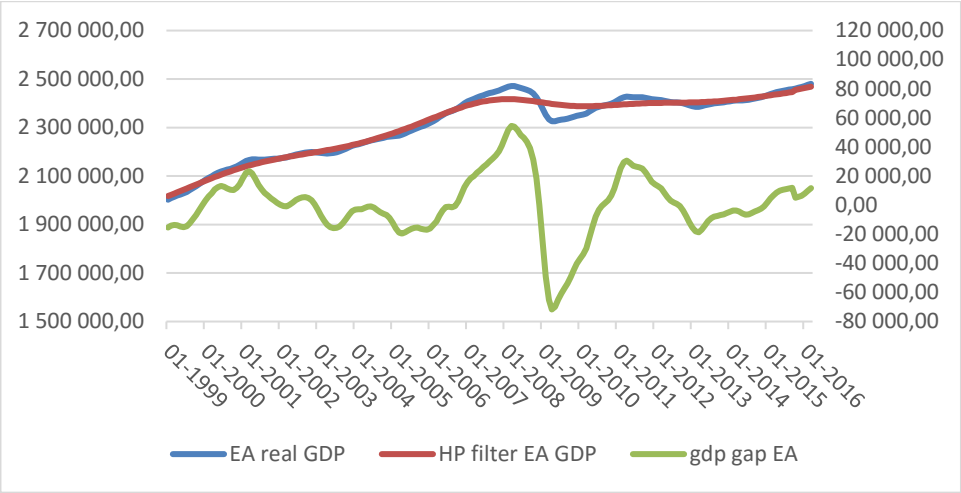


Figure 6: EA GDP and potential GDP (LHS in mil. EUR) and GDP gap (RHS in mil. EUR)

According to the ADF tests euro zone's output suffers from a unit root even at 10% level of significance. On the other hand, output gap passes this test.

Exchange rate CZE/EUR

The exchange rate has changed a lot in the observed period. It started at the exchange rate of 37.69 CZE/EUR which is the highest measured exchange rate. Figure 7 displays two periods of higher volatility and that is in the period after the Euro in a physical form was introduced in 2002 and during the financial crisis. Otherwise, the exchange rate shows a downward sloping trend until 2011 when it stagnated and later it was experiencing slight increase. At the end of 2013 CNB intervened at the market and gave its promise to keep the rate above 27 CZK/EUR. The lowest rate value was taken during global financial crisis when it dipped to 23.53 CZK/EUR. The average rate for the studied period is 28.93 CZK/EUR with standard deviation of 3.66. Data are nonstationary.

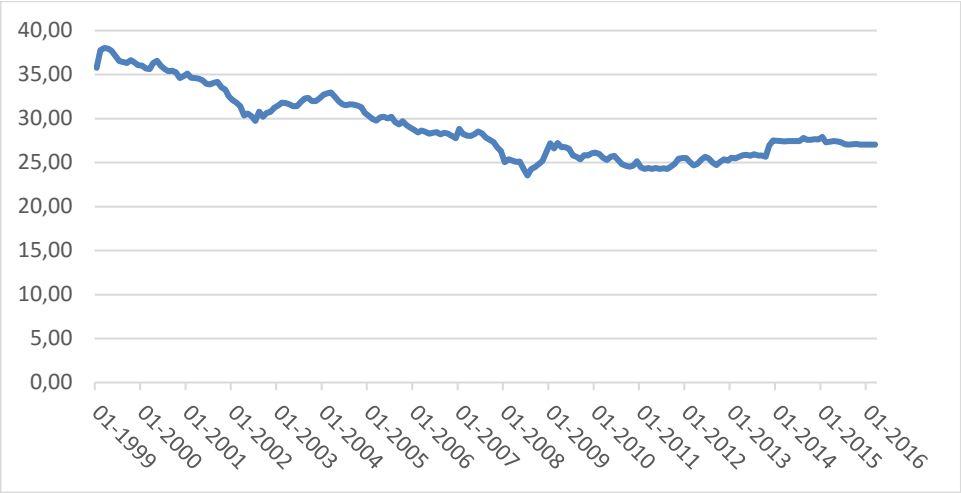


Figure 7: CZK/EUR Exchange rate

3M EURIBOR and PRIBOR

Data description of short term interest rates show again some harmonization over time. It seems that harmonization started even before joining European Union in 2004. Whereas, at the beginning it was PRIBOR that showed more volatile interest rate, in the second part of data span, it is EURIBOR that fluctuates more. Recently both Czech and EA's monetary policies are influenced by record low interest rates. Both countries have basically reached the zero level. EA is already slightly in negative numbers in short-term.

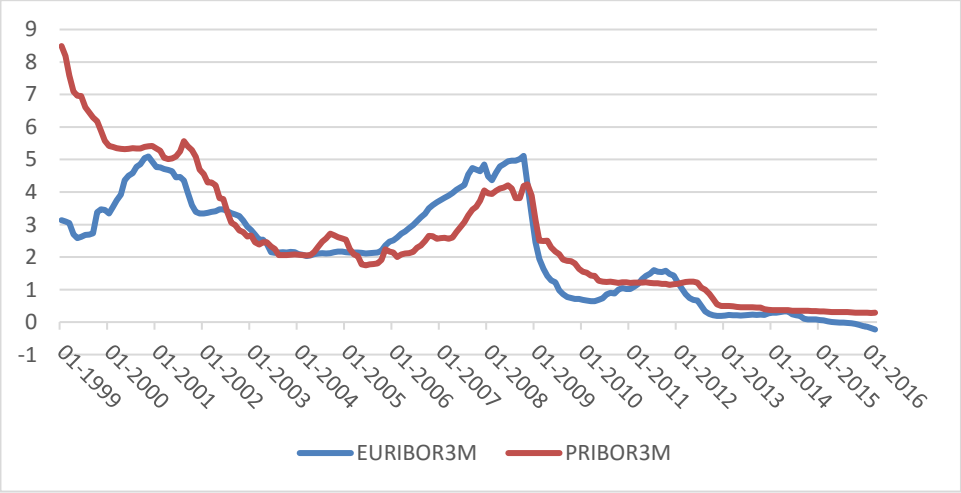


Figure 8: 3 month EURIBOR and PRIBOR (in %)

7 Results

In this chapter a SVAR model analysis is conducted on the data that are described in the previous chapter 6 data descroption. All estimations are carried out with a statistical package JMulti.

Models will be studied by impulse response functions and the error variance decomposition. The main focus will be on responses of Czech price level to domestic and foreign shocks and the contribution of each shock to the Czech price level error variance. Moreover, a typical check on functioning of Czech monetary transmission mechanism will be provided.

The SVAR model will be run at first on data covering the whole observed period (from January 1999 till March 2016). After investigating the whole period with statistical tests for stability of the system, model will be tested for structural changes as significant structural changes might have occurred during and after the global financial crisis from macroeconomic point of view.

In the previous chapter 6 data description it was discussed that most of the variables do not fulfill the stationary condition that is necessary in order to avoid spurious regression. Nevertheless, taking first differences of data may result in losing some important (so called “long run”) relationships between the levels. Sims et al (1990) argue with the same arguments that data transformation comes with the cost of some additional information loss. Stock and Watson (1988) claim that the main property that has to hold in VAR models is the stability. Because keeping such information in VAR modelling of macroeconomic variables is crucial and because most empirical literature uses this attitude, models will be run with variables in levels rather than following text book procedure. Moreover, in the chapter 6 data description it was found that most of the variables show to track some trend. That is why a trend will be included in models. As it is dealt with macroeconomic variables that tend to show seasonality, seasonal dummies will be added as well. The question lies in whether to include output gaps or actual outputs. The theoretical model advise to use output gap, however, we think that by creating output gap, by subtracting actual output from its smoothened data, can lead to losing additional information in the data. In order to take into account both pros and cons, first models will be run with actual outputs and the same analysis will be conducted with output gaps and their results will be compared. Furthermore, price levels, real outputs and exchange rate are in logarithmic form.

In the next subsections under this chapter results of different models will be discussed.

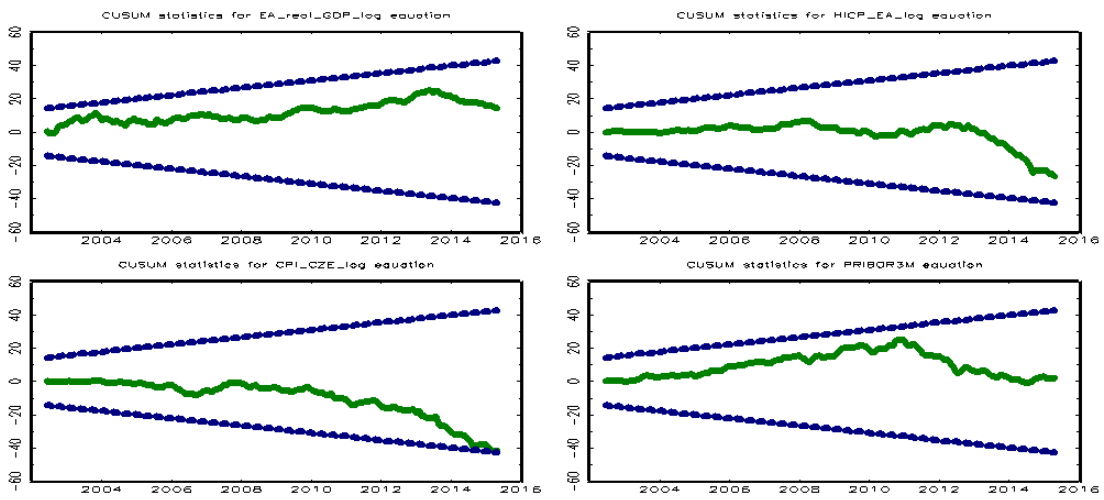
7.1. SVAR model– full period (model 1)

We start with considering the full period (model 1). First of all, simple SVAR model with Cholesky decomposition is studied. It needs to be kept in mind that the ordering of variables and setting restrictions do matter and the model that was derived in chapter 5 empirical model is followed.

Firstly, VAR model needs to be estimated and in order to do so, number of optimal endogenous lags needs to be determined. This number can be estimated by employing numerous tests. Most common is the use of Akaike information criterion (AIC), Schwarz criterion (SC) and Hannah-Quinn criterion (HQC). With respect to other studies on the similar topic low number of lags is usually included. Regarding this fact tests are restricted to consider maximally 4 lags. Beside SC all advise to use 4 lags even without the restriction. Due to these results 4 lags of endogenous variables are chosen to be in the model.

Next step is determining the stability of the model. First of all, the modulus of the eigenvalues can be checked (appendix 2).

We can count with the stability of the model due to the fact that eigenvalues are bigger than 1 in all cases. To confirm these findings, the cumulative sum control chart (CUSUM test) can be further performed. As it can be seen from the figure 9 cumulative sums do not exceed the threshold which is based on 5% significance level thus the model is stable.



