Masaryk University
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MODELLING LABOUR MARKET RIGIDITIES

Modelování rigidit na trhu práce

PhD thesis

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Annotation

The aim of the submitted thesis: *Modelling Labour Market Rigidities* is to examine the strucural and dynamical characteristics of the economies of the Visegrad Group using a dynamic stochastic general equilibrium model enriched with search and matching mechanisms. The main aim is to investigate the labour market rigidities that affect the macroeconomic variables. For my estimations I expand a standard model with a more complex foreign sector. Furthermore, I implement a switching mechanism to account for the monetary regime change in Slovakia. Finally, I investigate the long term impacts of the recession in 2009 on these economies.

My findings are the following: I find much higher labour market frictions in Hungary and Poland than in the rest of the economies. The parameter estimates together with the impulse responses indicate that the labour markets are more flexible in Slovakia and the Czech Republic. I discovered that the effects of the recession are negligible in the long time horizon. The results of estimation on two sub-samples are really similar. Furthermore, the robustness of the model estimates is examined by estimating four different versions of the model. Each result is close together.

Anotácia

Predmetom dizertačnej práce *Modelování rigidit na trhu práce* je preskúmanie štrukturálnych a dynamických vlastností ekonomík Vyšehradskej skupiny pomocou dynamického stochastického modelu všeobecnej rovnováhy obohateným search and matching rigiditami. Hlavným cieľom je preskúmanie frikcií na trhu práce, ktoré ovplyvňujú makroekonomické veličiny. Pre svoje odhady som rozšíril štandardný model o komplexnejší zahraničný sektor. Zaviedol som aj prepínací mechanizmus, ktorý slúži na prepínanie monetárneho režimu v Slovenskej republike. Preskúmavam aj dlhodobé dopady recesie v roku 2009 na tieto ekonomiky.

Moje zistenia sú nasledovné: Maďarský a Poľský trh práce sa vykazuje omnoho väčšími frikciami, než zvyšné dva štáty. Odhady parametrov spolu s impulznými odozvami naznačujú, že trh práce na Slovensku a v Česku je flexibilnejší. Taktiež som zistil, že dopady recesie sú v dlhom období zanedbateľné. Výsledky odhadov na dvoch kratsích časových intervaloch sú podobné. Testovaná bola aj robustnosť odhadov. Štyri odlišné odhady boli prevedené a každý z nich je celkom podobný.

Keywords

DSGE model, small open economy, rigidity, labor market, search and matching, unemployment, Visegrad Group

Kľúčové slová

DSGE model, malá otvorená ekonomika, rigidita, trh práce, search and matching, nezamestnanosť, Vyšehradská skupina

Declaration

Hereby I declare that this dissertation is my original authorial work, which I have worked out by my own under supervision of Ing. Daniel Němec Ph.D. All sources, references and literature used during elaboration of this work are properly cited and listed in complete reference to the due source.

Brno, November 22, 2016

signature

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I would like to express my greatest gratitude to everyone who helped me during times when I was at my lowest. A big THANK YOU goes to my supervisor who showered me with advices. I am grateful for my family and friends for their neverending support. I would also like to thank Julien Albertini, Ph.D. for sending me an older version of the model which made my work much easier.

Contents

Chapter 1

Introduction

The labour market plays an important role in the functioning of an economy. Countries with better conditions on the labour market usually have lower rates of unemployment and better morale of workers. Furthermore, this market is interwoven with the households, so the changes affect the people directly. It is therefore desirable for the policy makers to find and understand the driving forces that are responsible for the shifts in key labour market variables. If possible, the government as well as the monetary authority should choose such measures that lead to labour market stabilization. There are several factors that contribute to changes of the workers wages, unemployment, number of vacancies and other labour market variables. Some of them are in the hands of the central bank while others are determined by the government. The monetary authority can adjust the nominal interest rates or the money supply to raise the willingness of economic subjects to work. Similarly, the government can give incentives to firms, e.g. through tax benefits, to increase their production by hiring more employees, thus reducing the unemployment.

The authorities are not the only initiators in the fluctuation shifts of the labour market. As the observed data shows, the financial crisis of 2007-2008, which then led to the Great Recession, had a significant impact on the entire world. This negative shock caused serious disturbances in the real economies. In the majority of the developed countries the output plummeted, while the unemployment rate rose. In such times, the aim of the authorities should be to get the economy back to its growth path.

Econometric models can be used to investigate the impacts of different policies. Nowadays, the dynamic stochastic general equilibrium (DSGE) models play a crucial part in the world of macroeconomic modelling. Because the DSGE framework allows these models to be modified to a great degree, they are used for a variety of reasons by a large amount of different institutions. Using DSGE models, a central bank can investigate the impacts of different monetary policies on various parts of the economy. Government sector can examine the effects of different taxation methods, such as which taxes cause the greatest inefficiencies in the economy to minimize their occurrence. Private institutions can explore potentially risky investments in different countries based on the projections of risk premiums.

The inclusion of labour market into the DSGE model framework began in the mid 2000s, when the researchers realized the influence of labour market variables on rest of the economy. This step increased the accuracy and improved the results of estimation in general. Furthermore, with the incorporation of frictions more and more complex models are used to capture the cyclical properties of economies.

1.1 Stylized facts

Stylized facts are used to describe the relation among variables. Table 1.1 reports the deviations and correlations of the data. Given the nature of the HP filtration method, which will be adressed later, all variables have zero steady-state (mean). Deviation of interest rate with respect to the deviation of output differs greatly among the countries and so does the deviation of real exchange rate, which is almost three times as high in Poland as in the second largest, Hungary. The volatilities of unemployment and vacancies are much higher in each country than the volatility of product. This difference is given by the logarithms of these variables, where for example a rise of unemployment rate by one percentage point from 4% to 5% would mean an increase around 25%.

After examining the correlations, there are several interesting findings that are worth mentioning. First, the nominal interest rate of Hungary is only slightly, however negatively correlated with the output, while Slovakia and the Czech Republic have high correlation between these variables. Second, the inflation in Hungary is also significantly less correlated with the output, than in the other countries. Third, the real exchange rate correlates with the output weakly in Slovakia, probably because of the long period of constant exchange rate. Next, the unemployment's correlation to the output is really high and negative, as could be expected. Similarly, the correlation of vacancy with the output shows high positive numbers, with the exception of Hungary. Finally, wages are in a strong positive relation with the product, while the development hours is independent of the development of output. Two questions arise from the correlations. The first is, "how is the volatility of output around its potential (steady-state) affected by the volatility of

Table 1.1: Stylized facts - observed data

	CZE		HUN		POL		SVK	
Var.	D. to $\widehat{y}_t$	*Corr.*	D. to $\widehat{y}_t$	*Corr.*	D. to $\widehat{y}_t$	*Corr.*	D. to $\widehat{y}_t$	*Corr.*
$\widehat{y}_t$	1.0000	*1.0000*	1.0000	*1.0000*	1.0000	*1.0000*	1.0000	*1.0000*
$\widehat{r}_t$	0.2719	*0.6313*	0.7955	*-0.0757*	0.6222	*0.2458*	0.3396	*0.7993*
$\widehat{\pi}_t$	0.1967	*0.5186*	0.2887	*0.0087*	0.2255	*0.4728*	0.2142	*0.2457*
$\widehat{rer}_t$	1.5219	*-0.4250*	1.8839	*-0.2577*	5.4252	*-0.3506*	0.8293	*-0.0292*
$\widehat{u}_t$	6.2533	*-0.7811*	4.2679	*-0.6535*	9.1988	*-0.5441*	4.3064	*-0.7272*
$\widehat{v}_t$	14.7079	*0.8564*	6.7577	*0.2494*	12.5941	*0.6392*	13.9978	*0.7500*
$\widehat{w}_t$	0.5421	*0.7657*	0.6421	*0.6062*	1.2667	*0.6997*	0.5998	*0.4060*
$\widehat{h}_t$	0.3780	*0.0500*	0.2902	*0.0039*	0.3869	*0.1810*	0.4559	*0.1474*

Note: standard deviations with respect to $\widehat{y}_t$ are calculated as a ratio between the std. dev. of the variable over the std. dev. of domestic output. The std. dev. of outputs are: 0.0205 for the Czech Republic, 0.0162 for Hungary, 0.0134 for Poland and 0.0231 for Slovakia. *Corr.* represent the correlations between the variable and output.

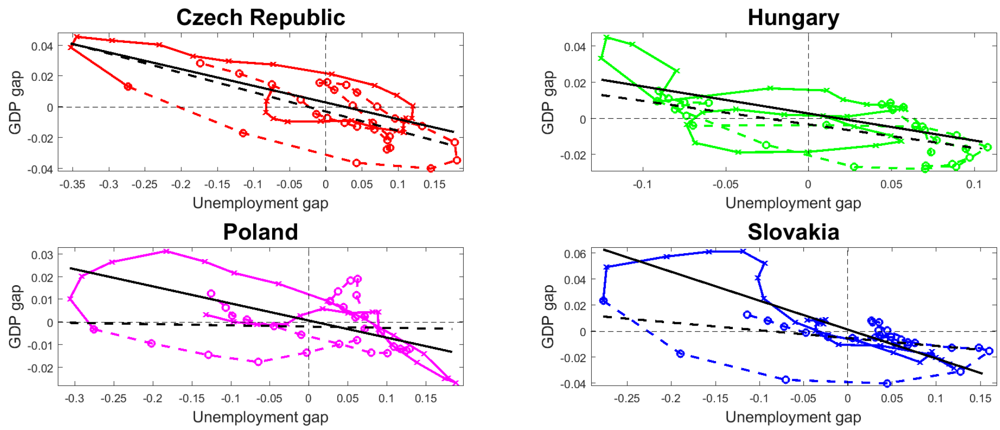
the unemployment around its natural level?" Second, "what is the connection between unemployment and vacancies, given their opposite correlation with the output?" The first of these questions can be answered with the use of the Okun's law, while the answer for the second lies in the examination of the so-called Beveridge-curve.

Okun's law

One easily comprehensible way to look at the relationship between the labour market and the rest of the economy is the Okun's law, which is investigated on a regional level for Slovakia and the Czech Republic by Durech et al. (2014). Okun (1962) observed a negative correlation between unemployment and output in the post-World War II USA data. In his paper, he derived three options to model this relationship. The first approach included the *first differences* of unemployment (in percentage points) and output (as a percentage change in the real product). The second method used *percentage gaps* from the natural rate of unemployment and potential product. The main drawback of this approach is the inability to measure these trends. The third technique combined *fitted trend and elasticity*. However, as Okun argues, his results are not universal to every economy at any time. Knotek (2007) also examines the usefulness of the Okun's law and discusses some alternative formulations of this relationship, like the dynamic version and production function version.

Given the nature of my data (quarterly deviations from steady state), the second

Figure 1.1: Gap version of Okun's law



Note: solid lines depict the development before 2008-Q4, dashed lines represent after. The black lines are the OLS estimates of the relationship between the two variables. Author's processing.

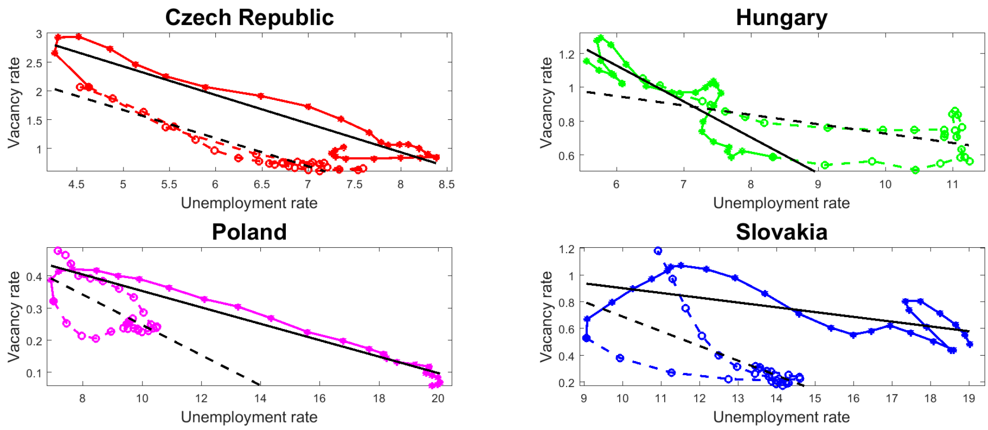
method is presented in figure 1.1. The natural rate of unemployment and potential product are the trends removed by the HP filter around which the observed data oscillate. The observed period is divided into two sub-periods to reveal possible structural changes in the examined economies. The ordinary least squares (OLS) estimation is carried out in Matlab and the resulting regression lines are plotted in back. The figure indicates that the Okun's law holds for each country in both periods, except Poland during the recession. The Czech Republic and Hungary have similar coefficients in both periods, while for Poland and Slovakia they differ. This could indicate some changes in structural parameters.

Beveridge curve

The correlation of output with unemployment and vacancies in table 1.1 may suggest a relationship between unemployment gap and vacancy gap. A straightforward method to look at the relationship between these variables is the Beveridge curve (or UV curve, for unemployment-vacancy) developed by Dow and Dicks-Mireaux (1958). This curve is a graphical representation of the relationship between unemployment rate and vacancy rate. As is presented in figure 1.2, this relationship is negative. Because this figure is in original rates and not gaps, the intercept is no longer zero. In the case of the Czech Republic, only the intercept changed between the two time periods. In the rest of the countries, the slope of the OLS regression line changed as well.

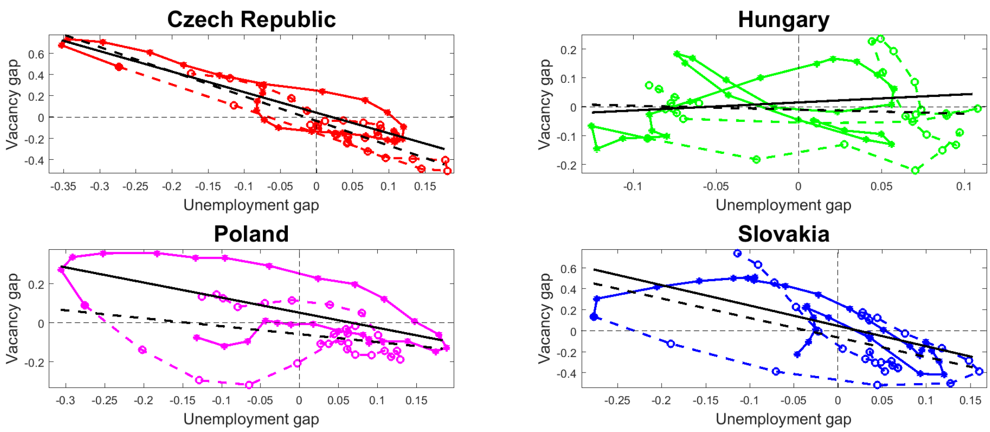
Because I use data which represent gaps from steady-states in my thesis, I present also

Figure 1.2: Beveridge curve - rates



Note: solid lines depict the development before 2008-Q4, dashed lines represent after. The black lines are the OLS estimates of the relationship between the two variables. Author's processing.

Figure 1.3: Beveridge curve - gaps



Note: solid lines depict the development before 2008-Q4, dashed lines represent after. The black lines are the OLS estimates of the relationship between the two variables. Author's processing.

the gap version of Beveridge curve (figure 1.3). Here the relation between unemployment gap and vacancy gap is no longer correlated in Hungary.

1.2 Aims of the thesis

In the light of the motivation outlined above, the aim of my dissertation thesis is to examine the structural and dynamical characteristics of the countries of the Visegrad Group (V4), namely the Czech Republic, Hungary, Poland and Slovakia. My focus lies mainly on the investigation of labour market variables. However, I am also interested in the impacts of the monetary policy and the influence of the financial crisis on the examined economies. To examine the labour markets of the selected economies, the following research questions are formulated:

- What are the structural characteristics of the labour markets of the examined economies? Also, is the structure of these markets stable or is it time-varying, or does it depend on the specification of the model?
- Which rigidities are present in the economy and to what degree?
- What is the connection between the dynamics of the labour market and the rest of the economy?
- How does the monetary authority influence the unemployment and other real variables by setting the nominal interest rates?
- Is the impact of the financial crisis still observable? Also, did the degree of frictions change due to the recession?

Each of the four countries is examined separately and then a comparison is made to find possible similarities and differences among these countries. By answering these research questions, I aim to identify the main causes of labour market frictions and their different effects on the four economies.

1.3 Methodology

If one wants to investigate the characteristics of a real economy, the easiest way is to use a model, which serves as a simplification of an otherwise complex system. To examine the labour market characteristics I chose a New Keynesian dynamic stochastic general equilibrium model. Given the nature of V4 countries, a small open economy model is used. Although one can argue about the size and openness of Poland, I will show that the selected model represents the Polish economy relatively well.

The New Keynesian (NK) version has a major advantage over neoclassical models, like the real business cycle (RBC) model. It allows the researcher to implement real and nominal rigidities, for example hiring costs or price frictions. Thanks to these extensions the estimation results of the model fit the observed data better.

According to Wickens (2008), in the dynamic general equilibrium (DGE) model "*the economy is viewed as being in continuous equilibrium in the sense that, given the information available, people make decisions that appear to be optimal for them, and so do not make persistent mistakes. This is also the sense in which behavior is said to be rational. Errors, when they occur, are attributed to information gaps, such as unanticipated shocks to the economy.*" Furthermore, he states that "*the equilibrium – short or long – is described as general because all variables are assumed to be simultaneously in equilibrium, not just some of them, or a particular market, which is a situation known as partial equilibrium.*" And also "*DGE models are intertemporal. The models are forward looking. Current decisions are affected by expectations about the future.*"

The main advantage of the general equilibrium model compared to its partial equilibrium counterpart is its ability to examine the economy as a whole rather than individual pieces of the economy put together. This allows us to follow the effect of a change in one macroeconomic variable to the other parts of the economy. Therefore, a policy maker has a better understanding of the impacts of his decision.

Another advantage of the NK DSGE models is that they are resilient against the Lucas critique, which Lucas (1976) summarized as follows: "*Given that the structure of an econometric model consists of optimal decision rules of economic agents, and that optimal decision rules vary systematically with changes in the structure of series relevant to the decision maker, it follows that any change in policy will systematically alter the structure of econometric models.*" DSGE models are structural, micro-founded models with deep parameters. Considering this, Hurtado (2013) points out that if they are well specified, then they are not affected by policy changes. Therefore DSGE models are not affected by the Lucas critique either.

Although, as Levine (2010) argues, there are several shortcomings to NK DSGE models. The first is the problem with rationality and expected utility maximization. As many economists have pointed out, agents often behave irrationally. But as was mentioned above, agents in DSGE models make optimal decisions and avoid persistent mistakes, thus behave rationally. The next issue with DSGE models is the absence of endogenous growth. This is because the majority of these models deal with short run fluctuations around a steady state and not the development of the long run trend. Another problem concerns all macroeconomic models based on microeconomic foundations: heterogeneity of agents and aggregation of goods. To minimize this problem, it is possible to divide agents and goods into smaller groups to get a higher rate of heterogeneity.

Despite these imperfections the NK DSGE small open economy (SOE) models are a widely used tools for estimations and forecasts. Mostly because they have proven to represent the economy more realistically than other models. In the structural vector autoregression (SVAR) models the equations are based on presumed relationships between variables. This definition of model equations can often be unintuitive. On the other hand, the DSGE models are derived from microeconomic foundations to represent each agent separately. This allows us to implement more structure on the modeled economy. Therefore we can examine not only changes in the dynamics but also structural changes. Also, the interpretation of parameters and exogenous shocks is more straightforward. Each variable is influenced by a combination of shocks. This is a more realistic view on the actual economy. Shocks in one part of the economy are able to influence variables in other sectors and the final change is given by a combination of shocks.

To be able to search for possible structural or dynamical changes and to investigate the long term effects of the crisis, I decided to split the examined time period at the time of the recession in 2009. As the National Bureau of Economic Research (NBER) typically dates the start of a recession by the first quarter in which the economy undergoes two quarters of negative growth, it is reasonable to divide the observed time period here. The second significant drop of output happened in the first quarter of 2009, thus this observation is the first in the *after* crisis period.

1.3.1 Bayesian estimation

To estimate the model I use Bayesian techniques instead of classical econometric approach. Griffoli (2010) points out five reasons why it is more advantageous to use Bayesian methods to estimate a DSGE model. First, if the model is well-specified, the Bayesian estimation fits the complete, solved DSGE model, as opposed to generalized method of moments (GMM) estimation which is based on particular equilibrium relationships. Second, the presence of priors in Bayesian methods can tilt the peak of the posterior distribution from values that are contradictory with common observations even if the likelihood peaks there. Third, the prior setting also helps in the problem of parameter identification. It can be helpful by adding enough information to the posterior distribution to allow for numerical maximization. Fourth, Bayesian estimation addresses the problem of model misspecification by including shocks in the structural equations, which can be interpreted as observation errors. Fifth, Bayesian estimation allows an easy comparison of models. By comparing the posterior distributions of different models with the data, the best fitting model can be discovered.

1.3.2 Tools of empirical analysis

After the estimations of the NK DSGE SOE models, the following analytical tools are used to find the answers to the research questions:

- *Impulse response functions (IRFs)* show us what happens to the endogenous variables if a single exogenous shock causes a deflection from their steady state values. This also allows us to make a distinction between the immediate impact of the shock and the over-time effect. With the help of economic theory, IRFs help us determine the transmission mechanisms among the shock and the selected variables. More specifically, this tool will be used to evaluate the influence of the monetary policy on the labour market.

- *Parameter estimation* helps us determine the structure of the economy. It will be used among other things to find the degree of labour market frictions, determine the strength of trade unions and to specify the monetary policy making rule.

- *Historical shock decomposition* displays the deviations of endogenous variables from their steady states throughout the observed period. But more importantly, it shows the decomposition of variables to contributions of exogenous shocks in each period. Therefore, this tool helps us find the shocks which caused the disturbances in the variables in different time periods.

- *Smoothed variables and shocks* show the paths of both observed and unobserved endogenous variables as well as the exogenous shocks estimated by the model. Using the Kalman filter allows us to investigate the trajectories of unobservable variables, like matching efficiency or labour market tightness.

1.4 Structure of the thesis

Before I can answer the research questions set in section 1.2, I first outline the existing literature in chapter 2. This part collects papers and articles which investigate labour market characteristics, as well as the implications of monetary authority's decisions. The following chapter 3 describes the technical side of the selected NK DSGE SOE model, which is used for estimation. This chapter is ended with modifications that are implemented into the model to improve its ability to match the volatility of the data. Chapter 4 then depicts the time series obtained for the estimation. The data transformation and model calibration is also described in this section. Chapter 5 provides technical definitions of the methods mentioned in section 1.3. It also lists the tools which are used for the empirical analysis and serve to answer the research questions. The most essential part of this thesis is contained in chapters 6 - 10, where the results of my investigations are described. Each result is presented with a commentary for all examined countries and also a comparison is made among the economies. Finally, chapter 11 concludes.

1.5 Chapter's summary

This chapter introduced the examined topic with an outline of motivation which contained some basic relations among macroeconomic variables, like standard deviations, Okun's law and the Beveridge curve, that will be examined in this thesis. The following section defined the aims of the thesis in form of research questions. The next part of this chapter contained the methodological background that explains the reasons of the selected methods. The subsequent chapters are organized to bring me closer to answering the research questions.

Chapter 2

Literature review

Due to the fact that my thesis is focused on the frictions of labour market and I aim to investigate the structural and dynamical characteristics of economies using a DSGE model, this chapter covers mainly the current state of knowledge of different methods to model the frictions of this sector of the economy with a DSGE model.

Because of the high degree of variability, DSGE models are widely used tools of macroeconomic researchers and monetary policy makers. Depending on the goal of the research, the DSGE models differ greatly. Some contain government sector and try to implement different fiscal policies, others focus on the importance of the financial market or the housing sector. It is a generally accepted and proved fact, see for example Krause and Lubik (2007) or Sheen and Wang (2012), that models with nominal and real rigidities represent the actual economies better at matching the short term fluctuations than the models without these frictions. First, I mention several ways to implement real and nominal rigidities to the model. Next, I present models that investigate the effects of rigidities on the monetary policy. Finally, there exist several interesting modifications and improvements to labour market, such as inclusion of minimal wage or different labour market institutions. At the end I will also discuss a few models estimated on the economies of V4.

2.1 Models with labour market

Many influential papers before 2007 neglected the role of labour markets in the behaviour of the economy and did not explicitly include labour market relations. This was the case of Smets and Wouters (2007) who estimate a model on US data for the period between the first quarter of 1966 and the last quarter of 2004. They provide out-of-sample forecasts to examine the models capacity to fit the real data and to compare the results of their NK DSGE model with standard and Bayesian VAR models. Their results suggest that the DSGE model is comparable to the VAR models in most cases. They also investigate, which frictions play the most important role in making the results more accurate. While the price and wage rigidities contribute evenly, the investment adjustment cost is the most crucial for improving the prediction errors. Finally, they divide their data set to two subsamples – period from 1966Q2 to 1979Q2 and from 1984Q1 to 2004Q4 – to investigate the stability of parameters over time. Most of the structural parameters remain unchanged during these two time periods. However, the variances of structural shocks differ to explain the change of volatilities in observed variables.

After the critique of Chari et al. (2008) concerning the inability to distinguish between the effects of wage markup shocks and preference shocks on the volatility of real gross domestic product (GDP), Galí et al. (2012) expand the Smets and Wouters (2007) model by implementing the labour market by adding involuntary unemployment. For some interesting comments about this paper see Christiano (2012) and Rogerson (2012) or the discussion (2012) that followed the presentation at the 2011 National Bureau of Economic Research conference. The labour market is added in line with a series of papers by Galí (2011a, 2011b and 2011c) who stressed the importance of labour market implementation and explained how to include unemployment into New Keynesian DSGE models. The modified model presented by Galí et al. (2012) results in a conclusion that wage markup shock, indeed, does not play such a significant part in output and employment volatility, as was estimated by the benchmark model. They also find the demand shocks to be the main driving factor behind unemployment fluctuations and the adverse risk-premium shock had the greatest influence on the unemployment during the recession in 2009. They also provide several robustness checks based on a number of alternative specifications.

The concept of search and matching function was introduced by Mortensen and Pissarides (1994). Prior to this, the estimated models contained either no labour market or perfectly competitive market. The matching process is a real rigidity that prevents job seekers to pair with vacancies. The authors examine job creation and job destruction processes and study their properties in the United States. They conclude that when the labour productivity is high, there is a higher chance for the unemployed to find a job and a lower probability of destruction of existing job.

Lubik (2009) estimates a model for the United States containing vacancy posting cost developed by Rotemberg (2008). This is another way to implement real labour market frictions to the model: the firms are less willing to hire and fire workers, because they cannot create vacancies for free. Lubik states that most of the structural parameters of the model are not dependent on the model specification. However, specific parameters, like the search costs or worker benefit, can vary widely across specifications, and thus are likely not identified in either an econometric or economic sense.

Riggi and Tancioni (2010) debate, whether the model with real or nominal wage rigidities fits the empirical data of the U.S. better. Their research shows an undeniable preference of the model with the nominal rigidities, which gives more data-consistent results. Similarly, Sheen and Wang (2012) investigate the presence of nominal and real wage rigidities in the Australian economy with possible hiring cost. They estimated four models and the results confirmed the presence of hiring costs in Australia and significantly long periods of fixed prices. Contrary to Riggi and Tancioni, the model containing real wage rigidities fits the data better.

Furlanetto and Groshenny (2012) point out the importance of matching efficiency shock in the U.S. during the Great Recession. They show that the effect of the matching efficiency shock greatly depends on the form of the hiring costs. In the case of post-match hiring costs (cost of training), the effect of the matching shock on unemployment is minimal. When the hiring cost is pre-match (vacancy posting cost), a positive matching shock decreases the unemployment. However, as they imply, this would suggest a positive relationship between the unemployment and the vacancies, which is in contrast with the empirical evidence (negative relationship in the Beveridge curve). In the second case, the presence of nominal rigidities is crucial for the transmission mechanism.

The model I use for my research, was developed by Albertini et al. (2012). They estimated the interactions between labour market and the other parts of the economy on New Zealand data. The results show a disconnection between these two sectors. Also, rigidities play a significant role in the transmission mechanism of the monetary policy. The main features of this model are price and wage setting frictions, search and matching rigidities and vacancy creation costs. This model is described in more details in the chapter 3.

2.2 Monetary policy and labour market frictions

Thomas (2008) decided to investigate the optimal monetary policy under different levels of wage rigidities. Under completely flexible wages, he finds the ideal inflation to be zero. However under wage frictions, the monetary authority should secure a positive inflation to decrease the volatility of unemployment. Therefore, the monetary policy holds a tool which can actively help in the labour market stabilization.

Christiano et al. (2010) estimate a series of models focusing on the analysis of the monetary policy. They describe the implications of the monetary policy maker's decisions as well as the factors that influence the monetary authority. They also investigate the appropriateness of the usage of Hodrick-Prescott filter as an estimator of the output gap and the benefits of estimation with Bayesian techniques. Finally, they compare the impulse response functions of the DSGE model with the results obtained by vector autoregression estimation.

The role of monetary policy for labour market dynamics is discussed also by Christoffel et al. (2009). They use a DSGE model augmented with search and matching frictions and wage rigidities to determine the factors important for the monetary policy's effectiveness in the euro area. They find flexible wages to increase the efficiency of the central bank. However, apart from the wage rigidities, other labour market characteristics have limited impact on the transmission of the monetary policy. They also suggest the bargaining power of workers to be an important information carrier for the monetary policy makers, and they emphasize the need for labour market modeling for the central banks.

Blanchard and Galí (2010) also investigate the presence of labour market frictions and the role of monetary policy in such setting. They find the relationship between inflation and unemployment to be dependent on the relation between labour market tightness and unemployment, while this relation depends on other labour market characteristics. The different characteristics can then explain the varying effects of shocks between the economies. The authors furthermore suggest that the central bank cannot aim to stabilize inflation and unemployment at the same time, because there is a trade-off between these two variables.

Another study about the implications of monetary policy, where search and matching mechanism is implemented in the model is presented by Tang (2010). He uses linear-quadratic approach to obtain the optimal policies of macroeconomic decision makers. He states that when there is no government intervention, search externalities can be internalized through the wage bargain only if the elasticity of the firms' worker-finding rate equals the workers' bargaining power. This is known as the Hosios (1990) condition. Inefficiency may arise if the Hosios condition fails. If so, the government may use appropriate labour-market policies (e.g., unemployment benefit, distortionary taxes, etc.) to correct such inefficiency. Yet, if the government has limited access to those policies, monetary policy may be used to correct for search externalities. In that case, search inefficiency may play a role in shaping optimal monetary policy. The assumption of Hosios condition and wage rigidities imply that job search is efficient in the deterministic steady-state, but inefficient during the course of economic fluctuations. Tang found that the monetary policy maker should take into consideration the stabilization of employment dynamics. He concludes that inefficiency in the labour market may result in a trade-off between stabilizing inflation and stabilizing real activities.

As Faia (2009) notes, in the absence of a labour market frictions, the monetary policy maker faces no trade-off between unemployment and inflation. However, when the Hosios condition is not met, search externalities make the flexible price allocation unfeasible. She analyzes the optimal monetary policy in the environment with Rotemberg type sticky prices[1] and matching frictions. In response to both productivity and government expenditure shocks, the optimal policy deviates from price stability. Also, the optimal inflation volatility increases with the workers' bargaining power.

For other interesting articles on the models with nominal and real wage rigidities and monetary policy making see e.g. Krause and Lubik (2007), who investigate the (ir)relevance of real wage rigidities on labour market and inflation dynamics; Kuester (2010), who argues that real rigidities at firm level are important in the understanding of the macroeconomic dynamics or Thomas (2011), who shows real price rigidities to have the effect of slowing down the adjustment of the price level to shocks which causes inflation to become less volatile and more persistent.

2.3 Labour market and other sections of the economy

By implementing financial frictions for capital and employment frictions for labour, Christiano et al. (2011) estimate a small open economy model on Swedish data. They reacted to the situation shortly after the crisis by recognizing the need of implementing the financial sector into the model. Their findings suggest that the labour supply shock is unimportant in explaining the volatility of GDP. On the other hand, the development of GDP and investments depends to a great extent on the introduced financial shocks. In this article, the authors also differentiate between cost of vacancy posting and cost of

[1] Rotemberg (1982) type friction induces additional costs to the wage optimizing firm. The difference between Calvo and Rotemberg frictions is described in section 3.1.1. This thesis also uses frictions as in Rotemberg, see section 3.4.

hiring. They find evidence for the latter, but not for the former. Finally, they conclude with a note that the foreign sector plays an important role in the Swedish economy.

Faccini and Ortigueira (2010) investigate the influence of investment-specific technology shock to the frictional labour market. They deviate from the standard literature which leaves out the capital formation of the models investigating the labour market and incorporate capital as an additional production factor. According to the results the technology shocks have only limited impact on the labour market variables. On the other hand investment-specific technology shocks have influence on the unemployment, vacancies and the worker's job finding rate. These shocks explain around one third of the volatility of labour market variables.

Coenen et al. (2007) examine the effect of taxes on the labour market. Especially, the taxes that drive a wedge between the effective wage of households and the effective labour cost of firms. These taxes cause inefficiencies on the labour market. They compare these taxes between the U.S. and the euro area. Their results suggest that if the taxes in the euro area were on the same level as in the U.S. the hours worked would increase, which would raise the output. This would also have a positive effect on the euro area's trading partners.

The difference of labour market institutions[2] among four major euro area countries (Germany, Spain, France and Italy) is examined by Consolo and Hertweck (2008). They are interested whether the difference in the dynamics of wages, job flows, unemployment and other labour market variables among the selected countries can be explained by these institutions. They use a DSGE model with matching frictions, hiring costs, price rigidities and different labour market structure for each country. They argue that even though the institutions play a significant part in the development of labour market variables, not all of them are bad or harmful.

Heberer (2010) takes a different approach. She incorporates the notion of minimum wage – in both nominal and real terms – into the DSGE model. Her findings support the general view on the minimal wage. If it is restrictive, it decreases the output, consumption and investment, while this decline cannot be compensated by a positive technology shock.

Zhang (2012) connects the analysis of the labour market with the examination of financial sector for the Canadian economy. Furthermore, he implements a two sector

[2] Boeri and van Ours (2013) define labour market institution as a system of laws, norms and conventions resulting from a collective choice and providing constraints or incentives that alter individual choices over labour and pay.

labour market (tradables and non-tradabeles) and differentiates between domestic and international financial market. The author finds the domestic shocks to be more important for the development of the Canadian unemployment and the effect on the non-tradable sector is stronger.

The aim of Ernst and Semmler (2010) is to investigate the global macroeconomic dynamics when search frictions are present in both labour and capital markets. Instead of relying on first or second order approximations around a (unique) steady-state, their paper uses dynamic programming techniques to compute decision variables and the value function directly and assess the local and global dynamics of the model. They investigate the impacts of monetary policy decisions when capital markets exhibit severe frictions. The improvement of asset values and de-leveraging will strengthen firms' credit worthiness and borrowing capacity and increase capital stock and employment.

2.4 Models of V4 countries

There are several articles that use DSGE models for the estimation of the economies of V4. However, to my knowledge, the DSGE literature covering the labour market of these countries in detail is scarce. With this thesis I also aim to fill this knowledge gap. The presented papers either aim to examine the labour market or at least contain some sort of labour market implementation.

The working paper of Benk and Jakab (2012) examines the macroeconomic effects of various fiscal consolidation policies in an estimated open-economy DSGE model of Hungarian economy. Moreover, it attempts to identify the possible non-Keynesian effects that fiscal consolidation may generate. As the authors state, a 'non-Keynesian effect' is such, when the final effect of a fiscal consolidation becomes expansionary. The authors find that the effects of fiscal consolidation in Hungary are mostly contractionary regardless of the fiscal instrument. Also, considering the high level of indebtedness in foreign currency, a fiscal consolidation policy is able to generate positive output responses through the exchange rate effect on household and public sector balance sheets. And finally, if inflation expectations are well anchored, expansionary effects are more likely to arise.

The above model of Hungary is focused on the fiscal part of the economy. The aim of Jakab and Kónya (2016) is to specifically investigate the properties of Hungarian labour market. To achieve this, the authors add matching frictions to a otherwise standard DSGE model by Jakab and Világi (2008). They find that the implementation of labour market to the model plays a significant role in the monetary transmission mechanism and gives a more realistic picture of Hungarian economy. While the shocks of the economy influence the labour market variables, the relevance of labour market shock to the other variables is not significant. Furthermore, the foreign shocks have a significant influence on the labour market, mainly on the domestic wages.

The Czech National Bank (CNB) uses a structural model for its forecasts since 2008. This core DSGE model of the CNB (also called the 'g3' model) and its contribution to policy analysis is outlined in Andrle et al. (2009). This small open economy model captures the key properties of the Czech economy, among others the import intensity of exports, growth in the trade openness of the economy, nominal rigidities or the observed level of persistence in selected variables. Several alternative versions of this model exist or are currently developed to help the central bank in its decision making.

Tonner et al. (2015) investigate the predictive ability of the CNB's core DSGE model with explicitly defined labour market. They implement various forms of labour market to find out, which specification reduces the forecasting errors of labour market variables, while keeping the required changes at minimum. While several implementations yield similar improvements in the overall predictive ability, the modified Galí et al. (2012) labour market specification requires the lowest amount of interventions to the core model. They also identified that these models with more elaborate labour market would suggest an even greater need for exchange rate depreciation in late 2013, than the CNB actually carried out. Further modifications of the CNB's core model are for example Tonner and Brůha (2014) who examined the housing sector of the Czech Republic or Ambriško et al. (2012) who implement a more complex fiscal features to investigate the characteristics of the Czech fiscal sector.

To complement the models used by the CNB for macroeconomic predictions and monetary policy analysis, the Czech Ministry of Finance also uses its own DSGE model. The latest form, HUBERT3, is described by Aliyev et al. (2014). This model is made to fit the needs of Ministry of Finance of the Czech Republic on the field of macroeconomic and fiscal policy analysis. Despite the fact that this model serves for fiscal analysis and not the investigation of labour market, it contains an explicitly defined labour market with households that can (saver households) and cannot (spender households) re-optimize their wages in each period using Calvo wage setting mechanism The authors describe and justify the performed modifications compared to the older versions and finally provide simulations of response functions to different shocks.

Antosiewicz and Lewandowski (2014) analyze the factors behind the financial crisis and their transmission into labour markets of selected European countries, including the Czech Republic and Poland. They find a significantly higher effect of productivity shock to the wages in the Czech Republic than in Poland. Also, in all analyzed countries except of the Czech Republic, job destruction shocks influenced consumption significantly. For Poland, this suggests a decrease of consumption in times of high job loss probability. In both countries, the unemployment rate is mostly influenced by foreign demand and job destruction shocks.

Another examination of Polish (and Romanian) economy is carried out by Nalban (2015), who estimated a small-scale closed economy model with three observed variables. Despite the elemental structure of the model, it managed to match the busyness cycle properties of Polish economy considerably well. The model indicated the preference shocks to be the main driving factor behind Polish recession in 2008-2009.

The model of Grabek and Kłos (2013) contains nominal wage and price rigidities as well as real frictions in form of external habit formation or capital adjustment costs. This model is estimated on Polish data and it is used to analyze the relevance of labour market specific parameters and their impact on monetary transmission mechanism. They estimate the wage mark-up shock to be the driving factor behind Polish unemployment, which suggest labour heterogeneity and structural mismatch of labour. The article also describes that the reaction of output to a shock to the interest rates is not influenced substantially by the elasticity of labour supply. With more elastic labour supply, the response of unemployment is larger, however, it is offset by the less distinct reaction of real wages. The authors also compare this model with an older specification, which left out the labour market. During their comparison they found that the extended model has better forecasting properties and sometimes very different impulse response functions.

Apart from the examination of labour market, a large-scale, multi-sector DSGE model is constructed by Bukowski and Kowal (2010). They use this huge model with multiple agents and markets to make conditional macroeconomic projections for the 2010-2030 period about the implications of potential reduction of greenhouse gases in Poland. Because these effects influence so many agents, they incorporate different areas of the economy into the model, like capital market, government and labour market. In their forecasts they find that many environment-friendly technologies need to be subsidized by the government to make them more attractive for the firms.

Zeman and Senaj (2009) describe a SOE DSGE model that is designed to simulate the dynamic behaviour of Slovak economy. All of the key macroeconomic variables are incorporated into the model to ensure better results of simulations and wider explanatory potential. The model also contains Calvo type price and wage rigidities to improve the dynamic behaviour of model variables. The authors evaluate the appropriateness of the model using comparison of simulated second moments with moments from data, impulse responses to shocks and replicating historical data.

A DSGE model of Slovakia is estimated, for the first time using Bayesian techniques, by Senaj et al. (2010). They use a two-country model suitable for policy analysis of Slovak economy as a part of the euro area. Their specification of the model allows switching between two types of monetary regimes, which were present in Slovakia. In the first regime, the model is be specified for two countries with autonomous monetary policies, while in the second regime, the two countries constitute the euro area with a common monetary policy. In their comparison of the two regimes, they find that the absence of exchange rate adjustment tool of the monetary policy in the monetary union regime causes the same shocks to affect the economy in different volumes.

The focus of Múčka and Horváth (2015) lies in the examination of Slovak fiscal policy. This model is calibrated to fit the requirements of Slovak economy. While it contains a labour market with frictional wage setting, it focuses in detail on the fiscal part of the economy. The authors conducted several analyses of various strategies used to lower the public debt permanently from an elevated level. Cuts in government wage bill are least harmful for the real economy especially if the economy is in a recession. Among tax measures, labour income tax increases are the most harmful for growth in the long term in general.

Slovak labour market is compared to the Czech in the paper of Němec (2013b). He estimates a SOE model using Bayesian techniques and finds a low bargaining power of workers in both economies, which suggests a low participation in trade unions. According to the results, the unemployment benefits are significantly higher in the Czech Republic. On the other hand, the cost of creating an additional vacancy is larger in Slovakia. Altogether, the model supports the view that the structure of Slovak and Czech labour market is similar.

2.5 Chapter's summary

This chapter contained the overview of the existing literature. Because I aim to investigate the labour market, I divided the chapter into four consequential sections. In the first, I presented some models with widely used labour market specifications, such as search and matching frictions, Nash bargaining or Calvo type wage rigidities. The following section focuses on the models that investigate the impacts of monetary policy with explicitly defined labour market frictions. The next section presents several alternative approaches and interesting features concerning the labour market, like labour market institutions or minimal wage. The final part of this chapter brings an overview of the literature of DSGE models for V4 countries that contain labour market.

Chapter 3

The model

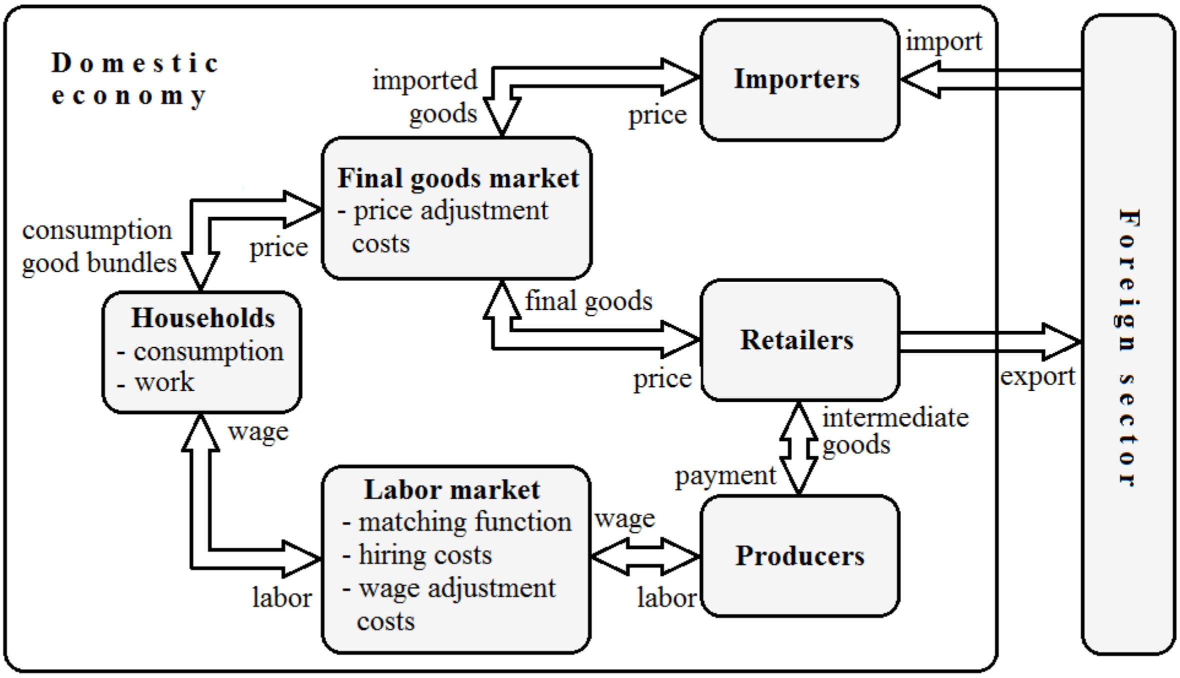
In this chapter I present a new-Keynesian DSGE model for small open economy, which is used to answer the research questions. The first section states the general properties of the model. Sections 3.2 - 3.6 introduce a slightly modified version of the model developed by Albertini et al. (2012), together with the log-linearized model equations in section 3.7. The following section contains the description of the modifications made that serve to find a model specification which fits the dynamic properties of the investigated economies better. The summarizing tables of model variables and parameters can be found in Appendix A.

I made several modifications to the original model of Albertini et al. (2012) each of which is in detail described in this chapter. These modifications include the implementation of switching mechanism for Slovak economy to allow it to transfer from autonomous monetary policy to monetary union. I also removed the vacancy posting shock since it had no effect on any result and it was redundant, because the model had 12 shocks for 11 variables. Furthermore I extended the simple AR(1) foreign sector with a more complex definition to capture the interactions among the foreign variables. I also extended the market clearing condition to account for the loss of output from having vacant job positions in the steady-state. In the following section I present the original model with some of the changes. A whole section is dedicated to the description of the implemented changes.

3.1 Model characteristics

The model contains standard features that can be found in other DSGE models. The structure of the model is presented in figure 3.1. It consists of several agents (households, three kinds of firms and a monetary authority), which represent particular components of the economy. As is typical for DSGE models, the behavior of each agent can be described by equations that have microeconomic foundations. These agents interact among each other on the labour and goods markets. The consumers buy bundles of goods from the domestic final goods producers and foreign goods importers. They also supply their labour to the intermediate goods producing firms, where the bargaining over worked hours and paid wages takes place. Finally, the manufacturers of unfinished goods sell their merchandise to the domestic retailers who combine these goods into the final product, which is sold to the customers. On the other hand, to focus more on the labour market and to cut back the complexity of the model, there is no capital input to production and no sector of government. When investigating the labour market, abstracting from capital or government is a often used practice. One or the other can be found in e.g. Christoffel et al. (2009), Costain and Reiter (2008), Galí et al. (2012) or Krause and Lubik (2007).

Figure 3.1: Structure of the model



Source: Author's sketch

Furthermore, to better capture the flows on the non-Walrasian[3] labour market, the authors augmented the model with Nash type bargaining process and search and matching frictions as introduced by Mortensen and Pissarides (1994). The inclusion of the former allows to set the wages above the market-clearing level. The latter mechanism allows

[3] As Zanetti (2007), p. 2414 states, "*the structure of the labor market is non-Walrasian, when wages are set by the bargaining process between firms and unions somewhere above the market-clearing level. This generates unemployment as some individual workers are unable to sell as much labor services as they wish to supply, given the established wages.*"

to implement an additional friction to the model due to the inability of the job seekers and vacancies to always match perfectly. Finally, the model contains hiring costs in the form of vacancy creation costs, which represent the expenses firms face when opening and advertising a new job position.

3.1.1 Price and wage setting mechanisms

The model is filled with different rigidities which help capture the situation in the real economies. The literature distinguishes between two major directions in modelling wage and price frictions: Calvo type and Rotemberg type. The former was first described in Calvo (1983). The main principle of the Calvo price rigidity states that there exists a probability $1-\theta$ that a firm can re-optimize its nominal price. This price re-optimization of a fraction of firms leads to different prices. $1-\theta$ firms will have a new, optimal price, while the rest, θ, will not be able to optimize. The resulting price dispersion leads to a less efficient aggregate production, or in other words to a inefficient allocation of production. A wedge is created between aggregate output and aggregate employment which causes the inefficiency. On the other hand, the in the approach introduced by Rotemberg (1982), all the firms face the same optimization problem and therefore set the same price. However, changing the price induces additional cost. To change the price, firms have to spend additional resources. This cost represents the wedge between aggregate consumption and aggregate output. The Rotemberg-type rigidities are modelled using quadratic equations to ensure that any change (not only an increase) of price induces an increase of costs.

There are many papers discussing these two pricing assumptions. The general view is that both pricing mechanisms result in the same first order approximation under zero steady-state inflation and full indexation. Nisticò (2007) takes it a bit further by investigating the welfare implications. He reveals that under an efficient steady-state both methods generate the same welfare losses to the second order approximation and set the same policy implications for welfare-maximizing central banks. Lombardo and Vestin (2008) expand this thought to an inefficient steady-state. Under such assumptions, the Calvo approach evinces larger welfare costs.

However, if the steady-state level of inflation is positive instead of zero, the two mechanisms result in different log-linearized dynamic macroeconomic models. Ascari et al. (2011) investigate the two price setting approaches in an economy with positive trend inflation. Their results suggest that models with positive trend inflation should be favoured instead of the models with zero inflation in steady-state. Under this assumption, the Calvo pricing scheme outperforms the Rotemberg approach. Furthermore, they implemented indexation into the Calvo and Rotemberg pricing systems. The estimated degree of this indexation is really low. This again put the Calvo approach ahead of the Rotemberg method, if the assumption of full price indexation is empirically questioned (as in Nakamura and Steinsson (2008)). Ascari and Rossi (2012) also investigated the effects of trend inflation. They find that under trend inflation, the shape of the long-run New-Keynesian Phillips Curve (NKPC) differs depending on the applied pricing method. While within Calvo approach, the relationship between inflation and output is negative, in case of Rotemberg, this relation has a positive slope. If there is positive trend inflation and the model is log-lienarized around this generic (non zero) inflation level, the log-linear NKPCs differ greatly between the two pricing specifications. In the Calvo model, the price dispersion creates a backward looking variable that is missing in the Rotemberg model, where the marginal costs depend on inflation due to the price adjustment term.

Since the baseline Calvo and Rotemberg pricing mechanisms yield the same results after first order approximation and as is shown by Lombardo and Vestin (2008) and Ascari et al. (2011), the choice of stickiness type has influence both on welfare and optimal policy, Ivashchenko (2015) aimed to investigate the problem of identifying the type of stickiness. He estimated the nonlinear versions of models for 11 countries. His results indicate that the Calvo approach is mostly better when it comes to model fitting. However, it does not hold for each economy.

Because there are no differences between the two pricing mechanisms that influence my results, I follow Albertini et al. (2012) and use the Rotemberg approach. The Rotemberg type quadratic price and wage adjustment costs induce extra expenses to profit maximizing firms. These can be looked upon as costs to renegotiate the wages with the employees or, as Rotemberg (1982) (p. 522) states "*changing prices is costly for two reasons: First, there is the administrative cost of changing the price lists, informing dealers, etc. Secondly, there is the implicit cost that results from the unfavourable reaction of customers to large prices changes.*"

3.2 Labour market

Similar to Albertini et al. (2012), I start the description of the model with its most crucial part, the labour market. It is a place, where the households supply their labour to the producers. It is also important to note that an unemployed person is unproductive, as well as the vacant job position. Only an employed person matched with the job can create an output. However, this matching process consumes resources, in form of vacancy posting costs that are available in the economy. The number of matches, M_t is given by the Cobb-Douglas matching function taken from Mortensen and Pissarides (1994):

$$M_t = \chi S_t^{\nu} V_t^{1-\nu} \varepsilon_t^{\chi}, \tag{3.1}$$

where S_t is the number of job seekers, V_t is the number of vacancies, $\nu \in (0,1)$ is the matching elasticity parameter with respect to job searchers, χ determines the matching efficiency and ε_t^{χ} is the matching efficiency shock. The labour market tightness, Θ_t, is defined as

$$\Theta_t \equiv \frac{V_t}{S_t}. \tag{3.2}$$

With this type of specification, increase of vacancies or decrease of job seekers increases the labour market tightness, which is more beneficial for the households.

Furthermore, we can define the job finding rate (the probability of an unemployed person to find a job, F_t), as:

$$F_t \equiv \frac{M_t}{S_t} = \chi \Theta_t^{1-\nu} \varepsilon_t^{\chi}. \tag{3.3}$$

This probability increases with rising labour market tightness, meaning that a worker is more likely to find a job, when the number of vacant positions is higher. On the contrary, from the definition of vacancy filling rate (probability of finding a worker, K_t):

$$K_t \equiv \frac{M_t}{V_t} = \chi \Theta_t^{-\nu} \varepsilon_t^{\chi}, \tag{3.4}$$

follows that the growing tightness reduces the probability of firms to employ new workers. The size of the workforce is considered to be constant and is normalized to one. This labour force consists of employed (N_t) and unemployed (U_t) population:

$$1 = N_t + U_t. \tag{3.5}$$

Log-linearization of the matching function (3.1) around the steady-state[4] yields[5]:

$$\widehat{m}_t = \nu \widehat{s}_t + (1-\nu)\widehat{v}_t + \widehat{\varepsilon}_t^{\chi}, \tag{3.6}$$

[4] Log-deviations from steady-state follow $\widehat{x}_t = log(X_t) - log(\overline{X})$, where $\widehat{x}_t$ is the log-linearized form of variable X_t with steady-state $\overline{X}$. Henceforth, letters without the time subscript t represent the steady-state level of the corresponding variable.

[5] The formulation $\widehat{\varepsilon}_t$ denotes the log-linearized form of shock, such that $\widehat{\varepsilon}_t = log(\varepsilon_t)$

with the following labour market properties:

$$\widehat{\theta}_t = \widehat{v}_t - \widehat{s}_t, \qquad \widehat{f}_t = \widehat{m}_t - \widehat{s}_t \qquad \text{and} \qquad \widehat{k}_t = \widehat{m}_t - \widehat{v}_t. \tag{3.7}$$

Apart from the movement from unemployment to employment given by (3.1), there is a part of the population that loses its job in each time period. This flow of workers to unemployment is governed by a job separation parameter ρ^x. The model takes this parameter as exogenous and constant over time. The fraction of population that is looking for a job is given by:

$$S_t = 1 - (1 - \rho^x) N_{t-1}. \tag{3.8}$$

This means that the part of the whole population that got separated from its workplace in the previous time period $(t - 1)$ is looking for a new job in the current period t. This setting allows employees to get rehired in the same period in case of job loss. The dynamics of employment is defined as follows:

$$N_t = (1 - \rho^x) N_{t-1} + M_t, \tag{3.9}$$

meaning that employed are those, who kept their job from the previous period and who found a new one in the current. The log-linear form of number of job seekers (3.8) and employment law of motion (3.9) is given by:

$$\overline{S}\widehat{s}_t = -(1 - \rho^x)\overline{N}\widehat{n}_{t-1}, \tag{3.10}$$

$$\overline{N}\widehat{n}_t = (1 - \rho^x)\overline{N}\widehat{n}_{t-1} + \overline{M}\widehat{m}_t. \tag{3.11}$$

Finally, the relationship between unemployed workers and job seekers can be calculated combining the equations of total labour force (3.5) and employment development (3.9):

$$U_t = S_t - M_t. \tag{3.12}$$

This shows a difference of the size of new matches between job seekers and the unemployed, who receive unemployment benefits. The above equation expresses the unemployed being those people who are searching for job in time t, but do not get matched with a vacancy in the search and matching process.

3.3 Households

The goal of the representative household is to maximize its inter-temporal utility function. The utility depends positively on the level of consumption, while labour causes dis-utility to the households. It is defined as:

$$\max_{\{C_t,D_t,B_t\}_{t=0}^{\infty}} E_0 \sum_{t=0}^{\infty} \beta^t \varepsilon_t^c [log(C_t - \vartheta C_{t-1}) - N_t V(H_t)]. \tag{3.13}$$

E_0 is the expectation operator, parameter $\beta \in (0,1]$ represents the discount factor, ε_t^c is the preference shock, C_t denotes the consumption bundle consisting of domestic and foreign goods. The households perceive the volume of their previous period consumption and the consumption of other families. As the data suggest, households want to keep this volume relatively stable over time. The deep-habit parameter ϑ governs the smoothness of the consumption. N_t is the total employment defined in equation (3.9). $V(H_t)$ represents the disutility from work and it has the following form:

$$V(H_t) = \kappa_t^h \frac{H_t^{1+\phi_h}}{1+\phi_h}, \tag{3.14}$$

where κ_t^h is the work disutility parameter, H_t is hours worked and ϕ_h is the inverse of Frisch elasticity of labour supply, which captures the elasticity of hours relative to wage.

The utility function is subject to the following budget constraint:

$$\begin{aligned} P_t C_t + D_t + NER_t B_t = {} & D_{t-1} R_{t-1} + NER_t B_{t-1} R_{t-1}^* \phi_t(A_t) \\ & + W_t N_t H_t + (1 - N_t) b_u P_t + \Psi_{H,t} + \Psi_{F,t} + T_t. \end{aligned} \tag{3.15}$$

Here, P_t represents the aggregate price index of domestic and imported goods, D_t and B_t are one period domestic and foreign bonds respectively, NER_t is the nominal exchange rate. R_t and R_t^* represent the domestic and foreign interest rates. The working members of the households, N_t, receive nominal wages, W_t for the hours worked, H_t, while the unemployed receive unemployment benefits of b_u. Profits from holding shares in domestic ($\Psi_{H,t}$) and foreign ($\Psi_{F,t}$) enterprises is an additional form of income for the households and T_t is a lump-sum tax. To achieve a well-defined steady-state, a debt elastic risk premium, $\phi_t(A_t)$ is implemented to the model to stationarize the position of net foreign assets[6]. It is defined as follows:

$$\Phi_t = \exp(-\phi A_t). \tag{3.16}$$

This implies that the risk premium depends on the aggregate net foreign asset position of the domestic households:

$$A_t = (NER_{t-1} B_{t-1})/(\overline{Y} P_{t-1}), \tag{3.17}$$

[6] For more information about this suggestion, see Schmitt-Grohe and Uribe (2003) or Adolfson et al. (2007).

defined by the exchange rate and the steady-state output. If the domestic economy as a whole is a net lender, the households receive lower returns due to the lower risk premium. The economy is a net lender if the volume of domestically owned bonds of foreign firms is higher than the volume of domestic bonds owned by foreign individuals, $B_t^* > 0$. Since the households are able to hold negative amount of foreign bonds (the domestic economy is a net borrower, $B_t^* < 0$), they can be compensated by higher returns with higher risk premium.

Before I turn to the solution of the households' maximization problem, it is convenient to define the form of the consumption (C_t) and price (P_t) indices. The composite consumption index is defined as:

$$C_t = \left[(1-\alpha)^{\frac{1}{\eta}} C_{H,t}^{\frac{\eta-1}{\eta}} + \alpha^{\frac{1}{\eta}} C_{F,t}^{\frac{\eta-1}{\eta}}\right]^{\frac{\eta}{\eta-1}}, \tag{3.18}$$

where parameter α represents the share of imported goods in the domestic economy, η is the substitution elasticity of domestic and foreign products. $C_{H,t}$ and $C_{F,t}$ denote the Dixit-Stiglitz aggregates of the domestic and imported goods[7].

To derive the representative household's demand functions for domestic and foreign produced goods, the following Lagrangian has to be solved:

$$\mathcal{L}^C(C_{H,t}, C_{F,t}, \nu_t) = C_t - \nu_t(C_{H,t}P_{H,t} + C_{F,t}P_{F,t} - M_{C,t}). \tag{3.19}$$

The households choose the maximal value of $C_{H,t}$ and $C_{F,t}$, while they take the budget $M_{C,t}$ and price indices $P_{H,t}$ and $P_{F,t}$ as given. The first order conditions are

$$\frac{\partial \mathcal{L}^C}{\partial C_{H,t}} : \qquad \nu_t^\eta P_{H,t}^\eta = (1-\alpha)\frac{C_t}{C_{H,t}}, \tag{3.20}$$

$$\frac{\partial \mathcal{L}^C}{\partial C_{F,t}} : \qquad \nu_t^\eta P_{F,t}^\eta = \alpha\frac{C_t}{C_{F,t}}. \tag{3.21}$$

Combining the two first order equations results in

$$C_{H,t} = C_{F,t}\frac{1-\alpha}{\alpha}\left(\frac{P_{H,t}}{C_{F,t}}\right)^{-\eta}. \tag{3.22}$$

After substituting it into the constraint and simplifying:

$$C_{F,t}\left[(1-\alpha)P_{H,t}^{1-\eta} + \alpha P_{F,t}^{1-\eta}\right] = \alpha M_{C,t} P_{F,t}^{-\eta}. \tag{3.23}$$

[7] In the notation of this work, the subscripts represent the place of origin: H is the domestic economy, F is the foreign economy. Furthermore, variables with asterisk are applied in the foreign economy, for example $C_{H,t}^*$ stands for foreign consumption of home produced goods (exports).

The composite price index of domestic and foreign bundles of goods is defined as:

$$P_t = \left[(1-\alpha)P_{H,t}^{1-\eta} + \alpha P_{F,t}^{1-\eta}\right]^{\frac{1}{1-\eta}}, \tag{3.24}$$

which further simplifies the equation above to

$$C_{F,t}P_t^{1-\eta} = \alpha M_{C,t}P_{F,t}^{-\eta}. \tag{3.25}$$

From this, the domestic and foreign goods consumption indices can be derived as

$$C_{H,t} = (1-\alpha)M_{C,t}P_{H,t}^{-\eta}P_t^{\eta-1}, \tag{3.26}$$

$$C_{F,t} = \alpha M_{C,t}P_{F,t}^{-\eta}P_t^{\eta-1}. \tag{3.27}$$

Substituting these results into the composite consumption index (3.18) and after some algebraic operations gives $M_{C,t} = C_tP_t$. Finally, replacing $M_{C,t}$ in the equations above results in the domestic and foreign goods demand functions:

$$C_{H,t} = (1-\alpha)C_t\left(\frac{P_{H,t}}{P_t}\right)^{-\eta}, \tag{3.28}$$

$$C_{F,t} = \alpha C_t\left(\frac{P_{F,t}}{P_t}\right)^{-\eta}. \tag{3.29}$$

The representative household can also decide between the consumption of different domestic or foreign goods. Since they are defined analogously, only the domestically produced good index is presented here. The household maximizes the consumption of different domestic goods, while its budget $M_{H,t}$ and prices $P_{H,t}(i)$ are given. The household's optimization problem can be written using Lagrangian as follows:

$$\mathcal{L}_H^C(C_{H,t}(i), \nu_{H,t}) = C_{H,t} - \nu_{H,t}\left(\int_0^1 C_{H,t}(i)P_{H,t}(i) - M_{H,t}\right). \tag{3.30}$$

The first order condition with respect to $C_{H,t}(i)$ is

$$C_{H,t}(i) = \frac{\nu_{H,t}^{-\epsilon}P_{H,t}(i)^{-\epsilon}}{C_{H,t}}. \tag{3.31}$$

From this, the relation between any two goods results in

$$C_{H,t}(k) = \left(\frac{P_{H,t}(k)}{P_{H,t}(j)}\right)^{-\epsilon}C_{H,t}(j). \tag{3.32}$$

After substituting into the constraint

$$\frac{C_{H,t}(j)}{P_{H,t}(j)^{-\epsilon}}\int_0^1 P_{H,t}(k)^{1-\epsilon}\mathrm{d}k = M_{H,t}. \tag{3.33}$$

For further analysis, the domestic goods price index is defined as

$$P_{H,t} = \left(\int_0^1 P_{H,t}(k)^{1-\epsilon} \mathrm{d}k \right)^{\frac{1}{1-\epsilon}}. \tag{3.34}$$

Using this, the previous equation simplifies to

$$C_{H,t}(j) = \frac{M_{H,t} P_{H,t}^{\epsilon-1}}{P_{H,t}(j)^{\epsilon}}, \tag{3.35}$$

and it can be substituted into the home good consumption index, which is defined as:

$$C_{H,t} = \left(\int_0^1 C_{H,t}(j)^{\frac{\epsilon-1}{\epsilon}} \mathrm{d}j \right)^{\frac{\epsilon}{\epsilon-1}}, \tag{3.36}$$

to get:

$$C_{H,t} = \left\{ \int_0^1 \left[\frac{M_{H,t}}{P_{H,t}} \left(\frac{P_{H,t}}{P_{H,t}(j)} \right)^{\epsilon} \right]^{\frac{\epsilon-1}{\epsilon}} \mathrm{d}j \right\}^{\frac{\epsilon}{\epsilon-1}}. \tag{3.37}$$

The result of this, $M_{H,t} = C_{H,t} P_{H,t}$, can be substituted into (3.35) to obtain the demand function for different domestic goods:

$$C_{H,t}(j) = C_{H,t} \left(\frac{P_{H,t}(j)}{P_{H,t}} \right)^{-\epsilon}, \tag{3.38}$$

where $\epsilon > 1$ is the elasticity of substitution between the heterogeneous goods, $C_{H,t}(j)$. The demand function of imported goods and the foreign good price index is derived analogously to (3.38) and (3.34) respectively.

To find the optimal decision of the household, the intertemporal utility function, (3.13) is maximized subject to the budget constraint, (3.15):

$$\begin{aligned} \mathcal{L}^U(C_t, D_t, B_t) = E_0 \Bigg\{ \sum_{t=0}^{\infty} \beta^t \Bigg[& \varepsilon_t^c \big[log(C_t - \vartheta \overline{C}_{t-1}) - N_t V(H_t) \big] \\ & + \frac{\Lambda_t}{P_t} (R_{t-1} D_{t-1} + R_{t-1}^* NER_t B_{t-1} \phi_t(A_t) + \Psi_{H,t} + \Psi_{F,t} + T_t \\ & + W_t N_t H_t + (1 - N_t) b_u P_t - P_t C_t - D_t - NER_t B_t) \Bigg] \Bigg\}, \end{aligned} \tag{3.39}$$

where Λ_t is the Lagrange multiplier. The households choose the amount of consumed goods and the amount of domestic and foreign bonds they wish to hold. The first order conditions with respect to C_t, D_t and B_t respectively have the following forms:

$$\frac{\partial \mathcal{L}^U}{\partial C_t} : \qquad \Lambda_t = \frac{\varepsilon_t^c}{C_t - \vartheta C_{t-1}}, \tag{3.40}$$

$$\frac{\partial \mathcal{L}^U}{\partial D_t} : \qquad \frac{\Lambda_t}{P_t} = E_t \left[R_t \beta \frac{\Lambda_{t+1}}{P_{t+1}} \right], \tag{3.41}$$

$$\frac{\partial \mathcal{L}^U}{\partial B_t}:\frac{\Lambda_t NER_t}{P_t}=E_t\left[R_t^*\beta\phi_{t+1}\frac{\Lambda_{t+1}NER_{t+1}}{P_{t+1}}\right]. \tag{3.42}$$

Equation (3.40) is the Euler equation, which represents an inter-temporal first-order condition for a dynamic problem. Equations (3.41) and (3.42) represent the households choice of domestic and foreign bonds respectively. Merging these two first order conditions gives us the uncovered interest rate parity condition:

$$\beta E_t\frac{\Lambda_{t+1}}{\Lambda_t}\frac{P_t}{P_{t+1}}\left[R_t-R_t^*\phi_{t+1}\frac{NER_{t+1}}{NER_t}\right]=0. \tag{3.43}$$

The log-linearization of these equations results in:

$$\widehat{\lambda}_t=-\frac{\widehat{c}_t-\vartheta\widehat{c}_{t-1}}{1-\vartheta}+\widehat{\varepsilon}_t^c, \tag{3.44}$$

$$\widehat{\lambda}_t=\widehat{r}_t+\widehat{\lambda}_{t+1}-\widehat{\pi}_{t+1}, \tag{3.45}$$

$$\widehat{b}_t-\frac{\widehat{b}_{t-1}}{\beta}=\widehat{y}_t-\widehat{c}_t-\alpha\Big(\widehat{tot}_t+\widehat{lop}_t\Big), \tag{3.46}$$

$$\Delta\widehat{rer}_{t+1}=\widehat{r}_t-\widehat{\pi}_{t+1}-\widehat{r}_t^*+\widehat{\pi}_{t+1}^*+\tau^b\widehat{b}_t+\widehat{\varepsilon}_t^{rer}. \tag{3.47}$$

where τ^b represents the debt elastic risk premium and $\widehat{\varepsilon}_t^{rer}$ is the shock to uncovered interest rate parity. Variables $\widehat{tot}_t$, $\widehat{lop}_t$ and $\widehat{rer}_t$ are defined below, in section 3.6.

Finally, for the analysis of the labour market, it is important to quantify the marginal value of an employee for the household, φ_t. To acquire this value, it is necessary to take a derivative of the household's value function with respect to N_t:

$$\varphi_t=\Lambda_t\left(\frac{W_tH_t}{P_t}-b_u\right)-\varepsilon_t^cV(H_t)+\beta E_t(1-\rho^x)(1-F_{t+1})\varphi_{t+1}. \tag{3.48}$$

This equation expresses the value of employment (represented by the wage an employed person receives, W_tH_t/P_t compared to the value of unemployment (represented by the unemployment benefits, b_u), while it also takes into consideration the disutility caused by loss of leisure ($V(H_t)$) and the future marginal value of employment (φ_{t+1}) modified by the probabilities of staying employed ($1-\rho^x$) and not finding a job ($1-F_{t-1}$). A person will want to be employed, if the benefits of having a job outweigh the disadvantages of working. Another way to look at φ_t is that it represents the surplus the worker gets from the production process. This surplus has the following log-linear form:

$$\begin{aligned}\overline{\varphi}\widehat{\varphi}_t=&\overline{\Lambda WH}\Big(\widehat{\lambda}_t+\widehat{w}_t+\widehat{h}_t\Big)-b_u\overline{\Lambda}\widehat{\lambda}_t-\kappa^h\frac{\overline{H}^{1+\phi_h}}{1+\phi_h}\Big(\widehat{\varepsilon}_t^c+\kappa_t^h+\widehat{h}_t(1+\phi_h)\Big)\\&+\beta(1-\rho^x)\overline{\varphi}\Big(\widehat{\varphi}_{t+1}(1-\overline{F})-\overline{F}\widehat{f}_{t+1}\Big).\end{aligned} \tag{3.49}$$

3.4 Firms

There are three types of producers that create goods or sell them to the households on the domestic market:

1. domestic intermediate goods producers,
2. domestic final goods producers,
3. foreign final goods importers.

Each firm faces different kinds of rigidities, depending on its role in the process of goods creation. The form of the rigidities described in the model is taken from Rotemberg (1982), where he introduced quadratic price adjustment costs. Furthermore, following Rotemberg (2008), a recruiting cost is also implemented into the model. These frictions increase the production costs and thus decrease the overall output created. The decision making of wage setting is separated from the decision making of price setting. This is achieved by allowing only the intermediate good producers to hire employees and set their wages. The other two firms sell their goods on a monopolistically competitive market, which allows them to adjust their prices. Now I turn to the description of the different types of firms.

3.4.1 Domestic intermediate goods producers

The domestic intermediate sector is populated by perfectly competitive firms. Only these firms hire workers, which is their sole input. The production function has the following form of a Cobb-Douglas-type function without capital:

$$Y_{I,t} = \varepsilon_t^a (N_t H_t)^\zeta, \quad \text{or in log-linear terms:} \quad \widehat{y}_t = \zeta\left(\widehat{h}_t + \widehat{n}_t\right) + \widehat{\varepsilon}_t^a, \tag{3.50}$$

where $Y_{I,t}$ represents the output level of the intermediate goods, ε_t^a is a technology shock and parameter ζ is the labour share in production. This production function standard properties: it is increasing and concave, so that the marginal product is decreasing. As any rationally behaving economic agent, the firms on a perfectly competitive market maximize their gains. In the case of domestic intermediate goods producers, the optimization has the following inter-temporal form:

$$\max_{\{V_t\}_{t=0}^{\infty}} E_0 \sum_{t=0}^{\infty} \beta^t \frac{\Lambda_t}{\Lambda_0} \left[MC_t Y_{I,t} - \frac{W_t}{P_{H,t}} H_t N_t - \Gamma(V_t) - \Upsilon(W_t) N_t \right], \tag{3.51}$$

where MC_t is equal to the price (marginal cost) that a final goods producer pays to the intermediate goods producer for the unfinished product. Therefore, $MC_tY_{I,t}$ represents the total revenue of the manufacturer.

This type of firm faces three types of costs. First, $\frac{W_t}{P_{H,t}}H_tN_t$ is the total real wage cost paid to the employees. The firm negotiates number of worked hours and wages with employees based on its bargaining power. The process of bargaining will be described below in section 3.4.2.

Secondly, $\Gamma(V_t)$ denotes the vacancy creation costs[8]:

$$\Gamma(V_t) = \frac{\kappa^v}{e}V_t^e, \tag{3.52}$$

where κ^v is the scaling factor and parameter e governs the elasticity of the vacancy posting function. If $e = 1$, the function is linear with respect to vacancies. For $e > 1$, the function is convex, which results in increasing vacancy adjustment costs. Alternatively, when $0 < e < 1$, the function is concave, which means decreasing costs. This cost can also be interpreted as cost of hiring additional workers.

Finally, the firm also faces Rotemberg-type quadratic wage adjustment cost $\Upsilon(W_t)$, which is measured in terms of the finished goods. This cost represents the negative effects of wage changes, which are increasing with the size of the domestic economy. It has the following quadratic form:

$$\Upsilon(W_t) = \frac{\psi_W}{2}\left(\frac{\Pi_{W,t}}{\widetilde{\Pi}_{W,t-1}} - 1\right)^2 H_tY_{I,t}, \tag{3.53}$$

where $\psi_W \geq 0$ determines the magnitude of nominal wage rigidity, $\Pi_{W,t} = \frac{W_t}{W_{t-1}}$ is the wage inflation and $\widetilde{\Pi}_{W,t-1} = \Pi_{W,t-1}^{\gamma_W}\overline{\Pi}_W^{1-\gamma_W}$. $0 \geq \gamma_W \geq 1$ represents the wage indexation parameter[9] and $\overline{\Pi}_W$ is the steady-state wage inflation. The value of γ_W determines the degree of backward looking wage setting. If it is equal to 1, the the wage setting is completely backward looking and it is costless for firms to adjust the wages in line with the previous period wage inflation. Analogously, when $\gamma_W = 0$, the firms find it costless to adjust the wages according to the steady-state wage inflation.

To maximize its profit, a domestic intermediate goods producing firm chooses the number of vacancies (V_t) in each period subject to the dynamics of employment (3.9) and

[8] The definition is taken from Lubik (2009), which is a slightly modified version of Rotemberg (2008)

[9] The original adjustment cost in Rotemberg (1982) was used without indexation. With indexation, it appears for example in Ireland (2007) or in even more general form in Ascari et al. (2011).

with respect to the production function (3.50). The Lagrange function can be written as follows:

$$\begin{aligned} \mathcal{L}^Y = E_0\Bigg\{\sum_{t=0}^{\infty}\beta^t\frac{\Lambda_t}{\Lambda_0}\Bigg[\Bigg(MC_tY_{I,t}-\frac{W_t}{P_{H,t}}H_tN_t-\Gamma(V_t)-\Upsilon(W_t)N_t\Bigg) \\ -\mu_t(N_t-(1-\rho^x)N_{t-1}-K_tV_t)\Bigg]\Bigg\}, \end{aligned} \tag{3.54}$$

where μ_t is the Lagrange multiplier. From this, one can derive the first order condition of a optimizing domestic intermediate goods producer. It has the following form:

$$\frac{\partial\mathcal{L}^Y}{\partial V_t}:\mu_t=\frac{\kappa^v {V_t}^{e-1}}{K_t},\quad \text{or after log-linearization:}\quad \widehat{\mu}_t=(1-e)\widehat{v}_t-\widehat{k}_t. \tag{3.55}$$

$\kappa^v {V_t}^{e-1}$ in the previous equation can be interpreted as a marginal cost of posting a new vacant job position, while $1/K_t$ is its average duration. Therefore, μ_t represents the marginal costs of hiring a new worker.

Similarly to the derivation of marginal value of employed worker to the household (3.48), it is useful to derive the expected value of hiring an additional employee for the firm. It can be obtained by differentiating the firms' value function with respect to N_t:

$$\mu_t=MC_t\zeta\frac{Y_{I,t}}{N_t}-\frac{W_t}{P_{H,t}}H_t-\Upsilon(W_t)+\beta(1-\rho^x)E_t\frac{\Lambda_{t+1}}{\Lambda_t}\mu_{t+1}, \tag{3.56}$$

where μ_t is equal to the marginal gain the firm acquires from employing an additional worker, which in log-linear terms yields:

$$\begin{aligned} \overline{\mu}\widehat{\mu}_t =& \overline{MC}\zeta\frac{\overline{Y}}{\overline{N}}(\widehat{mc}_t+\widehat{y}_t-\widehat{n}_t)-\frac{\overline{WH}}{\overline{A}^x}\Big(\widehat{w}_t+\widehat{h}_t-\widehat{a}^x_t\Big) \\ &+\beta(1-\rho^x)\overline{\mu}\Big(\widehat{\lambda}_{t+1}-\widehat{\lambda}_t+\widehat{\mu}_{t+1}\Big). \end{aligned} \tag{3.57}$$

The job creation condition is given by the combination of (3.55) and (3.56). The domestic intermediate goods producer creates a vacancy if the expected gain from an employee is equal to the expected cost of searching for one:

$$\frac{\Gamma'(V_t)}{K_t}=MC_t\zeta\frac{Y_{I,t}}{N_t}-\frac{W_t}{P_{H,t}}H_t-\Upsilon(W_t)+\beta(1-\rho^x)E_t\frac{\Lambda_{t+1}}{\Lambda_t}\frac{\Gamma'(V_{t+1})}{K_{t+1}}. \tag{3.58}$$

To be able to express the wage in real terms $(\frac{W_t}{P_t})$, the following fraction is defined:

$$A^x_t=\frac{P_t}{P_{H,t}}. \tag{3.59}$$

After substituting (3.59) into (3.58), the job creation condition takes the form:

$$\frac{\Gamma'(V_t)}{K_t}=MC_t\zeta\frac{Y_{I,t}}{N_t}-\frac{W_t}{P_t}A^x_tH_t-\Upsilon(W_t)+\beta(1-\rho^x)E_t\frac{\Lambda_{t+1}}{\Lambda_t}\frac{\Gamma'(V_{t+1})}{K_{t+1}}. \tag{3.60}$$

3.4.2 Wage and hour bargaining

Before I continue in the characterization of the types of firms (the other two being the domestic retailers and the foreign goods importers), I turn to the description of the setting of wage and hours worked. Household members choose between work and unemployment, while producers decide whether to create and fill an additional vacancy or not. As was mentioned above, only employed workers together with the filled jobs create output. The surplus generated by an employed person is the sum of the value of a job for the employee (φ_t) and the value of a worker to the firm (μ_t):

$$\mathcal{S}_t = \frac{\varphi_t}{\Lambda_t} + \mu_t. \tag{3.61}$$

The process of negotiating wages is realized between each worker and his employer. During this so called Nash bargaining process, the wages and hours are set in a way to maximize the combined surplus. Each employee and the firm agree on the wage and hours that bring higher gains for them, than the second best option. Which for the worker is to be unemployed and for the firm is to have a vacant job. The total surplus is then divided between the worker and the firm based on their negotiating strength. In reality, this bargaining parameter reflects the power or the rate of participation in trade unions. This surplus maximizing problem can be written as follows:

$$\max_{W_t, H_t} \left(\frac{\varphi_t}{\Lambda_t}\right)^{1-\xi_t} \mu_t^{\xi_t}, \tag{3.62}$$

where $0 \leq \xi_t \leq 1$ is the bargaining power of firms, while $(1-\xi_t)$ represents the negotiating strength of employees. To solve this problem, it is necessary to take the derivative of (3.62) with respect to the nominal wage (W_t) and hours worked (H_t):

$$\xi_t \varphi_t \frac{\partial \mu_t}{\partial W_t} + (1-\xi_t)\mu_t \frac{\partial \varphi_t}{\partial W_t} = 0, \tag{3.63}$$

$$\xi_t \varphi_t \frac{\partial \mu_t}{\partial H_t} + (1-\xi_t)\mu_t \frac{\partial \varphi_t}{\partial H_t} = 0, \tag{3.64}$$

where the derivatives of φ_t (3.48) and μ_t (3.56) are:

$$\frac{\partial \varphi_t}{\partial W_t} = \frac{\Lambda_t H_t}{P_t}, \tag{3.65}$$

$$\begin{aligned} \frac{\partial \mu_t}{\partial W_t} = & -\frac{H_t}{P_{H,t}} - \psi_W \frac{H_t}{W_t} \frac{Y_{I,t}\Pi_{W,t}}{\widetilde{\Pi}_{W,t-1}} \left(\frac{\Pi_{W,t}}{\widetilde{\Pi}_{t-1}} - 1\right) \\ & + \beta E_t \frac{\Lambda_{t+1}}{\Lambda_t} \psi_W \frac{H_{t+1}}{W_t} \frac{Y_{I,t+1}\Pi_{W,t+1}}{\widetilde{\Pi}_{W,t+1}} \left(\frac{\Pi_{W,t+1}}{\widetilde{\Pi}_t} - 1\right), \end{aligned} \tag{3.66}$$

$$\frac{\partial \varphi_t}{\partial H_t} = \Lambda_t \frac{W_t}{P_t} - \varepsilon_t^c V'(H_t), \tag{3.67}$$

$$\frac{\partial \mu_t}{\partial H_t} = MC_t \zeta^2 \frac{Y_{I,t}}{N_t H_t} - \frac{W_t}{P_{H,t}}. \tag{3.68}$$

After substituting (3.65) and (3.66) into (3.63) and using the definitions of (3.48) and (3.56), the equation for nominal wage results in:

$$\begin{aligned}
&\frac{W_t H_t}{P_{H,t}}(H_t + \xi_t P_{H,t} \Upsilon'(W_t)) = \xi_t \left(b_u + \varepsilon_t^c \frac{V(H_t)}{\Lambda_t} \right) G_t A_t^x \\
&+ (1-\xi_t) H_t \left(MC_t \zeta \frac{Y_{I,t}}{N_t} - \Upsilon'(W_t) \right) \\
&+ \quad \beta(1-\rho^x) E_t \frac{\Lambda_{t+1}}{\Lambda_t} \mu_{t+1} \left(H_t(1-\xi_t) - \frac{G_t A_t^x}{G_{t+1} A_{t+1}^x}(1-F_{t+1}) \xi_t \frac{1-\xi_{t+1}}{\xi_{t+1}} H_{t+1} \right),
\end{aligned} \tag{3.69}$$

where G_t is defined as:

$$G_t = -\frac{\partial \mu_t}{\partial W_t} P_{H,t} = H_t + P_{H,t} \Upsilon'(W_t). \tag{3.70}$$

The final wage the employee and the producer agree upon is a weighted combination of the benefit that the firm has an occupied job position (the worker produces goods and the firm does not have to post new job offers) and the second best option for the employee (the benefit a person receives when being unemployed together with the positive utility stemming from the increase in leisure time when not having to go to work). The weight is determined by the bargaining power, ξ_t.

The hours worked result from inserting (3.67) and (3.68) into (3.64):

$$H_t \left(MC_t \zeta^2 \frac{Y_{I,t}}{N_t H_t} - \frac{W_t}{P_{H,t}} \right) = \left(A_t^x \frac{V'(H_t)}{\Lambda_t} \varepsilon_t^c - \frac{W_t}{P_{H,t}} \right) G_t. \tag{3.71}$$

The hours are set in a way to match the marginal product of the employee to the marginal rate of substitution between leisure and consumption.

3.4.3 Domestic final goods producers

The domestic final goods creators buy the homogenous products of the intermediate goods producers on a perfectly competitive market for price mc_t and combine them to manufacture a differentiated product. This is then sold on a monopolistically competitive market to the households, which allows the retailers to modify their prices $P_{H,t}(i)$. Firms aim to maximize their profits by setting the pices of their product, while they can not influence the price level of domestic goods, $P_{H,t}$. To adjust their prices, the final goods producers face quadratic price adjustment costs. Similarly to the wage adjustment costs, the domestic goods' price modification costs are Rotemberg-type with indexation as in Ireland (2007). The profit maximization problem of this type of firm is:

$$\max_{\{P_{H,t}(i)\}_{t=0}^{\infty}} E_0 \sum_{t=0}^{\infty} \beta^t \frac{\Lambda_t}{\Lambda_0} \left[\frac{P_{H,t}(i)}{P_{H,t}} Y_{H,t}(i) - mc_t Y_{H,t}(i) - \Upsilon(P_{H,t}(i)) \right], \tag{3.72}$$

where $\Upsilon(P_{H,t}(i))$ is the quadratic price adjustment cost:

$$\Upsilon(P_{H,t}(i)) = \frac{\psi_H}{2} \left(\frac{P_{H,t}(i)}{\widetilde{\Pi}_{H,t-1} P_{H,t-1}(i)} - 1 \right)^2 Y_{H,t}. \tag{3.73}$$

$P_{H,t}(i)$ represents the prices of different goods and $Y_{H,t}(i)$ is the output of individual producers. It holds that:

$$Y_{H,t}(i) = \left(\frac{P_{H,t}(i)}{P_{H,t}} \right)^{-\epsilon} Y_{H,t}. \tag{3.74}$$

$\psi_H \geq 0$ in (3.73) is the price adjustment cost parameter for the domestically produced final goods and $\widetilde{\Pi}_{H,t-1} = \Pi_{H,t-1}^{\gamma_H} \overline{\Pi}_H^{1-\gamma_H}$, where $0 \leq \gamma_H \leq 1$ is the price indexation parameter, which determines the degree of backward looking price setting, the domestic gross inflation rate is defined as $\Pi_{H,t} = P_{H,t}/P_{H,t-1}$ and $\overline{\Pi}_H$ is the steady-state inflation of domestic goods.