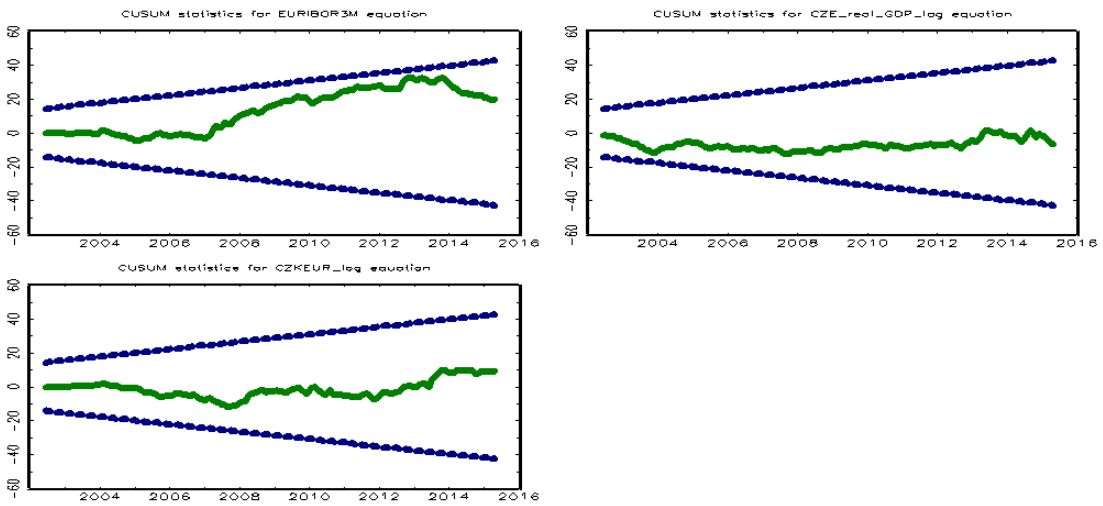


Figure 9: CUSUM test (model 1)

Now, since we know that statistics are in order we can proceed to impulse responses. Our attention will be turned to reaction of Czech price level after shocks in other variables. Around response functions 95% confidence intervals are built based on Hull (1988) method with 250 bootstrap replications.

Czech CPI response to shock in euro zone's output gap and HICP

Shock in euro zone's output gap of one standard deviation (0.03 basis points) seems to make rise Czech inflation after 5 months and then it increases until it hits its maximum after 15 months where the impulse response reaches value of 0.13 basis points. Then it gradually decreases. Even though the response is surrounded by quite wide confidence interval, the response seems to be significant after 9 months. On the other hand, response to EA price level shock is swifter. When the shock of 1 standard deviation (0.0025%) occurs Czech price level tends to increase immediately by 0.0017%. The response almost doubles in the next 10 months, then it starts to wear off. The response looks very significant for the whole observed period.

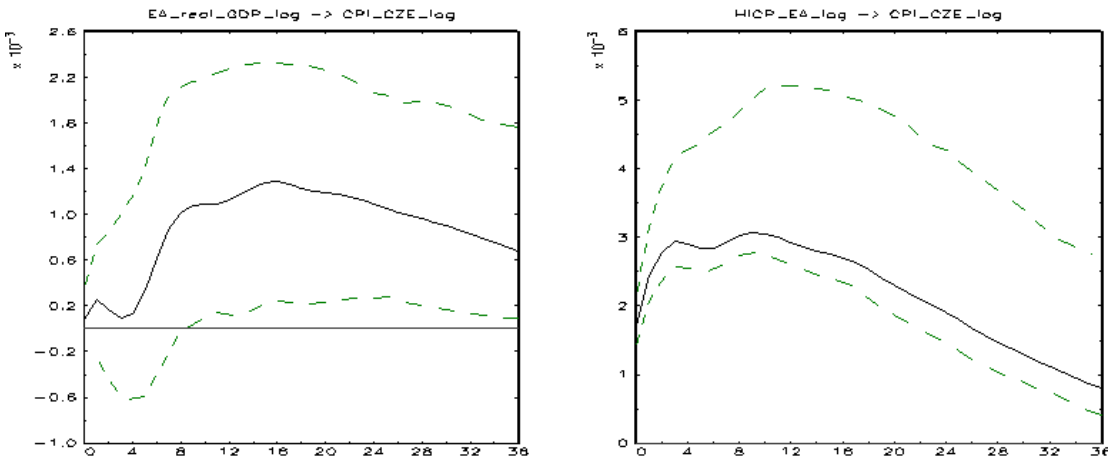


Figure 10: Impulse response function of Czech CPI to EA output (LHS) and EA HICP shock (RHS)

Czech CPI response to shock in EURIBOR and Czech output

According to the impulse responses presented in figure 11, response to shock in EURIBOR and Czech output seems to be rather insignificant. Response to EA's monetary shock is at first negative but 4 months later it becomes positive hitting maximum around 16th month. The same process can be depicted in response to Czech output's shock with the difference that it turned out positive after a year and a half. If the studied period was longer, then response to Czech output would probably become significant.

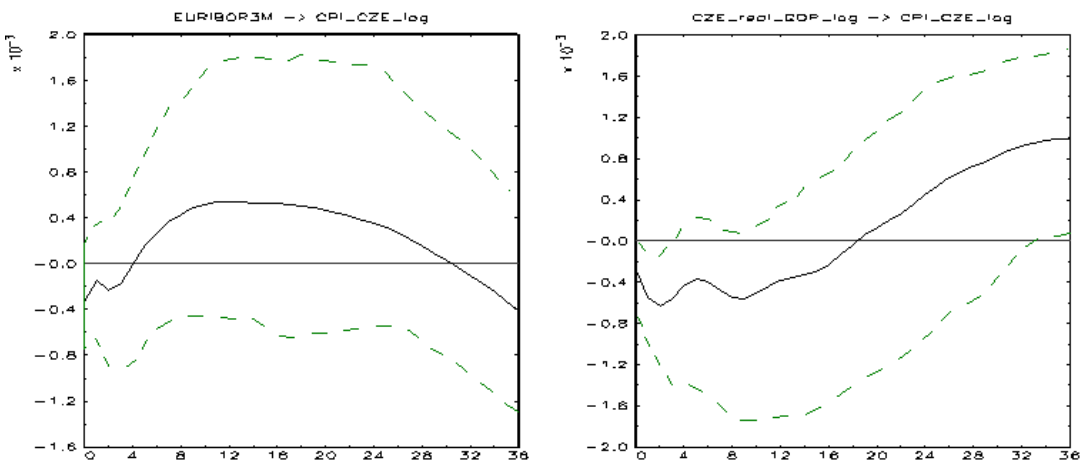


Figure 11: Impulse response function of Czech CPI to EURIBOR (LHS) and Czech output shock (RHS)

Czech CPI response to shock in PRIBOR and exchange rate

Shock in PRIBOR rate results in negative response after 7 months and the response picks up on the value (negative) and it reaches its maximum after 2 years. More precisely, PRIBOR shock that amounts to 9.27 basis points results in the strongest response after 2 years or so when the impulse accounts for 0.04 decrease in price index. The response itself is bounded with wide confidence interval that contains zero value but it gets more significant just after 2 years. Depreciation is followed by the drop in price level rather than increase and only after one year it gets to positive response. Nevertheless, the response shows a lot of insignificance.

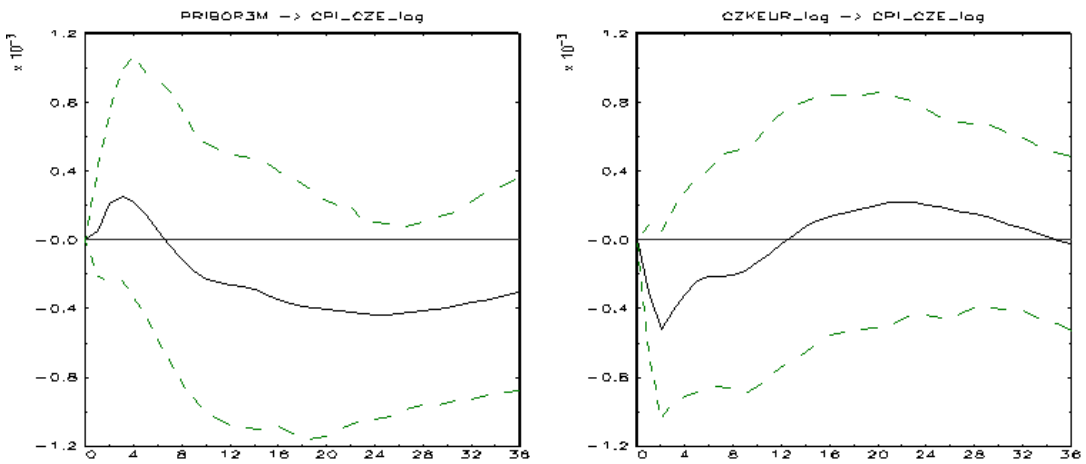


Figure 12: Impulse response function of Czech CPI to PRIBOR (LHS) and Exchange rate shock (RHS)

Forecast error variance decomposition of Czech CPI

From studying impulse responses, it can be estimated that Czech and EA's price levels together with EA's output will be the main variables that describe variability in Czech price level due to insignificancy of other variables. The forecast error variance decomposition of Czech CPI indeed reveals so. Particularly, vast majority of Czech CPI movement is described by Czech CPI itself and EA's HICP. The first one mentioned especially at the beginning and the latter one after one quarter.

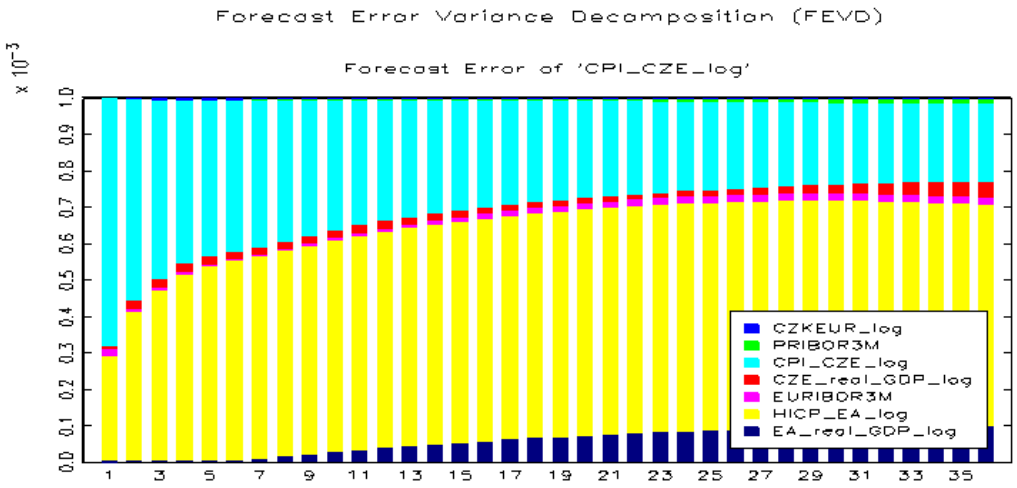


Figure 13: FEVD of Czech CPI (model 1)

Monetary transmission mechanism

Next, attention is turned into further studying monetary transmission mechanism. After a monetary shock of one standard deviation (0.0026%), Czech output decreases continuously and bottoms out between 1.5 years and 2 years by 0.0016%. Exchange rate appreciates immediately but soon it starts to depreciate and reveals signs of delayed overshooting.

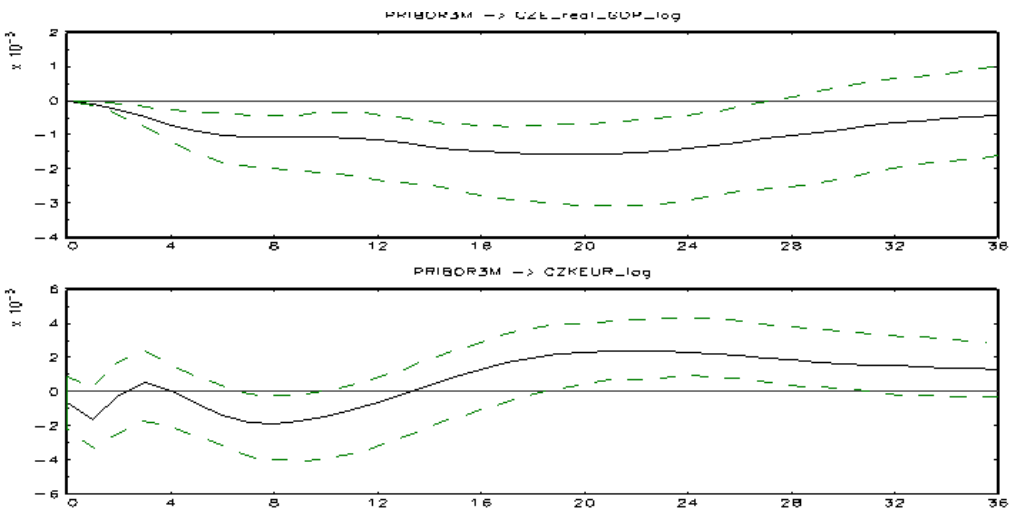


Figure 14: Impulse response functions of Czech output and exchange rate to PRIBOR shock

In the chapter 6 data description we found outliers in data in all variables around and during the period of global financial crisis. The consequences of the crisis in most cases are the breakdowns of macroeconomic identities. There is no doubt that during this period the international trade was at least partly broken, the same is probably true for domestic transmission mechanism and so on. That is why it is assumed that during this

time some structural changes might have happened. This does not only mean that during crisis the responses to shocks that are subject of the study in this thesis could have been different and results might be biased by this period, but also it means that responses to shocks might have changed considering the pre-crisis and post-crisis period. In literature, the global financial crisis is dated from the fall of Lehman Brothers which was in September 2008. The end is a little bit uncertain and mostly it depends on the economy how it was hit by the crisis and how the economy managed to overcome it. That is why the period will be defined according to the variables that are considered in the model. By studying variables, we arrive to a conclusion that variables started to vary a lot already in September 2007[3] and it seems it got back to "normal" at the beginning of 2010. That is why this period will be tested for structural stability. This is done by running Chow's forecast test for that period.