Solving (3.72) subject to (3.74) with respect to $P_{H,t}(i)$ results in the New Keynesian Phillips Curve (NKPC), which shows the relationship between inflation and output:

$$\begin{aligned} 0 =& (1-\epsilon) \left(\frac{P_{H,t}(i)}{P_{H,t}} \right)^{-\epsilon} + MC_t \epsilon \left(\frac{P_{H,t}(i)}{P_{H,t}} \right)^{-\epsilon-1} \\ & - \psi_H \frac{\Pi_{H,t}(i)}{\widetilde{\Pi}_{H,t-1}} \left(\frac{\Pi_{H,t}(i)}{\widetilde{\Pi}_{H,t-1}} - 1 \right) \\ & + \psi_H \beta E_t \left\{ \frac{\Lambda_{t+1}}{\Lambda_t} \frac{\Pi_{H,t+1}(i)}{\widetilde{\Pi}_{H,t}} \left(\frac{\Pi_{H,t+1}(i)}{\widetilde{\Pi}_{H,t}} - 1 \right) \frac{Y_{H,t+1}}{Y_{H,t}} \right\}. \end{aligned} \tag{3.75}$$

When there are no price adjustment costs ($\psi_H = 0$), the first order optimality condition simplifies to a situation, where the firm sets its price $P_{H,t}(i)$ as its marginal cost MC_t modified by the markup $\epsilon/(\epsilon-1)$. In the case when the price adjustment cost is positive ($\psi_H > 0$) the optimized price can be different from this value.

3.4.4 Foreign goods importers

The final type of firm present in the described model is the import sector. It sells heterogeneous foreign goods on the domestic market in monopolistically competitive environment. The profit maximizing importer faces the following optimization problem:

$$\max_{\{P_{H,t}(i)\}_{t=0}^{\infty}} E_0 \sum_{t=0}^{\infty} \beta^t \frac{\Lambda_t}{\Lambda_0} \left[\frac{P_{F,t}(i)}{P_{F,t}} Y_{F,t}(i) - MC_{F,t} Y_{F,t} - \Upsilon(P_{F,t}(i)) \right], \tag{3.76}$$

where $MC_{F,t}$ is the marginal cost of acquiring the foreign goods and bringing it to the domestic market. This cost is equal to the price of the foreign goods abroad $P^*_{F,t}(i)$ multiplied with the current nominal exchange rate NER_t. The optimization is carried out subject to:

$$Y_{F,t}(i) = \left(\frac{P_{F,t}(i)}{P_{F,t}}\right)^{-\epsilon} Y_{F,t}. \tag{3.77}$$

The importing firm sets the price of its foreign goods $P_{F,t}(i)$ on the home market. However, this price modification causes additional costs to the firm. The quadratic foreign goods price adjustment costs are:

$$\Upsilon(P_{F,t}(i)) = \frac{\psi_F}{2}\left(\frac{P_{F,t}(i)}{\widetilde{\Pi}_{F,t-1}P_{F,t-1}(i)} - 1\right)^2 Y_{F,t}, \tag{3.78}$$

where $\psi_F > 0$ is the parameter determining the cost of price adjustment, $\frac{P_{F,t}(i)}{P_{F,t-1}(i)}$ represents the inflation of the price of foreign goods i and $\widetilde{\Pi}_{F,t-1} = \Pi^{\gamma_F}_{F,t-1}\overline{\Pi}_F^{1-\gamma_F}$. Similarly to the previous two types of firms, $0 \leq \gamma_F \leq 1$ is the indexation parameter governing the cost of price adjustment with respect to previous period foreign goods inflation $\Pi_{F,t-1}$ and the steady-state inflation of foreign goods $\overline{\Pi}_F$.

Solving the optimality condition with respect to $P_{F,t}(i)$ results in the NKPC for the foreign goods:

$$\begin{aligned}
0 =&(1-\epsilon)\left(\frac{P_{F,t}(i)}{P_{F,t}}\right)^{-\epsilon} + MC_{F,t}\epsilon\left(\frac{P_{F,t}(i)}{P_{F,t}}\right)^{-\epsilon-1}\\
&-\psi_F\frac{\Pi_{F,t}(i)}{\widetilde{\Pi}_{F,t-1}}\left(\frac{\Pi_{F,t}(i)}{\widetilde{\Pi}_{F,t-1}} - 1\right)\\
&+\psi_F\beta E_t\left\{\frac{\Lambda_{t+1}}{\Lambda_t}\frac{\Pi_{F,t+1}(i)}{\widetilde{\Pi}_{F,t}}\left(\frac{\Pi_{F,t+1}(i)}{\widetilde{\Pi}_{F,t}} - 1\right)\frac{Y_{F,t+1}}{Y_{F,t}}\right\}.
\end{aligned} \tag{3.79}$$

3.4.5 Symmetric equilibrium

Following Ireland (2007), it can be said that in a symmetric equilibrium, each firm faces the same optimization problem and therefore makes the same decision as the others. This leads to $P_{H,t}(i) = P_{H,t}$ and $Y_{H,t}(i) = Y_{H,t}$, which silplifies (3.75) to:

$$\begin{aligned}
(\epsilon-1) =&MC_t\epsilon - \psi_H\frac{\Pi_{H,t}}{\widetilde{\Pi}_{H,t-1}}\left(\frac{\Pi_{H,t}}{\widetilde{\Pi}_{H,t-1}} - 1\right)\\
&+\psi_H\beta E_t\left\{\frac{\Lambda_{t+1}}{\Lambda_t}\frac{\Pi_{H,t+1}}{\widetilde{\Pi}_{H,t}}\left(\frac{\Pi_{H,t+1}}{\widetilde{\Pi}_{H,t}} - 1\right)\frac{Y_{H,t+1}}{Y_{H,t}}\right\}.
\end{aligned} \tag{3.80}$$

With a cost push shock, ε_t^H entering additively, the above equation in log-linear form yields:

$$\widehat{\pi}_{H,t} = \frac{\beta}{1+\beta\gamma_H}\widehat{\pi}_{H,t+1} + \frac{\gamma_H}{1+\beta\gamma_H}\widehat{\pi}_{H,t-1} + \frac{(\epsilon-1)\widehat{mc}_t}{(1+\beta\gamma_H)\psi_H} - \frac{\widehat{\varepsilon}_t^H}{(1+\beta\gamma_H)\psi_H}. \tag{3.81}$$

The same approach holds for the foreign goods importers.

3.5 The central bank

The monetary authority sets the nominal interest rates according to the modified Taylor (1993) rule:

$$R_t = R_{t-1}^{\rho_r}\left[\frac{1}{\beta}\left(\frac{E_t\Pi_{t+1}}{\overline{\Pi}}\right)^{\rho_\pi}\left(\frac{Y_t}{\overline{Y}}\right)^{\rho_Y}\left(\frac{Y_t}{Y_{t-1}}\right)^{\rho_{\Delta Y}}\left(\frac{NER_t}{NER_{t-1}}\right)^{\rho_{\Delta ner}}\right]^{1-\rho_r}\varepsilon_t^m. \tag{3.82}$$

Thus, the current value of nominal interest rate R_t depends on its previous value, on the deviation of future inflation from its steady-state, on output gap and difference and on nominal exchange rate difference. However, equation (3.82) holds only if the domestic economy has an autonomous monetary policy, like it is in the case of the Czech Republic, Hungary and Poland, and Slovakia until it joined the Economic and Monetary Union of the European Union. For Slovakia after the integration into the euro area, the following modification is applied:

$$R_t = \left\{R_{t-1}^{\rho_r}\left[\frac{1}{\beta}\left(\frac{E_t\Pi_{t+1}}{\overline{\Pi}}\right)^{\rho_\pi}\left(\frac{Y_t}{\overline{Y}}\right)^{\rho_Y}\left(\frac{Y_t}{Y_{t-1}}\right)^{\rho_{\Delta Y}}\left(\frac{NER_t}{NER_{t-1}}\right)^{\rho_{\Delta ner}}\right]^{1-\rho_r}\varepsilon_t^m\right\}^{1-SW_t} R_t^{*SW_t}, \tag{3.83}$$

where R_t^* is the foreign interest rate and a new variable SW_t is introduced that allows the monetary policy to '*switch*' between the two monetary regimes. It has a form of a dummy variable and it is zero, while the country is in an autonomous regime, so that the Taylor rule is the same as (3.82), and one for the joint monetary policy, so that the domestic nominal interest rate is the same as the foreign. This alternate version allows us to use a single and simple monetary policy rule for the domestic economy in the model.

After log-linearization, the two monetary policy rules have the following form:

$$\widehat{r}_t = \rho_r\widehat{r}_{t-1} + (1-\rho_r)(\rho_\pi\widehat{\pi}_{t+1} + \rho_y\widehat{y}_t + \rho_{\Delta y}\Delta\widehat{y}_t + \rho_{\Delta ner}\Delta\widehat{ner}_t) + \widehat{\varepsilon}_t^m, \tag{3.84}$$

$$\widehat{r}_t = (1-sw_t)(\rho_r\widehat{r}_{t-1} + (1-\rho_r)(\rho_\pi\widehat{\pi}_{t+1} + \rho_y\widehat{y}_t + \rho_{\Delta y}\Delta\widehat{y}_t + \rho_{\Delta ner}\Delta\widehat{ner}_t) + \widehat{\varepsilon}_t^m) + sw_t\widehat{r}_t^*. \tag{3.85}$$

3.6 Other definitions and closing the model

To finish the building of the model, it is useful to define some relationships between different variables. It is also necessary to implement some equations to close the model.

3.6.1 Real exchange rate

The real exchange rate RER_t defines the relationship between the domestic P_t and foreign P_t^* price indices:

$$RER_t = NER_t \frac{P_t^*}{P_t}, \tag{3.86}$$

where NER_t is the nominal exchange rate expressed as the domestic currency over foreign currency.

The derivation of the log-linearized version of (3.86) is straightforward:

$$\widehat{rer}_t = \widehat{ner}_t + \widehat{p}_t^* - \widehat{p}_t, \tag{3.87}$$

or (3.87) expressed in differences:

$$\Delta\widehat{rer}_t = \Delta\widehat{ner}_t + \widehat{\pi}_t^* - \widehat{\pi}_t, \tag{3.88}$$

where $\Delta\widehat{rer}_t = \widehat{rer}_t - \widehat{rer}_{t-1}$, $\Delta\widehat{ner}_t = \widehat{ner}_t - \widehat{ner}_{t-1}$ are the differences in real and nominal exchange rates and $\widehat{\pi}_t^* = \widehat{p}_t^* - \widehat{p}_{t-1}^*$ and $\widehat{\pi}_t = \widehat{p}_t - \widehat{p}_{t-1}$ are the foreign and domestic inflation respectively.

3.6.2 Terms of trade

Terms of trade TOT_t measure the relative price of foreign and domestic goods and are denoted in home currency:

$$TOT_t = \frac{P_{F,t}}{P_{H,t}}, \tag{3.89}$$

or in log-linearized form:

$$\widehat{tot}_t = \widehat{p}_{F,t} - \widehat{p}_{H,t}. \tag{3.90}$$

The domestic intermediate goods producers described in section 3.4 evaluate their inputs and outputs in home prices. However, due to the openness of the economy, the households take into consideration also the imported goods and evaluate their wages in terms of aggregate prices. Therefore, terms of trade influence the wage negotiation process by entering the job creation condition (3.60) through A_t^x:

$$A_t^x = \left[1 - \alpha + \alpha TOT_t^{1-\eta}\right]^{\frac{1}{1-\eta}}. \tag{3.91}$$

This equation was acquired by using the definitions (3.89) and (3.59) combined with the equation for the composite price index (3.24).

3.6.3 Law of one price gap

The law of one price gap states that the price of a goods is the same across countries if the nominal exchange rate is taken into consideration. For example, if the law of one price gap holds, it will have the following form (for the case of domestic exports):

$$LOP_t = NER_t \frac{P^*_{H,t}}{P_{H,t}} = 1. \tag{3.92}$$

However, in the case of this model, this condition is not satisfied for the imports, i.e. $LOP_t \neq 1$, meaning there is a wedge between the price of foreign goods in the domestic economy and the price level of foreign country:

$$LOP_t = NER_t \frac{P^*_t}{P_{F,t}} \neq 1, \tag{3.93}$$

or in log-linear form:

$$\widehat{lop}_t = \widehat{ner}_t + \widehat{p}^*_t - \widehat{p}_{F,t}. \tag{3.94}$$

From the log-linearized definitions of the law of one price gap (3.94), real exchange rate (3.87) and terms of trade (3.90), the following relation can be derived:

$$\widehat{lop}_t = \widehat{rer}_t - (1-\alpha)\widehat{tot}_t. \tag{3.95}$$

3.6.4 Market clearing

The model assumes that government benefits to the unemployed b_u are financed by lump-sum tax. The domestic economy's goods market clearing requires that[10]

$$Y_{H,t} = C_{H,t} + C^*_{H,t} + \Gamma(V_t) + \Upsilon(W_t, P_t), \tag{3.96}$$

where $\Gamma(V_t)$ denotes the vacancy creation cost (3.52) and $\Upsilon(W_t, P_t)$ collects the wage and price adjustment costs. Both of these Rotemberg costs create a wedge between output and consumption. In other words, these terms decrease the amount of domestically produced

[10] Here I decided to deviate from the original article of Albertini et al. (2012) and add the two Rotemberg type costs to the domestic market clearing condition. The inclusion of adjustment costs is used in most of the papers written about this topic, like Ascari et al. (2011), Ascari and Rossi (2012) or Ireland (2007) who use closed models. The inclusion of vacancy creation cost is based on Lubik (2009) and Němec (2013b).

output that can be used for final consumption on the home and foreign markets. The market clearing condition has the following log-linearized form:

$$\widehat{y}_{H,t} = \frac{\overline{C}_H}{\overline{Y}_H}\widehat{c}_{H,t} + \frac{\overline{C}^*_H}{\overline{Y}_H}\widehat{c}^*_{H,t} + \frac{\Gamma(\overline{V})}{\overline{Y}_H}\Gamma(\widehat{v}_t) + \frac{\Upsilon(\overline{W},\overline{P})}{\overline{Y}_H}\Upsilon(\widehat{w}_t,\widehat{p}_t), \tag{3.97}$$

where $1-\alpha = \frac{\overline{C}_H}{\overline{Y}_H}$ and $\alpha = \frac{\overline{C}^*_H}{\overline{Y}_H}$ and since wages and prices do not change in steady state, it can be shown that $\Upsilon(\overline{W},\overline{P}) = 0$ for both adjustment costs. Therefore, (3.97) can be rewritten as:

$$\widehat{y}_{H,t} = (1-\alpha)\widehat{c}_{H,t} + \alpha\widehat{c}^*_{H,t} + \frac{\frac{\kappa^v}{e}\overline{V}^e}{\overline{Y}_H}(e\widehat{v}_t), \tag{3.98}$$

where $\widehat{c}_{H,t}$ and $\widehat{c}^*_{H,t}$ represent the log-linearized versions of domestic and foreign demands for domestically produced goods. These log-linear forms can be derived from (3.28) and the equation for export:

$$C^*_{H,t} = \alpha Y^*_t\left(\frac{P^*_{H,t}}{P^*_t}\right)^{-\eta}, \tag{3.99}$$

while assuming $Y^*_t = C^*_t$, and using the definitions of $\widehat{rer}_t$ (3.87), $\widehat{tot}_t$ (3.90) and $\widehat{lop}_t$ (3.94), as follows:

$$\widehat{c}_{H,t} = \widehat{c}_t - \eta(\widehat{p}_{H,t} - \widehat{p}_t) = \widehat{c}_t + \eta\alpha\widehat{tot}_t, \tag{3.100}$$

$$\widehat{c}^*_{H,t} = \widehat{c}^*_t - \eta(\widehat{p}_{H,t} - \widehat{ner}_t - \widehat{p}^*_t) = \widehat{c}^*_t + \eta(\widehat{tot}_t + \widehat{lop}_t). \tag{3.101}$$

3.6.5 Foreign sector

The foreign sector is represented in the model by three observed variables: output Y^*_t, inflation Π^*_t and nominal interest rate R^*_t. It is exogenous to the domestic economy and modelled as auto-regressive process of first order.

3.7 Log-linear model equations

This section summarizes the log-linear model equations that are used in the model. The model consists of 48 endogenous variables for which there is equal number of log-linear equations. Starting with the labour market from section 3.2 that introduced the movements from and into unemployment and other relations:

$$\widehat{m}_t = \nu\widehat{s}_t + (1-\nu)\widehat{v}_t + \epsilon^{\chi}_t, \tag{3.102}$$

$$\overline{N}\widehat{n}_t = (1-\rho^x)\overline{N}\widehat{n}_{t-1} + \overline{M}\widehat{m}_t, \tag{3.103}$$

$$\widehat{s}_t = -(1-\rho^x)\frac{\overline{N}}{\overline{S}}\widehat{n}_{t-1}, \tag{3.104}$$

$$\widehat{f_t} = \widehat{m}_t - \widehat{s}_t, \tag{3.105}$$
$$\widehat{k}_t = \widehat{m}_t - \widehat{v}_t, \tag{3.106}$$
$$\widehat{u} = -\widehat{n}\frac{\overline{N}}{\overline{U}}, \tag{3.107}$$
$$\widehat{\theta} = \widehat{v} - \widehat{s}. \tag{3.108}$$

Next, in section 3.3, the first order conditions of the household's optimization problem are defined:

$$\widehat{\lambda}_t = -\frac{\widehat{c}_t - \vartheta\widehat{c}_{t-1}}{1-\vartheta} + \widehat{\varepsilon}_t^c, \tag{3.109}$$
$$\widehat{\lambda}_t = \widehat{r}_t + \widehat{\lambda}_{t+1} - \widehat{\pi}_{t+1}, \tag{3.110}$$
$$\widehat{b}_t - \frac{\widehat{b}_{t-1}}{\beta} = \widehat{y}_t - \widehat{c}_t - \alpha\left(\widehat{tot}_t + \widehat{lop}_t\right), \tag{3.111}$$

with the uncovered interest rate parity condition:

$$\Delta\widehat{rer}_{t+1} = \widehat{r}_t - \widehat{\pi}_{t+1} - \widehat{r}_t^* + \widehat{\pi}_{t+1}^* + \tau^b\widehat{b}_t + \widehat{\varepsilon}_t^{rer}, \tag{3.112}$$

and the marginal value of a worker for the household:

$$\begin{aligned}\overline{\varphi}\widehat{\varphi}_t =& \overline{\Lambda W H}\left(\widehat{\lambda}_t + \widehat{w}_t + \widehat{h}_t\right) - b_u\overline{\Lambda}\widehat{\lambda}_t - \kappa^h\frac{\overline{H}^{1+\phi_h}}{1+\phi_h}\left(\widehat{\varepsilon}_t^c + \kappa_t^h + \widehat{h}_t(1+\phi_h)\right) \\ &+ \beta(1-\rho^x)\overline{\varphi}\left(\widehat{\varphi}_{t+1}(1-\overline{F}) - \overline{F}\widehat{f}_{t+1}\right).\end{aligned} \tag{3.113}$$

Section 3.4 introduced, among others, the behaviour of entrepreneurs: the production function, the marginal value of a job for the firm and the job creation condition

$$\widehat{y}_t = \widehat{\varepsilon}_t^a + \zeta\left(\widehat{h}_t + \widehat{n}_t\right), \tag{3.114}$$
$$\begin{aligned}\overline{\mu}\widehat{\mu}_t =& \overline{MC}\zeta\frac{\overline{Y}}{\overline{N}}(\widehat{mc}_t + \widehat{y}_t - \widehat{n}_t) - \frac{\overline{WH}}{\overline{A}^x}\left(\widehat{w}_t + \widehat{h}_t - \widehat{a}_t^x\right) \\ &+ \beta(1-\rho^x)\overline{\mu}\left(\widehat{\lambda}_{t+1} - \widehat{\lambda}_t + \widehat{\mu}_{t+1}\right),\end{aligned} \tag{3.115}$$
$$\widehat{\mu}_t = (e-1)\widehat{v}_t - \widehat{k}_t. \tag{3.116}$$

Furthermore, this section contains the process of wage and hours determination together with the auxiliary variables of derivations

$$\widehat{\mu}_t + \widehat{h}_t = \widehat{\varphi}_t - \widehat{\lambda}_t + \widehat{\mu}_t'^w - \frac{\xi_t}{1-\overline{\xi}}, \tag{3.117}$$
$$\widehat{\varphi}_t + \widehat{\mu}_t'^h = \widehat{\mu}_t + \widehat{\varphi}_t'^h + \frac{\xi_t}{1-\overline{\xi}}, \tag{3.118}$$
$$\widehat{\mu}_t'^w = \widehat{h}_t - \widehat{a}_t^x + \frac{\psi_W\overline{A}^x\overline{Y}}{\overline{W}} + \widehat{\pi}_{w,t} - \gamma_W\widehat{\pi}_{w,t-1} - (\widehat{\pi}_{w,t+1} - \gamma_W\widehat{\pi}_{w,t}), \tag{3.119}$$

$$
\begin{aligned}
\widehat{\mu}_t^{\prime h}\overline{\mu}^{\prime h} =& \zeta^2\overline{MC}\frac{\overline{Y}}{\overline{NH}}\left(\widehat{mc}_t + \widehat{y}_t - \widehat{n}_t - \widehat{h}_t\right) - \frac{\overline{W}}{\overline{A}^x}(\widehat{w}_t - \widehat{a}_t^x), && (3.120)\\
\widehat{\varphi}_t^{\prime h}\overline{\varphi}^{\prime h} =& \overline{\Lambda W}\left(\widehat{\lambda}_t + \widehat{w}_t\right) - \kappa^h\overline{H}^{\phi_h}\left(\widehat{\varepsilon}_t^c + \kappa_t^h + \phi_h\widehat{h}_t\right). && (3.121)
\end{aligned}
$$

This part of my thesis also discusses the domestic and foreign New Keynesian Phillips Curves

$$
\begin{aligned}
\widehat{\pi}_{H,t} =& \frac{\beta}{1+\beta\gamma_H}\widehat{\pi}_{H,t+1} + \frac{\gamma_H}{1+\beta\gamma_H}\widehat{\pi}_{H,t-1} + \frac{(\epsilon-1)\widehat{mc}_t}{(1+\beta\gamma_H)\psi_H} - \frac{\widehat{\varepsilon}_t^H}{(1+\beta\gamma_H)\psi_H}, && (3.122)\\
\widehat{\pi}_{F,t} =& \frac{\beta}{1+\beta\gamma_F}\widehat{\pi}_{F,t+1} + \frac{\gamma_F}{1+\beta\gamma_F}\widehat{\pi}_{F,t-1} + \frac{(\epsilon-1)\widehat{lop}_t}{(1+\beta\gamma_F)\psi_F}. && (3.123)
\end{aligned}
$$

Before closing the model, additional relations, like the real exchange rate, terms of trade and law of one price gap are introduced in section 3.6. Furthermore, the price and wage inflation is defined as well:

$$
\begin{aligned}
\widehat{rer}_t =& \widehat{ner}_t + \widehat{p}_t^* - \widehat{p}_t, && (3.124)\\
\Delta\widehat{tot}_t =& \widehat{\pi}_{F,t} - \widehat{\pi}_{H,t}, && (3.125)\\
\widehat{lop}_t =& \widehat{rer}_t - (1-\alpha)\widehat{tot}_t, && (3.126)\\
\widehat{\pi}_t =& (1-\alpha)\widehat{\pi}_{H,t} + \alpha\widehat{\pi}_{F,t}, && (3.127)\\
\widehat{\pi}_{w,t} =& \widehat{w}_t - \widehat{w}_{t-1} + \pi_t, && (3.128)\\
\widehat{a}_t^x =& -\alpha\widehat{tot}_t. && (3.129)
\end{aligned}
$$

Closing the model includes the definitions of consumption of home and foreign produced goods by domestic and foreign households. These definitions are described in chapters 3.3 and 3.6:

$$
\begin{aligned}
\widehat{c}_{H,t} =& \alpha\eta\widehat{tot}_t + \widehat{c}_t, && (3.130)\\
\widehat{c}_{H,t}^* =& \eta\left(\widehat{tot}_t + \widehat{lop}_t\right) + \widehat{c}_t^*, && (3.131)\\
\widehat{c}_{F,t} =& -\eta(1-\alpha)\widehat{tot}_t + \widehat{c}_t, && (3.132)\\
\widehat{y}_t =& (1-\alpha)\widehat{c}_{H,t} + \alpha\widehat{c}_{H,t}^* + \frac{\frac{\kappa^v}{e}\overline{V}^e}{\overline{Y}_H}(e\widehat{v}_t). && (3.133)
\end{aligned}
$$

The decision making rule of the monetary authority (Taylor rule) and its alternative form is described in section 3.5

$$
\begin{aligned}
\widehat{r}_t =& \rho_r\widehat{r}_{t-1} + (1-\rho_r)(\rho_\pi\widehat{\pi}_{t+1} + \rho_y\widehat{y}_t + \rho_{\Delta y}\Delta\widehat{y}_t + \rho_{\Delta ner}\Delta\widehat{ner}_t) + \widehat{\varepsilon}_t^m, && (3.134)\\
\widehat{r}_t =& (1-sw_t)(\rho_r\widehat{r}_{t-1} + (1-\rho_r)(\rho_\pi\widehat{\pi}_{t+1} + \rho_y\widehat{y}_t + \rho_{\Delta y}\Delta\widehat{y}_t + \rho_{\Delta ner}\Delta\widehat{ner}_t +)\widehat{\varepsilon}_t^m) + sw_t\widehat{r}_t^*. && (3.135)
\end{aligned}
$$

The foreign sector is defined by AR(1) processes with the corresponding shocks:

$$\text{Output:} \quad \widehat{y}_t^* = \rho_{y^*}\widehat{y}_{t-1}^* + \widehat{\varepsilon}_t^{y^*} \quad \rightarrow \quad \widehat{\varepsilon}_t^{y^*} = \rho_{\widehat{\varepsilon}^{y^*}}\widehat{\varepsilon}_{t-1}^{y^*} + \epsilon_t^{y^*}. \tag{3.136}$$

$$\text{Interest rate:} \quad \widehat{r}_t^* = \rho_{r^*}\widehat{r}_{t-1}^* + \widehat{\varepsilon}_t^{r^*} \quad \rightarrow \quad \widehat{\varepsilon}_t^{r^*} = \rho_{\widehat{\varepsilon}^{r^*}}\widehat{\varepsilon}_{t-1}^{r^*} + \epsilon_t^{r^*}. \tag{3.137}$$

$$\text{Inflation:} \quad \widehat{\pi}_t^* = \rho_{\pi^*}\widehat{\pi}_{t-1}^* + \widehat{\varepsilon}_t^{\pi^*} \quad \rightarrow \quad \widehat{\varepsilon}_t^{\pi^*} = \rho_{\widehat{\varepsilon}^{\pi^*}}\widehat{\varepsilon}_{t-1}^{\pi^*} + \epsilon_t^{\pi^*}. \tag{3.138}$$

To acquire results from the model's estimations, it is necessary to implement as many shocks to the model as there are observed variables. In this case, the following shocks have been used:

$$\text{Technological shock:} \quad \widehat{\varepsilon}_t^a = \rho_a\widehat{\varepsilon}_{t-1}^a + \epsilon_t^a. \tag{3.139}$$

$$\text{Preference shock:} \quad \widehat{\varepsilon}_t^c = \rho_c\widehat{\varepsilon}_{t-1}^c + \epsilon_t^c. \tag{3.140}$$

$$\text{Cost-push shock:} \quad \widehat{\varepsilon}_t^H = \rho_H\widehat{\varepsilon}_{t-1}^H + \epsilon_t^H. \tag{3.141}$$

$$\text{UIP shock:} \quad \widehat{\varepsilon}_t^{rer} = \rho_{rer}\widehat{\varepsilon}_{t-1}^{rer} + \epsilon_t^{rer}. \tag{3.142}$$

$$\text{Monetary shock:} \quad \widehat{\varepsilon}_t^m = \rho_m\widehat{\varepsilon}_{t-1}^m + \epsilon_t^m. \tag{3.143}$$

$$\text{Matching efficiency shock:} \quad \widehat{\varepsilon}_t^\chi = \rho_\chi\widehat{\varepsilon}_{t-1}^\chi + \epsilon_t^\chi. \tag{3.144}$$

$$\text{Bargaining shock:} \quad \xi_t = \rho_\xi\xi_{t-1} + \epsilon_t^\xi. \tag{3.145}$$

$$\text{Work dis-utility shock:} \quad \kappa_t^h = \rho_h\kappa_{t-1}^h + \epsilon_t^h. \tag{3.146}$$

3.7.1 Steady-state equations

The steady-state values of variables are acquired from the equations defined in sections 3.2-3.6 by simply removing the time index t. The steady-state values of $\overline{A}^x = \overline{RER} = \overline{LOP} = \overline{TOT} = \overline{\Pi}_H = \overline{\Pi}_F = \overline{\Pi}_W = 1$ and $\overline{R} = \overline{R}^* = 1/\beta$. For the other variables, the following equations hold:

Variables of the labour market:

$$\overline{M} = \chi\overline{S}^\nu\overline{V}^{1-\nu}, \qquad \overline{N} = \frac{\overline{M}}{\rho^x}, \tag{3.147}$$

$$\overline{S} = 1 - (1-\rho^x)\overline{N}, \qquad \overline{\Theta} = \frac{\overline{V}}{\overline{S}}, \tag{3.148}$$

$$\overline{K} = \frac{\overline{M}}{\overline{V}}, \qquad \overline{F} = \frac{\overline{M}}{\overline{S}}, \tag{3.149}$$

$$\overline{U} = 1 - \overline{N}. \tag{3.150}$$

Other variables of households, firms and wage and hour setting:

$$\overline{\Lambda} = \frac{1}{\overline{C}(1-\vartheta)}, \qquad \overline{Y} = \left(\overline{NH}\right)^{\zeta}, \tag{3.151}$$

$$\Gamma(\overline{V}) = \frac{\kappa^{v}}{e}\overline{V}^{e}, \qquad \overline{C} = \overline{Y} - \Gamma(\overline{V}), \tag{3.152}$$

$$\Gamma'(\overline{V}) = \kappa^{v}\overline{V}^{e-1}, \qquad \overline{\mu} = \frac{\Gamma'(\overline{V})}{\overline{K}}, \tag{3.153}$$

$$V\left(\overline{H}\right) = \kappa^{h}\frac{\overline{H}^{1+\phi_h}}{1+\phi_h}, \qquad \overline{\varphi} = \frac{\overline{\Lambda}\left(\overline{WH} - b_u\right) - V\left(\overline{H}\right)}{1-\beta(1-\rho^{x})\left(1-\overline{F}\right)}, \tag{3.154}$$

$$V'(\overline{H}) = \kappa^{h}H^{\phi_h}, \qquad \frac{V'(\overline{H})}{\overline{\Lambda}} = \overline{MC}\zeta^{2}\frac{\overline{Y}}{\overline{NH}}, \tag{3.155}$$

$$\tag{3.156}$$

$$\overline{W} = (1-\xi)\left(\overline{MC}\zeta\frac{\overline{Y}}{\overline{N}} + \beta(1-\rho^{x})\Gamma'(\overline{V})\overline{\Theta}\right) + \xi\left(b_u + \frac{V(\overline{H})}{\overline{\Lambda}}\right). \tag{3.157}$$

3.8 Model modifications

To find a model that fits the dynamics of the examined economies better, I made some modifications to the model of Albertini et al. (2012). Some of these changes were already mentioned above, like adding a *switch* mechanism into the monetary policy's decision rule (3.85) or adding the vacancy posting cost $\Gamma(V_t)$ to the resource constraint (3.98). The first change is implemented to the model of Slovakia to capture the country's entry to the euro area and surrendering its autonomous monetary policy to the European Central Bank. Similar regime switching is implemented by Senaj et al. (2010). Furthermore, the uncovered interest rate parity adjustment cost (3.43) had to be corrected to account for the equality between the domestic and foreign interest rates and to reduce the risk premium of assets. It has the following log-linear form:

$$\Delta\widehat{rer}_{t+1} = \widehat{r}_t - \widehat{\pi}_{t+1} - \widehat{r}^{*}_t + \widehat{\pi}^{*}_{t+1} + (1-sw_t)\tau^{b}\widehat{b}_t + \widehat{\varepsilon}^{rer}_t. \tag{3.158}$$

To estimate Slovak economy *after* the crisis, two simplifications are made to the model. First, the domestic interest rate is removed from the pool of observed variables because it is strictly equal to the foreign nominal interest rate. Second, the above defined UIP condition is reformulated as $\Delta\widehat{rer}_t = -\widehat{\pi}_t + \widehat{\pi}^{*}_t + \tau^{b}\widehat{b}_{t-1} + \widehat{\varepsilon}^{rer}_t$. The one period shift backward is made to satisfy the Blanchard-Kahn conditions. The Blanchard and Kahn (1980) conditon states that the solution of the rational expectations model is unique if the number of unstable eigenvectors of the system is exactly equal to the number of forward-looking (control) variables. The debt elastic risk premium, τ^b is reduced from 0.001 to

0.00001 to capture the decrease of risk stemming from different interest rates.

The adjustment of the resource constraint was made due to the fact that vacancies are not zero in steady-state and maintaining vacant jobs is costly for the firm in the steady-state. On the other hand, as Ireland (2007) states, price and wage adjustment costs do not enter the log-linear version of aggregate resource constraint. This is due to the wage and price inflations being one in steady state. In other words, there are no adjustment costs, because there are no changes in prices nor wages in steady-state.

Another modification is the replacement of the simple foreign AR(1) processes with more complex foreign sector. Following Múčka and Horváth (2015) I implement a simple three equation foreign sector that defines the behaviour of three foreign agents. The foreign households maximize their utility based on the same function as the domestic households. The firms maximize their profits and set the output prices following the Rotemberg price setting mechanism. The monetary authority sets the nominal interest rates in accordance with the Taylor-rule. Since the foreign sector is much greater than the domestic, it is not affected by small open economies.

$$\widehat{y}_t^* - \vartheta^* \widehat{y}_{t-1}^* = \widehat{y}_{t+1}^* - \vartheta^* \widehat{y}_t^* - (1-\vartheta^*)\big(\widehat{r}_t^* - \widehat{\pi}_{t+1}^*\big) + (1-\vartheta^*)\Big(\widehat{\varepsilon}_t^{y^*} - \widehat{\varepsilon}_{t+1}^{y^*}\Big), \tag{3.159}$$

$$\widehat{r}_t^* = \rho_{r^*}\widehat{r}_{t-1}^* + (1-\rho_{r^*})\big(\rho_{\pi^*}\widehat{\pi}_{t+1}^* + \rho_{y^*}\widehat{y}_t^* + \rho_{\Delta y^*}\Delta\widehat{y}_t^*\big) + \widehat{\varepsilon}_t^{m^*}, \tag{3.160}$$

$$\widehat{\pi}_t^* = \frac{\beta}{1+\beta\gamma^*}\widehat{\pi}_{t+1}^* + \frac{\gamma^*}{1+\beta\gamma^*}\widehat{\pi}_{t-1}^* + \frac{(\epsilon-1)\kappa^y\widehat{y}_t^*}{(1+\beta\gamma^*)\psi^*} - \frac{\widehat{\varepsilon}_t^{\pi^*}}{(1+\beta\gamma^*)\psi^*}. \tag{3.161}$$

where the first equation is the combination of (3.109) and (3.110) for the foreign sector together with the foreign market clearing condition $\widehat{c}_t^* = \widehat{y}_t^*$. The second equation represents the Taylor-rule of the European Central Bank and the final equation is the foreign new-Keynesian Phillips Curve. In steady-state $\beta = 1/\overline{R}$ and I assume that $\overline{R} = \overline{R}^*$, because otherwise investments would flow between the economies. From this, the discount factor has to be the same in the domestic and foreign economies, $\beta = 1/\overline{R} = 1/\overline{R}^*$. Furthermore, I assume same preferences concerning the substitution of differentiated goods, therefore ϵ is the same as in the domestic NKPC. The term $\kappa^y\widehat{y}_t^*$ represents the marginal costs of the foreign producers, which is a fraction of the output, with κ^y serving as a scaling factor.

The final modifications are conducted in the Taylor-rule. I investigate, to what extent do the changes in the central bank's policy rule affect the results. Whether the interest rate setting depends on the changes in the output and exchange rates or not. To evaluate the possible improvements of my estimation results, I shall use model comparison methods described in section 5.2.3.

3.9 Chapter's summary

This chapter contained the basis of my thesis. The whole model that is used to obtain the results and the answers to my research questions is outlined here. I start this chapter with a short summary of the properties of the selected model followed by a comparison of the two most widely used price and wage setting mechanisms – Calvo and Rotemberg approaches. I continue my description with the definition of the labour market. The next sections contain the decision making rules of the three agents of the model – households, firms and the central bank – and the foreign sector.

After the listing of log-linear and steady-state equations, which are used as the model equations in the econometric software, I end this chapter with the presentation of the modifications made to the original model. This part represents a significant difference between my thesis and other authors papers, who use a single model in their works.

Chapter 4

Data and calibration of parameters

The current chapter focuses on the description of data sets that are selected for the estimation and on the calibration of parameters that form the model described in chapter 3. As was outlined above, this thesis also aims to compare the structural and dynamical properties of the countries of the Visegrad Group, namely the Czech Republic, Hungary, Poland and Slovakia. To fulfill this aim, the model is estimated for each of the four investigated economies separately. Each country represents, in its respective estimation, the domestic economy, while the foreign sector is represented by the 19 countries of the euro area[11]. This group of countries gathers the main trading partners of the Visegrad Group outside the Group itself. Although Slovakia is a part of this foreign sector, its influence on the overall performance of it is negligible. The GDP of Slovakia is around 0.5% of the total output of the euro area countries.

This chapter is organized as follows: Section 4.1 presents the data series and the transformations that are carried out in order to provide the model with the correctly specified data. The data are discussed in a way that allows comparison amongst the countries, to point out differences stemming from the different properties of the economies. Finally, in section 4.3, the calibration of model parameters and the setting of prior distributions is discussed.

4.1 Data of the Visegrad Group

Because my thesis aims to investigate the labour market of four different economies, it is important for the comparison among countries to acquire data sets from comparable

[11]At the time of constructing this work, the euro are consisted of the following 19 countries (listed alphabetically in order of entrance): Austria, Belgium, Finland, France, Germany, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain (1999); Greece (2001); Slovenia (2007); Cyprus, Malta (2008); Slovakia(2009); Estonia (2011); Latvia (2014) and Lithuania (2015).

databases. Efforts were made to obtain data sets which are as close to each other, in methodology and data collection technique, as possible. The sources of each time series are presented in table 4.1. Because of this careful data selection process, the differences resulting from different definitions of the same variable are minimized. Therefore, the achieved results are comparable amongst countries and the differences depict the differences between the characteristics of the economies.

Following Albertini et al. (2012), 8 time series (gross domestic product, interest rate, inflation, exchange rate, unemployment, vacancies, wage and worked hours) are selected for each domestic economy and 3 time series (gross domestic product, interest rate and inflation) for the foreign sector, which is common for the four countries. Quarterly data sets of observed variables are obtained for the examined economies for the time period from the first quarter of 2002 to the fourth quarter of 2015[12]. The first observation is defined by the availability of Polish data. The last observation is given by the availability of data in general. One advantage of this time span that might not be recognized at first glimpse is that the Great Recession of 2008 divides the observation period to two parts of equal length. This increases the value of comparison of data evolution *before* and *after* (or *during*) the crisis. The *before* period therefore spans form 2002-Q1 to 2008-Q4 which is 28 observations and the period after contains observations from 2009-Q1 to 2015-Q4 which is also 28 observations.

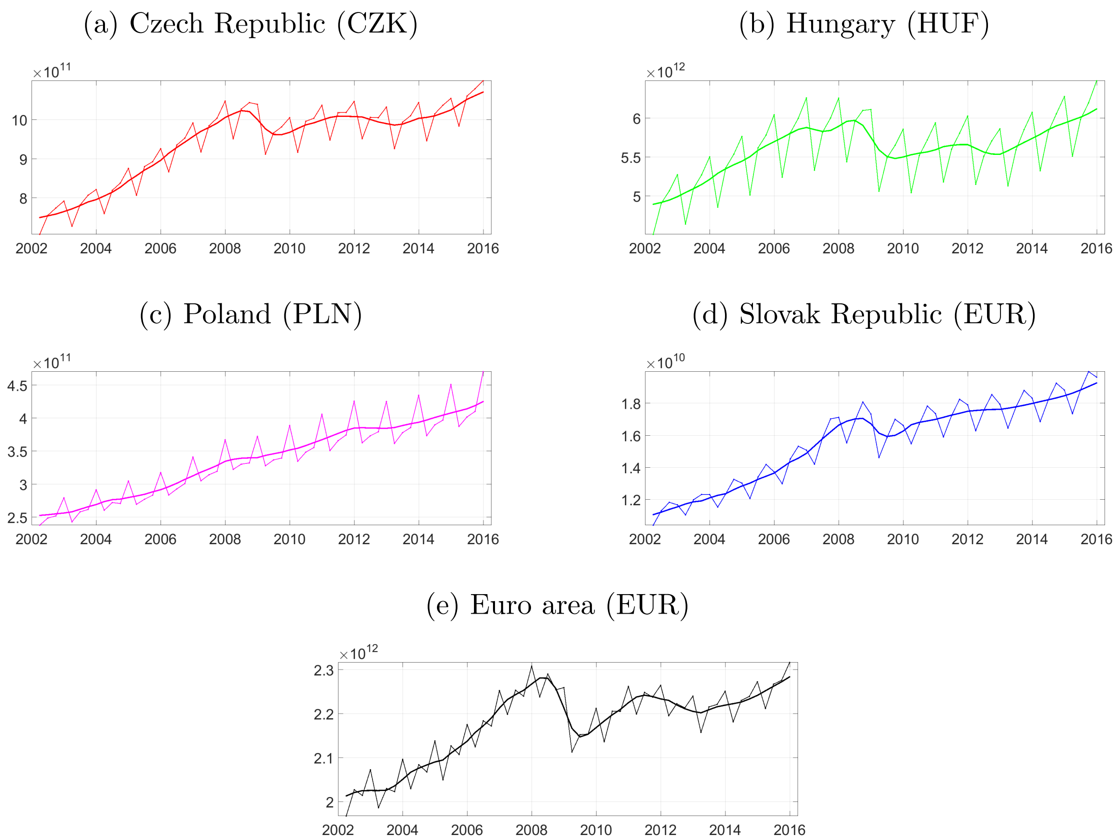
Each of the time series is obtained in seasonally unadjusted form, so the same type of seasonal adjustment can be performed on all observed variables. In general, a time series consists of three components: trend, cyclical movements and seasonal disturbances. The aim of my thesis is to investigate the second. To be able to fulfill this aim, I transformed the original time series to remove the seasonal influences and the trend. The seasonal adjustment is done using the *dseasq.m* function of Matlab, version 2016a. This function is based on the Kalman smoother, which removes the seasonal properties of the data. To remove the trend, and stationarize the time series, the Hodrick and Prescott (1980) filter is used with the standard smoothing parameter, $\lambda = 1600$ for quarterly data.

[12] The acquisition of the up-to-date time series and the re-estimation of all models would be really time consuming. I strongly believe that the extension of the observed time period by one to two observations would not change my results significantly.

4.1.1 Gross domestic product

The variable for domestic and foreign output is selected from the OECD database. It is the GDP calculated using expenditure approach divided by the active labour market population older than 15 years. Each output is a representation of chained volume estimates from the national reference year in national currency. Figure 4.1[13] shows the seasonally unadjusted (thin) and adjusted (thick) time series of output in national currencies. It is apparent from this figure that the original time series of output significantly depends on seasonal influences. Furthermore, each economy experienced a steady growth of GDP during the period before the crisis.

Figure 4.1: Gross domestic product in national currency



Source: data from OECD database; author's processing. Thick - seasonally adjusted, thin - seasonally unadjusted.

Figure 4.1(a) depicts the GDP of Czech Republic. It exhibited an average annual growth around 4.5% before the financial crisis in 2008. Although, the impact of the recession was substantial, the economy showed signs of recovery in 2010 and 2011. However,

[13]For easier orientation and consistency, the figures are colored as follows: Czech Republic - red, Hungary - green, Poland - magenta, Slovakia - blue and euro area - black.

this recuperation was set back due to the debt crisis in 2012. From that point forward, the Czech economy is going through a period of moderate expansion.

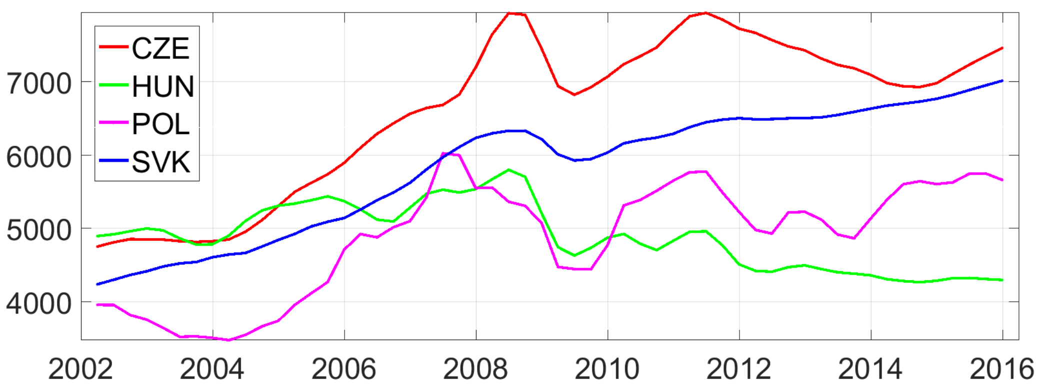
The GDP of Hungary is captured in figure 4.1(b). Hungarian output was increasing on average by more than 3% each year until 2006. Starting in 2006, Hungarian government realized that the economy is well over the production capabilities and therefore began a restrictive policy to prevent the potential overheating of the economy[14]. These involvements led to a slight decline of output in 2007, as can be seen in the presented figure. Among the examined economies, the worldwide crisis of 2008-09 had the most stunning impact in Hungary. Not only is the initial effect the most perceptible, but also the recovery of the economy is sluggish. Similarly to the Czech Republic, Hungary struggled for around six years to reach the output volumes before the crisis.

The situation is completely different in Poland. As Polish GDP in figure 4.1(c) reports, Polish economy was almost untouched by the events in 2008. Only a slight slowdown of growth is noticeable in the years 2008-09 and 2012-13, when the Czech Republic and Hungary were affected the most by the events abroad. This inspection of the development of Polish output further strengthens the view on the relative closedness and hugeness of Polish economy. Since then, Poland continues in its expansion rates around 4% annually from before the crisis.

Slovak economy, depicted in figure 4.1(d), exhibited the fastest growth rate of more than 6% on average annually before the recession hit. The acceptance of euro as the official

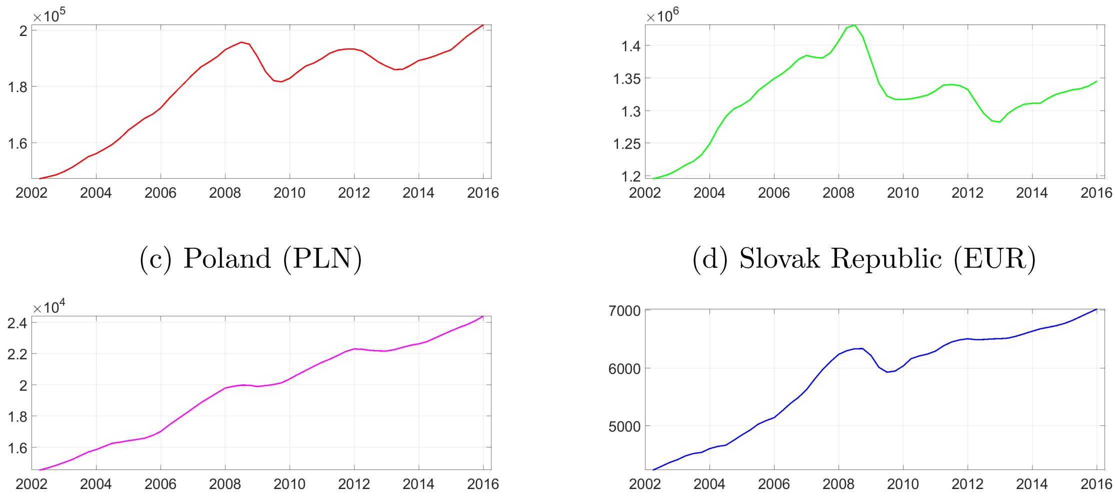
[14]Source: `http://mek.oszk.hu/06200/06209/06209.pdf`, own translation.

Figure 4.2: Gross domestic product per economically active population older than 15 years (EUR)



Source: data from OECD database; author's processing.

Figure 4.3: Gross domestic product per economically active population older than 15 years in national currency



(a) Czech Republic (CZK) (b) Hungary (HUF) (c) Poland (PLN) (d) Slovak Republic (EUR)

Source: data from OECD database; author's processing.

currency in Slovakia coincides with the negative events affecting economies worldwide. This ideal timing possibly helped to minimize the impact of the crisis and aided the economy out of the recession. Even though the growth rate since the recession was cut in half, Slovak economy remained untouched by debt crisis and continues in a steady growth. On the other hand, the euro area was affected severely by the events of 2012, as can be seen in figure 4.1(e). This was caused mainly because of countries that accumulated enormous amounts of debt, like Greece, Ireland and Portugal.

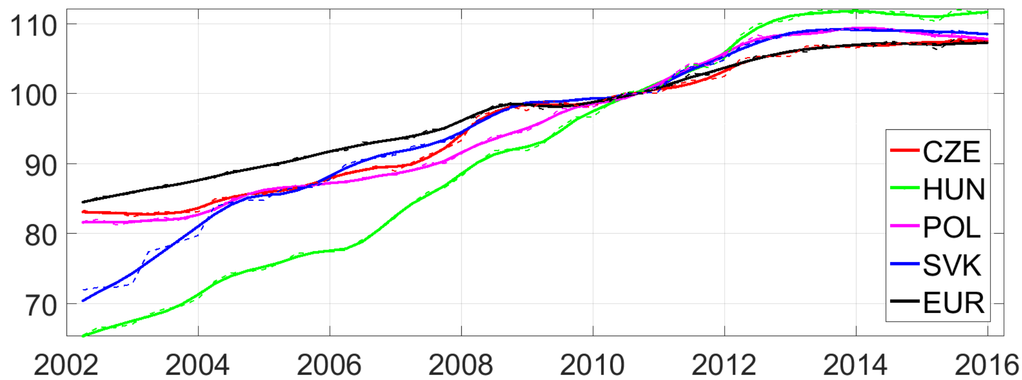
Figure 4.3 displays the development of output per economically active population older than 15 years[15] divided by the actual nominal exchange rate to get a variable that allows comparison amongst countries. However, before any conclusions could be made about the influence of the exchange rate on the output, it is important to differentiate its effect from the impact of changes in the labour force presented in figure 4.3. This set of figures represents the development of output per capita. The most noticeable change takes place in Hungarian economy after the recession. While the output per person of other countries copies the development of overall output, Hungary experienced a significant growth of economically active population, which slowed the growth of output per capita. This happened while the total population of the examined age interval remained relatively

[15]From now on, I will refer to the economically active population older than 15 years as the labour force. Also, if a variable is divided by this fraction of the population, I will refer to it as a variable in per capita or per person terms.

constant over time, which means that the shift in active population was caused mainly by the movements from being economically inactive to being active. Returning to figure 4.2, the depreciation of Hungarian forint also negatively affected the development of output in euro. However, the biggest change compared to 4.3 can be seen in the case of Poland. While Polish GDP per capita follows the trend of overall product, the output in euro becomes highly volatile, which suggests unstable exchange rate. The outputs of Slovakia and the Czech Republic remain almost unchanged by these transformations.

4.1.2 CPI inflation

Figure 4.4: Consumer price index (2010=100)

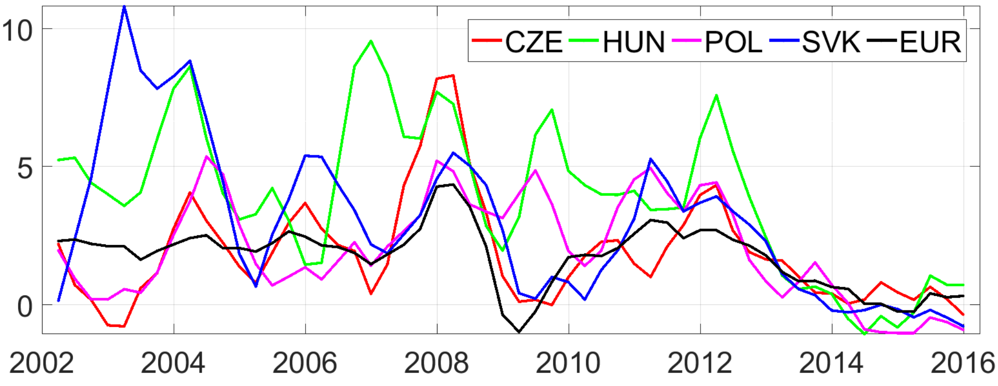


Source: data from OECD database; author's processing. Thick - seasonally adjusted, thin - seasonally unadjusted.

Figure 4.2 captures the development of consumer price indices downloaded from the OECD database. Although CPI does not reflect much seasonal variability, for consistency reasons it was also seasonally adjusted to better fit within the model specification. The lowest inflation throughout the whole observed time period in the euro area was followed by the Czech Republic and Poland. The highest rate of price index growth can be observed in Hungary.

It is worth mentioning that each of the investigated economies have, or in case of Slovakia, had inflation targeting monetary policy. The target however differs among the countries: for the Czech Republic, the target is 2%±1 percentage point, for Poland 2.5%± 1 p.p. and for Hungary 3%±1 p.p. Information about inflation targets was obtained from each country's respective central bank's website. Slovakia had an inflation target before entering the euro area, to fulfill the Maastricht criterion based on the average twelve-month inflation. The annualized inflation rate (calculated as $400 * (log(CPI_t) - log(CPI_{t-1}))$)

Figure 4.5: Annualized inflation rate (%)



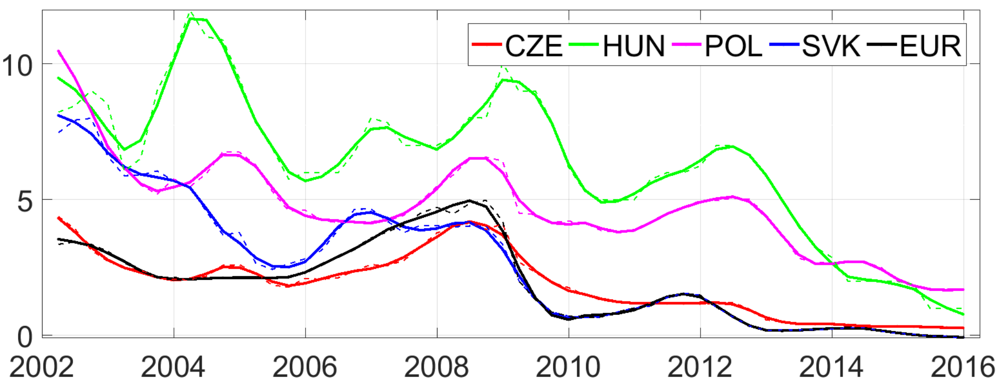
Source: data from OECD database; author's processing.

of each country is captured in figure 4.5. Since 2013, each country's inflation is below it's point target and since 2014 some of the countries even face deflationary pressures.

4.1.3 Interest rate

The data sets of interest rates are obtained from OECD database and presented in figure 4.6. However, some observations are missing in case of Hungary. To deal with this shortcoming, data from Hungarian central bank's Budapest Interbank Offered Rate (BUBOR) index are used to fill in the gaps. The data represent 3 month interbank interest rates. There are several interesting properties of this time series. First, each of the time series has a downward trend. While Hungary and Poland still have positive interest rates, the Czech Republic struggles to prevent this variable to reach negative numbers and the

Figure 4.6: 3 month interbank interest rate (%)



Source: data from MNB and OECD database; author's processing. Thick - seasonally adjusted, thin - seasonally unadjusted.

euro area already reports negative interest rates. Second, since the accession of Slovakia to the euro area, the National bank of Slovakia has no authority in the setting of the nominal interest rate. Therefore, in 2009, the blue and black lines in figure 4.6 "merged". Third, in 2009, when the global recession was the deepest, each of interest rate plummeted. Finally, similar, although smaller drop took place during the debt crisis in 2012-13.

4.1.4 Exchange rate

Figure 4.7 shows the seasonally unadjusted and adjusted time series of nominal exchange rates. The notation of amount of domestic currency for one euro is in line with equation (3.86). This means that increase of nominal exchange rate in figure 4.7 represents depreciation of domestic currency and decrease is appreciation. The Czech crown, presented in figure part (a), experienced a rather steady appreciation from the admission to the European Union in 2004 till 2011, which was temporarily interrupted by the depreciation during the financial crisis in 2008-09. Since then, the most notable change in the exchange rate of the Czech Republic was an intervention of the Czech national bank in the late 2013 to depreciate the crown to 27 CZK/EUR.

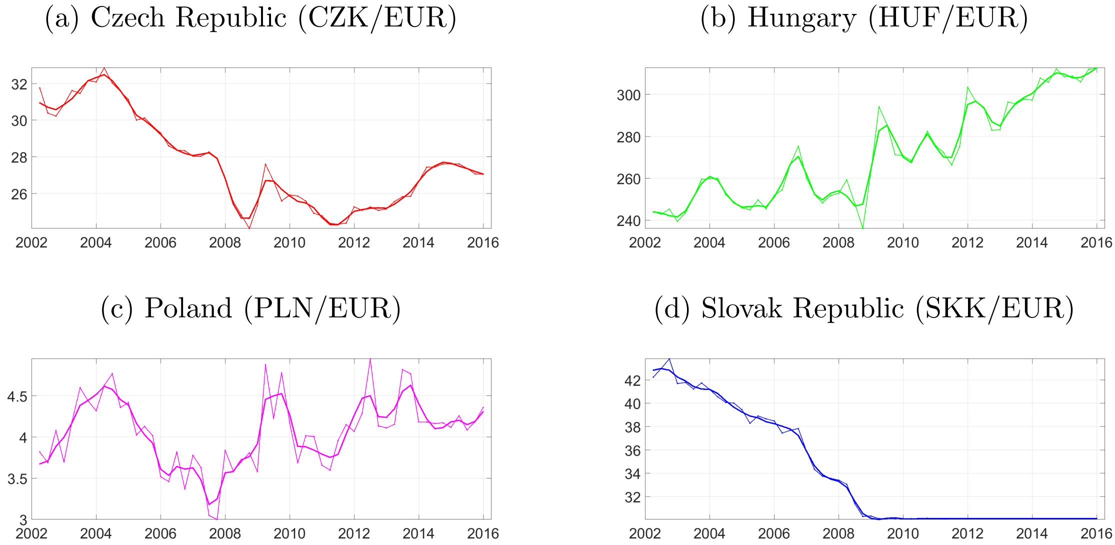
Hungarian forint, depicted in figure 4.7(b), underwent a completely opposite trend. Throughout the observed period, Hungarian forint depreciated significantly with several peaks, most notably the one during the recession in 2008. The continuous weakening of the forint represents a great burden for Hungarian people who took foreign currency loans, especially mortgages worth billions of Swiss francs[16].

The same thing happened in Poland (figure 4.7(c)), where the strong złoty depreciated during the global recession compared to the euro and Swiss franc. The development of złoty also explains, why the GDP per capita of Poland in euro in figure 4.2 is much more volatile compared to the GDP per capita of Poland in złoty in figure 4.3(c).

Figure 4.7(d) shows the development of Slovak crown relative to euro before the entrance of the Slovak Republic to the euro area. Two significant appreciation periods stick out in the otherwise steady trend: the first is by the turn of 2006-07 and the second shortly before accepting the euro as the official currency of Slovakia. Both of these changes were aimed to bring a beneficial exchange rate for Slovak population. The horizontal value since 1.1.2009 represents the accepted constant exchange rate at 30.1260 SKK/EUR.

[16]See e.g. `http://www.economist.com/news/europe/21639760-poles-were-slow-get-out-swiss-franc-mortgages-now-they-are-paying-price-currency-risk`

Figure 4.7: Nominal exchange rates



Source: data from the Statistical Data Warehouse of the ECB; author's processing. Thick - seasonally adjusted, thin - seasonally unadjusted.

4.1.5 Unemployment

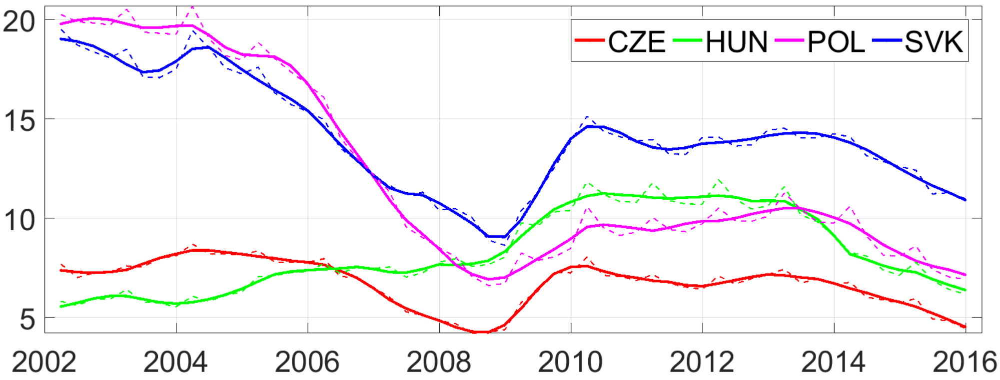
Figure 4.8 summarizes the development of unemployment rate in the examined economies, which is calculated as the fraction of unemployed people over the economically active population of 15 years and older. This figure shows that historically the lowest unemployment is observed in the Czech Republic. This is more than true nowadays, when the unemployment rate is around 4%, which is the lowest rate throughout the whole European Union. The economy has already reached similar low values before the crisis. However this recession had negative effects on the employment. The decline of output was accompanied by an increase of unemployment. Between years 2010 and 2014, the unemployment stagnated, but since then it decreases steadily.

Hungarian unemployment rate did not evince signs of improvement prior to the recession. This variable grew steadily during this period. The arrival of the crisis only worsened the situation and caused a jump in the rate of unemployment. This unfavourable state is being reversed in the last three years.

Poland's unemployment rate was decreasing formidably from 17.5% in 2005 to 7.5% before the crisis. This trend was interrupted by the recession, which caused a 5 year long period of increasing unemployment rate. The unemployment rate in Poland has decreasing tendencies nowadays.

A steady declining trend can be observed in the unemployment rate of Slovakia since

Figure 4.8: Unemployment rate (%)



Source: data from OECD database; author's processing. Thick - seasonally adjusted, thin - seasonally unadjusted.

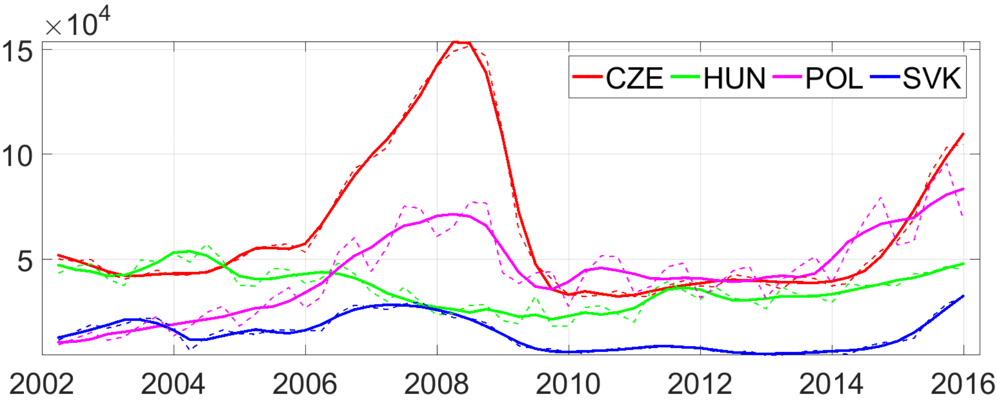
it's entry to the European Union in 2004 till it halted due to the recession in 2008. In 5 quarters during the recession the unemployment rose by more than 6%. Similarly to the Czech Republic, the other countries also experienced a more or less stable unemployment rate from 2010 to 2014 and Slovakia is not an exception. However its unemployment rate is much higher than in the other V4 countries.

4.1.6 Vacancies

The development of seasonally unadjusted and adjusted time series of total vacancies is captured in figure 4.9. The data sets of the Czech Republic and Poland are acquired solely from the OECD database, while the vacancies for Slovak Republic are obtained from the NBS, due to the unavailability of data on the sites of OECD. Since Hungarian vacancies are accessible on the site of OECD from the beginning of my observed period only until the fourth quarter of 2014 and Eurostat[17] provides the data between the first quarter of 2009 and my last observation, I had to make some adjustments to acquire the data for the whole period: because the data is available only from one source in periods from the first quarter of 2002 to the second quarter of 2008, and from the first quarter of 2015 to the last observation, it is taken from the respective databases. The overlapping period between the first quarter of 2009 and the last quarter of 2014 is then divided to three parts: (1) the first three periods are taken from the OECD as a transition between the two data sources; (2) the observations up to the last quarter of 2012 are calculated as the mean of the data; (3) the observations in the remaining time period are taken

[17]The data of Eurostat are the same as the official data of the Hungarian Statistical Office (KSH).

Figure 4.9: Total number of vacancies



Source: data from NBS, Eurostat and OECD; author's processing. Thick - seasonally adjusted, thin - seasonally unadjusted.

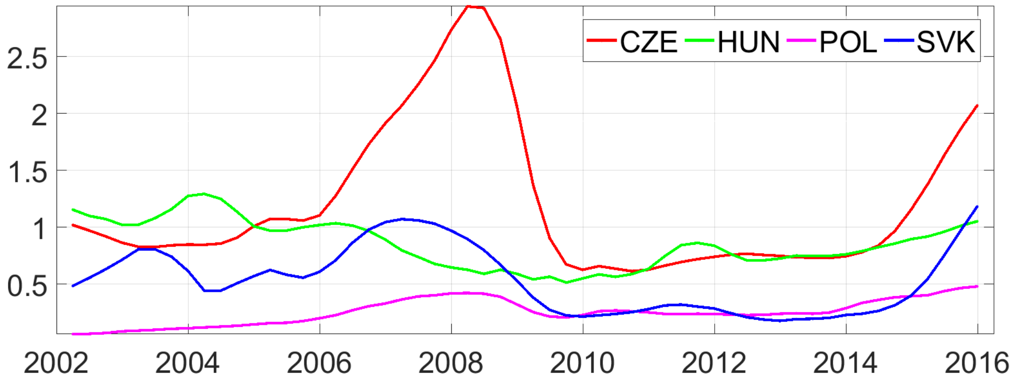
from the Eurostat as a transition from the mean to the purely Eurostat data. This last period is longer due to the unexplainable boom of vacancies in the OECD data. The two original seasonally unadjusted time series together with their merged variant are presented in Appendix B, figure B.1. Vacancies of Hungary in figure 4.9 represent the final combination of seasonally adjusted (thick) and unadjusted (thin) time series. This time series has a slightly decreasing trend prior to the crisis and mildly rising tendency since then.

The Czech vacancies show massive increase during years 2006 and 2007, when their number almost tripled from 53 to 151 thousand. However, this enormous rise was followed by a rapid decline in 2008 and 2009, partially because the economy has reached its limits and also because of the recession, during which firms withdrew their job proposals. Until the second quarter of 2014 the number of vacancies remained stable and since then it increases steadily with the decrease of unemployment. In the last two years the developments on the labour market resulted in lack of workforce in the Czech Republic. Given the low amount of unemployed people, the firms are pressured to create more attractive job positions.

The vacancies in Poland have had similar tendencies as in the Czech Republic during the observed period. The greatest difference between these two countries is in the volume of vacancies. Even though Poland has more than three times the economically active population as the Czech Republic, its number of vacancies falls behind the Czech volume in most time periods.

The number of vacancies also increased in Slovakia before the recession, which led

Figure 4.10: Vacancies per economically active population older than 15 years (%)



Source: data from OECD database; author's processing.

to its decline. Since late 2009 till early 2015, the volume of vacancies did not change significantly in any direction. Similarly to the previous two economies, the number of vacancies in Slovakia rises in the last four observed periods. This variable experienced qualitatively same development in each country of the Visegrad Group except Hungary, where it was virtually unaffected by the recession.

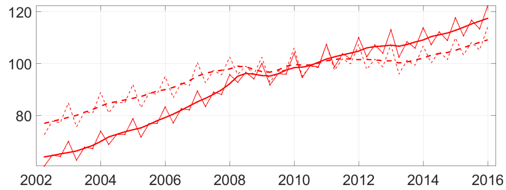
Figure 4.10 depicts the development of vacancy rate (calculated as the total number of vacancies over the economically active population older than 15 years). These rates copy the development of their respective total values. Polish vacancy rates are, however, closer to zero, because the higher population compared to the other economies.

4.1.7 Wage

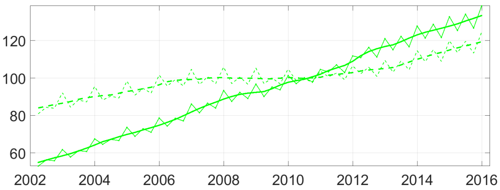
Figure 4.11 depicts the development of nominal wage index of hourly earnings obtained from OECD together with the real wage index calculated as $w_t^{real} = w_t^{nominal}/CPI_t$. The nominal wages are increasing in each country through the whole observed period with the exception of recession, when stagnation set in. The impact of the crisis is most notable on the Czech wages, nominal and real as well. Their increase is the lowest among the V4 countries. The highest increase in nominal wages can be observed in Hungary and Slovakia, however in case of Hungary, the more rapidly increasing consumer price index caused that real wages did not increase to such extent. Hungarian real wages also experienced a long period of stagnation between 2007 and 2012, while the nominal wages increased. The figure also shows that Polish real and nominal wages contain the lowest amount of seasonal disturbances.

Figure 4.11: Nominal and real wages (2010=100)

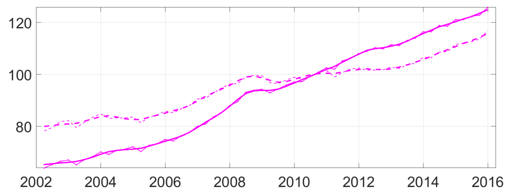
(a) Czech Republic



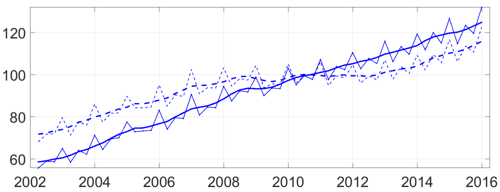
(b) Hungary



(c) Poland



(d) Slovak Republic



Source: data from OECD database; author's processing. Solid - nominal, dashed - real. Thick - seasonally adjusted, thin - seasonally unadjusted.

4.1.8 Hours worked

The final variable entering the model is the average hours worked, presented in figure 4.12. The seasonally unadjusted versions of this variable are much more volatile compared to the variables described above. It is important to mention that only the time series of Czech and Slovak hours worked are obtained from the official databases of each country. Czech statistical office for the former and National bank of Slovakia for the latter. The data for Hungary and Poland are approximated using the data available for the Czech Republic. The following ordinary least squares regression is estimated on the Czech data:

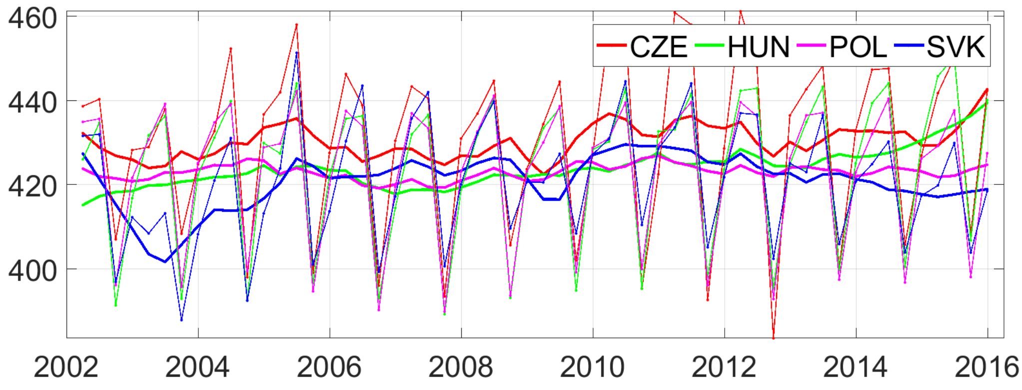
$$Hours\_Q = \beta_0 + \beta_1 Days\_Q + \beta_2 Hours\_A\_avg + \beta_3 Urate + \beta_4 D, \tag{4.1}$$

where $Hours\_Q$ represents the quarterly hours worked by one employee, $Days\_Q$ is the number of working days in one quarter[18], $Hours\_A\_avg$ denotes the annual average hours worked divided into four quarters[19], $Urate$ represents the unemployment rate in the Czech Republic and D is a dummy variable which captures seasonal influences. This regression is estimated in Matlab with the resulting coefficient of determination, $R^2 = 0.92$. The estimated values of regression parameters $\beta_{0...4}$ are then imputed to acquire the hours worked for Hungary and Poland.

[18] The number of quarterly working days is obtained from `http://calendar.zoznam.sk/worktime-encz.php`.

[19] This time series is available at the OECD database.

Figure 4.12: Hours worked



Source: data from OECD database; author's processing. Thick - seasonally adjusted, thin - seasonally unadjusted.

4.2 Data transformation

Section 4.1 focused on the description of each time series and the removal of one component from the data - the seasonal disturbances. This part of the thesis aims to separate the trend from the cyclical component, which is going to represent the input data of the model described in chapter 3.

There are several methods that allow the econometric researcher to differentiate the cyclical information from the underlying trend in the data. It is often desirable in the spirit of DSGE modelling to acquire data which oscillate around zero mean. If there is no apparent trend in the observed data a simple subtraction of mean (so called demeaning) is likely sufficient to achieve data with zero steady-state which are ready for the estimation. However, if there is a trend in the data, more sophisticated methods need to be considered, the simplest of which are a linear or quadratic trends. Although they are sometimes useful, more often than not the trend has a higher rank of curvature than quadratic. In that case, it is advised to use one of the more complex techniques, like first-difference filter or the Hodrick and Prescott (1980) filter (HP filter). The first mentioned takes the first differences of logarithmized data to obtain a stationary time series around a non-zero steady state. As Pfeifer (2015) states, taking logarithms of data, regardless of the filtering method, is a typical procedure that results in a scale invariant time series.

The literature distinguishes between two types of HP filters: one-sided and two-sided. The difference between the two is that the one-sided version constructs the filtered part of the variable based only on the current and previous states. On the other hand, the two-sided HP filter uses values up to three time periods not only from past states but also from future values, thus inadvertently assuming that the economic subjects take into consideration the data which is unavailable at that time. One of the greatest drawbacks to the HP filter is its end of sample bias. This means that at each end of the sample the HP filter may evaluate a trend to be over or under the observed data when the situation is actually the opposite. This follows from the fact that there does not exist a a value before the first and after the last observation. Regardless of this shortcoming, many authors, like Christoffel et al. (2009) for euro area, Albertini et al. (2012) for New Zealand, Faccini and Ortigueira (2010) for US data or Zeman and Senaj (2009) for Slovakia use HP filter to stationarize the data.

Although it is not the primary aim of Christiano et al. (2010) to validate or disprove the appropriateness of the HP filter, the authors suggest that it could be a relatively good approximation when computing the output gap. However, they emphasize that accuracy of the HP filter for extracting the output gap is very sensitive to the details about the underlying model. Pfeifer (2015) remarks that the two-sided HP filter is a non-casual filter which generates current data from future values for a model solution that has a form of backward-looking state-space system. Hence he suggests to apply the one-sided filter instead. On the other hand, Hamilton (2016) takes an even more sceptical look at this filter. He reproaches the two-sided version for making use of unknowable future values. He also questions the value of widely used smoothing parameter λ, which is not estimated from the data, but rather a suggested choice, a rule of thumb. He suggests a different approach to find the cyclical component of a trending series using a prediction from time t to period $t+h$. The difference between the forecast and the actually measured value can be considered the gap, because, as he states, the primary reason that we would be wrong in predicting the value of most macro and financial variables at a horizon of $h = 8$ quarters ahead is cyclical factors such as whether a recession occurs over the next two years.

I have selected the two sided HP-filter[20] for my data transformation with the smoothing parameter λ set to the commonly used value of 1600 for data with quarterly periodicity. The final form of data that enters the model is depicted in figure B.2[21]. Each data set

[20] The filtering is done in Matlab using a function developed by Alexander Meyer-Gohde of the Humboldt-University at Berlin. Available at `http://econpapers.repec.org/software/dgeqmrbcd/181.htm`.

[21] Actually, the data entering the model is divided by 100.

described above was logarithmized with the exception of interest rates and inflation to avoid taking logarithms of negative numbers and because these two variables are already in percentages. Following Albertini et al. (2012), logarithms are also taken from the variables of unemployment rate and vacancy per capita, because the model is in log-linear form. Deviations of these variables are thus going to be in percentages from steady state and not in percentage points. Table 4.1 summarizes the used data and the individual sources of data.

Table 4.1: Sources of data

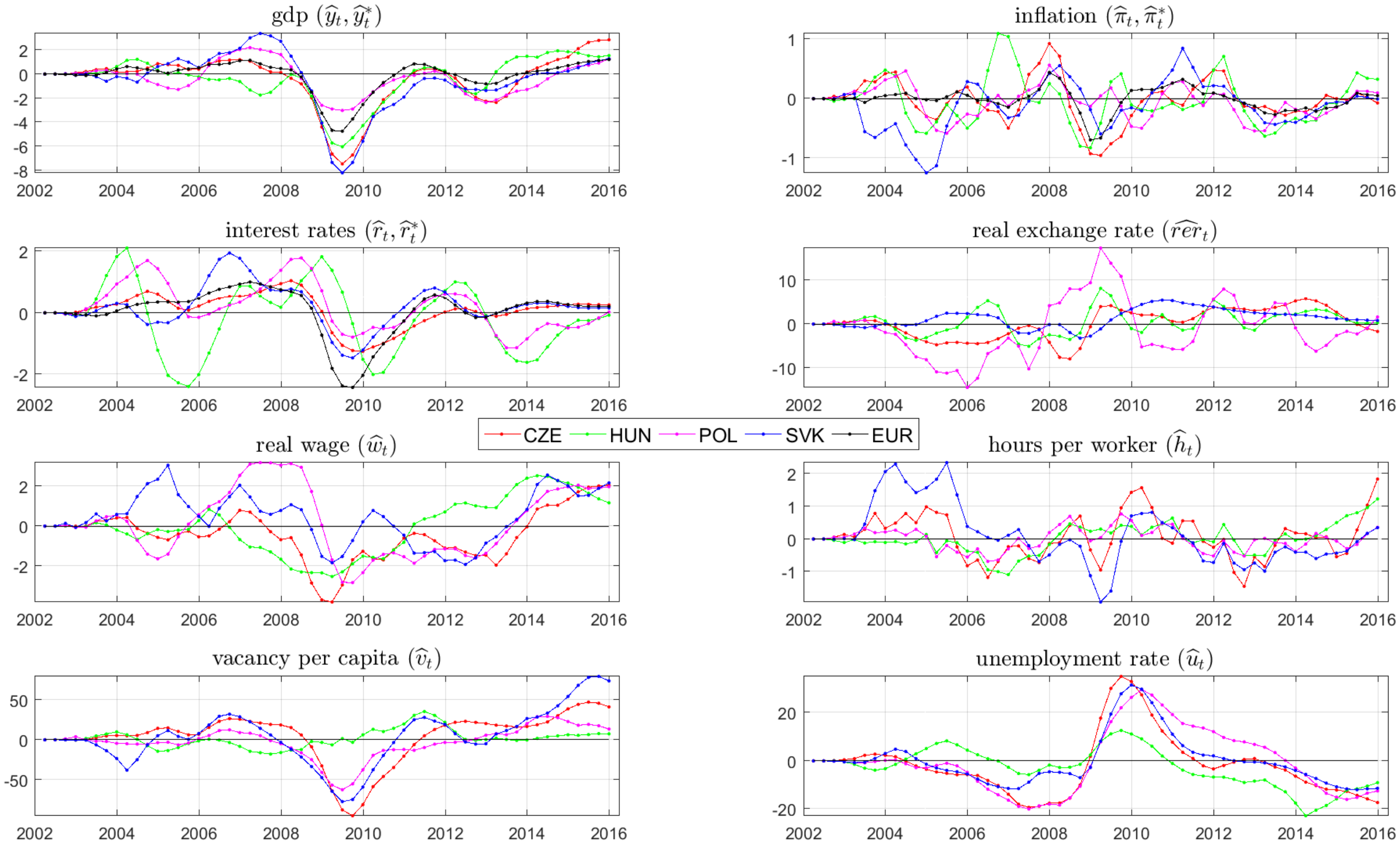
		Data source			
Variable	Name	CZE	HUN	POL	SVK
$\widehat{y}_t, \widehat{y}_t^*$	real GDP	OECD	OECD	OECD	OECD
$\widehat{r}_t, \widehat{r}_t^*$	nominal interest rate	OECD	OECD, MNB	OECD	OECD
$\widehat{\pi}_t, \widehat{\pi}_t^*$	CPI inflation	OECD	OECD	OECD	OECD
$\widehat{rer}_t$	real exchange rate	ECB	ECB	ECB	ECB
$\widehat{u}_t$	unemployment	OECD	OECD	OECD	OECD
$\widehat{v}_t$	vacancies	OECD	OECD, Eurostat	OECD	NBS
$\widehat{w}_t$	real wage	OECD	OECD	OECD	OECD
$\widehat{h}_t$	hours worked	CZSO	OECD*	OECD*	NBS

Note: the sources represent the source of original time series. *Hours for Hungary and Poland are imputed (see text for explanation of this method). For model variables holds that: GDP, vacancies and unemployment is divided by economically active population, inflation is the logarithmic difference of CPI and nominal exchange rate and wage index are transformed to real variables by dividing by CPI.

4.2.1 Alternative data filtering

Taking into consideration the critique of the two-sided HP filter outlined above, I conduct a robustness check using the one-sided version of this filter which is considered by some authors, listed above, to be a better and more representative filter of the actual observed data. Figure 4.13 contains the detrended data using the one-sided HP filter. Since the one-sided filter creates fluctuations around a non-zero mean, this mean is subtracted from the data that enters the model. The figure presents data with zero mean. Furthermore, from the definition of the one-sided HP filter follows that the variables start from their steady state since there cannot be drawn any expected value from observations that are outside the observed sample and therefore unavailable.

Figure 4.13: One-sided HP filtered input data - percentage deviations from steady state (%)



Source: data from OECD database; author's processing.

4.3 Calibration

Calibration of model parameters is essential in the Bayesian framework. It allows the researcher to impose additional information on the model. Table 4.2 contains the model parameters which are not estimated. Among these, there are the universal values for variables which are used in the literature. The labour share can be considered an empirical evidence with the value 2/3. The same value of debt elastic risk premium is used for Hungarian economy in Jakab and Kónya (2016). I follow, among others, Albertini et al. (2012) and Ireland (2007) in the setting of the elasticity of substitution between differentiated goods to 6, which corresponds to the price adjustment cost parameter values defined below. The second part of table 4.2 contains country specific parameter calibration, which depends on the data. The import share on output was calculated from the definition of α in equation (3.97). This variable reports that Poland is a more closed economy, than the rest. The steady state of unemployment, $\overline{U}$, is calculated as a sample mean of the unemployment rate. The scaling factor to vacancy posting, κ^v, is set in a way that vacancy costs represent 1% of output. The matching efficiency parameter, χ, and job separation rate, ρ^x, are set to reflect the steady-state values of unemployment and vacancies. The scaling factor to dis-utility of work, κ^h, targets steady-state hours to 1/3.

Table 4.2: Fixed parameter setting

Variable	Name	CZE	HUN	POL	SVK
Universal					
β	discount factor	0.99	0.99	0.99	0.99
ϵ	elasticity of substitution	6	6	6	6
ζ	share of labour in production	2/3	2/3	2/3	2/3
τ^b	el. of debt elastic risk premium	0.001	0.001	0.001	0.001
Data specific					
α	import share on GDP	0.3708	0.4372	0.2845	0.4411
$\overline{U}$	steady state of unemployment	0.0671	0.0826	0.1223	0.1411
κ^v	scaling factor to vacancy posting	0.1275	0.1780	0.5876	0.2732
χ	efficiency of matching	0.4783	0.4421	0.2117	0.2604
ρ^x	exogenous job separation rate	0.03	0.025	0.0075	0.015
κ^h	scaling factor to dis-utility of work	7.2184	7.3403	7.6723	7.8403

Note: the same *universal* parameters are set according to the literature for each country. The *data specific* parameters are calculated separately from each country's data.

Table 4.3 summarizes the estimated parameters and their prior distributions. All of these parameters are set rather uninformatively, since there exists little to no evidence

Table 4.3: Prior distributions of estimated parameters

	Parameter	Distribution	Mean	Std. dev.
ϑ	habit	*beta*	0.5	0.15
ϕ_h	inverse of Frisch elasticity	*gamma*	1	0.2
η	el. of substitution (dom. & for.)	*gamma*	1	0.2
ξ	bargaining power of firms	*beta*	0.5	0.2
ν	elasticity of matching	*beta*	0.5	0.2
e	elasticity of vacancy creation cost	*gamma*	1	0.5
Price and wage setting				
γ_H	back. looking price (dom. goods)	*beta*	0.75	0.1
γ_F	back. looking price (for. goods)	*beta*	0.75	0.1
γ_W	back. looking wage parameter	*beta*	0.75	0.1
ψ_H	price adj. cost (dom. goods)	*gamma*	50	15
ψ_F	price adj. cost (for. goods)	*gamma*	50	15
ψ_W	wage adj. cost	*gamma*	50	15
Monetary policy				
ρ_r	interest rate smooth.	*beta*	0.5	0.15
ρ_π	inflation	*gamma*	1.5	0.25
ρ_y	output gap	*normal*	0.25	0.1
$\rho_{\Delta y}$	difference of output	*normal*	0.25	0.1
$\rho_{\Delta ner}$	difference of exchange rate	*normal*	0.25	0.1

Note: table contains prior distributions of estimated parameters, which are the same for each economy.

about these parameters in the real economy. I decided to set the adjustment cost parameters to a prior mean of 50. The same value is suggested by Maršál (2011) for the Czech economy. Furthermore, the same prior distributions are set for each country to minimize the differences in estimations which are not related to the data.

The persistence of each shock $\rho = \{\rho_a,\ \rho_q,\ \rho_c,\ \rho_h,\ \rho_m,\ \rho_\chi,\ \rho_\xi,\ \rho_{\kappa^h},\ \rho_{y^*},\ \rho_{\pi^*},\ \rho_{r^*}\}$ has a *beta* distribution with prior mean 0.5 and standard deviation 0.25. The prior distribution of standard errors of innovations is presented in table 4.4. Efforts were made, to select prior distributions that can be used for each estimation of each country, while keeping some of the parameters relatively tight.