Chow's forecast test runs on the idea of estimating two models – one using all data and the other one containing only subsample of the data. The differences of the outcomes are statistically compared based on the F-test:

$$F = \frac{(u'u - e'e)/N_2}{e'e/(N_1 - k)} \tag{7.1}$$

where $u'u$ is the residual sum of the squares when the model is run on all observations (N observation), $e'e$ is the residual sum of the squares when the model is estimated on the subsample of N_1 observations. N_2 is then number of all observations excluding the number of observations in the subsample and k is the number of parameters.

[3] An active phase of crisis is dated from August 2007 when BNP Paribas blocked withdrawals from three hedge funds because of complete evaporation of liquidity.

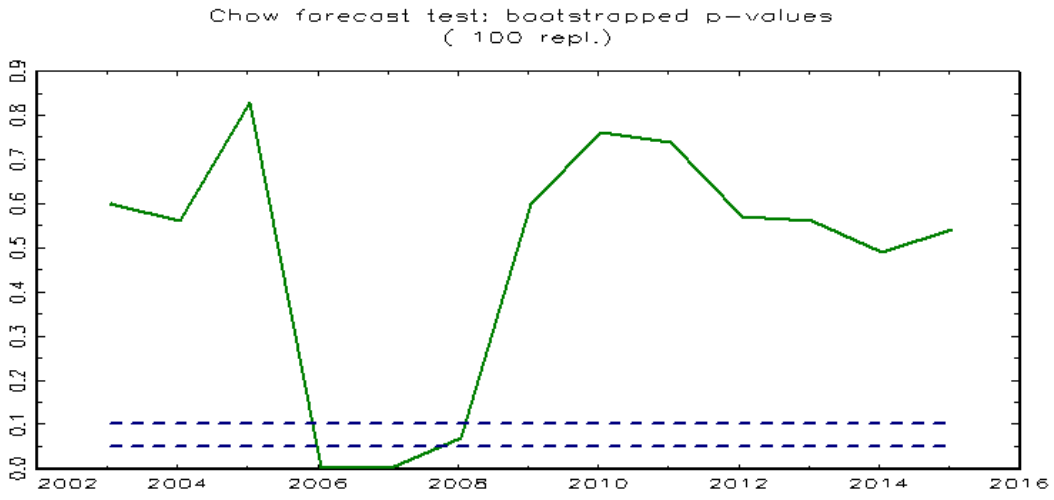


Figure 15: Chow's forecast test – subsample period of 2007 M9 – 2009 M12 – p-values

According to the Chow's forecast test with the results depicted in the figure 15, the null hypothesis that estimated coefficients of both models are the same can be rejected. Thus in this case a structural change can be found in this period around global financial crisis.

Even though this test shows that there are some structural changes, another type of Chow's test that is based on different assumptions can be performed. A break point Chow's test assumes that at some point of time a structural change occurs and model estimates would be of different values. In a nutshell it splits data in two parts and two models are estimated. If the coefficient on some level of significance are found the same, then there is no structural change. In order to compare these statistics another F-test must be computed:

$$F = \frac{(u'u - (e'_1 e_1 + e'_2 e_2))/k}{(e'_1 e_1 + e'_2 e_2)/(N - 2k)} \tag{7.2}$$

where $u'u$ is the residual sum of the squares when the model is run on all observations (N observation), $e'_i e_i$ is the residual sum of the squares when the model is regressed on subsamples.

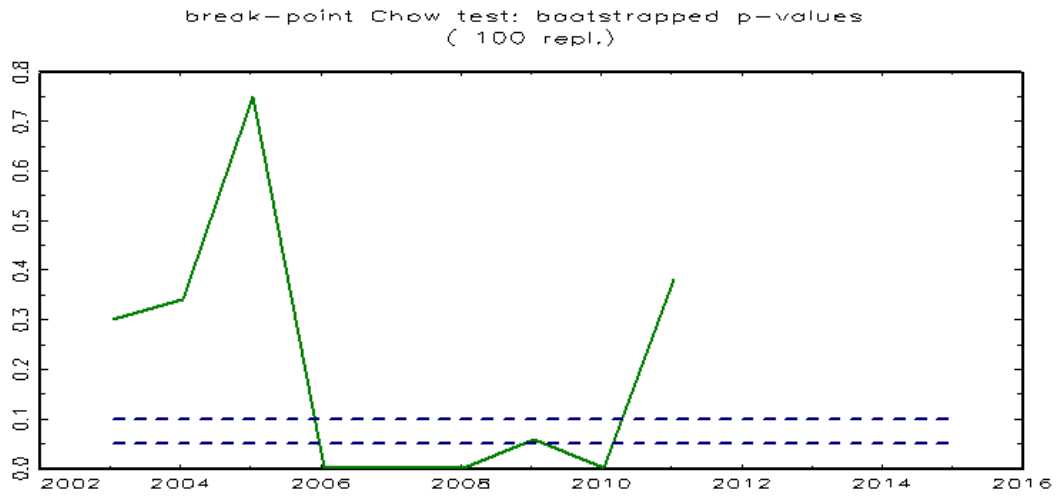


Figure 16: Break point Chow's test – p-values

In figure 16 we see that setting break point at any point in period between 2008 and 2010 would lead to rejecting null hypothesis of no structural change. Based on this test we decide to consider two subsamples. One that contains data up to August 2007 and the other one starting in January 2010. Note, the dataset was not split in two periods but the period of high volatility that lasted from September 2007 till December 2009 was dropped out from models.

7.2. SVAR model – pre-crisis period (model 2)

When searching for optimal number of lags SC advise 2 lags and the other ones 4. This time as the dataset is smaller and we rather use lower number of lags than higher, thus 2 lags will be added to the model. CUSUM test proves stability in the model as it can be seen in figure 17.

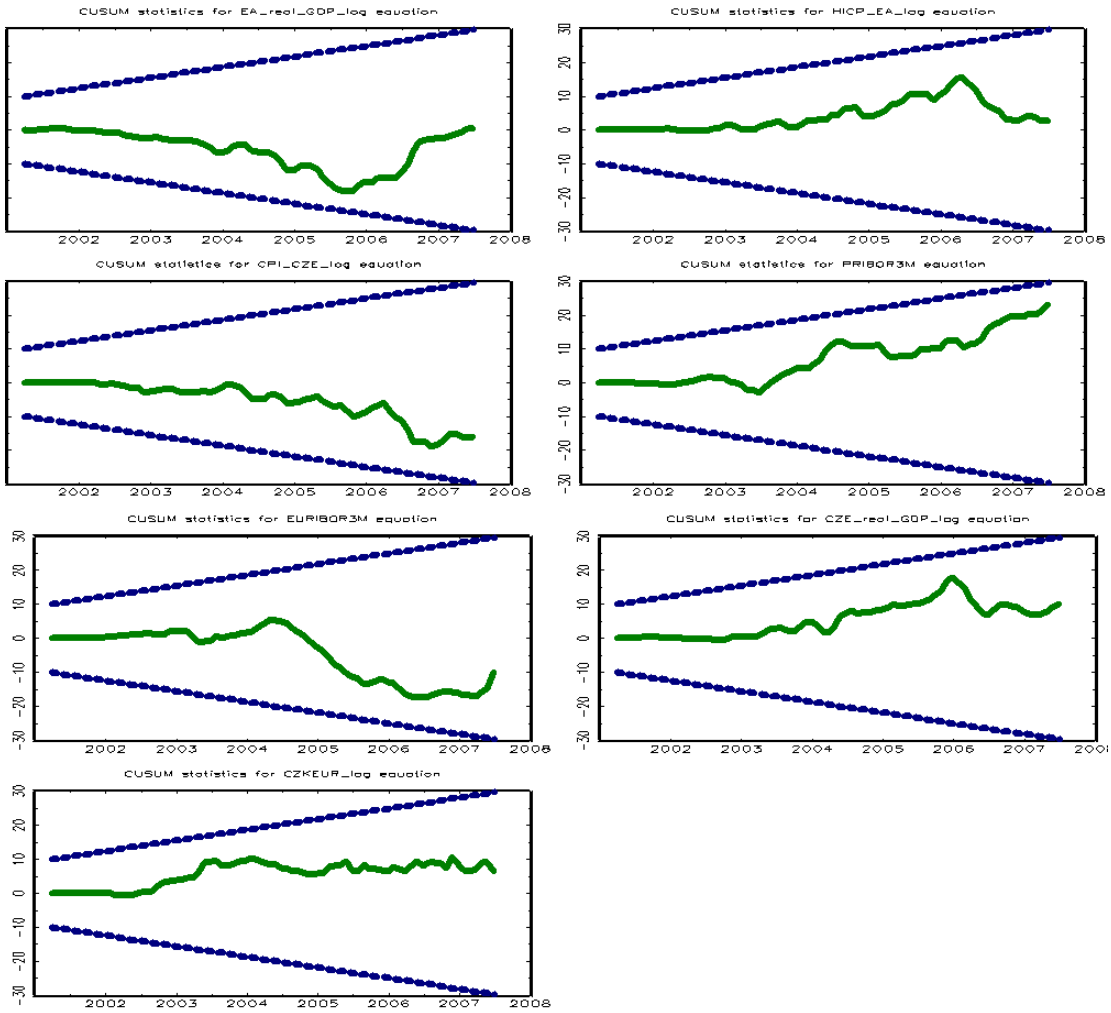


Figure 17: CUSUM test (model 2)

Czech CPI response to shock in euro zone's output gap and HICP

Shock in euro zone's output gap seems to make rise Czech inflation after 5 months and then it increases until it hits its maximum after 15 months. Then it gradually decreases until the end of the third year. The response is most significant in the second year. On the other hand, response to EA's price level shock is swifter. When the shock of 1 standard deviation (0.0016%) occurs Czech price level tends to increase immediately by 0.0014%. The response rises in its magnitude in the first month, then it starts to wear off and after 10 months the impulse is gone.