Table 4.4: Prior distributions of shocks' standard deviations

Parameter	Distribution	Mean	Std. dev.
σ_{ϵ^a}	*inverse gamma*	0.01	*inf*
$\sigma_{\epsilon^{rer}}$	*inverse gamma*	0.15	*inf*
σ_{ϵ^c}	*inverse gamma*	0.1	*inf*
σ_{ϵ^H}	*inverse gamma*	0.4	*inf*
σ_{ϵ^m}	*inverse gamma*	0.01	0.2
σ_{ϵ^χ}	*inverse gamma*	0.20	*inf*
σ_{ϵ^ξ}	*inverse gamma*	0.4	*inf*
$\sigma_{\epsilon^{y*}}$	*inverse gamma*	0.01	0.2
$\sigma_{\epsilon^{i*}}$	*inverse gamma*	0.01	0.2
$\sigma_{\epsilon^{\pi*}}$	*inverse gamma*	0.01	0.2
σ_{ϵ^h}	*inverse gamma*	0.1	*inf*

Note: table contains prior distributions of innovations' standard errors, which are the same for each economy. Standard deviation inf represents uninformative prior.

4.4 Chapter's summary

This chapter contains the description of the 11 observed variables – three for the common foreign sector and eight for each of the four the domestic economies. First, the original time series are presented in seasonally adjusted and unadjusted form. Each time series is displayed for each country for comparison. The seasonal adjustment is made to get rid of the seasonal influences that are present in the data.

After the seasonal adjustment, the data the trend component is removed using two types of HP filter. The different transformation methods are used to examine whether the one-sided version outperforms its two-sided counterpart.

The final section contains the calibration of model parameters. The section contains the explanation of parameter value selection. Some of the parameters are calibrated for each country the same. However, some parameters are calibrated to be country specific from each country's data.

Chapter 5

Estimation techniques and model identification

For the purpose of my dissertation I have selected a NK SOE DSGE model which is described in detail in chapter 3. On the other hand, the current chapter focuses on introducing the applied methods to the reader, which are required to achieve the desired results and which enable me to draw conclusions. These techniques are essential for understanding the mechanics behind the econometric software.

First, models with rational expectations are derived in their basic form. This section contains also the solution to such systems and their generalization. Furthermore, the functioning of the Kalman filter is presented, which is used to obtain the dynamics of unobserved variables. Next, the Bayesian methodology is outlined. A focus is put to the Metropolis-Hastings algorithm and its random-walk representation. The chapter ends with the description of Bayesian model comparison.

5.1 Models with rational expectations

As presented by Blanchard and Kahn (1980), a wide variety of dynamic models can be written in rational expectations system given by equations (5.1), (5.2) and (5.3). The structural model is described by (5.1) as:

$$\begin{bmatrix} X_{t+1} \\ {}_tP_{t+1} \end{bmatrix} = A \begin{bmatrix} X_t \\ P_t \end{bmatrix} + \gamma Z_t \qquad X_{t=0} = X_0, \tag{5.1}$$

where a distinction between predetermined and non-predetermined (forward looking) variables is made. X is an $(n \times 1)$ vector of predetermined variables at time t, P is an $(m \times 1)$ vector of variables non-predetermined at time t, Z is a $(k \times 1)$ vector of exogenous variables, ${}_tP_{t+1}$ represents the expectations of agents of P_{t+1} at time t. A is a constant matrix

$(n+m) \times (n+m)$ and γ is a constant matrix $(n+m) \times k$. ${}_tP_{t+1}$ is defined as follows:

$$ {}_tP_{t+1} = E(P_{t+1}|\Omega_t), \tag{5.2} $$

where $E(\cdot)$ represents the standard mathematical operator for expectations, Ω_t stands for the information set at time t, consisting of all the available information at that time. Ω_t contains at least, but not exclusively, past and current values of X, P and Z. It may include other exogenous variables than Z or their future values. It holds that $\Omega_t \supseteq \Omega_{t-1}$. Equation (5.2) defines rational expectations in a form that agents make use of all the available information in current time (Ω_t) when they are making their expectations. Finally, it is important to restrict the growth of the expectation of Z_{t+i}, held at time t, to eliminate exponential growth. It can be achieved by imposing the following condition:

$$ \begin{gathered} \forall t \exists \bar{Z}_t \in \mathbb{R}^k, \quad \theta_t \in \mathbb{R} \quad \text{such that} \\ -(1+i)^{\theta_t} \bar{Z}_t \leq E(Z_{t+1}|\Omega_t) \leq (1+i)^{\theta_t} \bar{Z}_t, \qquad \forall i \geq 0. \end{gathered} \tag{5.3} $$

At this point, it is important to make a distinction between predetermined and non-predetermined variables. A predetermined variable is defined only by variables known at time t, which are contained in Ω_t. This means that $X_{t+1} =_t X_{t+1}$ always holds, regardless of the realization of the variables in Ω_{t+1}. On the other hand, a non-predetermined variable can also be a function of variables from Ω_{t+1}. This implies that $P_{t+1} =_t P_{t+1}$ holds only if the realizations of all variables in Ω_{t+1} are the same as their expectations at time t conditional on Ω_t.

5.1.1 Solution to the rational expectation models

A solution (X_t, P_t) is a sequence of functions of variables in Ω_t which satisfies (5.1) for all possible realizations. It is also necessary to restrict the growths of X_t and P_t as is done for Z_t in (5.3):

$$ \forall t \exists \begin{bmatrix} \bar{X}_t \\ \bar{P}_t \end{bmatrix} \in \mathbb{R}^{n+m}, \quad \sigma_t \in \mathbb{R} \quad \text{such that} \tag{5.4} $$

$$ -(1+i)^{\sigma_t} \begin{bmatrix} \bar{X}_t \\ \bar{P}_t \end{bmatrix} \leq \begin{bmatrix} E(X_{t+1}|\Omega_t) \\ E(P_{t+1}|\Omega_t) \end{bmatrix} \leq (1+i)^{\sigma_t} \begin{bmatrix} \bar{X}_t \\ \bar{P}_t \end{bmatrix}, \qquad \forall i \geq 0. \tag{5.5} $$

The solution of the model can be reached by simplifying the model using transformation of matrix A into Jordan canonical form $A = C^{-1}JC$, where the diagonal elements of J (eigenvalues of A) are ordered by increasing absolute value. The existence and uniqueness of solution is determined by the number of eigenvalues of A outside the unit circle ($\tilde{m}$)

and the number of non-predetermined variables (m). If $\tilde{m} = m$, there is a single unique solution. In case of $\tilde{m} < m$, the system has infinite number of solutions. For $\tilde{m} > m$, there is no solution at all that satisfies (5.1) and the conditions regarding the growth of expectations.

5.1.2 Generalization of rational expectations' interpretation

The topic of dynamic models with rational expectations described above, was further investigated by other authors, like Lubik and Schorfheide (2006)[22]. They state that log-linearized models (like the one presented in chapter 3) can be expressed as a linear rational expectations system of the following form:

$$\Gamma_0(\theta)s_t = \Gamma_1\theta s_{t-1} + \Gamma_\epsilon(\theta)\epsilon_t + \Gamma_\eta(\theta)\eta_t, \tag{5.6}$$

where s_t represents the vector of model variables, ϵ_t denotes the innovations of exogenous shock processes and η_t consists of rational expectations forecast errors. Matrices Γ define the dynamics of the exogenous shock processes and are functions of model parameters θ. In case of the model described in chapter 3, ϵ_t=[ϵ_t^a, ϵ_t^c, ϵ_t^H, ϵ_t^{rer}, ϵ_t^m, ϵ_t^χ, ϵ_t^ξ, ϵ_t^h, $\epsilon_t^{y^*}$, $\epsilon_t^{r^*}$, $\epsilon_t^{\pi^*}$]$'$ and θ=[ϑ, β, α, ϵ, η, ζ, ϕ_h, e, b^u, τ^b, ν, ρ^x, γ_H, γ_F, γ_W, ψ_H, ψ_F, ψ_W, κ^v, κ^h, ξ, $\overline{V}$, $\overline{N}$, $\overline{M}$, $\overline{K}$, $\overline{F}$, $\overline{\Theta}$, $\overline{MC}$, $\overline{S}$, $\overline{Y}$, $\overline{H}$, $\overline{U}$, ρ_{rer}, ρ_H, ρ_a, ρ_m, ρ_c, ρ_ξ, ρ_χ, ρ_v, ρ_h, ρ_{y^*}, ρ_{r^*}, ρ_{π^*}, $\rho_{\varepsilon Y^*}$, $\rho_{\varepsilon i^*}$, $\rho_{\varepsilon\pi^*}$, ρ_i, ρ_π, ρ_Y, $\rho_{\Delta Y}$, $\rho_{\Delta e}$]'. Solving the linear system defined by (5.6) results in:

$$s_t = G_s(\theta)s_{t-1} + G_\epsilon(\theta)\epsilon_t. \tag{5.7}$$

This equation describes the transitions between states in times $t-1$ and t. A measurement equation is implemented to connect the model variable to a vector of observed variables y_t[23]:

$$y_t = A(\theta) + Bs_t. \tag{5.8}$$

$A(\theta)$ is the mean of y_t, which is connected to the structural parameters. In the case, when the observable variables are around zero steady-state, this constant can be left out. Matrix B does not depend on the parameters of vector θ, because it just picks elements of s_t. In case of this thesis, y_t=[$\widehat{y}_t$, $\widehat{y}_t^*$, $\widehat{\pi}_t$, $\widehat{\pi}_t^*$, $\widehat{r}_t$, $\widehat{r}_t^*$, $\widehat{rer}_t$, $\widehat{u}_t$, $\widehat{v}_t$, $\widehat{w}_t$, $\widehat{h}_t$].

[22] For others, see e.g. Klein (2000) for the use of generalized Schur form (QZ decomposition) or Sims (2002), who uses an analysis similar to Blanchard and Kahn (1980) with four important differences.

[23] As stated in Lubik and Schorfheide (2006), other authors incorporate shocks not to the linear rational expectation system (5.6), but rather to the measurement equation (5.8). These so called measurement errors are related to non-model problems with the quality of data.

5.1.3 The Kalman filter

The Kalman filter[24] is used mainly to estimate the unobservable state of a variable or to evaluate the likelihood function associated with a state space model[25]. Following Griffoli (2010), the solution to the DSGE model described by (5.7) and (5.8) can be rewritten as a more general system of equations as follows:

$$\begin{aligned} y_t^* =& M\bar{s}(\theta) + M\hat{s}_t + N\theta x_t + w_t, && (5.9)\\ \hat{s}_t =& g_s(\theta)\hat{s}_{t-1} + g_\epsilon(\theta)\epsilon_t, && (5.10)\\ E(w_t w_t^{'}) =& W(\theta), && (5.11)\\ E(\epsilon_t \epsilon_t^{'}) =& Q(\theta), && (5.12) \end{aligned}$$

where equation (5.9) represents the more general form of measurement equation (5.8) with measurement error w_t. y_t^* represents the actually observed variables with possible trend, denoted as $N(\theta)x_t$, which enables the trend to depend on the deep parameters. $\hat{s}_t$ is the vector of variables in deviations from steady-state, $\bar{s}_t$ is the vector of steady state values and θ represents the vector of estimated structural parameters. Equation (5.10) is the transition equation, as in (5.7). However, this equation describes a relationship among not directly observed endogenous variables. These two equations define the state space system. The last two equations, (5.11) and (5.12), are the covariance matrices of measurement errors and exogenous variables respectively.

To solve this system of equations, the Kalman filter is used to estimate the likelihood. For initial values y_1 and P_t given and for time $t = 1, \ldots, T$ the recursion of Kalman filter follows:

$$\begin{aligned} v_t =& y_t^* - \bar{y}^* - M\hat{s}_t - Nx_t, && (5.13)\\ F_t =& MP_tM' + W, && (5.14)\\ K_t =& g_sP_tg_s'F_t^{-1}, && (5.15)\\ \hat{s}_{t+1} =& g_s\hat{s}_t + K_tv_t, && (5.16)\\ P_{t+1} =& g_sP_t(g_s - K_tM)' + g_\epsilon Q g_\epsilon'. && (5.17) \end{aligned}$$

[24]A more detailed overview of the Kalman filter is present in the original paper Kalman (1960) or in chapter 13 of Hamilton (1994).

[25]Kristoffer Nimark at the Barcelona GSE Summerschool 2016, available online: `http://www.kris-nimark.net/Applied_Macro_2016/Kalman_Filter_and_SSS_slides.pdf`

From this recursion, the log-likelihood can be derived as follows:

$$\ln\mathcal{L}(\Theta|Y_T^*) = -\frac{Tk}{2}\ln(2\pi) = \frac{1}{2}\sum_{t=1}^{T}|F_t| - \frac{1}{2}v_t'F_t^{-1}v_t, \tag{5.18}$$

where Θ contains the parameters to be estimated (θ, $W(\theta)$ and $Q(\theta)$) and Y_T^* represents the set of observable endogenous variables y_t^*.

Finally, the posterior distribution of the estimated parameters, the log posterior kernel, is given by:

$$\ln\mathcal{K}(\Theta|Y_T^*) = \ln\mathcal{L}(\Theta|Y_T^*) + \ln p(\Theta), \tag{5.19}$$

which is a sum of log-likelihood and the known priors.

5.2 Bayesian approach

The values of estimated model parameters θ can be obtained through Bayesian estimation method[26]. The Bayesian approach takes the parameters of the model θ as a random variable that depend on data, y. The Bayes theorem then can be written as:

$$p(\theta|y) = \frac{p(y|\theta)p(\theta)}{p(y)}, \tag{5.20}$$

where $p(\theta|y)$ represents the posterior density, $p(y|\theta)$ is the likelihood function (also called as the data generating process), $p(\theta)$ is the prior density[27], which does not depend on the data and $p(y)$ denotes the marginal density of the data, which does not depend on the parameter setting. Therefore, equation (5.20) can be rewritten as:

$$p(\theta|y) \propto p(y|\theta)p(\theta). \tag{5.21}$$

where $\propto$ symbolizes proportionality. The posterior is proportional to the likelihood times the prior density. The likelihood function can be calculated using the Kalman filter described in the previous section. Since the prior does not depend on the data itself, it contains all accessible information outside the data. The setting of priors can be done by out-of-the-sample analysis or simply by taking the priors from other authors' work, if it can be justified. Furthermore, uninformative prior can be chosen for parameters, which the researcher knows very little about.

[26]For detailed description of the Bayesian approach see, e.g. Koop (2003) or Geweke et al. (2011).
[27]The prior setting is presented in section 4.3.

5.2.1 Metropolis-Hastings algorithm

Since it is often impossible to know the exact form of the posterior distrubtion, a sampling method has to be used to simulate the desired distribution. For this thesis random-walk Metropolis-Hastings algorithm[28] is used, which is a Markov chain Monte Carlo (MCMC) method for obtaining a sequence of random samples from a probability distribution for which direct sampling is difficult.

This sampling method can be described as follows: Let $q(x, y)$ represent the candidate generating density, where if a process is at x, this density generates y from $q(x, y)$. It has to hold that $\int q(x, y)\mathrm{d}y = 1$. If $q(x, y)$ satisfies the following condition, called the reversibility condition:

$$\pi(x)q(x, y) = \pi(y)q(x, y), \tag{5.22}$$

for all x, y, the search for candidate ends. However, if for some x, y, the equality does not hold, for example $\pi(x)q(x, y) > \pi(y)q(x, y)$, the movements from x to y are more frequent than shifts from y to x. The frequency of movements can be easily equalized by implementing an acceptance probability of move $\alpha(x, y) < 1$. If the transition is not made, x is returned as a value from target distribution. Movements from x to y are made according to:

$$p_{MH}(x, y) \equiv q(x, y)\alpha(x, y) \quad \text{for} \quad x \neq y, \tag{5.23}$$

where $\alpha(x, y)$ is given as follows. If the reversibility condition does not hold, as described above, it is desirable to make the probability of transitions from y to x larger by setting the probability $\alpha(y, x)$ to 1. $\alpha(x, y)$ is then given by $p_{MH}(x, y)$ satisfying condition (5.22):

$$\pi(x)q(x, y)\alpha(x, y) = \pi(y)q(y, x)\alpha(y, x) = \pi(y)q(y, x). \tag{5.24}$$

From this, $\alpha(x, y) = \pi(y)q(y, x)/\pi(x)q(x, y)$ has to hold for $p_{MH}(x, y)$ to be reversible.

$$\begin{aligned} \alpha(x, y) =& \min\left\{\frac{\pi(y)q(y, x)}{\pi(x)q(x, y)}, 1\right\}, \quad && \text{if } \pi(x)q(x, y) > 0 && (5.25) \\ =& 1, && \text{otherwise.} && (5.26) \end{aligned}$$

The Metropolis-Hastings algorithm can be summarized by the following steps:

1. Choose an initial value $x^{(0)}$.

[28]For more information about the Metropolis-Hastings algorithm or other sampling methods see e.g. Chib and Greenberg (1995) or Koop (2003).

2. Generate a new candidate y from $q(x^{(j)}, \cdot)$ and u from an uniform distribution $\mathcal{U}(0, 1)$.

3. Set $x^{(j+1)} = y$ if $u \leq \alpha(x^{(j)}, y)$, otherwise set $x^{(j+1)} = x^{(j)}$.

4. Repeat 2. and 3. for $j = 1, 2, \ldots, N$.

5. Return the values $\{x^{(1)}, x^{(2)}, \ldots, x^{(N)}\}$.

The draws are regarded as a sample from the target density $\pi(x)$ only after there is a sufficient number of generated draws and the effect of the initial value $x^{(0)}$ is small enough to be ignored. To remove the influence of the choice of the initial value, the first N_1 draws can be dropped. N_1 is usually set to be around 60 to 75 percent of the total draws generated. The convergence to the target distribution is then investigated. In the case if my thesis, the convergence is checked according to the Brooks and Gelman (1998) convergence diagnostics which is implemented in the used software.

5.2.2 Adding a random-walk to the algorithm

To be able to solve a problem with the Metropolis-Hastings algorithm, a fitting candidate-generating density has to be declared. One way to do this is to set $q(x, y) = q_1(y - x)$, where $q_1(\cdot)$ is a multivariate density. The candidate y is drawn from $y = x + z$, where z is a random noise called increment random variable. The generation of candidates is given by a random walk. If q_1 is symmetric, $q_1(z) = q_1(-z)$, the probability of transition simplifies to a similar case, when $q(y, x) = q(x, y)$:

$$\alpha(x, y) = \min\left\{\frac{\pi(y)}{\pi(x)}, 1\right\}. \tag{5.27}$$

My estimations are carried out in Matlab R2016a with Dynare version 4.4.3. Dynare is a freely available software platform for handling a wide class of economic models. For more information visit `http://www.dynare.org/` or see Adjemian et al. (2011). For each estimation two chains of Metropolis-Hastings algorithm are generated. Each chain contains 600.000 draws of which the initial 66% is dropped as a burnin. I target the acceptance ratio to be around 0.35.

5.2.3 Comparison of models

As was mentioned above, the Bayesian approach enables a handy way to compare two different models, M_1 and M_2, which both explain the same data y. With each model having a prior probability $p(M_1)$ and $p(M_2)$, the posterior probabilities can be defined as:

$$p(M_1|y) = \frac{p(y|M_1) \cdot p(M_1)}{p(y)} \quad \text{and} \quad p(M_2|y) = \frac{p(y|M_2) \cdot p(M_2)}{p(y)}, \tag{5.28}$$

where $p(y)$ represents the data density and $p(M_1|y)$ and $p(M_2|y)$ denotes the marginal likelihoods. The posterior odds ratio, PO_{12}, is used to compare the two models:

$$PO_{12} = \frac{p(M_1|y)}{p(M_2|y)} = \frac{p(y|M_1)}{p(y|M_2)} \cdot \frac{p(M_1)}{p(M_2)}. \tag{5.29}$$

Setting the prior probability in favour of a model increases the posterior probability of that model. In case these probabilities can not be decided in advance, setting equal probabilities for both models, i.e. $p(M_1) = p(M_2) = 1/2$, (5.29) simplifies to the Bayes factor:

$$BF_{12} = \frac{p(y|M_1)}{p(y|M_2)}. \tag{5.30}$$

It is not necessary to calculate the posterior densities for both models for their comparison. Instead, it is only needed to obtain the marginal likelihood of these models from the following:

$$p(y|M_i) = \int p(y|\theta_i, M_i) \cdot p(\theta_i|M_i) \mathrm{d}\theta_i \quad \text{for} \quad i = 1, 2, \tag{5.31}$$

where θ_i represents the vector of structural parameters of model M_i. This likelihood can by calculated by Laplace approximation or harmonic mean estimator.

Both, the posterior odds ratio and the Bayes factor indicate to what extent is model M_1 more probable than model M_2. Values over 10 show significant evidence favouring model M_1, values larger than 100 are considered to be decisive against model M_2.

5.3 Chapter's summary

This chapter contains the technical background that is needed to understand the functioning of the estimation methods. First, rational expectation model is described. The used DSGE model is based on similar principles.

After that usage of Bayesian techniques is outlined. Bayesian methods, like the random-walk Metropolis-Hastings are used for my estimation. A section is devoted to comparison of models with Bayes factor which is used to select the best model specification.

Chapter 6

Estimation results of the Czech Republic

This and the following chapters contain the most crucial part of the thesis. The model described in chapter 3, calibrated in the following section 4.3, using the data derived in section 4.1, with the help of techniques outlined in chapter 5 is estimated for the countries of the Visegrad Group to answer the research questions that are presented in section 1.2. Taking into consideration the research questions, the aim is to examine the labour market rigidities and their impact on the economy using the available tools from section 1.3.2.

The Czech Republic can be characterized as an economy with a solidly performing labour marker. The unemployment is on its historically lowest values[29] and firms keep increasing number of vacancies. However, this low level of unemployment rate is misleading. The Czech economy has substandard labour productivity. This is given by the fact that the Czech Republic became a manufacturing hall of the foreign countries. It's industry focuses greatly on the production of intermediary goods which are then exported. On the other hand, the Czech economy has a strong monetary authority that currently actively intervenes on the foreign exchange market to prevent deflation and negative interest rates.

The chapter is organized as follows. First, results of four estimations are presented to select the best model and data for my analysis. After the model and data are selected, the description of estimated parameters follows. Furthermore, to investigate the models ability to match the dynamical properties of the data, the model is evaluated by comparing simulated and actual data moments. The subsequent section contains the historical shock decompositions of selected variables. Next, to capture the transmission mechanism of the monetary policy, impulse response functions are plotted. Finally, throughout the chapter

[29] In the second quarter of 2016, which lies outside of my observed period, the unemployment rate of the Czech Republic was the lowest among the countries of the European Union. It was lower than in the more developed economies like Germany and the United Kingdom.

the results of estimations of the two split time periods are presented to account for any structural change in the economy.

Before I am able to answer the research questions, I need to select a representative model. This section contains the results of the alternative model specifications (simplified Taylor rule and extended foreign sector) and the result of estimation using one-sided HP filtered data. Table 6.1 contains the parameter estimates of the four estimations. The *original* model represents the model of Albertini et al. (2012) and is estimated with two-sided HP filter. The *one-sided* model is specified the same way, but it uses one-sided HP filtered data. The model with the *new foreign sector* uses the foreign economy defined in section 3.8. The last model specification uses a *simple Taylor*-rule that contains only the interest rate's reaction to its preceding value, inflation gap and output gap difference.

6.1 Model comparison

The posterior parameter values of these estimations lie relatively close together with the exception of the last model. Based on these values alone, it is unfeasible to choose the best model. Because of this, the Bayes factor is used to compare the model specifications. However, one of the properties of the Bayes factor is that it compares different models for the same data. Although the original data are the same, the two different filters generate two different sets of data. This means that another comparison method needs to be selected to enable me to select the more preferred model of these two estimations. Simulated moments are generated to investigate, how these two detrending methods differ. Comparing these moments I found no decisive evidence that the one-sided HP filter would outperform its two-sided counterpart. Therefore I decided to follow the original article of Albertini et al. (2012) and use the two sided filter. Since the *original* model and the models with *new foreign sector* and a *simple Taylor*-rule differ solely in model specifications, the above mentioned Bayes factor can be used to compare them. Comparing the Modified Harmonic Mean estimators of the marginal density[30] I found out that the best of the three models is the one with the *new foreign sector*. It outperforms the other two by a Bayes factor[31] of e^{21} and e^{32} respectively. However, it is worth mentioning that the improvement is mainly connected to the better understanding of the foreign sector. The improvement of

[30]The Laplace Approximation of the marginal density gives identical results.

[31]Calculated as $e^{(2196-2175)}$ for the comparison of the model with the expanded foreign sector and the model without any change.

Table 6.1: Estimated parameters of the Czech Republic - models

Parameter	*original*	*one-sided*	*new foreign sector*	*simple Taylor*
ϑ	0.726	0.723	0.734	0.655
	(0.643 - 0.812)	(0.635 - 0.811)	(0.653 - 0.819)	(0.550 - 0.769)
ϕ_h	0.898	0.894	0.896	0.919
	(0.604 - 1.173)	(0.602 - 1.175)	(0.614 - 1.184)	(0.629 - 1.208)
η	0.566	0.568	0.572	0.536
	(0.443 - 0.680)	(0.451 - 0.678)	(0.458 - 0.688)	(0.438 - 0.627)
Labour market - elasticities				
ξ	0.365	0.300	0.385	0.288
	(0.199 - 0.533)	(0.129 - 0.462)	(0.233 - 0.536)	(0.107 - 0.457)
ν	0.695	0.706	0.699	0.690
	(0.613 - 0.784)	(0.625 - 0.791)	(0.614 - 0.785)	(0.607 - 0.773)
e	1.521	1.620	1.486	1.659
	(1.276 - 1.757)	(1.347 - 1.901)	(1.278 - 1.694)	(1.357 - 1.956)
Price and wage setting				
γ_H	0.815	0.803	0.819	0.754
	(0.700 - 0.936)	(0.682 - 0.931)	(0.704 - 0.934)	(0.611 - 0.900)
γ_F	0.774	0.768	0.783	0.795
	(0.626 - 0.932)	(0.620 - 0.921)	(0.642 - 0.929)	(0.661 - 0.935)
γ_W	0.571	0.588	0.557	0.654
	(0.382 - 0.768)	(0.391 - 0.783)	(0.364 - 0.748)	(0.460 - 0.855)
ψ_H	55.723	63.420	58.405	53.036
	(36.643 - 73.662)	(42.321 - 84.727)	(39.177 - 76.682)	(35.792 - 70.340)
ψ_F	63.224	62.594	65.096	50.695
	(39.939 - 86.244)	(38.759 - 85.069)	(41.176 - 88.074)	(30.328 - 70.081)
ψ_W	84.701	87.473	86.945	74.045
	(56.087 - 112.790)	(58.495 - 117.063)	(58.275 - 116.291)	(46.674 - 101.152)
Monetary policy				
ρ_r	0.814	0.822	0.817	0.780
	(0.777 - 0.854)	(0.785 - 0.863)	(0.780 - 0.852)	(0.733 - 0.829)
ρ_π	1.558	1.589	1.552	1.663
	(1.401 - 1.723)	(1.429 - 1.756)	(1.384 - 1.714)	(1.494 - 1.822)
$\rho_{\Delta y}$	0.312	0.316	0.291	0.248
	(0.162 - 0.456)	(0.173 - 0.470)	(0.146 - 0.438)	(0.102 - 0.397)
ρ_y	0.320	0.266	0.351	-
	(0.218 - 0.420)	(0.177 - 0.357)	(0.254 - 0.454)	(-)
$\rho_{\Delta ner}$	0.200	0.247	0.211	-
	(0.088 - 0.309)	(0.132 - 0.364)	(0.101 - 0.321)	(-)
Foreign sector				
ϑ^*	-	-	0.870	-
	(-)	(-)	(0.822 - 0.918)	(-)
ρ_{r^*}	-	-	0.718	-
	(-)	(-)	(0.673 - 0.763)	(-)
ρ_{π^*}	-	-	1.478	-
	(-)	(-)	(1.314 - 1.641)	(-)
ρ_{y^*}	-	-	0.534	-
	(-)	(-)	(0.430 - 0.636)	(-)
$\rho_{\Delta y^*}$	-	-	0.306	-
	(-)	(-)	(0.151 - 0.463)	(-)
γ^*	-	-	0.520	-
	(-)	(-)	(0.372 - 0.666)	(-)
ψ^*	-	-	41.484	-
	(-)	(-)	(19.950 - 62.002)	(-)
κ^y	-	-	0.181	-
	(-)	(-)	(0.051 - 0.303)	(-)
Marginal Density	2175.768	2233.107	2196.038	2164.745

Note: Posterior means and highest posterior density intervals (in parentheses).

the model's explanatory power of the relations among the domestic variables is negligible.

6.1.1 Estimated parameters of the Czech Republic

Parameter estimates of the Czech Republic are depicted in the above mentioned table. Here I will concentrate on the results of the selected model with the *new foreign sector*. The deep-habit parameter, ϑ, which governs the external habit formation[32], moved significantly away from its prior mean (0.5) to 0.734. This parameter represents the extent to which the households are smoothing their consumption. Therefore, the Czech households insist on having a relatively steady consumption. The evidence found in the Czech data and other articles[33] support the value of this estimate. The model reports an even smoother consumption in the foreign economy with habit parameter, $\vartheta^* = 0.87$. The posterior mean of the inverse of Frisch elasticity, ϕ_h is lower than its prior value (1), although its 90% HPDI covers unity. This means that the elasticity of hours relative to wage ($1/\phi_h$) is higher than one, which in turn means that when wage changes, the worked hours change relatively more. The elasticity of substitution between domestic and foreign goods, $\eta = 0.572$ is estimated to be close to the result of Albertini et al. (2012), who estimated this parameter for New Zealand to be 0.51. This estimated value means that consumers are less willing to substitute domestic and foreign goods. The firm's bargaining power, ξ is estimated to be relatively low at 0.385, although not as low as in Gertler et al. (2008), who estimate the workers bargaining power to be 0.9. This would suggest that the power of trade unions is high in the Czech Republic. On the other hand, the elasticity of matching function with respect to job seekers, ν is estimated to be significantly above the prior mean (0.699). These last two parameters together seem to satisfy the Hosios condition, $\nu + \xi = 1$.

The parameter governing the elasticity of vacancy posting, e is estimated to be between 1.278 and 1.694, with the mean 1.486. Values higher than one indicate increasing hiring costs, while values lower than one would suggest decreasing expenses on creating an additional job position. The relatively low value is in contrast with my previous estimates (see Pápai (2015) or Pápai and Němec (2015)). This is because in this estimation an alternative version of vacancy posting is used. My previous models used $\Gamma(V_t) = \kappa_t^v V_t^e$. However, the model in this thesis uses vacancy costs as in Lubik (2009): $\Gamma(V_t) = \frac{\kappa^v}{e} V_t^e$.

[32] Also known as "catching up with the Joneses" from Abel (1990).

[33] Havránek et al. (2015) present a comprehensive study about the view of habit formation of different authors.

The resulting difference of this modification can be seen in the lower vacancy posting cost on one hand. On the other, the parameter governing the wage adjustment cost, ψ_W is proportionally higher. This result means that the employee hiring firm has either low vacancy creating cost and high wage adjustment cost or the other way around. Having both cost at low values is not an option for the entrepreneur. Taking this modification into account, the parameters adjusting the prices, ψ_H and ψ_F have lower values, than the wage adjustment parameter. The indexation parameters, γ_W, γ_H and γ_F show us that the wage rigidity has the lowest degree among the nominal frictions in the Czech Republic with posterior mean 0.557. Also, the posterior mean of the backward-looking domestic price indexation parameter is higher (0.819) than the value of the foreign parameter (0.783). This suggest a higher stickiness in the domestic economy, which is also confirmed by a low value of the backward-looking parameter of foreign price in the foreign sector, γ^* (0.520). Also, the price adjustment cost in the foreign sector, ϕ^* is much lower than in the Czech economy.

Looking at the parameters of the monetary policy's decision making rule, one could easily observe that the interest rate smoothing parameter, ρ_r is higher than its prior. Similar to the deep-habit parameter, parameter ρ_h serves as a smoother. This relatively high value suggests that the CNB aims to have less volatile nominal interest rate. The weight of inflation in the Taylor rule is close to its prior. This is in line with the condition stressed by Taylor that change in inflation should induce a higher change in the nominal interest rate. Amongst the other Taylor-rule parameters, the reaction to exchange rate change is the lowest. Similarly, the foreign interest rate is also relatively stable over time, although the foreign smoother parameter, ρ_{r^*} is smaller.

Table 6.2 presents the persistence of the model's shocks. Majority of the shocks has relatively high persistence. For a shock with persistence 0.86, like the bargaining shock

Table 6.2: Domestic shock persistence - Czech Republic

Parameter	mean	inf - sup		std
ρ_{rer}	0.179	0.043	0.300	0.087
ρ_H	0.452	0.270	0.639	0.112
ρ_a	0.824	0.755	0.889	0.040
ρ_c	0.768	0.660	0.876	0.066
ρ_ξ	0.869	0.800	0.937	0.041
ρ_χ	0.831	0.718	0.956	0.084
ρ_{κ^h}	0.466	0.290	0.640	0.108

Table 6.3: Domestic shock variance - Czech Republic

Parameter	mean	inf - sup		std
σ_a	0.006	0.005	0.007	0.001
σ_m	0.002	0.001	0.002	0.000
σ_{rer}	0.024	0.019	0.028	0.003
σ_c	0.058	0.043	0.072	0.008
σ_H	0.166	0.111	0.220	0.030
σ_ξ	0.131	0.091	0.170	0.020
σ_χ	0.049	0.041	0.056	0.004
σ_{κ^h}	0.098	0.061	0.134	0.021

ρ_ξ, it means that it would take more than 16 quarters to get within 10% of its initial size[34].

The variances of shocks are summarized in table 6.3. The cost-push and bargaining power shocks have the highest volatility. On the other hand, the monetary and technology shocks have the lowest standard deviation.

6.1.2 Period separation

Table 6.4 presents the posterior means and 90% highest posterior density intervals for the estimations of the Czech Republic on three time periods: *whole* (2002-2015), *before* (2002-2008) and *during* (2009-2015). Following Jakab and Kónya (2016), I use the same fixed parameter setting for both shorter periods. These parameters are taken from the calibration for the whole period and are presented in table 4.2. The prior setting of estimated parameters is the same for the complete period and the estimation of the first half. The posterior means and standard deviations of this estimation are then used as the prior distribution of the second time period.

The model does not suggest a presence of significant structural changes between the two examined time periods in the Czech economy. Even though the estimated means differ between the two short estimations, the HPD intervals overlap to a great degree for the majority of the parameters. This results from a relatively wide coverage of these intervals which include the posterior mean of the other period's estimation. However, looking solely at the mean values, a few interesting results can be pointed out. The negotiating power of firms, ξ, increased from 0.388 to 0.434. This might appear as an

[34] Lasting of the shock is calculated as follows: with AR(1) process, a shock can be written as $\varepsilon_t = \rho\varepsilon_{t-1}+\epsilon_t$. The innovation has an influence of ϵ_t on ε_t in time 1, $\rho\epsilon_t$ in time 2, $\dots$, $\rho^{k-1}\epsilon_t$ in time k. For the fraction X of initial shock, the following has to hold: $\epsilon_t = X\epsilon_t$. From setting the condition $\rho^{k-1}\epsilon_t \le X\epsilon_t$ it has to hold that $(k-1)log(\rho) = log(X)$. Finally, solving for k results in $k = log(X)/log(\rho) + 1$.

Table 6.4: Estimated parameters of the Czech Republic - periods

Parameter	*complete* 2002:Q1 - 2015:Q4	*before* 2002:Q1 - 2008:Q4	*during* 2009:Q1 - 2015:Q4
ϑ	0.734	0.651	0.711
	(0.653 - 0.819)	(0.563 - 0.797)	(0.631 - 0.794)
ϕ_h	0.896	1.053	0.950
	(0.614 - 1.184)	(0.697 - 1.256)	(0.672 - 1.214)
η	0.572	0.649	0.622
	(0.458 - 0.688)	(0.481 - 0.770)	(0.489 - 0.750)
Labour market - elasticities			
ξ	0.385	0.388	0.434
	(0.233 - 0.536)	(0.211 - 0.568)	(0.339 - 0.528)
ν	0.699	0.682	0.697
	(0.614 - 0.785)	(0.599 - 0.785)	(0.632 - 0.761)
e	1.486	1.385	1.452
	(1.278 - 1.694)	(1.135 - 1.737)	(1.340 - 1.564)
Price and wage setting			
γ_H	0.819	0.779	0.832
	(0.704 - 0.934)	(0.673 - 0.915)	(0.723 - 0.945)
γ_F	0.783	0.797	0.799
	(0.642 - 0.929)	(0.635 - 0.899)	(0.653 - 0.955)
γ_W	0.557	0.712	0.585
	(0.364 - 0.748)	(0.564 - 0.873)	(0.372 - 0.802)
ψ_H	58.405	53.888	61.244
	(39.177 - 76.682)	(33.203 - 65.789)	(46.738 - 75.030)
ψ_F	65.096	62.125	63.106
	(41.176 - 88.074)	(35.864 - 76.616)	(40.371 - 84.911)
ψ_W	86.945	62.082	79.532
	(58.275 - 116.291)	(41.693 - 85.970)	(55.832 - 102.605)
Monetary policy			
ρ_r	0.817	0.752	0.796
	(0.780 - 0.852)	(0.703 - 0.822)	(0.753 - 0.839)
ρ_π	1.552	1.514	1.545
	(1.384 - 1.714)	(1.387 - 1.672)	(1.389 - 1.705)
ρ_y	0.351	0.303	0.264
	(0.254 - 0.454)	(0.215 - 0.428)	(0.169 - 0.361)
$\rho_{\Delta y}$	0.291	0.260	0.230
	(0.146 - 0.438)	(0.134 - 0.406)	(0.085 - 0.378)
$\rho_{\Delta ner}$	0.211	0.199	0.279
	(0.101 - 0.321)	(0.108 - 0.325)	(0.169 - 0.390)
Foreign sector			
ϑ^*	0.870	0.859	0.883
	(0.822 - 0.918)	(0.792 - 0.920)	(0.848 - 0.921)
ρ_{r^*}	0.718	0.638	0.736
	(0.673 - 0.763)	(0.550 - 0.763)	(0.666 - 0.804)
ρ_{π^*}	1.478	1.489	1.456
	(1.314 - 1.641)	(1.359 - 1.643)	(1.294 - 1.612)
ρ_{y^*}	0.534	0.410	0.369
	(0.430 - 0.636)	(0.238 - 0.496)	(0.228 - 0.504)
$\rho_{\Delta y^*}$	0.306	0.298	0.324
	(0.151 - 0.463)	(0.123 - 0.409)	(0.165 - 0.483)
γ^*	0.520	0.691	0.624
	(0.372 - 0.666)	(0.530 - 0.828)	(0.460 - 0.793)
ψ^*	41.484	50.698	56.011
	(19.950 - 62.002)	(26.507 - 65.948)	(42.318 - 69.112)
κ^y	0.181	0.134	0.159
	(0.051 - 0.303)	(0.000 - 0.311)	(0.052 - 0.263)

Note: Posterior means and highest posterior density intervals (in parentheses).

improbable development in light of the recent situation on the labour market, when the unemployment is at its historical low. However, my observed period ends in 2015, when the conditions on the labour market were not yet so optimistic. Furthermore, although the average unemployment rate in the period during the recession was lower than before the crisis, the number of vacancies was, on average, much higher in the first observed time span. From this arises a lower labour market tightness in the period *after*, which puts the households in a more disadvantageous situation, because the job seekers have worse chance to find a job.

The rising tendencies in the number of job offerings cause that it is getting more and more expensive to create a new vacancy which is captured in the increase of the vacancy posting elasticity, e. The noticeable decrease of the backward looking wage parameter, γ_W from 0.712 to 0.585 means that the firms and employees renegotiate the wage little more in line with the steady state wage inflation than the previous period wage inflation. This decrease of wage stickiness is however paired with a higher cost of wage adjustment. Overall, the recession caused a increase of labour market frictions in the Czech economy.

The Taylor rule parameters of the reaction of interest rate to the development of output, ρ_y and $\rho_{\Delta y}$, decreased. This decline of the central bank's interest towards the deviations of output is compensated by the increase of $\rho_{\Delta ner}$ from 0.199 to 0.279. This shift is related to the monetary authority's intervention on the foreign exchange market in November 2013. Since then, the exchange rate replaced the interest rate as the main tool of the monetary policy.

6.2 Simulated moments

The comparison of actual and simulated data moments of the model with the *extended foreign sector* and on the *whole* time period are captured in table 6.5. 500 simulations are executed in order to generate enough variance in the simulated moments. The estimated standard deviations of shocks are used to simulate with the most of available information. The table shows that the model captures the variance of output, real exchange rate, unemployment and vacancies relatively closely. On the other hand, the greatest inaccuracies appear in the simulation of hours. The simulated data are much more volatile.

The correlation of hours with the output is also significantly higher in the simulated data. However, the model is able to replicate both the negative relationship between output and unemployment (Okun's law) with correlation of -0.5730 and the negative

Table 6.5: Simulated and data moments of the Czech Republic

Variable		*Standard deviation*	*Correlation with output*
y	data	0.0205	1.0000
	model	0.0241	1.0000
	90% HDPI	(0.0184, 0.0310)	(1.0000, 1.0000)
h	data	0.0077	0.0500
	model	0.0295	0.8753
	90% HDPI	(0.0219, 0.0365)	(0.7733, 0.9472)
u	data	0.1280	-0.7811
	model	0.1166	-0.5730
	90% HDPI	(0.0799, 0.1562)	(-0.7921,-0.3449)
w	data	0.0111	0.7657
	model	0.0224	-0.1920
	90% HDPI	(0.0154, 0.0301)	(-0.5045, 0.1665)
π	data	0.0040	0.5186
	model	0.0087	0.2164
	90% HDPI	(0.0065, 0.0109)	(-0.1248, 0.4759)
r	data	0.0056	0.6313
	model	0.0135	0.6117
	90% HDPI	(0.0098, 0.0174)	(0.3984, 0.7951)
rer	data	0.0312	-0.4250
	model	0.0380	0.1246
	90% HDPI	(0.0307, 0.0446)	(-0.1844, 0.4122)
v	data	0.3011	0.8564
	model	0.2718	0.4421
	90% HDPI	(0.2264, 0.3243)	(0.2426, 0.6422)

relation between vacancies and unemployment (Beveridge curve) with value of correlation -0.4648.

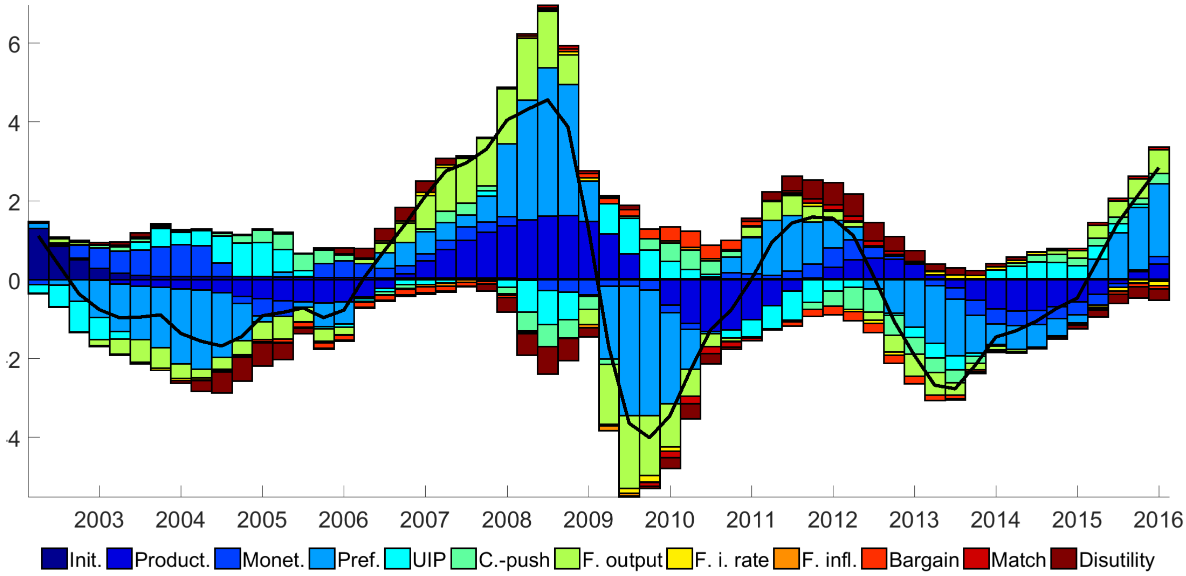
6.3 Historical shock decompositions

This section collects the results of shock decomposition which is used to investigate the influence of different shocks on the examined variables. This allows me to determine the main driving forces behind the fluctuations of variables throughout the observed time period. At this point, the benefits of the Kalman filter are applied. That is, I am able to examine unobserved variables, like consumption or labour market tightness.

6.3.1 Czech output and consumption

The historical shock decomposition of Czech GDP is depicted in figure 6.1. This figure shows that the preference shock has the greatest influence on the Czech output. Also, the

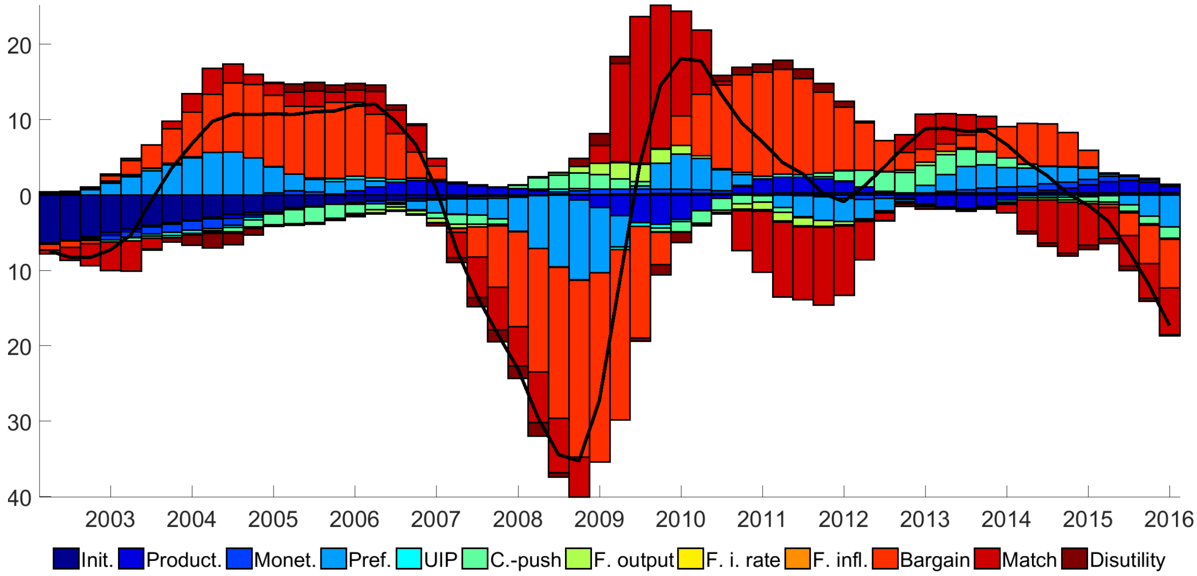
Figure 6.1: Shock decomposition of Czech output (deviations from s.s. in %)



shock to the uncovered interest rate parity condition played a role in pulling the output over the steady-state at the beginning of the observed period. In the expansionary period between 2006 and 2009, when the economy experienced a significant boom, the main shocks positively influencing the output were the productivity and preference shocks, as well as the foreign output shock. However, the last two of these shocks were also the reason for the decline of product in during the recession in 2009 and 2010. The model indicates that this recession arrived from the foreign sector and was also deepened by the changes in preferences of the domestic households. Given the absence of government and a financial sector in the model, it assigned the debt crisis in 2012 to be caused by a negative cost-push shock and, again, an unfavourable preference shock. In the last year of the observed period, the output is presented to be above its steady-state level mainly because of the optimistic behaviour of the households. From the labour market influences only the shock to the dis-utility from work affected the output noticeably.

The shock decomposition of consumption is pictured in figure C.1. It is noticeable from the first look that the preference shock dominates the development of this variable. The other significant shock influencing the Czech consumption is the foreign output shock. The increase of this variable before 2009 affected the domestic consumption negatively. Furthermore, Kalman filtered consumption indicates that this variable was further from its steady-state than the output before the recession and its fall caused by the crisis in 2008 was more substantial.

Figure 6.2: Shock decomposition of Czech unemployment (deviations from s.s. in %)



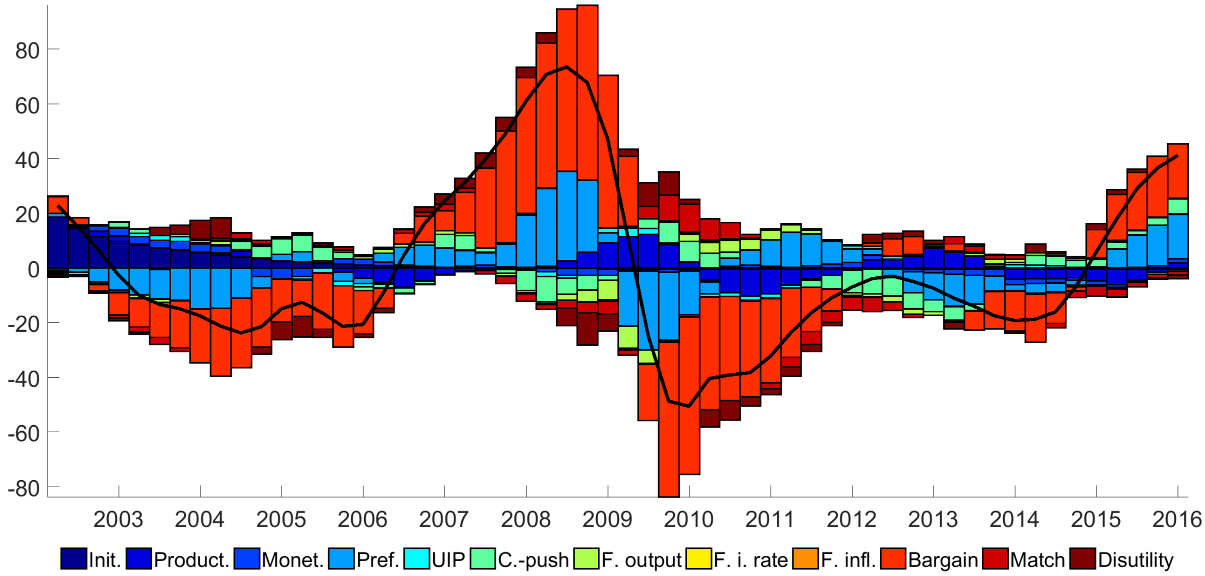
6.3.2 Czech labour market variables

Figure 6.2 presents the historical shock decomposition of unemployment. The figure indicates two main forces influencing this variable: the bargaining shock and the shock to the matching efficiency. Similarly to the original article of Albertini et al. (2012), the shocks outside the labour market have limited impact to the unemployment. Only in the period before the crisis are there negative signs of the preference shock affecting the unemployment. During the crisis in 2009 a significantly negative matching shock, which is transferred into the unemployment with a positive sign, caused the unemployment to increase rapidly. On the other hand, the periods prior to the recession are considerably affected by highly negative bargaining shocks, which decreased the bargaining power of firms. This created a more advantageous situation for the households and therefore caused a decline in the unemployment.

Such development also led to an increase of the labour market tightness, as is presented in figure C.2. The time series of the unobserved labour market tightness is calculated using the above mentioned Kalman filter. Given the definition of this variable ($\widehat{\theta} = \widehat{v} - \widehat{s}$, in log-linear form), it closely follows the movement of vacancies and the inverse of unemployment. The development of this variable is governed mainly by the bargaining shock and partially by the preference shock. The influence of other shocks is less significant.

The next figure (6.3) contains the shock decomposition of vacancies in the Czech Republic. By comparison of figures of unemployment's and vacancy's shock decomposition,

Figure 6.3: Shock decomposition of Czech vacancies (deviations from s.s. in %)



few interesting observations can be mentioned. First, because the Beveridge curve holds quite well on the Czech data, as is shown in section 1.1, it follows that the observed time series of unemployment and vacancies move the opposite way. Second, this inverse movement is supported by the same shocks with reversed signs. Third, although the majority of the shocks are the same in both figures, the matching shock affects the unemployment to a great degree, while vacancies are almost unaffected by it.

The wages of Czech employees are affected by a variety of shocks, as is presented in figure C.3. There is a period in 2004, when the real wages were positively influenced by dis-utility from labour shock. At this time, also the bargaining and foreign interest rate shocks begin to have impacts on the wage. Before the crisis, the preference, the productivity and the dis-utility from labour shocks were the main factors which kept the wage level above its steady state. On the other hand, the foreign output and the bargaining shock pushed the wage downwards. At the last two quarters of 2008 also the dis-utility shock put unfavourable pressures on the development of the wage. The decline of wages during the debt crisis in 2012 was mainly caused by negative cost push shocks.

When looking at the historical shock decomposition of hours worked in figure C.4, two opposing shocks stand out: the productivity shock on the one side and the preference shock on the other. The technology shock influences the hours negatively throughout the whole period with the exception of the two crises, when this shock pulled the hours upwards. On the other hand, the preference shock indicates that the households are less willing to work during recessions.

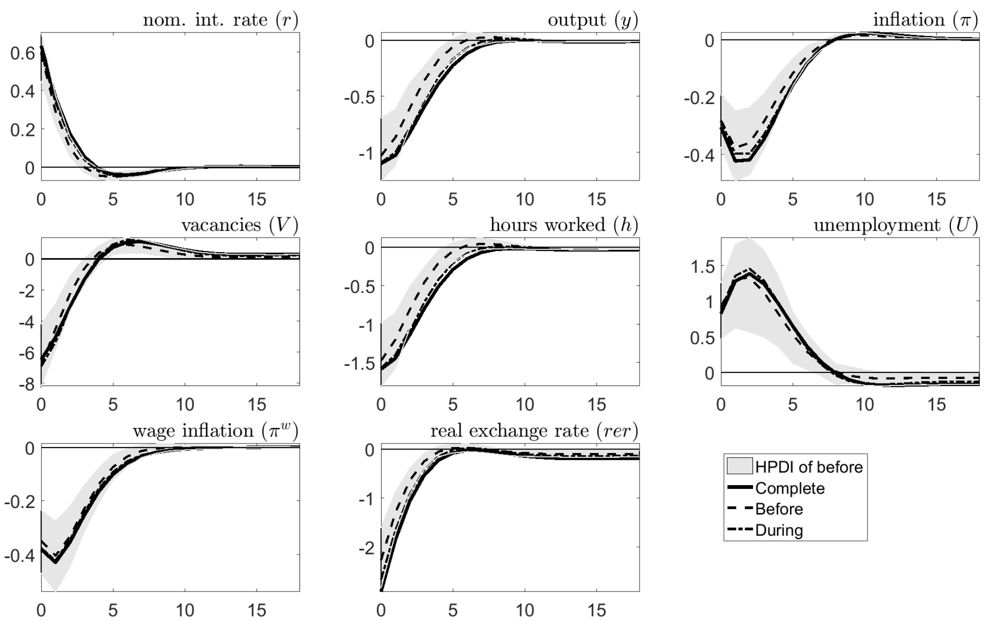
6.4 Impulse response functions

The IRFs represent the reactions of variables to one standard deviation of a single shock. They enable the tracing of the impact of different shocks throughout the economy. In this section, I present the results to a monetary and a technology shock.

6.4.1 Monetary shock

The impulse responses to a monetary shock that enters the model as an innovation in the Taylor rule (ϵ_t^m) are presented in figure 6.4. A positive monetary shock causes an increase of the nominal interest rates. This contractionary monetary policy decreases the output and dampens the CPI inflation. Higher interest rate and lower inflation also causes an appreciation of the real exchange rate. After a restrictive intervention of the monetary authority, the firms decrease the number of posted vacancies, because additional employees produce less due to the decrease of the marginal value of a position for firms. This leads to a decrease of employment in general, whether in the form of a decrease in the hours worked (intensive margin) or the increase of unemployment (extensive margin).

Figure 6.4: Czech impulse responses to monetary shock (% deviations from s.s.)



Note: The horizontal axis represents time periods. It holds that one time period is one quarter.

The increase of unemployed and decrease of vacancies lowers the labour market tightness, which in turn causes a decrease of wage inflation.

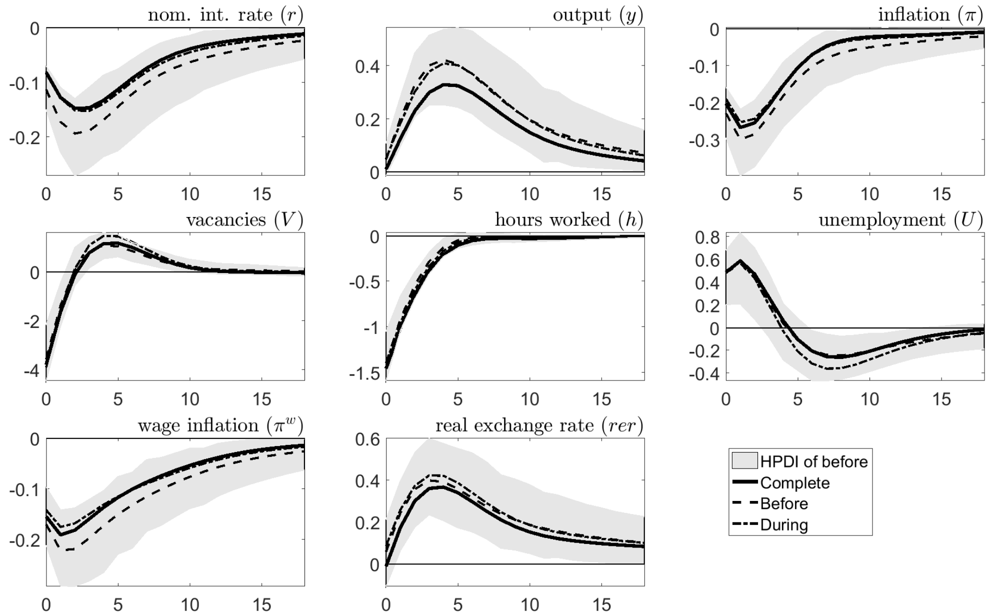
The IRF to monetary shock displays a way through which the monetary authority is able to influence the labour market variables. The same transmission mechanism can be found in the paper of Albertini et al. (2012). Figure 6.4 compares the IRFs of the estimations prior the recession and after 2009. The above described transmission mechanism of the monetary policy can be applied to both time periods. As can be seen, the recession kept the influence of the Czech monetary authority unaltered. The responses of variables before the crisis to an increase of nominal interest rates are similar in all cases to the responses during the crisis. Therefore, there is no statistically significant shift in the CNB's influencing power. The statistically negligible changes in the estimated parameters go hand in hand with the constancy of impulse response functions.

6.4.2 Technology shock

The technology shock, depicted in figure 6.5, is part of the production function (3.50), so a positive productivity shock is reflected in the increase of the output. Following the initial spring of the production, the output continues to increase for one more year. After this, the economy begins to cool down. The higher peak of output for the two shorter periods is given by the higher elasticity of substitution η. The households substitute the foreign goods for the domestically produced merchandise, because of its lower price. The growth of the output is accompanied by a decline of inflation. The monetary authority supports this boom by reducing the nominal interest rates. Furthermore, the depreciation of domestic currency also increases the domestic output by boosting the exports and diminishing the imports.

The productivity shock gives an incentive to the firms to replace the labour by other forms of input, like better technologies. This leads to the reduction of hours and the increase of unemployed. The entrepreneurs also reduce the number of posted vacancies. This decline in the quantity of vacancies and increase of unemployed workers decreases the labour market tightness, which is unfavourable for the households. This allows the firms to offer lower wages to their employees and so the nominal wage inflation decreases. After these initial impacts, the producers begin to open new job positions and start to rehire workers to such extent that the unemployment leaps temporarily under its seady-state value, while vacancies exceed it. These changes go hand in hand with the increase

Figure 6.5: Impulse responses to technology shock (% deviations from s.s.)



Note: The horizontal axis represents time periods. It holds that one time period is one quarter.

in hours worked and wages paid.

This shock has long lasting impact on most of the presented variables because its high persistence ($\rho_a = 0.824$). The hours return to their steady-state value after one and a half year while the vacancies take ten periods to go back. The other variables stay away from their respective steady-states even after five years. Furthermore, seven of the examined variables seem to return to their original steady-state. On the other hand, the real exchange rate has depreciated permanently and stabilized at a new, higher steady-state. Although the results differ in size of the impacts, they are qualitatively similar to articles like Jakab and Kónya (2009), who estimated a similar model on Hungarian economy.

6.5 Chapter's summary

This chapter is concerned with the estimation results of the Czech Republic. First, parameter estimates of four model specifications are discussed and the most preferred one is selected for further investigation. Then I examine whether the effects of the recession are still observable in the economy. Following the examination of estimated parameters I focus on the historical shock decompositions. I investigate which shocks play key role in the development of selected variables. Finally, the impulse response functions to a monetary shock show the transmission mechanism of the monetary authority's adjustment of the nominal interest rate.

The findings of this section are, that the model's estimate does not depend much on the model specification nor is it influenced by method of data filtering. The results also suggest that the Czech economy is no longer affected by the recession of 2009. Furthermore, the model finds several significant frictions present in this country, such as vacancy creation cost or wage adjustment cost. These rigidities play a role in the dynamics of variables as can be seen from the impulse response functions.

Chapter 7

Estimation results of Hungary

In this chapter I turn my attention to the examination of Hungarian economy. This country experienced a significant change slightly before my first observed period. In 2001Q2, the monetary regime of the National bank of Hungary changed from exchange rate targeting to inflation targeting. This resulted in a disinflationary efforts to reduce the inflation from 10% to a gradually lowered target, which is currently at 3%.

While Hungarian labour market has a comparable unemployment rate to the European Union average, it has one of the lowest activity rates in this area. After the recession in 2009, which had a negative impact on the number of employed, the unemployment rate remained on high levels for a significant period even after the output started to slowly recuperate. This finding could suggest that there are some frictions present in Hungarian economy.

For easier orientation, this part is organized like the previous chapter. First, I describe the model selection from the alternative versions then the list of estimated parameters is presented. Then follows the analysis of simulated moments. Next, historical shock decompositions are presented and impulse response functions are outlined and examined.

7.1 Model comparison

Similarly, as for the Czech economy, three model specifications and another data filtering method is estimated and compared to select the best fitting one. Table 7.1 reports the parameter estimates of these models. Again, the models estimate the posterior values of parameters relatively alike. Using the same comparison techniques as for the Czech Republic, the best fitting specification is the model with the *new foreign sector*. Therefore, this model is selected for further examination.

Table 7.1: Estimated parameters of Hungary - models

Parameter	*original*	*one-sided*	*new foreign sector*	*simple Taylor*
ϑ	0.657	0.662	0.658	0.601
	(0.568 - 0.748)	(0.578 - 0.751)	(0.565 - 0.755)	(0.503 - 0.702)
ϕ_h	0.955	0.948	0.977	0.978
	(0.648 - 1.258)	(0.624 - 1.244)	(0.671 - 1.292)	(0.656 - 1.286)
η	0.440	0.438	0.462	0.442
	(0.375 - 0.510)	(0.379 - 0.501)	(0.389 - 0.533)	(0.379 - 0.505)
Labour market - elasticities				
ξ	0.079	0.075	0.102	0.074
	(0.009 - 0.146)	(0.003 - 0.178)	(0.006 - 0.203)	(0.007 - 0.143)
ν	0.712	0.678	0.735	0.700
	(0.505 - 0.936)	(0.446 - 0.921)	(0.532 - 0.939)	(0.485 - 0.928)
e	2.006	2.047	1.944	2.035
	(1.664 - 2.366)	(1.607 - 2.464)	(1.542 - 2.341)	(1.670 - 2.381)
Price and wage setting				
γ_H	0.789	0.778	0.780	0.750
	(0.662 - 0.919)	(0.647 - 0.918)	(0.647 - 0.914)	(0.608 - 0.903)
γ_F	0.823	0.816	0.808	0.833
	(0.708 - 0.945)	(0.692 - 0.939)	(0.683 - 0.938)	(0.722 - 0.947)
γ_W	0.608	0.617	0.618	0.696
	(0.408 - 0.802)	(0.429 - 0.816)	(0.431 - 0.817)	(0.512 - 0.883)
ψ_H	53.379	59.006	54.440	48.609
	(34.825 - 71.680)	(38.140 - 79.314)	(34.690 - 72.984)	(31.743 - 65.378)
ψ_F	60.820	61.830	58.278	49.880
	(39.573 - 80.885)	(39.838 - 83.261)	(39.012 - 77.305)	(33.752 - 65.551)
ψ_W	86.403	92.421	83.187	79.970
	(59.193 - 112.606)	(62.998 - 119.868)	(57.287 - 110.320)	(54.000 - 105.938)
Monetary policy				
ρ_r	0.633	0.669	0.635	0.539
	(0.561 - 0.709)	(0.600 - 0.740)	(0.565 - 0.710)	(0.455 - 0.623)
ρ_π	1.591	1.596	1.576	1.666
	(1.421 - 1.756)	(1.420 - 1.763)	(1.400 - 1.743)	(1.500 - 1.831)
$\rho_{\Delta y}$	0.258	0.243	0.253	0.194
	(0.099 - 0.417)	(0.081 - 0.400)	(0.097 - 0.409)	(0.035 - 0.348)
ρ_y	0.335	0.293	0.346	-
	(0.198 - 0.473)	(0.170 - 0.424)	(0.203 - 0.482)	(-)
$\rho_{\Delta ner}$	0.372	0.384	0.369	-
	(0.245 - 0.506)	(0.256 - 0.515)	(0.241 - 0.498)	(-)
Foreign sector				
ϑ^*	-	-	0.879	-
	(-)	(-)	(0.833 - 0.928)	(-)
ρ_{r^*}	-	-	0.722	-
	(-)	(-)	(0.678 - 0.768)	(-)
ρ_{π^*}	-	-	1.480	-
	(-)	(-)	(1.321 - 1.630)	(-)
ρ_{y^*}	-	-	0.541	-
	(-)	(-)	(0.437 - 0.643)	(-)
$\rho_{\Delta y^*}$	-	-	0.295	-
	(-)	(-)	(0.137 - 0.451)	(-)
γ^*	-	-	0.521	-
	(-)	(-)	(0.378 - 0.663)	(-)
ψ^*	-	-	41.280	-
	(-)	(-)	(20.332 - 61.873)	(-)
κ^y	-	-	0.172	-
	(-)	(-)	(0.054 - 0.289)	(-)
Marginal Density	2123.449	2142.870	2143.482	2109.155

Note: Posterior means and highest posterior density intervals (in parentheses).

7.1.1 Estimated parameters

Table 7.1 collects the information about the parameter estimates of the model on Hungarian data of the selected model. The means and the 90% HPDI are presented. The prior distribution is the same as for the other countries and can be found in table 4.3. The majority of posterior means of parameters shifted away from their prior values. This signalizes that there is information about these parameters in the data.

The deep-habit parameter, ϑ has its posterior mean at 0.658. Similar value can be found in the paper of Jakab and Kónya (2009). This reflects a fairly smooth level of consumption over time. The inverse of Frisch elasticity, ϕ_h is estimated to be around one with a rather wide HPDI. Although, parameter α, representing the openness of the economy ranks Hungary as the second most open economy among the examined countries, as is shown in table tab:params fix in section 4.3, the elasticity of substitution between domestic and foreign goods, η is quite low.

Interestingly, the bargaining power of firms is estimated substantially lower, than in the existing literature. My estimate lies between 0.006 and 0.203, while authors like Jakab and Kónya (2009) or Němec (2013a) report values around 0.8. The elasticity of matching function with respect to the number of job seekers, ν, deflected away from its prior value towards higher reactions to the variability of the job seekers. If the 90% HPDI is taken into consideration for these two parameters, the Hosios condition is satisfied. The results report a convex form for the vacancy creation cost ($e = 1.944$), meaning that each subsequent job position is more expensive to create. This introduces a stickiness to the labour market.

Looking at the adjustment cost parameters, the modification of wage, ψ_W is yet again the most costly with a posterior mean high above its prior value. Among the two price adjustment costs, it is more expensive to change the prices. This can result from the high degree of openness of Hungary and also from a great volatility of the exchange rate. The model therefore captures that the importers face higher risks due to the uncertainty of the exchange rate's development. On the other hand, the indexation parameters, γ_H, γ_F and γ_W governing the degree of rigidities show that wages contain the least amount of frictions. This, together with the low bargaining power of firms suggests a rather frictionless wage negotiation.

The Taylor rule parameters of the monetary policy's decision making rule indicate that Hungarian central bank keeps the interest rate relatively smooth, with a smoothing parameter $\rho_r = 0.635$. When setting the nominal interest rates, the MNB also takes into consideration the development of output gap and the differences in nominal exchange rate gaps. This is also the reason why the model with the *simple Taylor*-rule, where this information is missing, is not preferred by the Bayes factor.

As expected, the parameter estimates of the foreign sector are estimated to be close to the values estimated in the previous chapter on Czech data. This finding underlines correctness of the specification of the independence of the foreign sector on the domestic economy.

Table 7.2: Domestic shock persistence - Hungary

Parameter	mean	inf - sup		std
ρ_{rer}	0.484	0.383	0.587	0.061
ρ_H	0.435	0.257	0.617	0.110
ρ_a	0.783	0.699	0.869	0.051
ρ_c	0.573	0.435	0.709	0.083
ρ_ξ	0.777	0.651	0.906	0.076
ρ_χ	0.833	0.719	0.954	0.081
ρ_{κ^h}	0.519	0.354	0.687	0.103

Persistence of Hungarian domestic shocks are collected in table 7.2. Note that there are only seven shock persistence parameters for eight domestic shocks. This is because the monetary shock enters the model only as an innovation without persistence. The labour market shocks are more persistent, than the other shocks. The persistence of the matching shock ρ_χ indicates that it takes more than 13 quarters for this shock to reach 10% of its initial value. On the other hand, the uncovered interest rate parity shock and the cost push shock are the least persistent shocks. It takes only around one year (four periods), for the shock to reach 10% of its initial impact.

Table 7.3: Domestic shock variance - Hungary

Parameter	mean	inf - sup		std
σ_a	0.007	0.006	0.008	0.001
σ_m	0.007	0.006	0.008	0.001
σ_{rer}	0.024	0.019	0.028	0.003
σ_c	0.048	0.037	0.060	0.007
σ_H	0.195	0.123	0.264	0.037
σ_ξ	0.120	0.086	0.152	0.021
σ_χ	0.067	0.057	0.078	0.006
σ_{κ^h}	0.067	0.043	0.091	0.014

Table 7.3 shows that the most volatile shock is the least persistent cost-push shock, with a standard devition $\sigma_H = 0.195$. On the other hand, the technology and monetary shocks are characterized with the lowest variance.

7.1.2 Period separation

The posterior estimates of parameters are presented in 7.4 for the *complete* period as well as for the two sub-samples. While the *before* estimation uses the same prior setting as the *complete* model, the priors for the period *after* the crisis are taken from the *before* posteriors.

The posterior mean values of several parameters lie quite far from each other for the two shorter estimations. The consumption smoothing parameter ϑ increased in the second period from 0.585 to 0.696. This reflects the households need to keep the level of consumption steady during unfavourable times even more. The elasticity of substitution between domestic and foreign goods, η decreased by 0.05, while the inverse of the Frisch elasticity, ϕ_h remained almost the same.

The negotiating power of firms, ξ slightly declined from 0.137 to 0.121. This change is in contrast with the decreased average labour market tightness. In the second examined time period, the average unemployment rate was higher, while the mean value of vacancy rate was lower than in the period *before* the crisis. However, if looking at the last few quarters of each examined period, the change of this variable becomes visible. Closely before the crisis, the unemployment rate was already increasing in Hungary, while the number of vacancies was low. On the other hand, at the end of the whole examined period the unemployment rate declines and vacancies are created more rapidly. The lower ξ thus reflects the improving situation on the labour market from the households' perspective. In spite of the higher number of posted vacancies, the vacancy creation cost, e, remained without change. This means that the vacancy posting expanses increase with the same elasticity regardless of the number of already created job positions. On the other hand, the current decreasing trends of unemployment increased the matching rate because of the rise in the matching elasticity, ν.

All of the adjustment cost parameters increased in the second period, although the increase is statistically negligible. The small decrease of firms' bargaining power caused that it is slightly more costly for the firm to change the wages. On the other hand, the wage indexation parameter, γ_W, is lower by 0.1, which means that the firms negotiate the

Table 7.4: Estimated parameters of Hungary - periods

Parameter	*complete* 2002:Q1 - 2015:Q4	*before* 2002:Q1 - 2008:Q4	*during* 2009:Q1 - 2015:Q4
ϑ	0.658	0.585	0.696
	(0.565 - 0.755)	(0.452 - 0.720)	(0.613 - 0.782)
ϕ_h	0.977	1.014	0.984
	(0.671 - 1.292)	(0.684 - 1.330)	(0.692 - 1.286)
η	0.462	0.550	0.498
	(0.389 - 0.533)	(0.412 - 0.683)	(0.412 - 0.579)
Labour market - elasticities			
ξ	0.102	0.137	0.121
	(0.006 - 0.203)	(0.019 - 0.251)	(0.036 - 0.205)
ν	0.735	0.697	0.833
	(0.532 - 0.939)	(0.461 - 0.938)	(0.680 - 0.991)
e	1.944	1.813	1.834
	(1.542 - 2.341)	(1.448 - 2.169)	(1.575 - 2.092)
Price and wage setting			
γ_H	0.780	0.786	0.768
	(0.647 - 0.914)	(0.659 - 0.928)	(0.630 - 0.910)
γ_F	0.808	0.788	0.808
	(0.683 - 0.938)	(0.653 - 0.932)	(0.686 - 0.938)
γ_W	0.618	0.712	0.600
	(0.431 - 0.817)	(0.534 - 0.890)	(0.395 - 0.816)
ψ_H	54.440	52.928	54.970
	(34.690 - 72.984)	(31.653 - 72.961)	(39.693 - 69.841)
ψ_F	58.278	53.167	56.619
	(39.012 - 77.305)	(31.554 - 72.988)	(38.529 - 74.721)
ψ_W	83.187	74.066	77.930
	(57.287 - 110.320)	(48.222 - 99.255)	(56.412 - 99.643)
Monetary policy			
ρ_r	0.635	0.573	0.606
	(0.565 - 0.710)	(0.463 - 0.684)	(0.527 - 0.688)
ρ_π	1.576	1.547	1.571
	(1.400 - 1.743)	(1.377 - 1.713)	(1.407 - 1.736)
ρ_y	0.346	0.304	0.342
	(0.203 - 0.482)	(0.154 - 0.450)	(0.207 - 0.483)
$\rho_{\Delta y}$	0.253	0.278	0.272
	(0.097 - 0.409)	(0.117 - 0.439)	(0.114 - 0.431)
$\rho_{\Delta ner}$	0.369	0.335	0.383
	(0.241 - 0.498)	(0.193 - 0.481)	(0.260 - 0.510)
Foreign sector			
ϑ^*	0.879	0.853	0.883
	(0.833 - 0.928)	(0.782 - 0.928)	(0.848 - 0.919)
ρ_{r^*}	0.722	0.739	0.781
	(0.678 - 0.768)	(0.665 - 0.813)	(0.735 - 0.827)
ρ_{π^*}	1.480	1.492	1.471
	(1.321 - 1.630)	(1.326 - 1.654)	(1.310 - 1.628)
ρ_{y^*}	0.541	0.479	0.478
	(0.437 - 0.643)	(0.341 - 0.614)	(0.355 - 0.601)
$\rho_{\Delta y^*}$	0.295	0.261	0.281
	(0.137 - 0.451)	(0.104 - 0.430)	(0.123 - 0.443)
γ^*	0.521	0.662	0.565
	(0.378 - 0.663)	(0.492 - 0.832)	(0.397 - 0.727)
ψ^*	41.280	41.872	48.261
	(20.332 - 61.873)	(20.350 - 62.845)	(35.114 - 60.952)
κ^y	0.172	0.241	0.230
	(0.054 - 0.289)	(0.045 - 0.455)	(0.126 - 0.332)

Note: Posterior means and highest posterior density intervals (in parentheses).

wages with the employees with a decreased weight on the previous level of wage inflation.

Looking at the monetary policy parameters, the interest rate became less volatile, due to the increase of the smoothing parameter, ρ_r. Furthermore, it is more influenced by the inflation gap, output gap and the change in the nominal exchange rate gap.

7.2 Simulated moments

Similarly to the Czech Republic 500 simulations are generated in order to obtain enough draws to compute the simulated moments. The comparison of actual and simulated data moments are presented in table 7.5. The model again captures the variance of output, real exchange rate and unemployment quite closely. Furthermore, the variance of nominal interest rates is matched well too. However, imperfections appear in the simulated data of hours and vacancies, which are significantly more volatile than in the data.

The correlation of hours with the output is also significantly higher in the simulated data. The model is able to replicate the negative correlation between output and un-

Table 7.5: Simulated and data moments of Hungary

Variable		*Standard deviation*	*Correlation with output*
y	data	0.0162	1.0000
	model	0.0166	1.0000
	90% HDPI	(0.0135, 0.0209)	(1.0000, 1.0000)
h	data	0.0047	0.0039
	model	0.0198	0.7779
	90% HDPI	(0.0151, 0.0247)	(0.6275, 0.8784)
u	data	0.0691	-0.6535
	model	0.0838	-0.3069
	90% HDPI	(0.0600, 0.1130)	(-0.6380, 0.0357)
w	data	0.0104	0.6062
	model	0.0216	0.0262
	90% HDPI	(0.0146, 0.0300)	(-0.2944, 0.3853)
π	data	0.0047	0.0087
	model	0.0082	0.1931
	90% HDPI	(0.0060, 0.0103)	(-0.1024, 0.4754)
r	data	0.0129	-0.0757
	model	0.0144	0.3328
	90% HDPI	(0.0117, 0.0181)	(0.0973, 0.5916)
rer	data	0.0305	-0.2577
	model	0.0314	-0.0051
	90% HDPI	(0.0255, 0.0407)	(-0.2368, 0.2587)
v	data	0.1094	0.2494
	model	0.2213	0.3575
	90% HDPI	(0.1742, 0.2653)	(0.0856, 0.6156)

employment (-0.3069). The lower quantile of the correlation between these two variables is close to the actual value calculated from the data, however the upper quantile is positive, thus the 90% HDPI contains zero. The negative relation between vacancies and unemployment is also generated with value of correlation -0.3219.

7.3 Historical shock decompositions

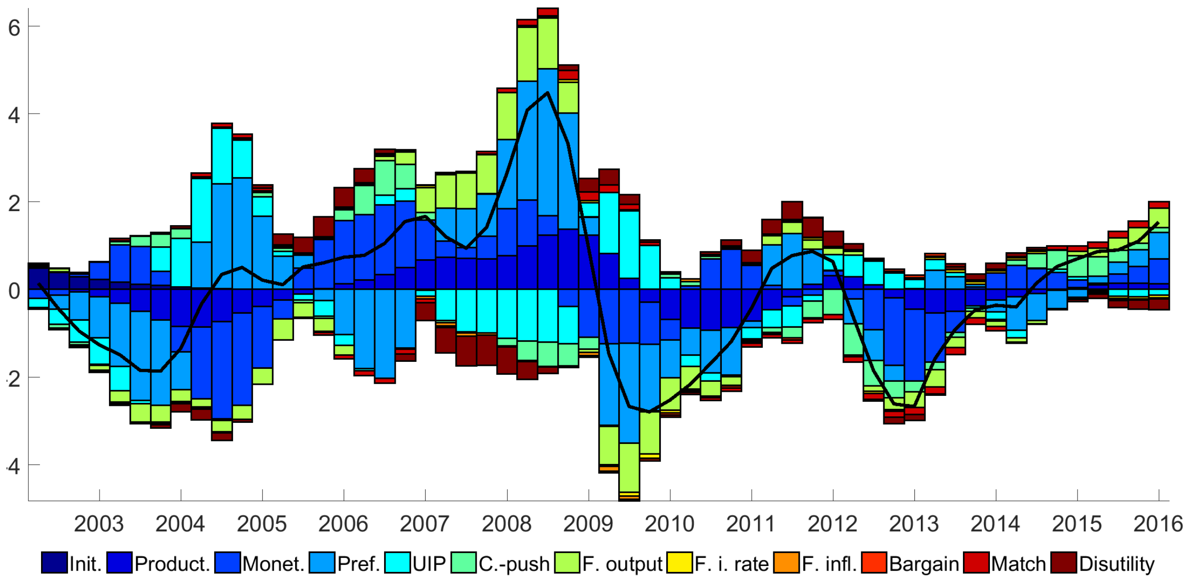
This section contains the shock decomposition of selected variables - output, consumption, unemployment, labour market tightness, vacancies, real wages and hours. Because my thesis focuses on the investigation of labour market, I describe the development of all observed ($\widehat{u}_t$, $\widehat{v}_t$, $\widehat{w}_t$ and $\widehat{h}_t$) and one unobserved ($\widehat{\theta}_t$) labour market variable.

7.3.1 Hungarian output and consumption

The shape of Hungarian output is defined mostly by the preference, monetary and technology shocks. In 2004, when the country entered the European Union, the positive influence of the preference shocks was magnified by the positive impact of UIP shock after Hungarian forint depreciated in 2003. On the other hand, this effect was slowed down by the central bank, which diligently tried to reduce the inflation since it started its inflation targeting policy in the second quarter of 2001.

The foreign output began to have a significant influence on Hungarian product in

Figure 7.1: Shock decomposition of Hungarian output (deviations from s.s. in %)



2007. However, this prosperous impact quickly changed in 2009, when the foreign situation began to seep into Hungarian economy. The shock decomposition indicates that the monetary, preference and foreign shocks had the largest influence on the decline of Hungarian output during the recession in 2009. Since then, Hungarian economy also got through the debt crisis in 2012. The drop of output, however, was not so radical and it was caused mainly by the monetary shock.

The shock decomposition of Hungarian consumption is depicted in figure C.5. Through the whole observed period, it is influenced mainly by the preference shock. A negative influence of foreign output shock appears before the crisis which is then transferred to a positive effect during the crisis. Furthermore, the UIP and foreign output shocks have opposite impacts on the consumption as they had on the output.

7.3.2 Hungarian labour market variables

The labour market variables of Hungarian economy are influenced by a variety of shocks. The unemployment, presented in figure 7.2, is defined mostly by the matching shock. The possitive effects of the matching process prior the the crisis helped to push and keep the unemployment under its seady-state. However, in 2009, the matches became less numerous and the unemployment began to increase. The bargaining shock also had significant influence on Hungarian unemployment in the period between 2008 and 2013. When the

Figure 7.2: Shock decomposition of Hungarian unemployment (deviations from s.s. in %)

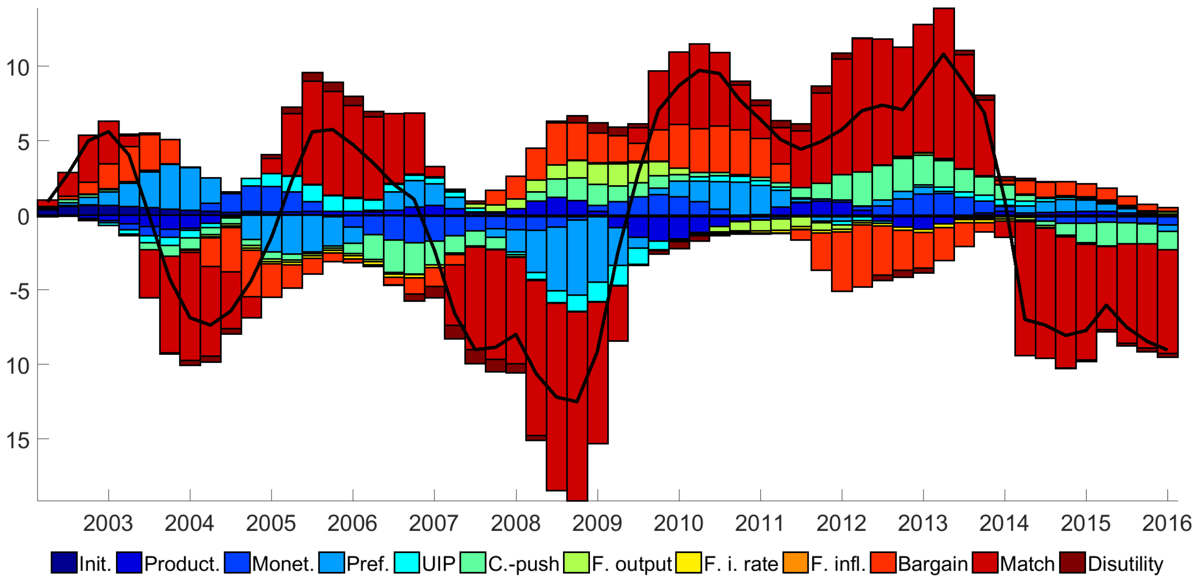
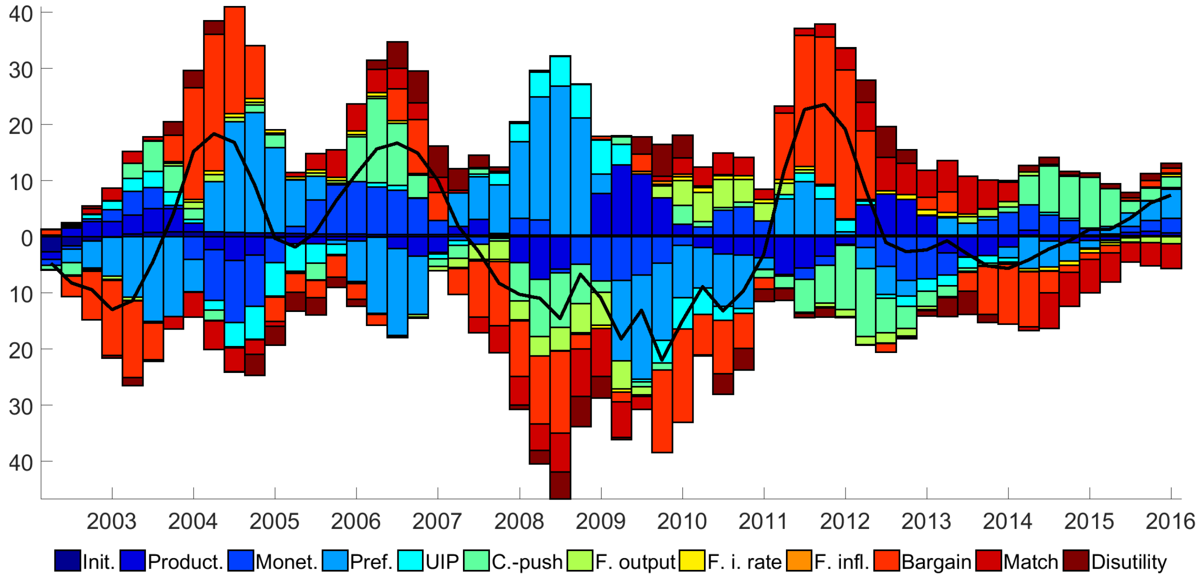


Figure 7.3: Shock decomposition of Hungarian vacancies (deviations from s.s. in %)



bargaining conditions on the labour market worsened the position of the households, the unemployment was increasing. During the crisis the preference shock also influenced the unemployment negatively. This signalizes that the workers were hit by the negative pressures from the outside and were less motivated to work.