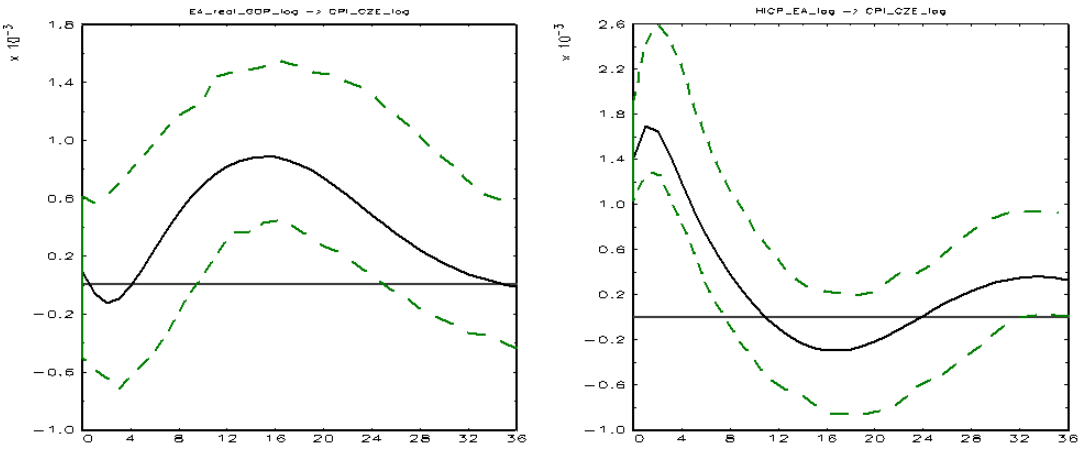


Figure 18 Impulse response function of Czech price level to euro zone's output gap (LHS) and price level shock (RHS)

Czech CPI response to shock in EURIBOR and Czech output

According to the impulse responses presented in the figure 20, when EURIBOR shock of one standard deviation (0.01%) occurs Czech price level tends to react immediately with -0.0002% response. This response even shows a growing tendency in other 5 months where response decreases by another -0.0003%. After the 5th month it gradually increases and after 10 months this response becomes even positive. Surprisingly, the reaction to Czech output is negative in the first year, then it becomes positive and reaches maximal positive response after 2 years where it gains on its significance.

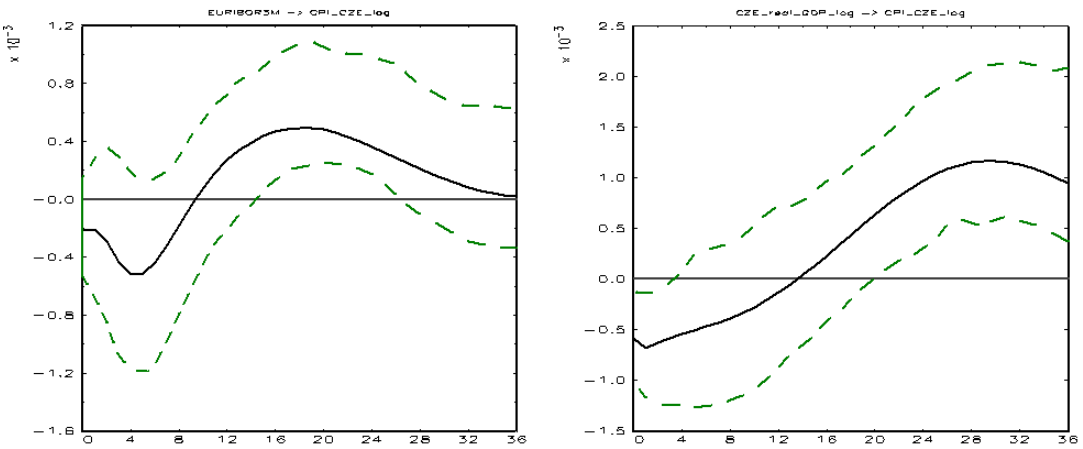


Figure 19: Impulse response function to EURIBOR shock (LHS) and Czech output shock (RHS)

Czech CPI response to PRIBOR and to exchange rate shock

Shock in PRIBOR rate results in negative response. There is no instant effect but the response picks up on the value (negative) and it reaches its maximum after 6 months. After 1 year it becomes insignificant. Czech price level reaction function to exchange rate shock becomes significant in the period between 4th and 12th month after the shock. The impulse increases from almost no effect at the time of occurrence to 0.0007% in 6 months when shock of 1 standard deviation (0.011%) happens.

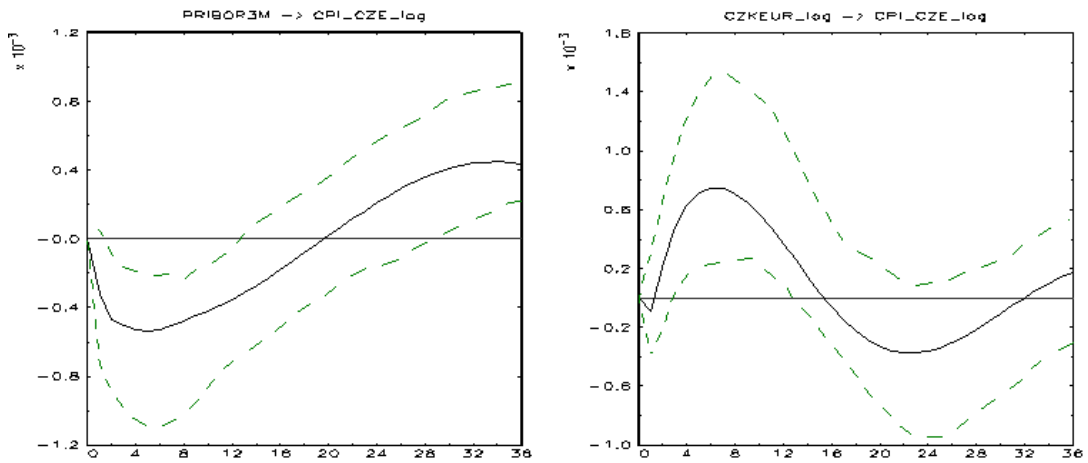


Figure 20: Impulse response function to Czech CPI shock (LHS) and PRIBOR shock (RHS)

Forecast error variance decomposition of Czech price level

Forecast error variance decomposition in figure 21 shows that variance in Czech price level is mostly explained by domestic shocks. In the first months the variation is mostly explained by the shock in Czech inflation itself (69%) and euro zone's price level (25%). Later the significance of the shock in Czech price level decreases and after 3 years it explains 36% of the total variation. On the other hand, euro zone's price level describes most variation in first 6 months, especially in the 3rd and 4th month when it accounts for 33% of Czech price level variation. In the long run shocks in outputs tend to explain more variation where Czech output accounts for 22% and euro zone's output for 11% after 3 years. Shocks in short term interest rates and exchange rate seem to describe very little variation in Czech price level.

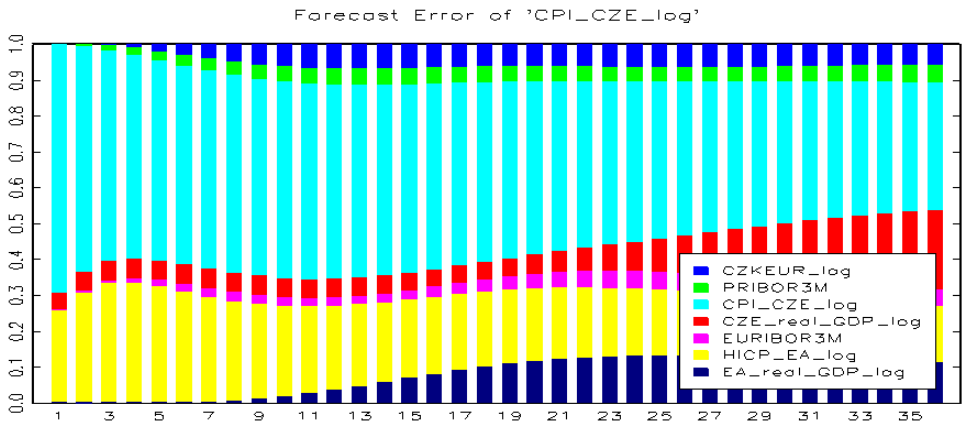


Figure 21: FEVD of Czech CPI (model 2)

Monetary transmission mechanism

MTM in details reveals some puzzle. After a monetary tightening a decrease in output would be expected. However, the model shows otherwise. With regards to reaction of exchange rate, it appreciates immediately but the effect diminishes very quickly. No sign of other puzzles is recorded.

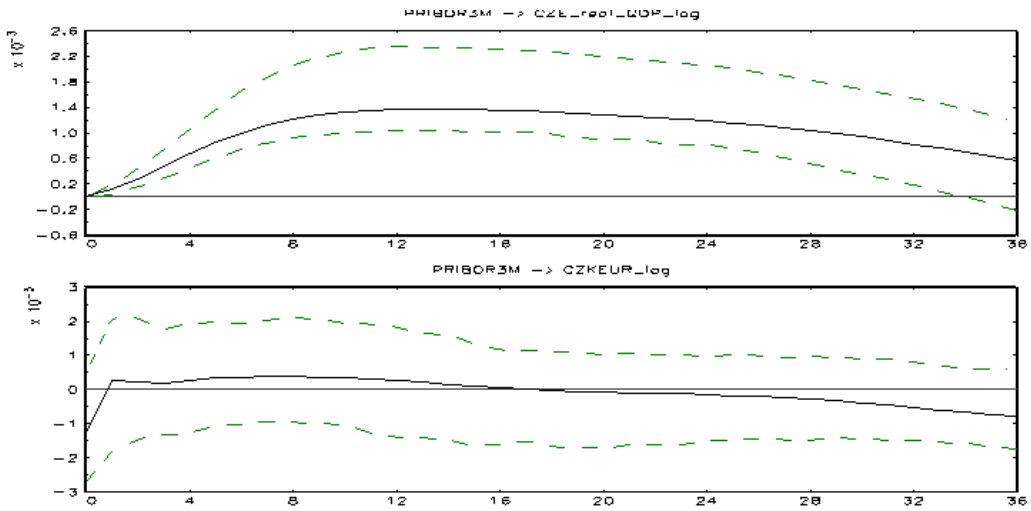


Figure 22: Impulse response functions of Czech output and exchange rate to PRIBOR shock

7.3. SVAR model – post-crisis period (model 3)

Next sample period was restricted to the period starting from January 2010 till March 2016. The optimal lag according to all criterions is 3 and therefore, 3 lags of endogenous variables are added to the model. Test for stability condition according to

CUSUM test reveals little instability at the beginning of 2013 in EA output but as all eigenvalues are greater than 1 (appendix 3) and therefore, the model can be said to be stable.

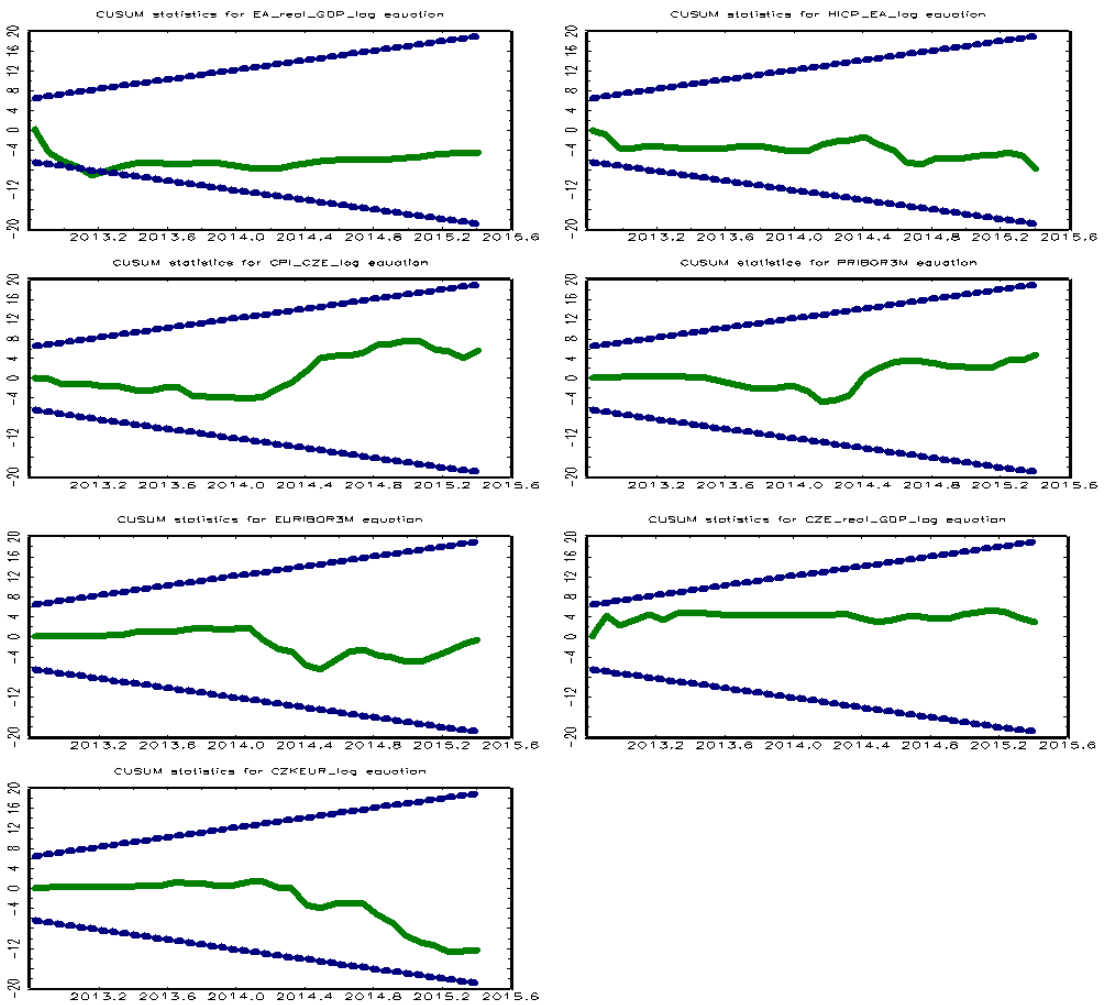


Figure 23: CUSUM test (model 3)

Czech CPI response to shock in EA's output and price level

The positive response of Czech price level to euro zone's output appears to rise on its significance between 8th and 16th month. Maximum response of 0.05 basis points (bp) was achieved in 16th month after a shock of 0.02 bp in EA's output. On the other hand, response to euro zone's price level is swifter and turns out to be very significant. There is an immediate effect that amounts to 0.0005% after a shock of 1 standard deviation (0.0017%). The response even rises in the next 3 months where it hits maximum (0.0016%). After reaching this point, the response decreases over the observed period.

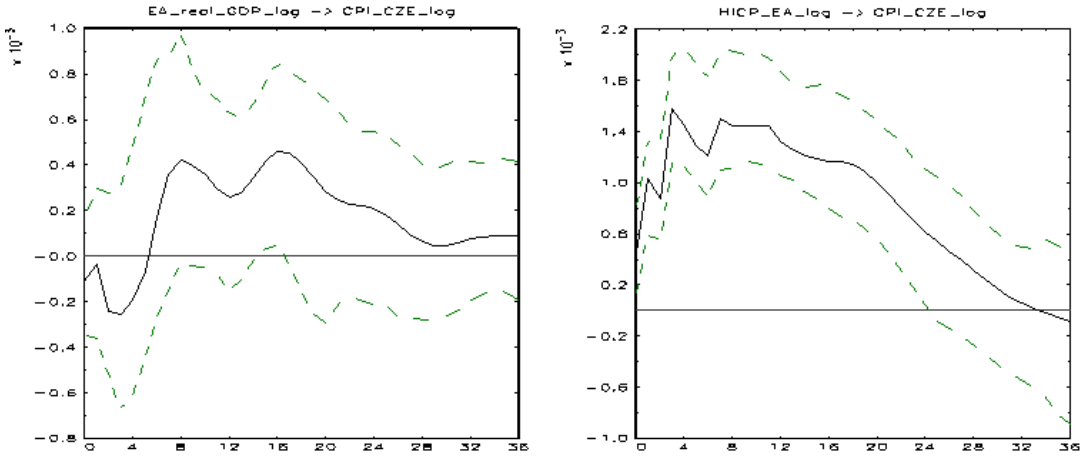


Figure 24: Impulse response function to EA output shock (LHS) and EA price level shock (RHS)

Czech CPI response to shock in EURIBOR and Czech output

Shock in EURIBOR rate causes Czech price level to react after 16 months statistically significantly. The response rises on its magnitude until the end of second year where it reaches its minimum of -0.0012%. Then the response decreases on its value and remains significant until the end of third year. Reaction to shock in Czech output is not instant but grows quickly in first three months where it reaches maximum and then it gradually decreases. After 6 months the response turns out be insignificant and after 14 months, positive effect on price index disappears.

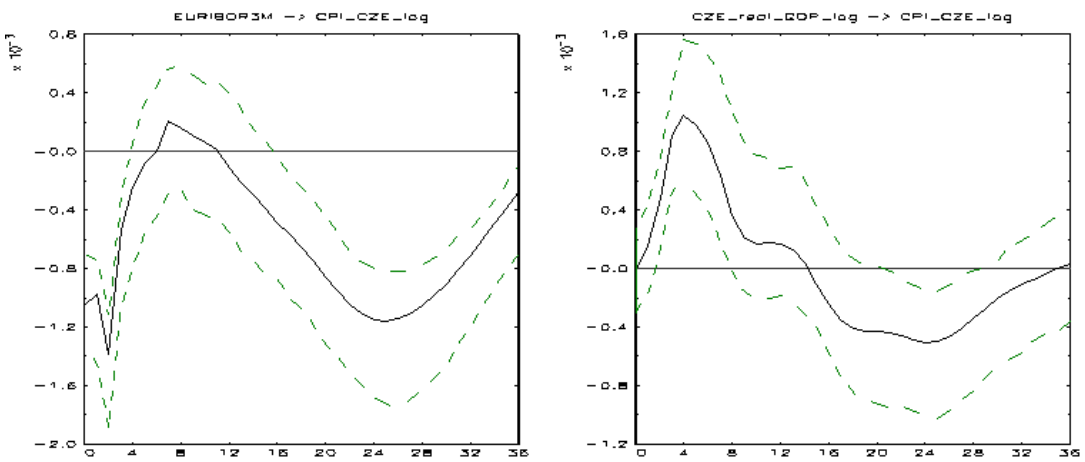


Figure 25: Impulse response function to EURIBOR shock (LHS) and Czech output shock (RHS)

Czech CPI response to shock in PRIBOR and exchange rate shock

According to impulse response to shock in PRIBOR rate of 0.0237%, the reaction of Czech price level is negative between 3rd and 17th month. The biggest impulse is measured in the 6th month when it reaches -0.0004%. Reaction to exchange rate depreciation seems to have a negative impact in 4-7 months especially in terms of magnitude. After a year or so there is rather no effect.

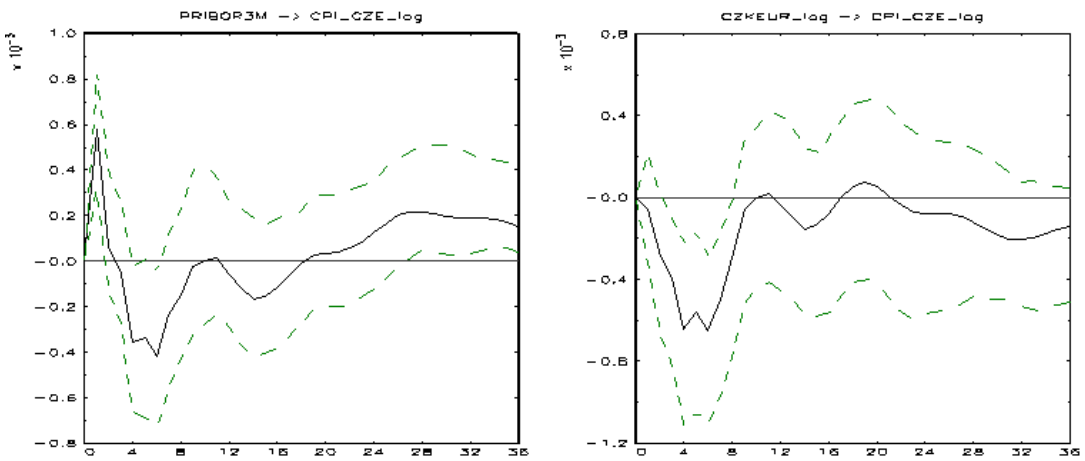


Figure 26: Impulse response function to PRIBOR shock (LHS) and exchange rate (RHS)

Forecast error variance decomposition

According to forecast error variance decomposition only in first month domestic variables dominate in explaining variation in Czech price level. In 6 months 62% variability in Czech price level is explained by foreign shocks when euro zone's price level shock accounts for 40% and shock in EURIBOR for 21%. In longer-term EA's variables rises on its importance in explaining Czech price level even to 70%

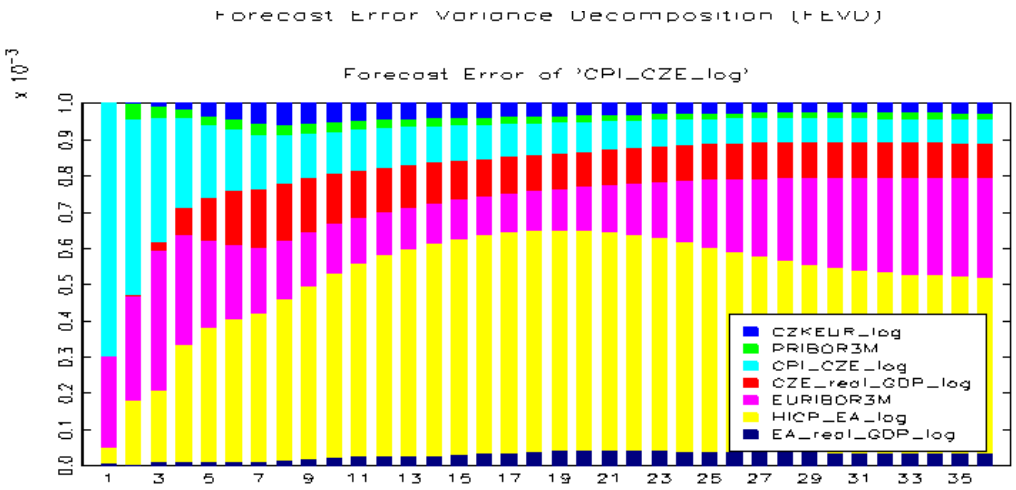


Figure 27: FEVD of Czech price level (model 3)

Monetary transmission mechanism

Similarly, as in the previous model, there is a puzzle in terms of output increase after a positive monetary shock. Exchange rate depreciates rather with slower pace which reveals signs of delayed overshooting.

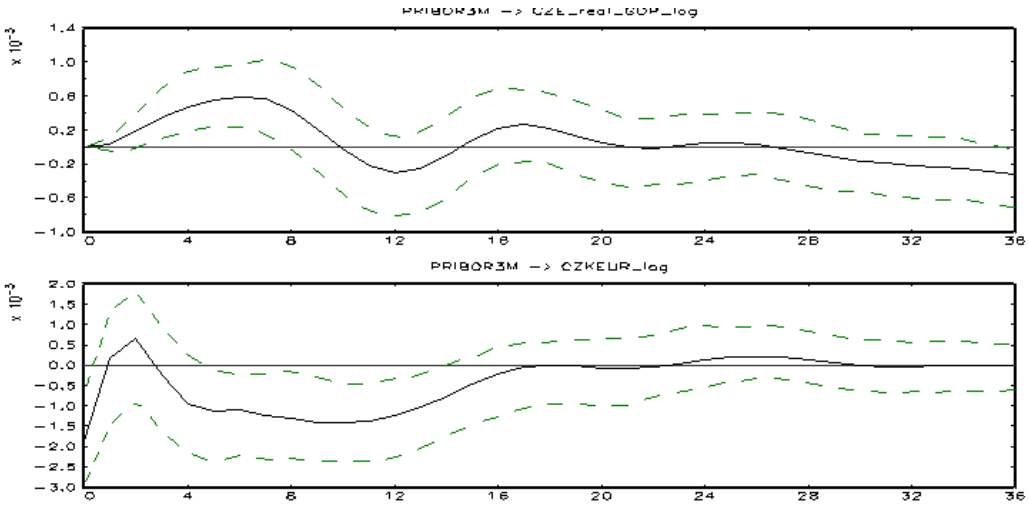


Figure 28: Impulse response functions of Czech output and exchange rate to PRIBOR shock

7.4. Sensitivity checks

SVAR with non-recursive identification

In late 1990s and early 2000s, numerous studies regarding small open economies suggested to use slightly different identification scheme in order to allow for contemporaneous effects between monetary policy and exchange rate (see for instance Kim and Roubini (2000)). One way how to achieve that is to use a non-recursive identification or to change ordering of variables in the model. Other studies from 2000s come in disagreement with this identification framework as in inflation targeting environment, there is no need for contemporaneous effect.