Apart from the preference, cost-push and technology shocks, the labour market tightness in figure C.6 is also greatly affected by the bargaining shock. The bargaining power and the labour market tightness are closely connected. If the market is tighter (higher amount of vacancies and lower number of job seekers), the situation is preferable for the households and the bargaining power tilts in favour of the households. On the other hand, if the labour market is looser, the situation favours the producers, who can choose from a higher pool of unemployed to fill their vacancies. High volatility of the labour market tightness is taken from the volatility of vacancies.

Unlike the vacancies in the Czech Republic, the volatility of vacancies in Hungary explained to a higher degree by also other, than labour market shocks - preference, cost-push and monetary shocks - although, their impact cancels out in most cases. The change in the bargaining power moves the vacancies away from their steady-state.

The dis-utility from working shock plays an important role in the explanation of the volatility of real wages in Hungary, portrayed in figure C.7. Higher wages are usually connected with lower dis-utility from work. This holds for my results, where the negative values of the dis-utility shock are transferred to the real wage as positive effects. The preference and UIP shocks also appear to explain the forces behind the volatility of wages. The positive changes in the preference and the uncovered interest rate parity condition create pressures to increase of wages. On the other hand, the increase of foreign output impacts the domestic wages negatively.

Interestingly, the hours worked do not seem to be influenced by the bargaining shock. Apart from the obvious impacts of the non-labour market shocks, namely the preference, monetary, technology and UIP shocks, the foreign output and dis-utility shocks have a significant impact. The former influences the hours mainly in the period around the crisis, when it increases the domestic hours worked, when the economy prospers and reduces them during the recession. The latter has similar impact as it had on the wage.

7.4 Impulse response functions of Hungary

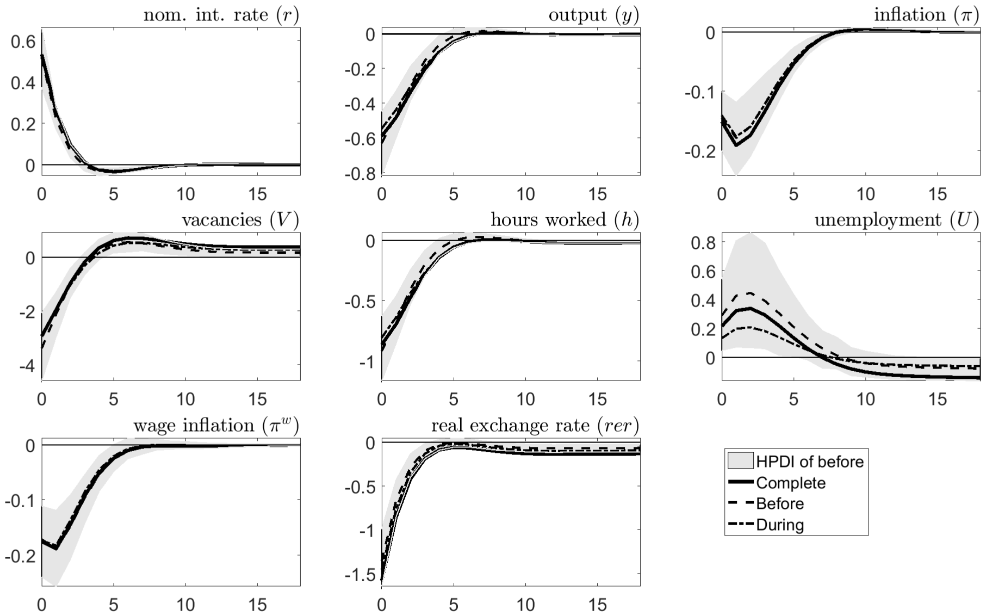
This subsection focuses on the description of the IRFs of several selected variables to monetary and technology shocks. To be able to find the possible differences among the whole time span and the two shorter time periods, each result is depicted in the same figure for both shocks.

7.4.1 Monetary shock in Hungary

The impulse response function to monetary shock is depicted in figure 7.4. The transmission mechanism of this shock for Hungarian economy is identical to the one in the Czech Republic. The contractionary monetary policy increases the interest rates, which in turn reduces the output and the CPI inflation. This leads to the appreciation of the forint. The firms react to the decreasing production by lowering the number of vacancies and demanding less labour. This increases the number of unemployed and decreases the hours worked. These changes lower the labour market tightness and allow the firms to offer lower wages.

Each variable moves significantly away from its steady-state value in the reaction of the shock. All three estimates give almost identical responses to this shock. The only noticeable difference can be observed in the reaction of unemployment. One possible explanation is the diverse posterior values of the matching function elasticity with respect to job seekers, ν. While in the period *before*, the lower value of this parameter (0.697) implies fewer matches, thus more unemployed, in the period *during*, the estimated value of this parameter is the highest (0.820), which leads to a greater reaction of matching rate

Figure 7.4: Impulse responses to monetary shock (% deviations from s.s.)



Note: The horizontal axis represents time periods. It holds that one time period is one quarter.

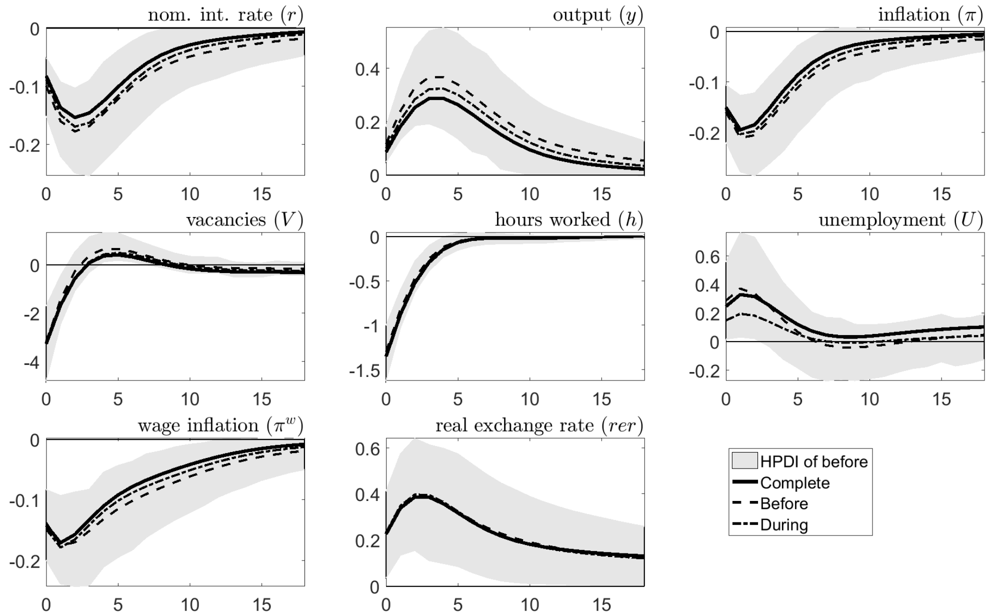
to the unemployment rate and leads to lesser number of unemployed. It is also mentionworthy that the 90% HPD intervals of both the parameters and the IRFs overlap.

7.4.2 Technology shock in Hungary

Hungarian technology shock affects the above mentioned variables in a way that is depicted in figure 7.5. Again, the model reports changes that are qualitatively the same to the reactions of the Czech variables to this shock. The comparison of impulse responses among countries is contained in chapter 10. Figure 7.5 compares the reactions within Hungarian economy for the different periods.

Similarly as in the case of the Czech Republic, the higher η stands behind the more substantial reaction of output to the technology shock prior the crisis. The high persistence ($\rho_a = 0.783$) keeps the variables away from their steady states for a significant amount of time. While the majority of the variables return to their long term levels, the real exchange rate and the unemployment stay permanently above their respective steady-states.

Figure 7.5: Impulse responses to technology shock (% deviations from s.s.)



Note: The horizontal axis represents time periods. It holds that one time period is one quarter.

7.5 Chapter's summary

The organization of this chapter follows the structure of the previous part. First the estimated parameters of different model specifications are presented together with the model selection method. This section is followed by simulated moments. Next, the historical shock decompositions are presented and finally, the responses to monetary and technology shock are displayed.

Hungarian economy is characterized by high degree of stickiness. The low bargaining power of firms and the high vacancy posting cost limits the motivation of firms to hire workers. On the other hand, the households benefit greatly from the situation on the labour market. The elasticity of the matching function with respect to job seekers supports this view. The historical shock decomposition of unemployment indicates, that the dynamism of this variable is given by the shocks in the matching function. The IRFs show the impact of the labour market and other frictions that are visible in the longer lasting and lower amplitude of the selected shocks.

Chapter 8

Estimation results of Poland

This chapter contains the estimation results of the largest of the four examined economies. Looking at the calibrated import share parameter α in table 4.2, the value 0.2845 in fact indicates that, compared to other countries, Polish economy does not depend on the import to such extent. Because Poland is a big economy, it was not affected so much by the global economic crisis in 2008-09. Although its output decreased, the development of product (depicted for example in figure 8.1) resembles a standard cyclical behaviour with periods of expansions (form 2005:Q3 to 2007:Q4 or between 2009:Q3 and 2011:Q4) and recessions (between 2004:Q2 and 2005:Q2, 2008:Q1 to 2009:Q2 or from 2012:Q1 to 2013:Q1).

Being a larger economy, Poland struggles with higher levels of unemployment rates, while the number of vacancies is comparable to the number in the Czech Republic. This results in a relatively low number of vacancies for the large number economically active people. Poland had the highest unemployment rate out of the examined countries at the beginning of the observed period. The country's accession to the European Union and the opening of the Western European labour markets to Polish citizens in 2004 significantly helped in the reduction of this high number. The unemployment decreased by almost 2/3 between 2004 and 2008, which is the most significant drop among the examined countries.

Following the previous chapters, I first present the parameter estimates of four different model variations. Then I estimate the most suitable model for two shorter periods to investigate the long lasting effects of the recession. Next, the simulated data moments are compared with the variability present in the data. The following two sections contain the historical shock decompositions and impulse response functions to investigate the dynamical properties of Polish economy and examine the effects of rigidities.

8.1 Model comparison

As for the previous countries, four models are used also for Poland to select the most fitting. To be able to estimate the model, I had to make some slight adjustments to prior distributions. I reduced the standard deviations of the preference, cost push and foreign inflation shocks and the elasticity of vacancy creation and firm's bargaining power parameters. With these changes the model could be estimated. The same alterations were made for all four models.

Table 8.1 presents the parameter estimates as well as the model selection criteria - the marginal density. The models' parameter estimates lie very close to each other. Each model reports similar values for most parameters. The parameter that stands out the most is the domestic price adjustment parameter for the *one-sided* HP filtered estimation with a value 121.437, while the other models estimate this parameter to be between 102 and 108. Other differences can be observed in the monetary policy's Taylor-rule parameters. The estimates of the model with the *simple Taylor*-rule differ from the rest. The nominal interest rate smoothing parameter, ρ_r is the lowest, while the reaction to inflation gap, ρ_π is the highest for this model. Interesting finding is that according to the models with the more extended Taylor-rule, Polish central bank does not react to the changes in the nominal exchange rate. The estimated value of this parameter lies close to zero for all three models.

I compare the models using the Bayes factor. This comparison technique favours the model with the *new foreign* sector against each of the other models with the same data. In case of Poland, the difference between the *original* and the *simplified Taylor* model is the smallest of all countries. This is given by the statistical insignificance of the $\rho\Delta ner$ parameter in the monetary policy's decision making rule. The *original* model gives comparable results to the model with the *one-sided* HP filtered data. Because the model with the *modified foreign* sector is preferred by the Bayes factor and for better comparisons among countries, I selected this model for the following examination of Polish economy.

Table 8.1: Estimated parameters of Poland - models

Parameter	*original*	*one-sided*	*new foreign sector*	*simple Taylor*
ϑ	0.638	0.645	0.625	0.635
	(0.535 - 0.740)	(0.547 - 0.748)	(0.524 - 0.728)	(0.528 - 0.748)
ϕ_h	0.649	0.603	0.691	0.709
	(0.423 - 0.867)	(0.377 - 0.818)	(0.459 - 0.921)	(0.464 - 0.946)
η	0.437	0.425	0.438	0.446
	(0.398 - 0.478)	(0.392 - 0.462)	(0.397 - 0.480)	(0.405 - 0.486)
Labour market - elasticities				
ξ	0.279	0.263	0.278	0.285
	(0.164 - 0.393)	(0.153 - 0.375)	(0.161 - 0.396)	(0.166 - 0.406)
ν	0.334	0.280	0.376	0.355
	(0.082 - 0.561)	(0.058 - 0.497)	(0.131 - 0.622)	(0.097 - 0.596)
e	1.687	1.707	1.694	1.670
	(1.561 - 1.811)	(1.580 - 1.831)	(1.567 - 1.822)	(1.541 - 1.800)
Price and wage setting				
γ_H	0.844	0.848	0.830	0.845
	(0.739 - 0.951)	(0.748 - 0.951)	(0.718 - 0.942)	(0.745 - 0.951)
γ_F	0.690	0.660	0.701	0.721
	(0.521 - 0.862)	(0.489 - 0.835)	(0.532 - 0.875)	(0.558 - 0.885)
γ_W	0.696	0.692	0.716	0.702
	(0.547 - 0.854)	(0.535 - 0.852)	(0.570 - 0.866)	(0.539 - 0.861)
ψ_H	107.501	121.437	107.658	102.204
	(79.447 - 134.466)	(89.726 - 152.125)	(79.355 - 135.945)	(74.983 - 127.947)
ψ_F	74.095	75.129	74.436	69.656
	(48.957 - 98.121)	(49.125 - 100.390)	(49.590 - 98.592)	(47.301 - 91.011)
ψ_W	91.208	94.931	88.816	86.248
	(61.808 - 119.480)	(66.301 - 123.564)	(60.105 - 117.170)	(58.381 - 113.220)
Monetary policy				
ρ_r	0.711	0.752	0.712	0.676
	(0.656 - 0.765)	(0.701 - 0.803)	(0.658 - 0.768)	(0.608 - 0.743)
ρ_π	1.690	1.664	1.687	1.755
	(1.521 - 1.863)	(1.497 - 1.829)	(1.518 - 1.863)	(1.579 - 1.928)
$\rho_{\Delta y}$	0.181	0.217	0.174	0.190
	(0.017 - 0.346)	(0.050 - 0.380)	(0.008 - 0.332)	(0.025 - 0.355)
ρ_y	0.393	0.391	0.396	-
	(0.262 - 0.523)	(0.262 - 0.525)	(0.269 - 0.531)	(-)
$\rho_{\Delta ner}$	-0.037	0.010	-0.040	-
	(-0.103 - 0.030)	(-0.066 - 0.080)	(-0.107 - 0.025)	(-)
Foreign sector				
ϑ^*	-	-	0.875	-
	(-)	(-)	(0.828 - 0.924)	(-)
ρ_{r^*}	-	-	0.719	-
	(-)	(-)	(0.676 - 0.765)	(-)
ρ_{π^*}	-	-	1.483	-
	(-)	(-)	(1.312 - 1.642)	(-)
ρ_{y^*}	-	-	0.543	-
	(-)	(-)	(0.440 - 0.648)	(-)
$\rho_{\Delta y^*}$	-	-	0.293	-
	(-)	(-)	(0.137 - 0.451)	(-)
γ^*	-	-	0.514	-
	(-)	(-)	(0.368 - 0.653)	(-)
ψ^*	-	-	43.279	-
	(-)	(-)	(25.423 - 60.275)	(-)
κ^y	-	-	0.184	-
	(-)	(-)	(0.072 - 0.290)	(-)
Marginal Density	2080.332	2149.893	2165.825	2075.879

Note: Posterior means and highest posterior density intervals (in parentheses).

8.1.1 Estimated parameters

The estimated parameters of the selected model are presented in table 8.1[35]. The habit smoothing parameter, ϑ is estimated to be higher then the prior mean with a value of 0.625. This is close to the value, generally estimated by other authors, like Christiano et al. (2011), who examine the economy of Sweden or Sheen and Wang (2012), who estimate a SOE model on Australian data. This parameter shows that the households like to smooth their consumption similarly regardless of the region they live in. The inverse of Frisch elasticity parameter, ψ_h is estimated to be significantly different from its prior value which is 1. The elasticity of substitution, η also lies far below its prior value. This suggests that the consumers are not willing to substitute domestic and foreign goods.

The model suggests low bargaining power of firms, ξ for Poland as well as for the previous countries. This low power causes frictions in away that Polish entrepreneurs might be less willing to produce higher output, because they will get only a small portion of the surplus created. The elasticity of the matching function with respect to the job seekers has posterior mean 0.376. The low elasticity indicates that the matching rate does not react highly to the changes in the unemployment. Furthermore, the vacancy posting elasticity larger than one means increasing job creating costs that make the labour market more sticky.

All adjustment cost parameters are significantly higher than their prior values. This result means that there are considerable frictions present in this economy. Although the wage adjustment cost is really high, it is not the highest among these costs. The adjustment cost of domestic prices is the most expensive cost. Because of the relatively closed property of the economy, the foreign prices face considerably lower changing costs due to the low dependence on the exchange rates. Also, the indexation parameter of domestic price is higher than the other parameters. All three prices are estimated to have really high rigidities.

The Taylor-rule parameter of interest rate smoothing, ρ_r is estimated to be considerably greater than its prior value, which indicates that the National Bank of Poland is keeping this variable relatively constant. The reaction of nominal interest rates to a change in inflation lies above the prior mean, but is still roughly in line with the value

[35]The same parameters are also presented in table 8.4, where the comparison between the two shorter periods is outlined and in chapter 10, where the similarities and differences among countries are investigated. This multiple manifestation serves to facilitate the comparison of the same data with other modifications.

proposed by Taylor. The reaction to the output gap has also increased significantly from its mean set before the estimation. This is probably the reason why the *original* model is preferred compared to the model with the *simple Taylor*-rule, because parameter $\rho_{\Delta y}$ is estimated to be almost insignificant and parameter $\rho_{\Delta ner}$'s 90% HPDI actually contains zero.

The model estimates similar posterior values for the extended foreign sector parameters as the models for previous economies.

Looking at the persistences of domestic shocks in table 8.2, the most persevering shock is the matching shock. It takes almost six and a half year for this shock to get to 10% of its initial value. The other persistent shocks are the bargaining, preference and technology shocks. Each of them lasts more than 11 quarters before they reach 10% of their respective initial value. The other shocks reach this threshold under five periods.

Table 8.2: Domestic shock persistence - Poland

Parameter	mean	inf -	sup	std
ρ_{rer}	0.537	0.450	0.626	0.052
ρ_H	0.423	0.292	0.555	0.081
ρ_a	0.802	0.725	0.881	0.047
ρ_c	0.843	0.766	0.916	0.040
ρ_ξ	0.889	0.800	0.983	0.061
ρ_χ	0.911	0.880	0.942	0.019
ρ_{κ^h}	0.520	0.373	0.676	0.093

Similarly to the previous countries, the lowest standard deviation is associated with the monetary and technology shocks as can be seen in table 8.3. The matching and cost-push shocks can be characterized as the most volatile shocks.

Table 8.3: Domestic shock variance - Poland

Parameter	mean	inf -	sup	std
σ_a	0.005	0.005	0.006	0.001
σ_m	0.003	0.003	0.004	0.000
σ_{rer}	0.028	0.021	0.035	0.004
σ_c	0.042	0.032	0.053	0.006
σ_H	0.294	0.223	0.361	0.040
σ_ξ	0.115	0.082	0.145	0.020
σ_χ	0.310	0.261	0.356	0.028
σ_{κ^h}	0.063	0.041	0.085	0.012

8.1.2 Period separation

While table 8.1 compared the parameter estimates of distinct models, table 8.4 presents the results of estimation on different time periods. The estimation procedure is the same as for the Czech Republic and Hungary. The model *before* the recession is estimated using the prior distributions of the *complete* model, while the posterior values of this estimation are used as priors for the period *during* the recession.

As far as the 90% HPDIs are concerned, there are no significant differences between the two shorter periods. The differences are significantly more visible between these two estimations and the parameters of the *complete* time period. The differences in the posterior means between the two sub-samples indicate that the hours worked react more to the changes in wages, due to the increase in the Frisch elasticity parameter ($1/\psi_h$). The bargaining power of firms experienced a slight drop from 0.365 to 0.301, which is given by a higher vacancy rate and similar unemployment rate at the end of the observed period compared to the values at the split. This increased the labour market tightness and gave the workers more negotiating power. Furthermore, the other labour market elasticities remained closely together in the two periods.

While the price and wage indexation parameters, $\gamma_{H,F,W}$ did not change much, there can be observed a noticeable rise in each of the adjustment cost parameters, $\psi_{H,F,W}$. The domestic price adjustment cost increased the most, from 85.292 to 106.710. The shift of wage adjustment is slightly smaller, with a change from 68.039 to 87.804. All visible changes lead to an increase of frictions in Polish economy. The Rotemberg parameters as well as the labour market elasticities indicate that the economic subjects in Poland face higher degrees of frictions in the period *after* the recession.

The parameters of the monetary policy's decision making rule and the parameters of the extended foreign sector are tightly close together for both of the shorter periods.

8.2 Simulated moments

The computation of simulated moments is the same as for the previous countries. First, I estimated the model to obtain the standard errors and correlations between the shocks which are then used as an input for the simulation. 500 different, randomized simulations are then conducted to gain some variability.

Table 8.4: Estimated parameters of Poland - periods

Parameter	*complete* 2002:Q1 - 2015:Q4	*before* 2002:Q1 - 2008:Q4	*during* 2009:Q1 - 2015:Q4
ϑ	0.625	0.567	0.580
	(0.524 - 0.728)	(0.420 - 0.716)	(0.476 - 0.683)
ϕ_h	0.691	0.899	0.703
	(0.459 - 0.921)	(0.601 - 1.194)	(0.488 - 0.919)
η	0.438	0.509	0.497
	(0.397 - 0.480)	(0.416 - 0.599)	(0.481 - 0.513)
Labour market - elasticities			
ξ	0.278	0.365	0.301
	(0.161 - 0.396)	(0.233 - 0.498)	(0.204 - 0.401)
ν	0.376	0.481	0.463
	(0.131 - 0.622)	(0.181 - 0.764)	(0.175 - 0.739)
e	1.694	1.605	1.663
	(1.567 - 1.822)	(1.476 - 1.733)	(1.575 - 1.752)
Price and wage setting			
γ_H	0.830	0.819	0.848
	(0.718 - 0.942)	(0.699 - 0.939)	(0.750 - 0.951)
γ_F	0.701	0.748	0.723
	(0.532 - 0.875)	(0.587 - 0.910)	(0.550 - 0.899)
γ_W	0.716	0.772	0.758
	(0.570 - 0.866)	(0.634 - 0.919)	(0.614 - 0.913)
ψ_H	107.658	85.292	106.710
	(79.355 - 135.945)	(58.260 - 111.802)	(80.334 - 131.292)
ψ_F	74.436	67.712	74.312
	(49.590 - 98.592)	(41.467 - 93.904)	(48.957 - 98.859)
ψ_W	88.816	68.039	87.804
	(60.105 - 117.170)	(41.635 - 91.900)	(63.319 - 111.947)
Monetary policy			
ρ_r	0.712	0.687	0.704
	(0.658 - 0.768)	(0.601 - 0.775)	(0.640 - 0.767)
ρ_π	1.687	1.621	1.699
	(1.518 - 1.863)	(1.453 - 1.791)	(1.533 - 1.865)
ρ_y	0.396	0.313	0.362
	(0.269 - 0.531)	(0.171 - 0.459)	(0.227 - 0.499)
$\rho_{\Delta y}$	0.174	0.212	0.207
	(0.008 - 0.332)	(0.044 - 0.377)	(0.043 - 0.370)
$\rho_{\Delta ner}$	-0.040	0.056	0.016
	(-0.107 - 0.025)	(-0.064 - 0.176)	(-0.060 - 0.092)
Foreign sector			
ϑ^*	0.875	0.850	0.881
	(0.828 - 0.924)	(0.783 - 0.920)	(0.845 - 0.919)
ρ_{r^*}	0.719	0.734	0.779
	(0.676 - 0.765)	(0.661 - 0.809)	(0.732 - 0.826)
ρ_{π^*}	1.483	1.494	1.476
	(1.312 - 1.642)	(1.332 - 1.656)	(1.314 - 1.639)
ρ_{y^*}	0.543	0.471	0.481
	(0.440 - 0.648)	(0.333 - 0.606)	(0.353 - 0.605)
$\rho_{\Delta y^*}$	0.293	0.265	0.281
	(0.137 - 0.451)	(0.102 - 0.425)	(0.122 - 0.444)
γ^*	0.514	0.649	0.550
	(0.368 - 0.653)	(0.481 - 0.825)	(0.390 - 0.713)
ψ^*	43.279	39.759	46.322
	(25.423 - 60.275)	(22.990 - 57.215)	(34.818 - 57.532)
κ^y	0.184	0.241	0.224
	(0.072 - 0.290)	(0.077 - 0.408)	(0.126 - 0.317)

Note: Posterior means and highest posterior density intervals (in parentheses).

The data moments presented in table 8.5 report that the model managed to simulate the standard deviations of output and unemployment quite realistically. On the other hand, the deviations of hours and vacancies are captured by the model to be much more volatile than in the actual data.

Both, the Okun's law and the Beveridge curve seems to hold on average. The simulated correlation between unemployment and product is -0.2942, while the correlation between vacancies and unemployment is somewhat lower, -0.1615. In spite of Poland being a significantly larger and less open economy, the SOE model manages to match the standard deviations and correlations to a similar degree as for the other, smaller and opener countries.

Table 8.5: Simulated and data moments of Poland

Variable		*Standard deviation*	*Correlation with output*
y	data	0.0134	1.0000
	model	0.0160	1.0000
	90% HDPI	(0.0120, 0.0198)	(1.0000, 1.0000)
h	data	0.0052	0.1810
	model	0.0243	0.6464
	90% HDPI	(0.0185, 0.0303)	(0.3327, 0.8793)
u	data	0.1229	-0.5441
	model	0.1187	-0.2942
	90% HDPI	(0.0612, 0.2081)	(-0.6161, 0.0417)
w	data	0.0169	0.6997
	model	0.0373	0.2922
	90% HDPI	(0.0247, 0.0535)	(-0.1316, 0.6472)
π	data	0.0030	0.4728
	model	0.0085	-0.0394
	90% HDPI	(0.0067, 0.0110)	(-0.3191, 0.2801)
r	data	0.0083	0.2458
	model	0.0100	0.2626
	90% HDPI	(0.0079, 0.0123)	(-0.0335, 0.5158)
rer	data	0.0725	-0.3506
	model	0.0491	-0.0818
	90% HDPI	(0.0393, 0.0578)	(-0.3812, 0.2737)
v	data	0.1682	0.6392
	model	0.6655	0.3290
	90% HDPI	(0.5545, 0.7884)	(0.0545, 0.5610)

8.3 Historical shock decompositions

Figures 8.1-C.12 depict the historical shock decompositions of seven selected variables. The first two, the output and consumption, is examined mainly to assess the degree at which the foreign sector influences the domestic economy. The other variables are connected to the labour market. I am interested in, whether the out of the labour market shocks influence the output and what are main driving forces behind the volatility of labour market variables. In the original article of Albertini et al. (2012) the authors found that the unemployment and vacancies are solely affected by labour market shocks. In their exercise, the other shocks are summarized in a single collective shock.

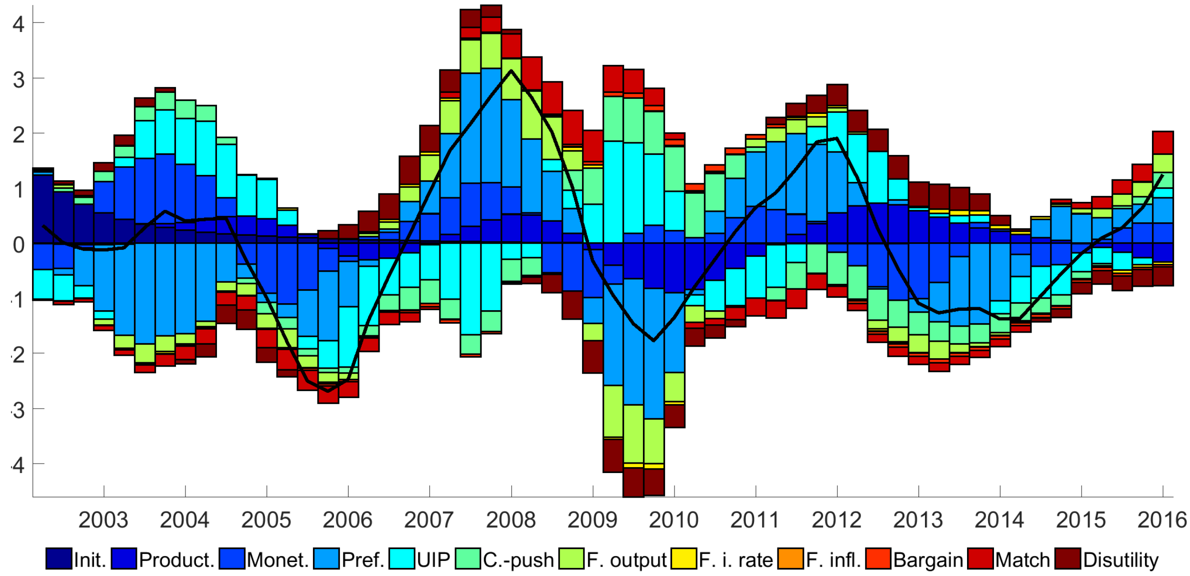
8.3.1 Polish output and consumption

The historical shock decomposition of Polish product is presented in figure 8.1. The solid line in this figure denotes the observed output gap, which fluctuated around its two-sided HP filtered steady-state quite periodically. The development of output is defined by a large number of shocks. Almost each of the 11 shocks had at least a limited impact on this variable at some time in the last 15 years. Historically the most influencing shocks are the preference, UIP, and productivity shocks. The preference shock transfers into the output with the same sign. The negative preference shocks before 2006:Q2 pressured the output downwards, while the positive shocks before the recession pushed the output higher. This exact shock had the most significant negative effect on the product in 2009. On the other hand, the negative shocks in the UIP condition were decreasing the degree of decline during the recession.

Although, the effect of the foreign output shock is not negligible, it is present in much smaller extent than in the other countries. This shock has the same effects on Polish output as it has on the smaller economies. Prior to the crisis, the foreign output supported the boom of Polish economy. However, in 2009:Q1 the foreign sector began to decline, which partially transferred to Poland.

Figure C.9 captures the development of consumption. Since the Kalman smoother identified the consumption to be far away from its steady-state at the beginning of the observed period, there is a significant amount of initial values present in the figure. Polish consumption, similarly to the other countries, is defined mainly by the impacts of the preference shock. Before the crisis, when Polish złoty depreciated, the UIP shock

Figure 8.1: Shock decomposition of Polish output (deviations from s.s. in %)



influenced the consumption positively. During this period the foreign shock had opposite effects on the domestic consumption.

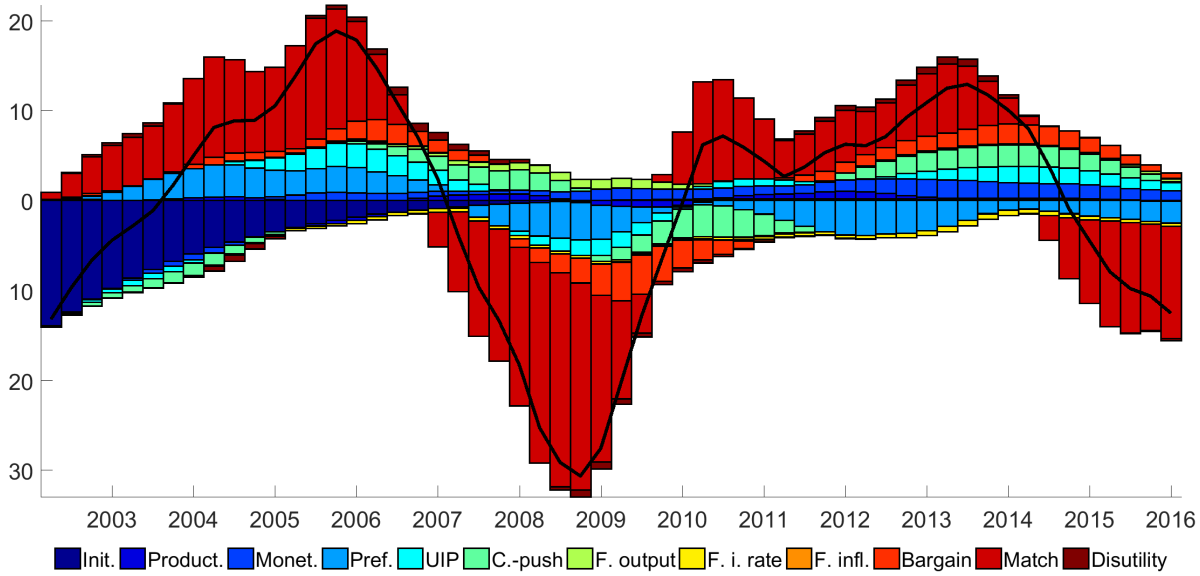
Although there are signs of the matching shock in both the output and consumption's historical shock decomposition, the overall influence of the labour market shocks is relatively small. Therefore, from this point of view, the results match the article of Albertini et al. (2012).

8.3.2 Polish labour market variables

The development of unemployment, captured in figure 8.2, is mainly driven by the matching shock. Unlike the unemployment in the Czech Republic, where the bargaining shock played a significant role, or in Hungary, where other shocks also presented themselves, the unemployment in Poland is given mostly by a single shock. The collective impact of other shocks is really small.

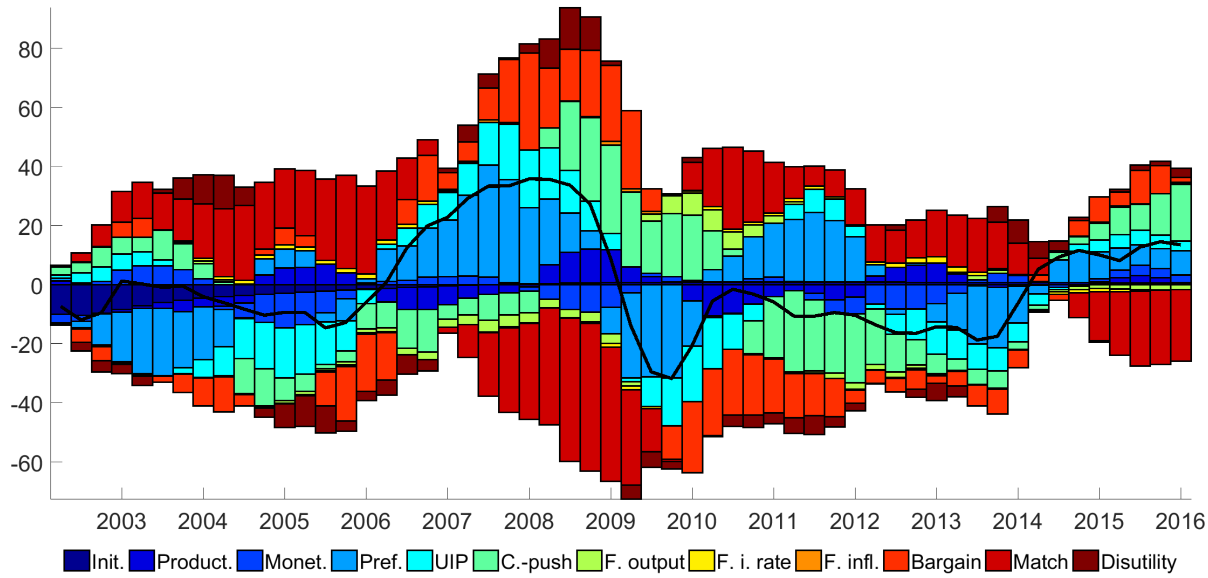
The variable of labour market tightness, presented in figure C.10 takes its variability and shock decomposition from the development of vacancies, outlined in figure C.11. Similarly as for the output, each shock takes a part in the formulation of these two variables, although the impact of the matching efficiency shock is more considerable in case of the latter. The bargaining and matching shocks have opposite effects on these variables. The increased matching efficiency reduces the number of vacancies, which can be observed in period between 2007:Q1 and 2009:Q2. With the decreasing bargaining

Figure 8.2: Shock decomposition of Polish unemployment (deviations from s.s. in %)



power of firms, which appears in the same period, the entrepreneurs have worse conditions on the labour market and decide to hire less workers, which keeps the vacancy rate high.

Figure 8.3: Shock decomposition of Polish vacancies (deviations from s.s. in %)



Strong impacts of the dis-utility from work shock appear in the development of the real wages in Poland, portrayed in figure C.11. Other factors influencing the wages are the shocks to preference, uncovered interest rate parity condition and cost-push shock. Positive preference shock increases the real wage. If the households want to increase their consumption, they need to negotiate higher wages. The UIP shock which coincides with the appreciation of exchange rate from 2007 to 2009 helped in the upward movement of real wage in this period. Positive matching shocks influenced the wage negatively during this period. Positive cost-push shocks in the period during the recession in 2009 pushed the wages upward. However, it is offset by the negative preference and UIP shocks. The cost-push shock is directly connected to the wage expenses. With the decreasing wages the firms' expenses are also lower, as it can be observed from 2011 to 2013.

The main driving forces behind the development of hours worked, in figure C.12 can be associated to the technology, preference and bargaining shocks. Throughout the whole observed time period, positive technology shocks affected the hours worked negatively and vice versa. With better technologies, the producers' need for labour decreases, so they reduce the hours of their employees. On the other hand, when the technologies worsen, the firms increase their demand for labour which is expressed in the increased hours worked. Positive matching shocks in 2007 and 2008 affected the hours negatively, because the hours of current employees are replaced with additional hired workers.

8.4 Impulse response functions of Poland

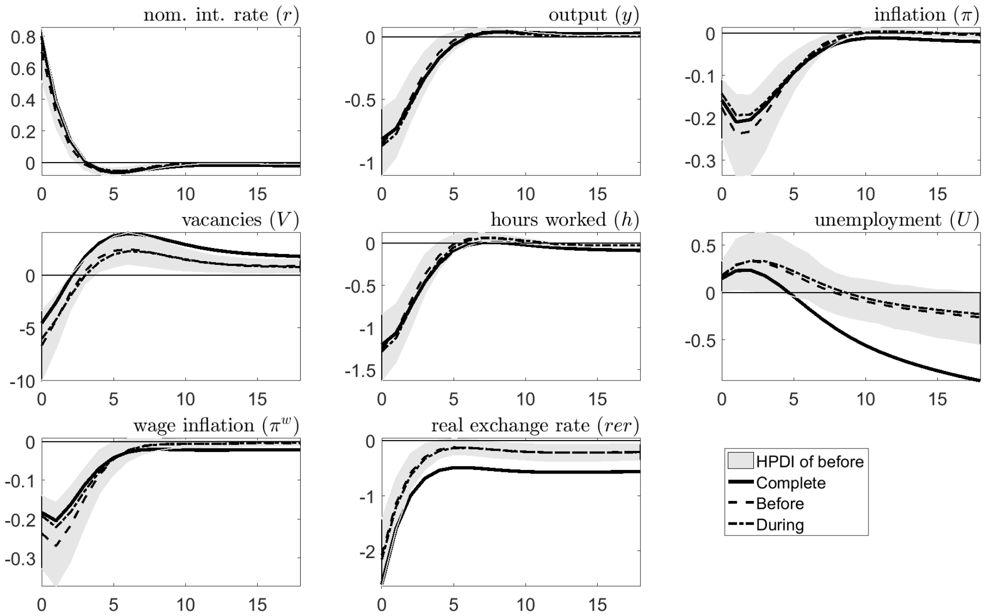
Finalizing my examination of Polish economy, I present the impulse responses to monetary and technology shocks for eight examined variables. Because the estimated parameters of the two shorter time periods are so close together (see table 8.4), the reactions of variables do not differ for these two estimations to a great degree. However, the differences between the two sub-samples and the whole period are visible due to the different values of estimated parameters.

8.4.1 Monetary shock in Poland

The monetary shock in Poland generates a similar flow of events as in the two previous economies. If the central bank wants to restrict or slow the growth of output, it can increase the nominal interest rates. The inflation responds to this by a decrease, which is relatively smaller than the increase of nominal interest rates. These changes combined increase the real interest rates. The higher real interest rates cause the persistent appreciation of real exchange rate. This shift is more significant in the case of the *whole* time period.

The decrease of output reduces the value of worker for the firm, thus the firms lay off a fraction of their workers and demand less hours from the ones they keep. While

Figure 8.4: Impulse responses to monetary shock (% deviations from s.s.)



Note: The horizontal axis represents time periods. It holds that one time period is one quarter.

unemployment increases slightly[36], the drop in vacancies is much more visible - six times as big as the drop of output. This development reduces the labour market tightness, which in turn causes the decrease of wage inflation.

Given the absence of the monetary shock's persistence, most of the variables return to their steady-states relatively quickly, under two years. The vacancies and real exchange rate stabilize around a new steady state. While there is a permanent increase in the vacancies, the real exchange rate appreciates permanently. However, the gradually decreasing unemployment does not seem to stabilize during the 20 periods depicted in the figure.

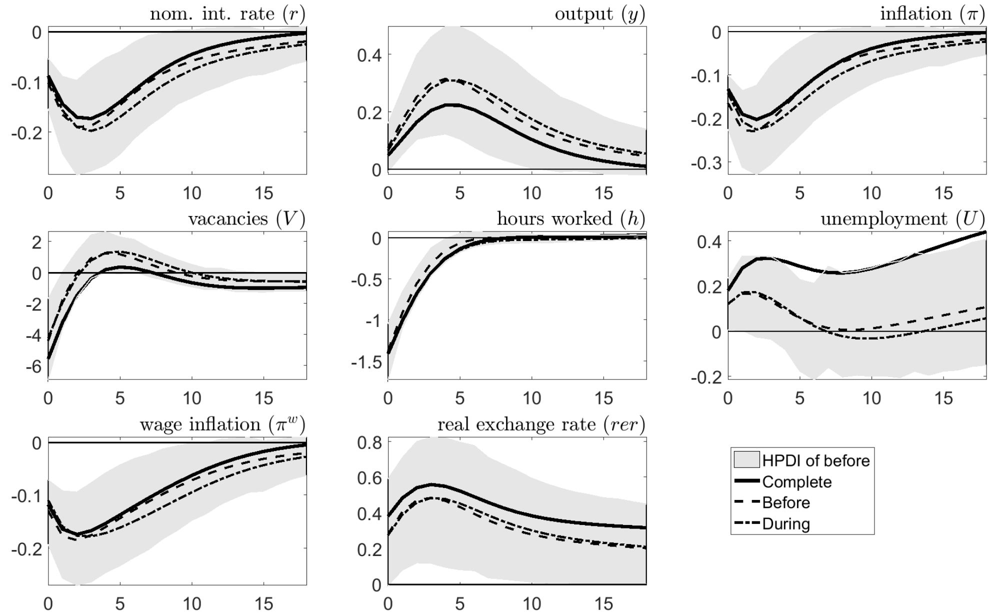
8.4.2 Technology shock in Poland

The technology shock leads to a gradual increase of output after the initial jump. During this period, the central bank reduces the interest rates to further fuel the economic boom. The higher product at lower costs means that inflation decreases. The model assigns approximately same change to the decrease of nominal interest rates as to the decline

[36] An important reminder is in place at this moment: although the permanent decrease of unemployment at 1% seems significant, the 1% is a percentage change from the steady state and not a percentage point change. The same principle holds for the temporary decrease of vacancies by 5%.

of inflation. This results in a unchanged real exchange rate. The increasing output is accompanied by a permanent depreciation of the real exchange rate.