First of all, non-recursive identification scheme was applied. The non-recursive scheme is depicted in equation 7.3 where changes are made at place $d_{65}=0$, where we do not allow for contemporaneous effect between price level and monetary policy and $d_{67}=*$ where we do allow for contemporaneous effect between monetary policy and exchange rate. Another test is also carried out when $d_{64}=0$.

$$\begin{pmatrix} e^*_{t,xf} \\ e^*_{t,\pi f} \\ e^*_{t,if} \\ e^*_{t,xcze} \\ e^*_{t,\pi cze} \\ e^*_{t,icze} \\ e^*_{t,ER} \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ d_{21} & 1 & 0 & 0 & 0 & 0 & 0 \\ d_{31} & d_{32} & 1 & 0 & 0 & 0 & 0 \\ d_{41} & d_{42} & d_{43} & 1 & 0 & 0 & 0 \\ d_{51} & d_{52} & d_{53} & d_{54} & 1 & 0 & 0 \\ d_{61} & d_{62} & d_{63} & d_{64} & 0 & 1 & d_{67} \\ d_{71} & d_{72} & d_{73} & d_{74} & d_{75} & d_{76} & 1 \end{pmatrix} \begin{pmatrix} e^{xf}_t \\ e^{\pi f}_t \\ e^{if}_t \\ e^{xcze}_t \\ e^{\pi cze}_t \\ e^{icze}_t \\ e^{ER}_t \end{pmatrix} \tag{7.3}$$

Outcomes of the models are depicted in appendix 5 and seem more or less similar except when studying monetary transmission mechanisms. It clearly helps to get rid of any signs of exchange rate puzzle or delayed overshooting but at the cost of causing reaction of economic activity and inflation to be less significant and with reactions showing prize puzzle.

Change in ordering

Another sensitivity test where we allow for contemporaneous effect of monetary policy to exchange rate shock is to change ordering of the variables. More precisely, in the model Cholesky ordering will remain and all variables except for interest rate and exchange rate will remain at the same places. Just interest rate and exchange rate will be exchanged. Nevertheless, different ordering yields similar result (appendix 6) as in the model 3.

Output gap vs Actual output

A similar sensitivity check has been done on whether output gap or actual output perform better in the models. The opposite is true when running models 1-3. Using output gap instead of actual GDP does not bring any better result in terms of improved significance or outcomes that would go more in line with economic theory (see appendix 4).

8 Results' comparison

This section is divided into two subsections. In first subsection the differences between models that have been estimated in the previous section will be discussed. In the second one outcomes will be compared with a literature that has already been written on this topic.

8.1. Results' comparison from chapter 6

In chapter 7 results, in total three models are presented. First model (model 1) is applied on data starting in January 1999 when Euro was introduced until the most recent publicly available data, March 2016. Variables are non-stationary, nevertheless are kept in this form and are only transformed into log level form. Moreover, the model seems to be stable and that is what matters most. As the goal of the thesis is to reveal how the domestic inflation is affected, different transmission mechanisms are studied. However, when structural event happens transmission mechanisms can change. This turns out to be the case of global financial crisis and thus, this period is excluded from modelling and subsequently two models are run on pre-crisis (model 2) and post-crisis (model 3) datasets. The crisis was identified for period September 2007 till December 2009 for the purpose of this thesis. Nevertheless, most studies disregard or do not observe this fact and that is why model 1's results will be kept and compared to other ones.

Firstly, in model 1 variation of price level is described mainly by EA's price index and then by Czech price level itself, whereas in pre-crisis period it is exactly the other way around and also in longer period, the importance of Czech and EA's output rises. In the post-crisis period we register that Czech price level is described by itself mainly only in first months and then most variation is explained by EA's price level. Moreover, in the post-crisis period significant explanatory variable seems to be EURIBOR and Czech output. In terms of numbers, in pre-crisis period around 30% of variation in Czech price index was explained by external factors, whereas in post-crisis period it accounts for around 70%.

Furthermore, attention is turned to impulse responses. Firstly, the comparison of impulse responses of Czech price level to various shocks is discussed. The impulse response to EA's output and price shock seems to have the same process in all cases. In model 1 and 2 impulse responses to EURIBOR shock have rather positive effect

than negative and after Czech output shock they start to react positively after a year and a half. Here a significant change in post-crisis model can be noted. Czech price level responds negatively to EURIBOR shock and the response is significant when compared to other models. Reaction to Czech output shock in model 3 is also more in line with the economic theory and the response is maximized (positively) after 4 months. Exchange rate transmission mechanism seems to work rather only in pre-crisis period where depreciation has a positive effect on Czech price index.

When studying the monetary transmission mechanism more in details, the effect that monetary shock has on output and exchange rate is confusing in some cases. According to economic theory, monetary tightening should be followed by decrease in output and appreciation. As of exchange rate response, in model 2 the impulse response diminishes very quickly, in model 1 and 3 responses show signs of delayed overshooting. Response of Czech output is in line with economic intuition only in model 1 where it has negative impact which bottoms out after 20 months. In other two models it shows positive effect, especially model 2 provides us with quite significant results.

8.2. Results' comparison with relevant literature

In this subsection models' results are compared mainly with literature that is mentioned under chapter 2 literature review. That comprises mostly of literature regarding Czech Republic and other CEE countries. A brief overview of findings of relevant literature are also summarized in tables 4 and 5.

The methodology of models performed in this thesis in a nutshell follows more or less paper by Havranek et al (2010). Models are the same in a way they use the same variables and of the same transformation except our models do not include financial variable. Moreover, for estimation they use VAR model as opposed to our SVAR framework. The reasoning for not including financial variable is as follows. They sum up the study that inclusion of financial variable seems to improve the forecast performance, however, the improvement varies over time. Moreover, the back test was performed partly on a data during global financial crisis where authors themselves confirm that the monetary transmission mechanism during this period slows down. Moreover, paper by Nalban (2015) finds that optimal number of variables in the case of Romania is seven and current data is employed in his study. Taking into account these facts plus considering that we anticipated the structural change resulting in running model on short datasets, employing less variables seems more appropriate.

CEE's relevant literature

Even though there is a significant amount of studies coping with monetary transmission mechanism in CEE which account for domestic, as well as for foreign variables, less studies focus on foreign shocks pass through on domestic variables. According to Maćkowiak (2005) shock in foreign interest rates have negative impact on both domestic output and price level after fairly long time. In this matter we find relatively puzzling results considering pre-crisis and full period where there is either positive impact or too fast negative response of Czech price level to EURIBOR. In post-crisis period our results go more in line with Maćkowiak (2005) and moreover it seems to provide us with more robust response. On the other hand, Horvath and Rusnak (2008) witness Slovakia's price level reacting quite quickly to EURIBOR and also the output puzzle appears which reveal the same patterns as our pre-crisis period. It is no surprise that Slovakia has similar response when considering same period.

Table 4: Comparison of other VAR studies, CEE region

Research	Estimation technique	Country	Sample period	Reaction of economic activity to MP shock	Reaction of price level to MP shock
Maćkowiak (2005)	VAR	Hungary	1992-2004 (M)	-; 24; (DE MP); *	-; 32; (DE MP); *
Maćkowiak (2005)	VAR	Poland	1992-2004 (M)	-; 20; (DE MP); *	-; 28; (DE MP); *
Jarocinski (2005)	BVAR	NMS4	mid 1990s-2004 (M)	-; 9; *	-; 9; *
Horvath and Rusnak (2008)	VAR	Slovakia	1999-2007 (M)	-; 3-4; insign.	-; 6; *
Horvath and Rusnak (2008)	VAR	Slovakia	1999-2007 (M)	+; 14; (EA MP) *	-; 7; (EA MP) *
Havranek and Rusnak (2009)	Meta-analysis	Post-transition economies			10-20
Oros and Romocea-Turcu (2009)	SVAR	Hungary	2000-2007 (M)	+; 2; insign.	+; 5; insign.
Oros and Romocea-Turcu (2009)	SVAR	Poland	2001-2007 (M)	-; 2; insign.	+; 2; *
Oros and Romocea-Turcu (2009)	SVAR	Romania	2000-2007 (M)	-; 2; insign.	+; 3; insign.
Oros and Romocea-Turcu (2009)	SVAR	Slovakia	1999-2007 (M)	-; 2; insign.	+; 10; insign.
Oros and Romocea-Turcu (2009)	SVAR	Slovenia	1998-2006 (M)	+; 2; insign.	-; 36; *
Andrle et al (2013)	Trend Cycle VAR	Poland	1999-2012 (Q)	-; 12;	-; 9;
Vasile (2013)	VAR	Poland	-2012 (Q)	-; 8; insign.	-; 6; insign.
Vasile (2013)	VAR	Romania	-2012 (Q)	-; 6; insign.	-; 9; *
Vasile (2013)	VAR	Slovenia	-2012 (Q)	-; 4; insign.	+; 4; insign.
Vasile (2013)	VAR	Hungary	-2012 (Q)	-; 24; insign.	-; 12; insign.
Nalban (2015)	BVAR	Romania	2000-2014 (M)	+; 22;	-; 13;

Note: Explanation of used shortcuts: M – monthly data, Q – quarterly data, DE MP – German monetary policy shock, * - significant response, insign. – insignificant; columns with data for reaction of economic activity and reaction of price level to monetary policy shock contain 3 different type of information – the

sign of a response (positive domestic MP shock is assumed unless stated otherwise), a month after a shock occurrence when the response is maximal, and significance.

Lags of domestic transmission mechanism of CEE countries varies a lot across countries. The average lag of MTM of post transition economies found by Havranek and Rusnak (2009) should be in range of 10-20 months. Literature provided here about CEE record, however, rather shorter responses, and so do our sample splits. The CEE literature show quite a lot evidence of price puzzles which is not in our case but also mention increase of output after monetary tightening what can also be found in our sample splits. Our model on all data shows rather longer responses with no output puzzle.

Czech relevant literature

In case of the Czech Republic, there are unfortunately not many studies that would discuss more in details the foreign shocks pass through on domestic variables. Maćkowiak (2005) finds long lags in both German monetary policy and economic activity pass through on Czech price level. In our pre-crisis outcomes, EURIBOR shows that it strongly influences Czech output also after a long period (3 years). Nevertheless, the impact on Czech price level is less significant, faster and also positive. According to Havranek and Rusnak (2009) papers about Czech Republic show on average monetary transmission mechanism functioning with the lag of around 15 months. Findings vary a lot across literature. The fastest MTM is found in the most recent paper by Koerner (2015), although, he uses transformed variables in order to have stationary variables. This way he loses some relationships among variables, especially in long run and we can thus expect faster responses. Besides paper by Vasile (2013) (one of the most recent ones, though) we can note well-functioning MTM in terms of that monetary policy shock has a negative effect on price level. Considering functioning of MTM through the impact on output, most literature reveal insignificant response of output but with correct negatively correlated direction. When our full dataset is applied, even significant output response is observed. In sample splits the impulse response of GDP brings a puzzle in terms of that it shows a positive reaction to monetary shock.

Table 5: Comparison of other VAR studies, Czech Republic

Research	Estimation technique	Sample period	Reaction of economic activity to MP shock	Reaction of price level to MP shock
Maćkowiak (2005)	VAR	1992-2004 (M)	-; >48; (DE MP);*	-; 32; (DE MP)
Jarocinski (2005)	BVAR	1997-2004 (M)	-; 11; *	-; 18; *
Arnoštová and Hurník (2005)	VAR, SVAR	1998-2004 (Q)	-; 4; insign.	-; 6; *
Borys and Horvath (2008)	VAR, SVAR	1998-2006 (M)	-; 2 (11); *	-; 7; *
Havránek and Rusnák (2009)	Meta-analysis			14.8
Oros and Romocea-Turcu (2009)	SVAR	1998-2007 (M)	-; 2; insign.	-; 8; insign.
Havranek et al (2010)	VAR	1999-2009 (M)	-; 5-15; *	-; 15;
Babecká-Kucharčuková et al (2013)	VAR	1998-2010 (Q)	+; 30; insign.	-; 18;
Babecká-Kucharčuková et al (2013)	BVAR	1998-2011 (M)	-; 10; insign.	-; 18; *
Vasile (2013)	VAR	-2012 (Q)	-; 18; *	+; 12; *
Koerner (2015)	VAR	1999-2011	-; 5-6; insign.	-; 2; insign.
Koerner (2015)	SVAR	1999-2012	-; 9-16; insign.	-; 3; *

Furthermore, Babecka-Kucharcukova et al (2013) do not reveal any significant changes in monetary transmission mechanism functioning when running model on pre-crisis data and full period data. Havranek et al (2010) claim that during global financial crisis the monetary policy has slowed down but they find signs that the monetary policy is getting back to pre-crisis functioning. Our study show otherwise, especially in terms of what explains variation in Czech price level.

FEVD of relevant literature

Table 6 indicates an increasing role of foreign shocks in explaining movement in domestic price level in CEE countries, including the Czech Republic. An exception is paper by Andrle et al (2013) who claim that only 25% of variation in price level is explained by foreign shocks, but that is the case of Poland. Nevertheless, it looks like that in different time periods foreign shocks have had lower impact on Czech price level than on other CEE countries'price level such as Hungary, Poland, Slovakia or Romania. Our results based on models run on subsamples reveal similar increasing trend that foreign variables have become more important in explaining variation in Czech price level. Whereas in pre-crisis period it was around 30%, in post crisis period they account for double as much.

Table 6: Variance decomposition of domestic price level

Research	Estimation technique	Country	Sample period	% of foreign factors explaining variation in Czech price level
Maćkowiak (2005)	VAR	CZE	1992-2004 (M)	28.5%; 39.3%; 54.4%
Maćkowiak (2005)	VAR	Hungary	1992-2004 (M)	22.3%; 51.0%; 75.7%
Maćkowiak (2005)	VAR	Poland	1992-2004 (M)	52.9%; 72.5%; 81.4%
Horvath and Rusnak (2009)	VAR	Slovakia	1999-2007 (M)	39%; 54%; 68%; 74%
Andrle et al (2013)	Trend Cycle VAR	Poland	1999-2012	25%
Krusper (2012)	Factor model	CZE	1998-2012	80% (45% EU, 35% CEE)
Krusper (2012)	Factor model	Pl, Ro, Hu	1998-2013	85% CEE

Note: % of foreign factors explaining variation in Czech price level column – when more data are included then the data represents different time periods in this order – after 6 months, 12 months, 24 months and 36 months.

9 Policy implication

In this chapter policy implication based on the findigs from chapter 7 are formed.

9.1. Is inflation in the Czech Republic influenced particularly by shocks from abroad?

Based on the models employed in this thesis the short answer would be yes. This finding shall not be surprising and goes along with the existing literature on the Czech Republic itself and other CEE countries. This, however, seems not to be true when considering pre-crisis period but nowadays all evidence support this finding.

9.2. Does low inflation in euro area affect Czech inflation and do we face a deflationary trap?

As discussed in previous point foreign shocks explain most of the variation in Czech price level. With regards to model 1 containing data from 1999 up to year 2016, movements in Czech price level are determined primarily by EA's price level shocks, especially in a period longer than 6 months. In model 3 when only post-crisis period is included the effect of EA's price level is not so high as in model 1, but still it is EA's price level shocks that explain most of the variation in Czech price level.

In order to predict future development of inflation in the Czech Republic we make a use of Czech price level forecast by VAR model. The forecast is run on full data set and on post-crisis data set.

Interpreting results on inflation from our findings of Czech price level has to be carried out cautiously as term inflation is mostly linked to year on year change in price level. The outcomes of forecasts are values of price level in logarithmic form. So it has to be at first transformed into its original form by taking exponential and then inflation can be calculated based on year on year price level. Inflation forecasts are depicted in figure 29. There are three different ones – CNB forecast and forecasts by our VAR models.

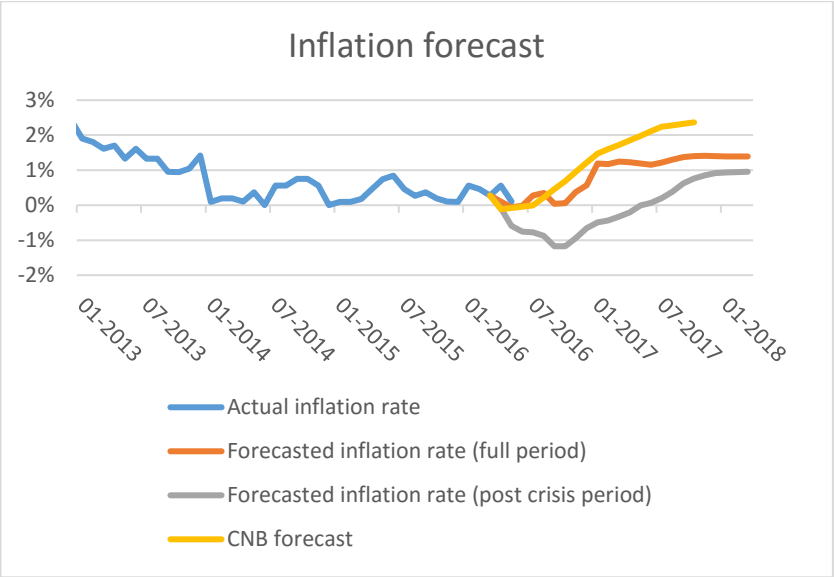


Figure 29: Inflation forecast

The primary target of CNB is to preserve price stability and inflation target which is set to 2%. It can be noted that since 2013 CNB has been unable to reach this level and the inflation rate has been many times close to zero value. With regards to current inflation development the CNB's forecast seems most promising. Even though it forecasts a disinflation that will result in deflation for 4 months, then it should bounce up and continue to rise until it reaches CNB's target in a year or so. However, we have seen that previous CNB's forecast was too optimistic and had to be corrected. Forecast based on our models do not show such optimistic attitude. The prediction by model 1 depict similar development as CNB's forecast in next half a year. Then the rise in inflation rate slows down but still it should remain in 1-3% band. Forecast based on model 3 show much more variation in inflation rate. In general, it captures similar trend which shows inflation rate will be at first decreasing and then it should be increasing. Nevertheless, it predicts the period of deflation will last for a year and then it should rise reaching a 1% value at the end of forecasted period.

The question whether Czech inflation faces a deflationary trap could be answered as follows. According to all forecasts inflation rate should really dip into negative number in the next few months but then it should rise and reach the band for inflation target which amounts to 1-3%. In this regard we do not see a threat of deflationary trap even though inflation rate will most likely experience deflation for a while.

9.3. How long does it take for inflation shock in euro zone to spread in the Czech Republic?

According to model 1 and model 3 the spread of euro zone's inflation shocks into Czech inflation is rather swift. In both models same patterns are observed. There is an immediate effect on Czech inflation which reaches maximum in the period between 3rd and 12th month. It also turns out to have very significant effect on Czech inflation development. This finding goes in line with the theory that Czech economy belongs to one of the most open ones.

10 Conclusion

The goal of this thesis was to investigate factors that influence Czech inflation development the most. For this purpose, a VAR model that proves to be reliable econometric method for estimating relationships among macroeconomic variables and especially for monetary transmission mechanism was used. More precisely, a structural VAR model that takes into account both domestic and external variables was used. Because euro area is the main trading partner with the Czech Republic, euro area's variables represent external variables.

The addition to the existing literature is primary the use of new dataset that covers period from 1999 till 2016 as most Czech literature have rather focused on pre-crisis period. Moreover, it was suspected that monetary transmission mechanism might have changed during global financial crisis and this hypothesis was proved by employed statistical tests. In summary, the thesis sheds a light on both pre-crisis and post-crisis monetary transmission mechanism development.

Due to the globalization, political and economic integration in European Union, it is not surprising that results show that nowadays, Czech price level movement is explained mainly by foreign factors as opposed to the pre-crisis period. Nonetheless, in both periods the main foreign variable that explains most the variation in Czech price level is euro area's price level. According to our results in the post-crisis period more than 70% of variation in Czech price level is explained by external shocks, out of which around 50% is explained by EA's price level. This is a big difference compared to pre-crisis period in which domestic variables explain around 70% variation. Over time the importance of EA's price level and EURIBOR raised when forecasting Czech price level. It takes 4-12 months for EA's price level to have biggest impact on Czech price level and during this period one standard deviation shock in EA's price level (0.17 basis points) results in positively correlated movement in Czech price level by 0.16 basis points. Impulse response of Czech price level to EURIBOR shock reaches its maximum after 2 years.

With regards to monetary transmission mechanism, impulse response of Czech price level after a monetary policy shock occurrence bottoms out after 6 months which seems to be faster response than what other studies have found and than what Czech National Bank claims about monetary transmission mechanism. Nevertheless, this outcome is not so rare in empirical papers especially when SVAR model is applied (see for

instance Arnostová and Hurnik (2005), Borys and Horvath (2008), Oros and Romocea-Turcu (2009) or Koerner (2015)). A little bit puzzling outcome is noticed in output response which is positive after a monetary tightening but the response shows also a lot of insignificance. There is no other significant sign of puzzle.

Recently, EA has recorded very low inflation rate and even deflation and EURIBOR has also plunged into negative numbers. As these two variables have proved to be major determinants of Czech inflation in our models, we can expect decline in Czech inflation rate as well. This outcome is also supported by our forecast which reveals that the Czech Republic will face a deflation in incoming few months but by 2018 it should be in the 1-3% band which is Czech National Bank's target. Thus, according to our findings no deflationary trap should appear in the Czech Republic.

All in all, the results based on our models show that Czech inflation is affected particularly by inflation development in euro area and currently it follows low inflation rates that are recorded in euro zone. Even though it seems a functioning monetary transmission mechanism is present in the Czech Republic, the impact of external shocks is too high to counter-attack it effectively with Czech monetary policy. Nevertheless, due to the monetary policy of cutting interest rate and unconventional measures taken by European Central Bank, inflation rate is expected to rise in long-term. As for the further research, I would recommend to use a larger dataset for the post-crisis period and inclusion of financial variable that shows to enhance forecasting performance in various models (for instance Havranek et al (2010)). In this study financial variable was omitted mainly due to the short post-crisis dataset.

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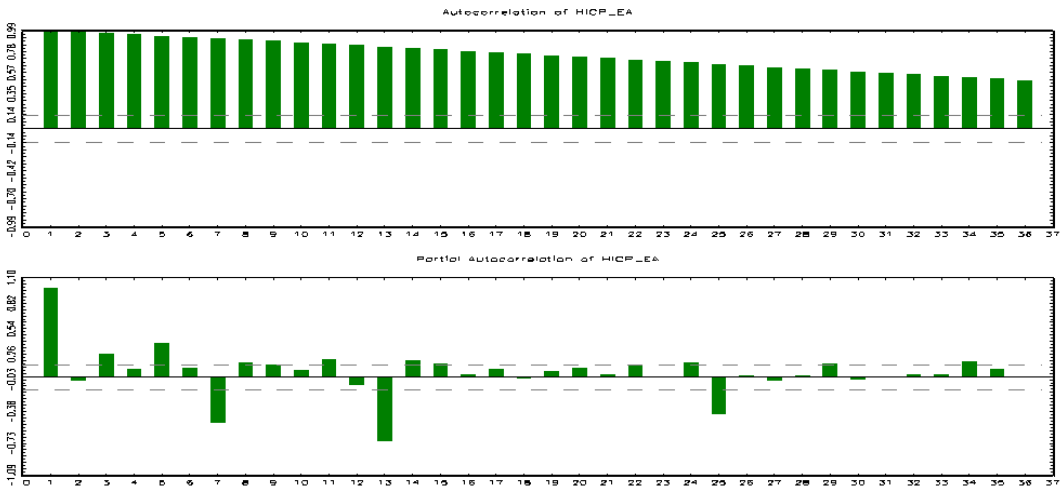
Appendix

Appendix 1: ACF and PACF of EA's HICP



Appendix 2: Modulus of Eigenvalues (model 1)

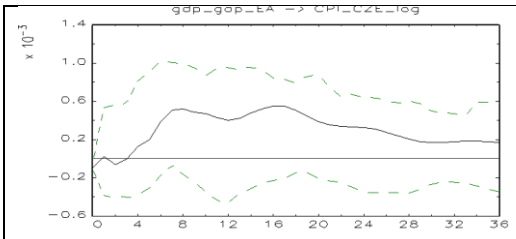
|z| = (2.1521 2.6950 2.6950 1.8019 1.8019 2.6118 2.6118 1.6247
1.6247 1.1090 1.1090 1.5406 1.5406 1.2663 1.2663 2.2495
2.2495 2.2449 1.4408 1.1548 1.1548 1.1016 1.1016 1.0190
1.0190 1.0179 1.0179 1.1024)

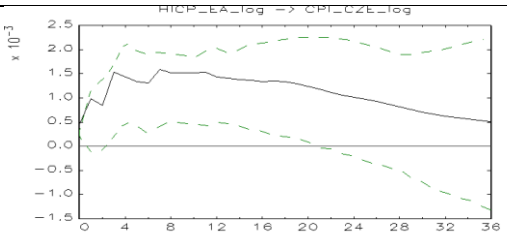
Appendix 3: Modulus of Eigenvalues (model 3)

|z| = (1.2958 1.8678 1.3448 1.3448 1.6454 1.6454 4.2674 1.2617
1.2617 1.1151 1.1151 1.1316 1.1316 3.3177 1.0187 1.0687
1.0687 1.0859 1.0859 1.2924 1.2924)

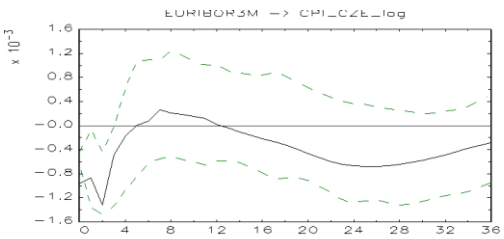
Appendix 4: SVAR model – post-crisis period; output gap instead of output

EA output gap shock	EA HICP shock

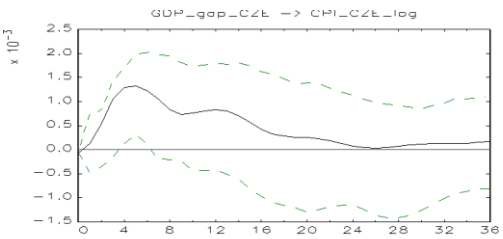




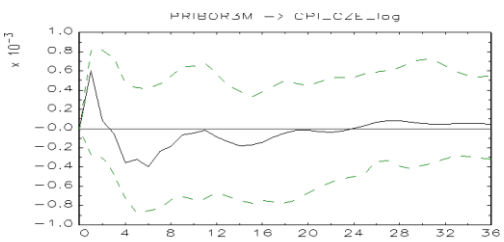
EURIBOR shock



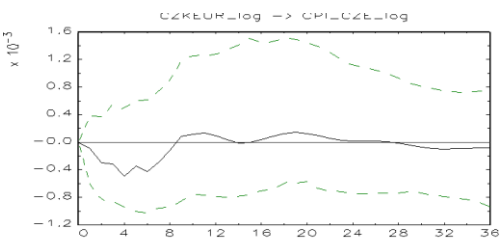
CZE output gap shock



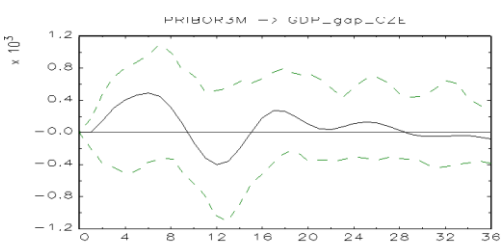
PRIBOR shock



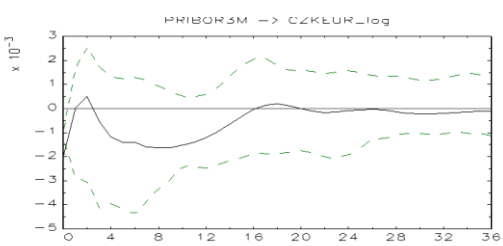
Exchange rate shock



PRIBOR shock → CZE output gap

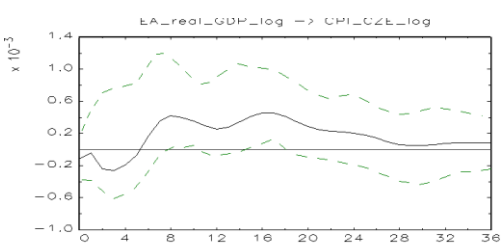


PRIBOR shock → Exchange rate

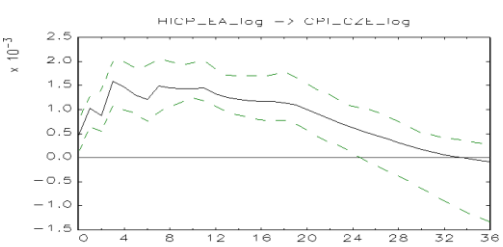


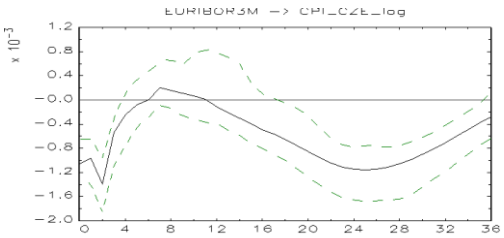
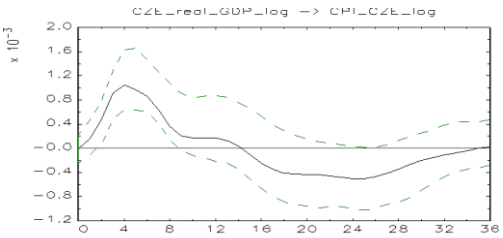
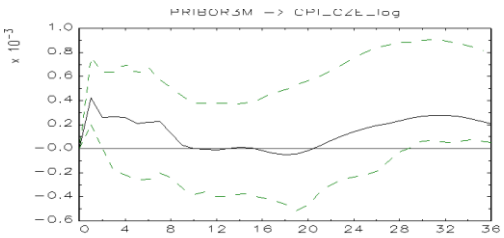
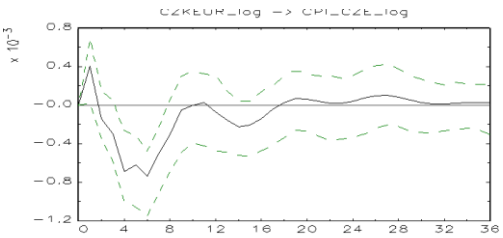
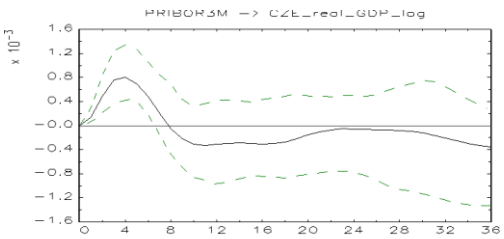
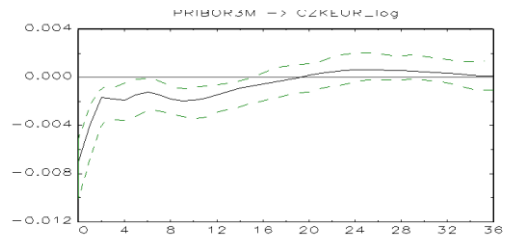
Appendix 5: SVAR model – post-crisis period; non-recursive scheme

EA output shock

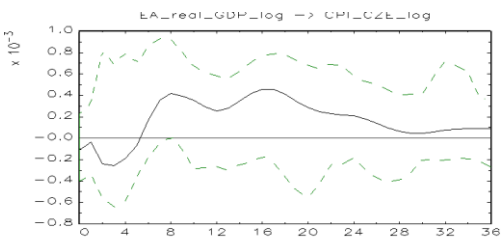
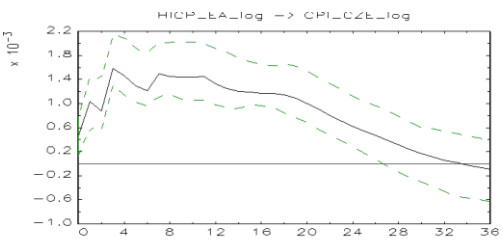


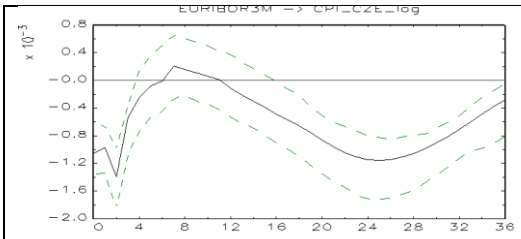
EA HICP shock

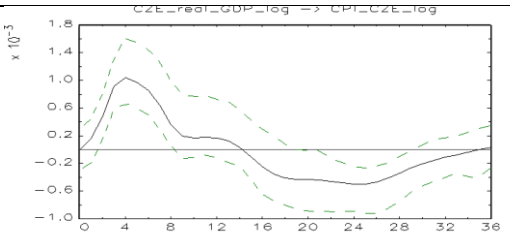


EURIBOR shock	CZE output shock
	
PRIBOR shock	Exchange rate shock
	
PRIBOR shock → CZE output gap	PRIBOR shock → Exchange rate
	

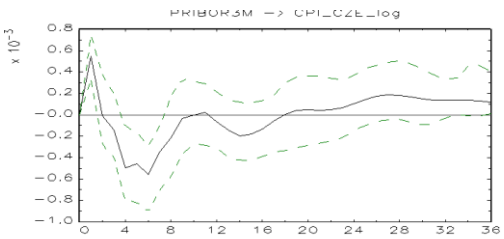
Appendix 6: SVAR model – post-crisis period; change in ordering

EA output shock	EA HICP shock
	
EURIBOR shock	CZE output shock

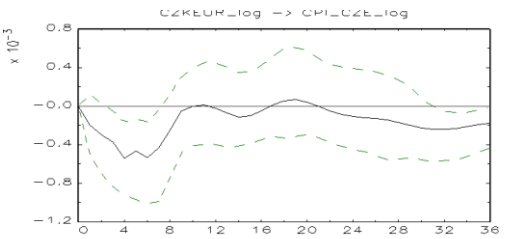




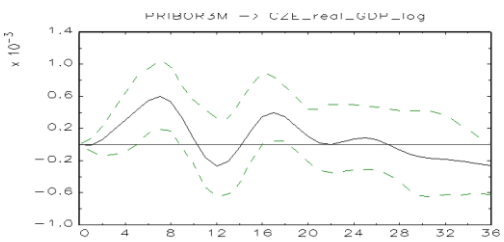
PRIBOR shock



Exchange rate shock



PRIBOR shock → CZE output gap



PRIBOR shock → Exchange rate