Figure 8.5: Impulse responses to technology shock (% deviations from s.s.)



Note: The horizontal axis represents time periods. It holds that one time period is one quarter.

The workers are substituted by better technologies, so the unemployment rate rises, while hours worked decline. Furthermore, the entrepreneurs reduce their demand for workers by decreasing the number of vacancies posted. This development is again unfavourable for the households, who in turn receive lower wages.

The higher persistence of the technology shock results in a longer time before the variables return to their steady-state. Similarly as to the monetary shock, there are permanent effects in the case of vacancies and real exchange rate. The effects are, however, opposite - the number of vacancies declines and the exchange rate depreciates. Unemployment is affected negatively and permanently by this shock. In case of the two shorter periods, it returns closer to its previous steady-state, than in case of the whole time period. This permanent effect on unemployment, which is not observed in the other countries, is caused by the significantly lower elasticity of the matching function with respect to the job seekers (below 0.5 for all estimates of Poland). The increasing number of unemployed exceeds the rate at which they can be matched with a vacant job position. This situation originates from the relatively much higher unemployment rate compared to the vacancy rate in Polish economy.

8.5 Chapter's summary

The chapter presents the estimation results of Poland. This economy is somewhat larger than the rest of the countries. Therefore some changes had to be done on the prior setting. Otherwise the chapter follows the steps outlined in the previous parts.

I find that even though Polish economy is much larger and much more closed, the model is able to match the volatility of selected variables similarly as was the case of the previous countries. Polish economy contains a significant amount of price setting frictions. Furthermore, its matching rate is really staggering when the unemployment rate is taken into consideration. The low matching elasticity results in increasing unemployment when a technology shock appears in the economy. On the other hand, monetary shock permanently decreases the unemployment rate. The historical shock decompositions indicate that Poland was affected by the recession only slightly by foreign shocks. The majority of the influence originated in the domestic economy.

Chapter 9

Estimation results of Slovakia

The last examined economy is the Slovak Republic. It is the smallest of the four countries, therefore it relies more on the development of the foreign sector. However, unlike the other countries, the National bank of Slovakia no longer possesses an autonomous monetary policy. It is subject to the European Central Bank's authority. Throughout the observed time period, the situation on the labour market was not favouring the households, with high levels of unemployment. Only in the past few quarters did the situation change. Although, the unemployment is still relatively high, due to the optimistic development of the economy the firms are looking for more and more employees.

This chapter presents the results of estimation on Slovak data. The same process is used in the evaluation of my results and the answering of the research questions as is presented in the previous chapters.

9.1 Model selection

Once more, four models are estimated to choose the best and once again the same method of selection is used. All estimated models in this chapter use Table 9.1 presents the posterior values of parameters of the four estimated models. There are some statistically significant differences among the results. The model with the *simple Taylor*-rule estimates the deep-habit parameter to be 0.587. The other models assign a value around 0.7 to this parameter. The model with the *one-sided* HP filtered data reports the lowest values of the bargaining power of firms, ξ and the elasticity of the matching function with respect to job seekers, ν. Furthermore, it estimates the highest elasticity of vacancy adjustment, e. With the largest wage adjustment cost parameter, ψ_W, the *one-sided* model shows the highest degree of labour market frictions. The Bayes factor again preferences the model with the extended foreign sector to the other two models with two-sided HP filter.

Table 9.1: Parameter estimates of Slovakia - models

Parameter	*original*	*one-sided*	*new foreign sector*	*simple Taylor*
ϑ	0.696	0.723	0.682	0.587
	(0.601 - 0.797)	(0.629 - 0.820)	(0.585 - 0.782)	(0.464 - 0.723)
ϕ_h	0.865	0.860	0.881	0.893
	(0.574 - 1.149)	(0.580 - 1.120)	(0.585 - 1.163)	(0.585 - 1.185)
η	0.776	0.757	0.744	0.859
	(0.586 - 0.956)	(0.578 - 0.948)	(0.559 - 0.926)	(0.656 - 1.046)
Labour market - elasticities				
ξ	0.251	0.176	0.225	0.232
	(0.021 - 0.451)	(0.009 - 0.356)	(0.001 - 0.433)	(0.022 - 0.430)
ν	0.596	0.393	0.608	0.586
	(0.326 - 0.884)	(0.101 - 0.674)	(0.330 - 0.892)	(0.298 - 0.888)
e	1.651	1.872	1.718	1.645
	(1.322 - 1.972)	(1.495 - 2.379)	(1.276 - 2.162)	(1.311 - 1.976)
Price and wage setting				
γ_H	0.778	0.800	0.786	0.789
	(0.640 - 0.919)	(0.673 - 0.932)	(0.655 - 0.924)	(0.656 - 0.929)
γ_F	0.782	0.775	0.782	0.769
	(0.646 - 0.926)	(0.628 - 0.927)	(0.646 - 0.923)	(0.625 - 0.925)
γ_W	0.593	0.539	0.591	0.631
	(0.408 - 0.781)	(0.355 - 0.719)	(0.400 - 0.779)	(0.439 - 0.834)
ψ_H	59.376	64.096	62.405	55.983
	(36.504 - 82.316)	(40.581 - 85.668)	(38.531 - 87.266)	(34.847 - 77.371)
ψ_F	45.927	44.545	48.240	39.564
	(24.805 - 66.784)	(24.936 - 63.196)	(27.281 - 69.715)	(22.091 - 56.401)
ψ_W	59.087	80.155	56.805	51.602
	(35.119 - 81.452)	(53.953 - 107.881)	(34.230 - 80.220)	(28.780 - 73.781)
Monetary policy				
ρ_r	0.729	0.720	0.732	0.714
	(0.668 - 0.790)	(0.661 - 0.777)	(0.675 - 0.786)	(0.647 - 0.782)
ρ_π	1.536	1.555	1.536	1.634
	(1.373 - 1.698)	(1.393 - 1.711)	(1.376 - 1.699)	(1.475 - 1.791)
$\rho_{\Delta y}$	0.348	0.320	0.336	0.365
	(0.197 - 0.485)	(0.181 - 0.452)	(0.190 - 0.474)	(0.221 - 0.505)
ρ_y	0.264	0.256	0.265	-
	(0.160 - 0.363)	(0.174 - 0.338)	(0.166 - 0.360)	(-)
$\rho_{\Delta ner}$	0.413	0.382	0.395	-
	(0.271 - 0.559)	(0.239 - 0.518)	(0.256 - 0.537)	(-)
Foreign sector				
ϑ^*	-	-	0.902	-
	(-)	(-)	(0.862 - 0.941)	(-)
ρ_{r^*}	-	-	0.720	-
	(-)	(-)	(0.678 - 0.763)	(-)
ρ_{π^*}	-	-	1.481	-
	(-)	(-)	(1.320 - 1.643)	(-)
ρ_{y^*}	-	-	0.570	-
	(-)	(-)	(0.473 - 0.664)	(-)
$\rho_{\Delta y^*}$	-	-	0.277	-
	(-)	(-)	(0.135 - 0.430)	(-)
γ^*	-	-	0.513	-
	(-)	(-)	(0.367 - 0.660)	(-)
ψ^*	-	-	41.009	-
	(-)	(-)	(20.360 - 60.990)	(-)
κ^y	-	-	0.149	-
	(-)	(-)	(0.046 - 0.263)	(-)
Marginal Density	2111.117	2209.824	2133.084	2100.319

Note: Posterior means and highest posterior density intervals (in parentheses).

9.2 Estimated parameters

Most of the parameter estimates for Slovakia of the model with extended *foreign sector* presented in table 9.1 shifted away from their prior values. The posterior value of deep-habit parameter's mean, $\vartheta = 0.682$ is estimated to be really high. This reflects the need of Slovak population to match its previous period living standard. In their simulation, Senaj et al. (2010) calibrate this parameter to 0.64, which is close to my estimate. The Frisch elasticity parameter $1/\phi_h$ is estimated to be larger than one, however its 90% percent density interval is considerably wide. The mean value of this parameter would suggest that Slovak labour market is flexible in a way that a low change of wages generates a relatively higher transition in worked hours. The domestic and foreign goods elasticity parameter, $\eta = 0.744$ reports a willingness to replace domestically produced goods by imported products. This is in line with the great degree of openness of Slovak economy and its dependance on imports.

The labour market parameters report that Slovak work force has a substantial negotiating power, $1-\xi$, when it comes to wage and hours bargaining. This contradicts other authors, like Němec (2013b), who estimates this parameter for Slovakia to be close to zero. My posterior density estimate of the elasticity of the matching function, ν lies close to the one presented in the above mentioned article. My results suggests this value to be between 0.330 and 0.892 with 90% probability, with the mean value of 0.608. Němec (2013b) reports this parameter with mean 0.8196 and 90% HPDI (0.7645, 0.8782). The matching rate rises only by a fraction of the increase of unemployment rate. However, its reaction is stronger to the changes in the unemployment rate than the changes in the vacancy rate. Unemployed workers tend to search for new job positions.

The elasticity of creating an additional empty work position to hire workers is significantly larger than one (1.718). This increasing vacancy posting cost reduces the motivation of firms to create and advertise new vacancies, thus imposing a rigidity on the labour market. The estimate of this parameter by Albertini et al. (2012) is significantly larger, with posterior mean 5.88, meaning firms in New Zealand create vacancies even less willingly. However, producers in New Zealand face much lower wage adjustment costs (15.53), than in Slovakia, where $\psi_W = 56.805$. The other adjustment costs are 62.405 for the domestic prices and 48.240 for the foreign goods' prices. Thus, it is more costly to change the prices of domestic goods. This can be given by the fact that Slovakia is already a member of the EMU, so the importers from the euro area, which is the foreign sector in the model, do not face exchange rate volatility risks. The foreign price setting cost in the foreign economy, ψ^* is also the lowest among the four expenses. The indexation parameters of the adjustment cost, $\gamma_{H,F,W}$ indicate that the domestic price is indeed the most sticky. On the other hand, there are not that high frictions, when it comes to adjusting the wages.

Looking at the monetary policy parameters, it is important to note that Slovak economy specific Taylor rule (3.85) is used. This means that the *switch* mechanism "turns off" these parameters in the period of common monetary policy and allows the foreign interest rate to dictate the development of the domestic. The Taylor rule parameter of interest rate smoothing, $\rho_r = 0.732$ reflects the low volatility in the development of this variable. The mean of parameter of interest rate's reaction to deviations of inflation from its steady state, $\rho_\pi = 1.536$ is estimated to be close to its prior mean. This result coincides with the value originally proposed by Taylor (1993). The reaction to the output is higher than the prior value. Furthermore, the estimated reaction to exchange rate movements shifted upward significantly from the prior value. This could be because of the strong appreciation of Slovak crown before the adoption of euro, while, at the same time the nominal interest rate exhibited decreasing tendencies.

Table 9.2 reports the posterior values of the shock persistence parameters. The lasting of a shock after its initial impact can be computed analogically to the previous countries. The bargaining shock is the most persistent. It takes more than 15 quarters for this shock to get to 10% of its initial value. On the other hand, the uncovered interest rate parity shock takes only half year to reach this threshold.

Table 9.2: Domestic shock persistence - Slovakia

Parameter	mean	inf - sup		std
ρ_{rer}	0.090	0.003	0.171	0.066
ρ_H	0.535	0.372	0.697	0.100
ρ_a	0.798	0.709	0.894	0.058
ρ_c	0.728	0.612	0.842	0.070
ρ_ξ	0.843	0.749	0.939	0.056
ρ_χ	0.842	0.744	0.942	0.055
ρ_{κ^h}	0.346	0.136	0.546	0.134
ρ_{sw}	0.959	0.935	0.982	0.014

Table 9.3: Domestic shock variance - Slovakia

Parameter	mean	inf - sup		std
σ_a	0.008	0.007	0.009	0.001
σ_m	0.003	0.003	0.004	0.000
σ_{rer}	0.021	0.018	0.024	0.002
σ_c	0.053	0.038	0.068	0.008
σ_H	0.272	0.164	0.368	0.056
σ_ξ	0.239	0.134	0.339	0.041
σ_χ	0.207	0.173	0.238	0.019
σ_{κ^h}	0.105	0.066	0.141	0.023
σ_{sw}	0.183	0.156	0.210	0.016

9.2.1 Period separation

Table 9.4 reports the parameter estimation results for Slovakia on the three examined time periods. As in the previous chapters, the *complete* and *before* estimations use the same prior setting, while the period *during* takes the posterior distribution of the *before* estimation as its prior setting. Due to the specific Taylor rule, the model was adjusted for the two shorter periods. Although the *switch* provides a solid approximation to the monetary regime change, the estimations on the two sub-samples are carried out without this feature. For the period *before* the standard Taylor rule is used, which is a part of the estimations for the other countries. In the period *during* the crisis, the Taylor rule, together with the domestic interest rate is completely left out. Furthermore, the uncovered interest rate parity condition is modified as is described in section 3.8.

Similarly as for the previous countries, in most cases the estimation results do not differ significantly between the two periods. A substantial increase can be observed in the deep habit parameter, ϑ which changed from 0.637 to 0.760. This increase of the consumption smoothing parameter is in direct contact with the lower variability of this variable presented in figure C.13. Another relevant changes are related to the adjustment cost parameters. Both the domestic price, γ_H and the wage adjustment γ_W costs increased, while the indexation parameters remained quite similar. On the other hand, the firms bargaining power slightly declined. All of these factors combined, together with the higher vacancy creation cost, e, indicate that Slovak labour market is more sticky in the period during the recession.

Table 9.4: Estimated parameters of Slovakia - periods

Parameter	*complete* 2002:Q1 - 2015:Q4	*before* 2002:Q1 - 2008:Q4	*during* 2009:Q1 - 2015:Q4
ϑ	0.682	0.637	0.760
	(0.585 - 0.782)	(0.499 - 0.782)	(0.695 - 0.829)
ϕ_h	0.881	0.983	0.971
	(0.585 - 1.163)	(0.658 - 1.287)	(0.664 - 1.270)
η	0.744	0.742	0.766
	(0.559 - 0.926)	(0.541 - 0.928)	(0.597 - 0.931)
Labour market - elasticities			
ξ	0.225	0.470	0.386
	(0.001 - 0.433)	(0.242 - 0.694)	(0.239 - 0.535)
ν	0.608	0.741	0.726
	(0.330 - 0.892)	(0.550 - 0.948)	(0.535 - 0.944)
e	1.718	1.334	1.415
	(1.276 - 2.162)	(1.161 - 1.512)	(1.320 - 1.507)
Price and wage setting			
γ_H	0.786	0.778	0.780
	(0.655 - 0.924)	(0.643 - 0.925)	(0.640 - 0.931)
γ_F	0.782	0.764	0.789
	(0.646 - 0.923)	(0.616 - 0.919)	(0.648 - 0.936)
γ_W	0.591	0.677	0.643
	(0.400 - 0.779)	(0.495 - 0.861)	(0.443 - 0.851)
ψ_H	62.405	54.078	79.820
	(38.531 - 87.266)	(31.178 - 75.702)	(57.107 - 102.144)
ψ_F	48.240	50.968	48.724
	(27.281 - 69.715)	(27.673 - 73.758)	(28.513 - 69.414)
ψ_W	56.805	43.511	59.765
	(34.230 - 80.220)	(23.829 - 62.673)	(40.736 - 78.545)
Monetary policy*			
ρ_r	0.732	0.690	-
	(0.675 - 0.786)	(0.595 - 0.791)	(-)
ρ_π	1.536	1.530	-
	(1.376 - 1.699)	(1.366 - 1.694)	(-)
ρ_y	0.265	0.240	-
	(0.166 - 0.360)	(0.123 - 0.355)	(-)
$\rho_{\Delta y}$	0.336	0.295	-
	(0.190 - 0.474)	(0.137 - 0.452)	(-)
$\rho_{\Delta ner}$	0.395	0.324	-
	(0.256 - 0.537)	(0.169 - 0.473)	(-)
Foreign sector			
ϑ^*	0.902	0.860	0.885
	(0.862 - 0.941)	(0.797 - 0.929)	(0.849 - 0.920)
ρ_{r^*}	0.720	0.735	0.774
	(0.678 - 0.763)	(0.664 - 0.807)	(0.727 - 0.820)
ρ_{π^*}	1.481	1.497	1.475
	(1.320 - 1.643)	(1.338 - 1.658)	(1.318 - 1.630)
ρ_{y^*}	0.570	0.491	0.496
	(0.473 - 0.664)	(0.358 - 0.625)	(0.376 - 0.612)
$\rho_{\Delta y^*}$	0.277	0.259	0.276
	(0.135 - 0.430)	(0.099 - 0.425)	(0.117 - 0.436)
γ^*	0.513	0.645	0.553
	(0.367 - 0.660)	(0.468 - 0.816)	(0.390 - 0.713)
ψ^*	41.009	41.168	48.188
	(20.360 - 60.990)	(19.401 - 61.524)	(34.656 - 61.159)
κ^y	0.149	0.226	0.215
	(0.046 - 0.263)	(0.000 - 0.392)	(0.115 - 0.312)

Note: Posterior means and highest posterior density intervals (in parentheses). *The Taylor rule for *complete* incorporates the switch mechanism, for *before* is the same as for the previous countries and for *during* is completely removed from the model.

9.3 Simulated moments

Table 9.5 contains the observed and simulated standard deviations and correlations with output of the observed data. The results are similar to the previous countries. The model is able to simulate the deviations of output and unemployment quite realistically. However, the model incapable to capture the variance of Slovak hours worked and wages.

Interestingly, the model's simulation of correlation between output and interest rates, and output and inflation matches the data quite well. However, yet again the correlation of hours with the output is significantly higher in the simulated data. The model simulates negative correlation between output and unemployment (-0.4352) and negative relation between vacancies and unemployment (-0.1922).

Table 9.5: Simulated and data moments of Slovakia

Variable		*Standard deviation*	*Correlation with output*
y	data	0.0231	1.0000
	model	0.0297	1.0000
	90% HDPI	(0.0229, 0.0382)	(1.0000, 1.0000)
h	data	0.0106	0.1474
	model	0.0341	0.8044
	90% HDPI	(0.0267, 0.0422)	(0.5835, 0.9198)
u	data	0.0997	-0.7272
	model	0.1183	-0.4352
	90% HDPI	(0.0715, 0.1755)	(-0.6458,-0.1287)
w	data	0.0139	0.4060
	model	0.0478	-0.1255
	90% HDPI	(0.0318, 0.0680)	(-0.5145, 0.2712)
π	data	0.0050	0.2457
	model	0.0114	0.2586
	90% HDPI	(0.0087, 0.0138)	(0.0117, 0.5371)
r	data	0.0079	0.7993
	model	0.0176	0.6783
	90% HDPI	(0.0140, 0.0211)	(0.4521, 0.8528)
rer	data	0.0192	-0.0292
	model	0.0341	0.5016
	90% HDPI	(0.0260, 0.0412)	(0.2689, 0.6916)
v	data	0.3239	0.7500
	model	0.5197	0.4246
	90% HDPI	(0.4138, 0.6151)	(0.2052, 0.6432)

9.4 Historical shock decompositions

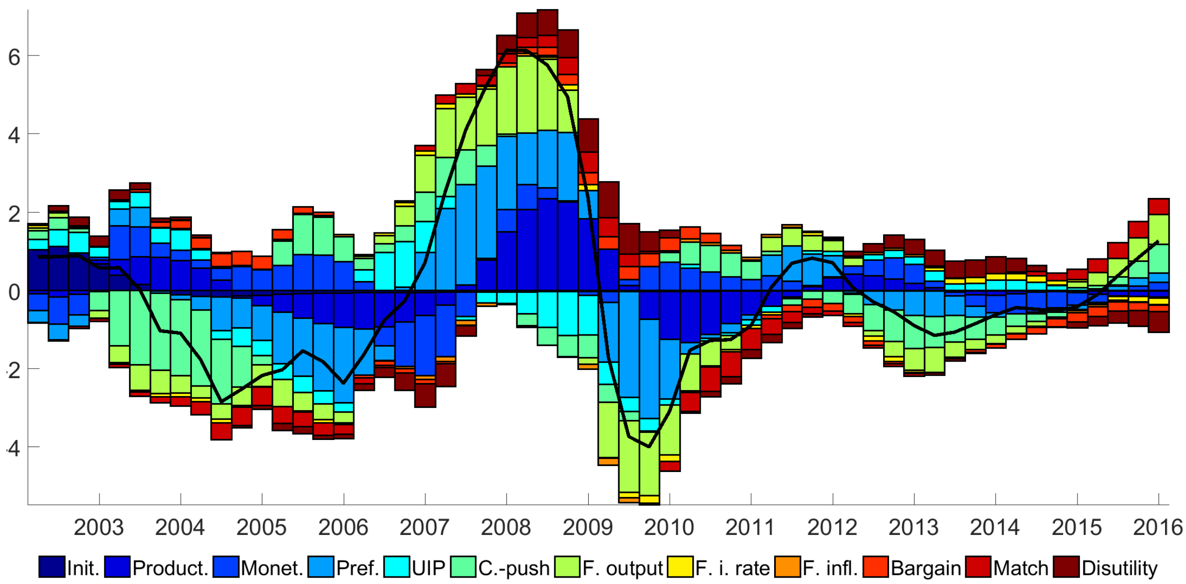
I continue my analysis with the description of the historical shock decompositions of the variables investigated in the previous chapters. Figures 9.1 - C.16 come from the estimation of the full time period model with the *new foreign* sector and the country specific Taylor-rule.

9.4.1 Slovak output and consumption

Similarly to the other economies, Slovak output is driven mainly by the productivity, preference and foreign output shocks. Apart from these shocks a two year period of negative cost-push shock can be observed from 2003. It is a time period closely preceding the entry of the country to the European Union. The increase of the output before the crisis is mainly related to the positive impacts of the three most influential shocks. Just before the crisis, UIP shocks started to decrease the output. This is because Slovak government together with the NBS targeted a strong appreciation of Slovak crown before the admission to the common monetary policy union. The appreciation was more convenient to the importers and less prosperous for the exporting industries. The first year of the recession, 2009, can be explained by strong influences from the foreign sector, and the pessimistic expectations of the households.

Unlike the Czech and Hungarian output, Slovak product is also partially influenced

Figure 9.1: Shock decomposition of Slovak output (deviations from s.s. in %)



by the labour market shocks. The bargaining and the matching, as well as the dis-utility from work shock take part in the forming of Slovak output. This suggests that Slovak output is more susceptible to changes in the labour market.

The consumption in the Slovak Republic, captured in figure C.13 is driven solely by two shocks, the preference shock and the shock of foreign output. Interestingly, the Kalman filter generates values from 2009 to be really close to the steady-state. During the global recession the consumption returned from its excessive values to its normal, steady-state level.

9.4.2 Slovak labour market variables

As can be seen in figure 9.2, the unemployment rate in Slovakia decreased steadily since the country joined the European Union in 2004. However, before the admission, the cost-push shock and negative development in the matching processes pressured the unemployment upwards. From 2006 until 2009, when the matching shock affected the labour market positively, the unemployment decreased by 33%. This represents the decrease of unemployment rate from around 15%in 2006 to approximately 9% in 2009. The positive development on the labour market was also supported by a decrease of the firms' negotiating power. There is no apparent reason behind the increase of the unemployment during 2009 other than the gradual, yet significant reduction of these shocks and the change

Figure 9.2: Shock decomposition of Slovak unemployment (deviations from s.s. in %)

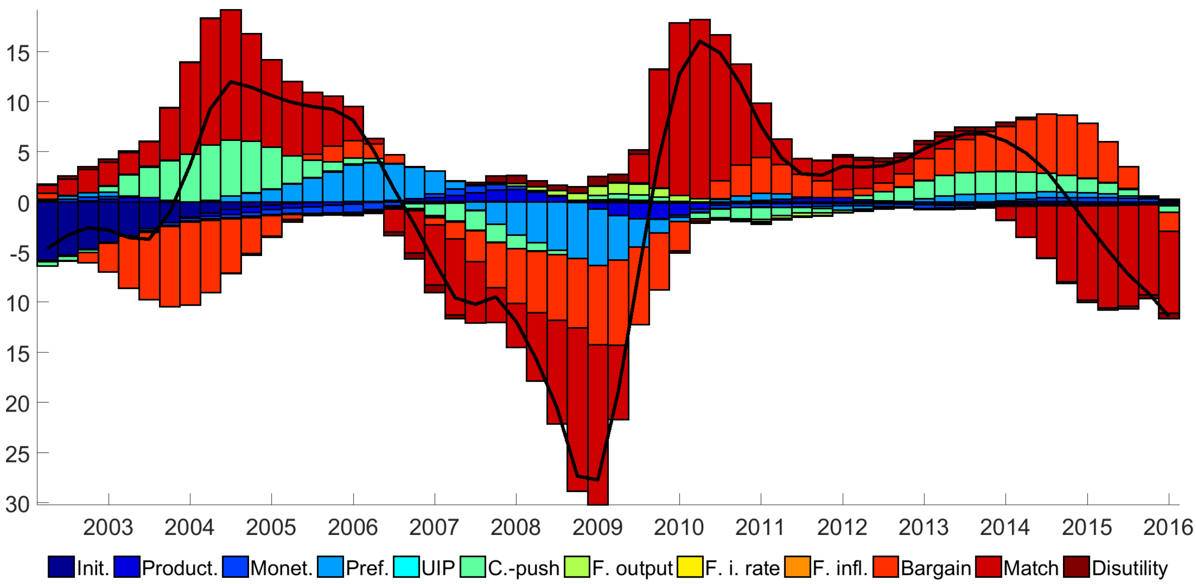
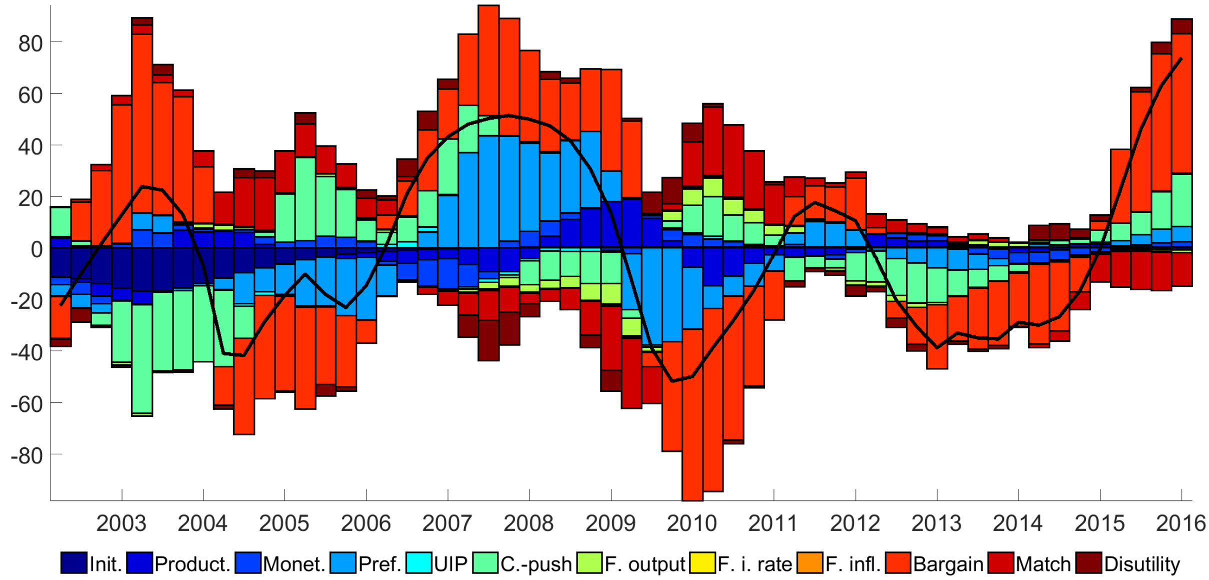


Figure 9.3: Shock decomposition of Slovak vacancies (deviations from s.s. in %)



of matching shock's sign. In 2014, despite the increased bargaining power of firms, the increasing matching rate started to lower the unemployment rate. In the last period the decreased negotiating power also reduced the unemployment.

The labour market tightness in figure C.14 represents the connection between the unemployment rate and the vacancy rate. It holds that increasing bargaining power of firms coincides with lower values of labour market tightness, because if the market is loose, there are more unemployed and fewer vacancies. In this situation, the firms have the advantage in a way that they can pick from a grater number of workers and negotiate better conditions for themselves while keeping more from the generated surplus.

Before the crisis, positive preference shocks increased the labour market tightness. Figure 9.3 reports that this shock pressured the firms to create more vacancies. Because the labour market tightness is derived partially from the vacancy rate, the development of these two variables is fairly similar. Both variables are affected unfavourably by the negative cost-push shock at the beginning of the observed period.

This negative cost-push shock also stands behind the decline of real wages at this point in time. The preference shock appears to dominate in the development of the real wages throughout the first two thirds of the observed period. In its negative phase in 2006 and 2007 it is weighted out by a positive cost-push shock and a beneficent shock to dis-utility from labour. From 2007 until the crisis, the favourable preference shocks pushed the wages upward. However, during this time the foreign output, bargaining and dis-utility affected the wages negatively. After the initial impact of the recession, these shocks exibited opposite effects.

Figure C.16 contains the historical shock decomposition of hours worked in Slovakia. This variable was greatly affected by the spikes of the technology shock in the quarters around the global crisis. Positive values of this shock tend to decrease the hours worked, because better technologies lead to a shorter working hours due to more productive labour. During this period also the foreign output influenced the hours. This effect had opposite direction to that of the domestic technology shock.

9.5 Impulse response functions

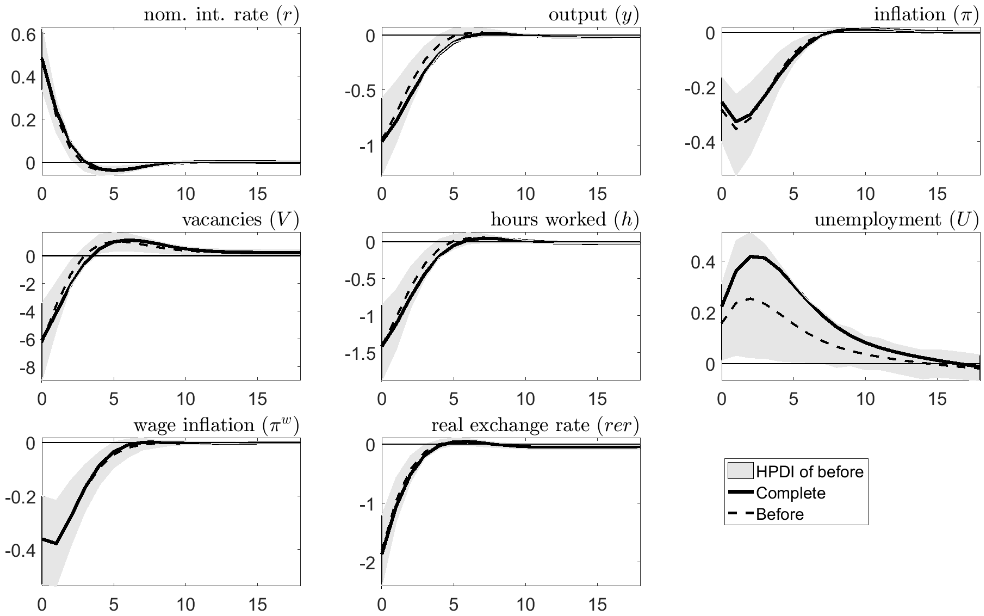
In this section I turn to the investigation of the monetary policy's transmission mechanism and the examination of a positive technology shock.

9.5.1 Monetary shock

Since Slovak economy is a part of the monetary union since 2009, the monetary shock is not present in the period *during* the recession. Figure 9.4 presents the impulse responses to the monetary shock for the whole period and the period before the crisis. The transmission mechanism worked for Slovak economy before the crisis identically as for the previous countries. Furthermore, the similarities between the two presented periods result in the fairly identical IRFs with the exception of the unemployment. This smaller reaction of unemployment in the shorter period is given by the larger matching elasticity, ν which is 0.608 in the *whole* period and 0.741 *before*. The lower ν means the monetary authority has a greater short term impact on the unemployment.

The reaction of output to the monetary shock is twice as large as the reaction of nominal interest rates and around four times as large as the inflation. The vacancies react even more significantly with an initial deviation from their steady-state six times larger then the decline of output. The convergence of the variables to their steady-states is relatively swift. Most of the variables return to their steady-state in two years with the exception of unemployment which decreases sluggishly.

Figure 9.4: Impulse responses to monetary shock (% deviations from s.s.)



Note: The horizontal axis represents time periods. It holds that one time period is one quarter.

9.5.2 Technology shock

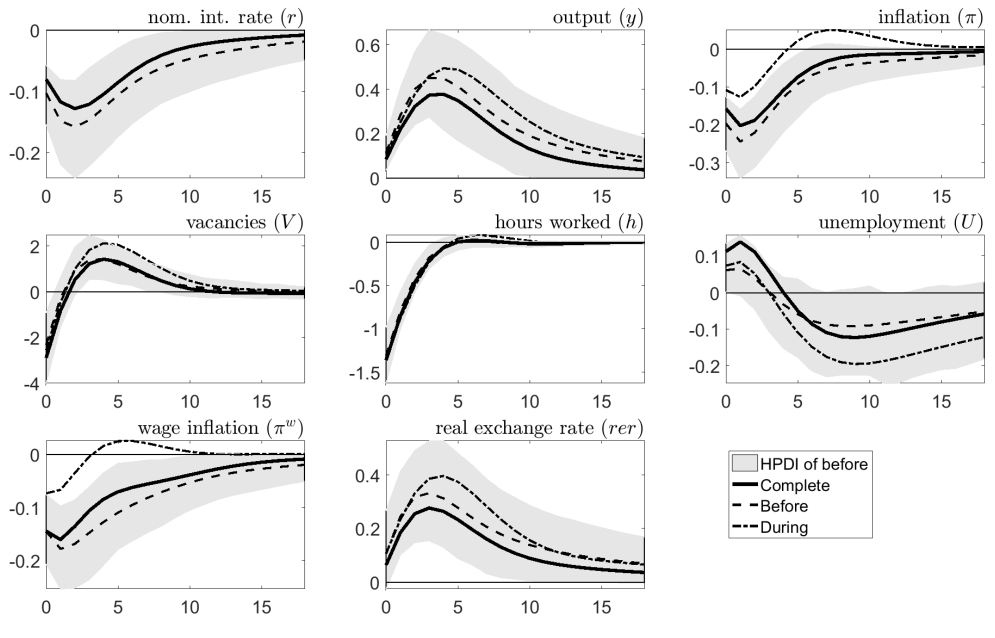
Figure 9.5 depicts the impulse responses of the above examined variables to a technology shock for all three samples with the exception of nominal interest rates which do not appear in the period after the crisis. It can be observed that the reactions of variables have similar development, but in most cases different degree of magnitude.

The direct impact of the productivity shock increases the product. With the better technologies, firms can produce more with lower prices, thus inflation decreases. To further boost the economy, the (autonomous) monetary authority decreases the interest rates. Since firms have better technologies, their need for employees decreases which causes an increase in unemployment and decrease in hours and vacancies. The decline of labour market tightness favours firms, therefore a decrease of wages is observed. The depreciation of real exchange rate also increases the domestic output. After the effects of the technology shock expire, the output begins to decline slowly. The producers start to post more job positions and hire more workers - both the vacancies and unemployment flip over to the other side of their respective steady states.

The high persistence of Slovak technology shock, $\rho_a = 0.798$ means that most of the variables do not return to their steady-states soon. While hours worked are near their stable level after five quarters, the output and real exchange rate are just getting close after five years and the unemployment is still far away.

The lower reaction of prices and wages in the period *after* the crisis stems from the change in the adjustment parameters. While adjusting the prices of domestically produced goods was possible *before* the crisis with a price adjustment cost parameter $\gamma_H = 54.078$, *after* 2009 this parameter increased to 79.820. Similarly the wage adjustment parameter, γ_W increased from 43.511 to 59.765. This increase of frictions causes a lower reaction of CPI and wage inflation to the technology shock. It is more expensive for the firms to change their prices more radically so they renew their contracts with smaller adjustments. The gradual increase of vacancies and decline of unemployed in the *during* period is so excessive that the increasing labour market tightness forces the firms to increase the wages of employees.

Figure 9.5: Impulse responses to technology shock (% deviations from s.s.)



Note: The horizontal axis represents time periods. It holds that one time period is one quarter.

9.6 Chapter's summary

This chapter contains the estimation results of the last and smallest of the examined countries, Slovakia. The uniqueness of this economy lies in the adoption of euro as the official currency of the country. The date of the admission to tie euro area coincides with the arrival of the Great recession. Because of this a country specific modification is made to improve the model's representation of the real economy. The chapter has the same structures as the previous three parts.

The results suggest that there are relatively low labour market frictions in Slovakia. Although there exist rigidities stemming from the low bargaining of firms and vacancy posting costs, the values of these parameters indicate lower stickiness than in other countries. Furthermore, the firms have lower wage adjustment costs with low wage indexation. The historical decompositions show, that Slovakia depends to an extent on the development of foreign variables. Finally, the impulse response functions indicate that the economy reacts swiftly to a sudden monetary shock.

Chapter 10

Country comparison

The four previous chapters investigated the four economies separately. The estimations of shorter time periods show that the effects of the recession have already passed and the economies roughly returned to their pre-crisis states. Thus there are but few noticeable differences for each country between different periods.

However, the examination of various economies resulted in significant differences in the obtained estimations. In this chapter I focus on the comparison of the results that are obtained by the same model, but for different countries. I am mainly interested in the labour market rigidities and their possible impact on the dynamics of variables. The model equations are the same for each country with the exception of Slovakia, where an adjustment to the Taylor-rule and the UIP condition had to be made, because the country's entry to the EMU. The prior setting of estimated parameters is kept identical with the exception of Poland, where more narrow densities are used to be able to run the model. Furthermore, the fixed non-data specific parameters are kept the same and since $\overline{R} = \overline{R}^* = 1/\beta$, the discount factor is also set equal for each country. With this setting I am able to investigate the differences between the economies that are given by different dynamics of each country's data set.

I look at the differences in the estimated parameters. The posterior estimates shed some light on the different degrees of frictions that are transferred to the dynamics of variables and the impacts of shocks. I also investigate the differences in the transmission mechanism of monetary shock and the degree to which it is affected by the different stickiness.

10.1 Structural characteristics of economies and their labour markets

The parameter estimates of the model with a *new foreign sector* presented for each country in the previous chapters is summarizer in table 10.1 for easier comparison.

By comparing the parameters affecting the households' utility and consumption, I find that the Czech population tends to smooth its consumption the most, because of the highest value of the deep-habit parameter, ϑ. The households want to keep their living standards relatively stable, which results in a lower volatility of consumption. On the other hand, this parameter is the lowest in Poland, although still significantly higher than the prior mean. The estimated values between 0.62 and 0.74 are also reported by other authors, like Christiano et al. (2005) or Adolfson et al. (2007). Polish households face a higher degree of variance in their consumption.

The parameter of Frisch labour supply elasticity, $1/\phi_h$ is estimated to be larger than one in each country. This is in contrast with most papers like, Burriel et al. (2010), who estimate this parameter to be smaller than one. The estimated mean is the highest in Poland. The worked hours react the most significantly to changes in wages in this economy. Poland is also the only one of the estimated economies, where the posterior of inverse of the Frisch elasticity, ϕ_h, is significantly different from one. On the other side, the households in Hungary adjust their hours worked in an approximately one-to-one ratio with the change in wages.

The elasticity of substitution between domestic and foreign goods, η, suggests that Slovak consumers are the most willing to substitute the domestic products for foreign goods. This results from the highest openness and smallest size of Slovak economy when compared to the others. On the other hand, this parameter is the smallest for Poland, which is the largest and least open of the examined economies. Albertini et al. (2012) estimate this parameter for New Zealand to be 0.51, which is between my estimates for Hungary and Czech Republic.

Parameters defining the elasticity of labour market reveal some frictions present in the examined economies. The bargaining power of firms, ξ is in each case lower than the prior, which is set to 0.5. These posterior values are lower than the estimates of other authors, like Jakab and Kónya (2016) or Christiano et al. (2011). However, my estimation ends in a time period that is much more beneficial to the households, than it was a few years before. The negotiating power of workers $(1-\xi)$ is the highest in Hungary. Lower values of ξ indicate higher rates of frictions in the economy, because firms with lower portion of the generated surplus are less motivated to bargain new wages. The firms in the Czech Republic have the highest negotiating power.

The differences among the countries in the elasticity of matching function with respect to the number of job seekers, ν are quite significant. This parameter is the highest in Hungary. The changes in unemployment affect the matching rate the most in this economy. The newly unemployed workers find a job relatively easier than in the other countries. Te matching process is the least effective (with respect to the unemployed) in Poland. Here only a fraction of unemployed gets matched with an empty job position. That could result in continuously increasing unemployment in a reaction to shocks. The low effectiveness of matching in Poland is however compensated in a way by the lowest calibrated value of the separation rate. When using the 90% HDPIs of ξ and ν, the Hosios condition is met in all countries, even in Poland. However, for this country this relation holds quite poorly.

The vacancy posting elasticity, e, is estimated to be significantly higher than one in each economy which indicates increasing vacancy posting costs. My estimates are noticeably lower than Lubik (2009) who estimated this parameter for the U.S. labour market to be 2.53. An even higher value (5.88) can be found in Albertini et al. (2012). The convex vacancy adjustment cost function prevents the firms from creating an excessive amount of new job positions. Higher values of this parameter could be a cause of another friction in the labour market. If the number of vacancies is low, the high vacancy posting elasticity discourages the firms to create jobs and therefore the matching rate declines. Creating an additional vacancy is the cheapest in the Czech Republic, while Hungarian producers have the highest costs.

The price and wage adjustment parameters indicate that the highest degree of stickiness is in Polish economy. Five of the six Rotemberg parameters are the highest for this country. In case of the Czech and Polish economies, the domestic goods' prices are more rigid than the foreign goods'. The prices behave the opposite way in Hungary, while in Slovakia the two frictions are identical partly because of the same currency. The wage is more flexible than the domestic price in each country. However, the firms pay the price of low bargaining power and high wage volatility with high adjustment cost parameters, $\psi_{H,F,W}$. In the Czech Republic and Hungary, it is much more expensive to adjust the wages of employees than to optimize the prices of goods. For Polish and Slovak economy the optimization of the domestic goods' price is the most costly. This cost is almost double in Poland compared to the other countries. Even though the foreign price adjustment cost is the lowest among the other costs in Poland, it is still the highest compared to the other countries. This results from the highest volatility of Polish exchange rate among the examined countries.

The monetary policy's decision making rule shows the least volatile nominal interest rates are in the Czech economy, where the smoothing parameter, ρ_r is the highest. On the other hand, the least stable interest rate can be observed in Hungary. Each country's central bank adjusts the nominal interest rate similarly to the inflation gap, ρ_π. The values slightly higher than the prior mean (1.5) are in line with the original value proposed by Taylor (also 1.5). The are some differences in the reaction of central banks to the output. While Slovak central bank (in the autonomous regime) reacted more to the changes in the output gap, ρ_{Deltay}, Polish central bank changes the nominal interest rates more considerably with the reaction of the output gap, ρ_y. Furthermore, while most of the monetary authorities react to the changes in the nominal exchange rate gap, the estimate for this parameter, $\rho_{Deltaner}$ is close to zero.

The parameter estimates of the foreign sector are estimated by each economy's model almost exactly the same. The parameter of habit formation, ϑ^* is estimated to be much higher in the euro area, than in the examined domestic economies. Also, the prices in the foreign sector are more flexible - both the indexation parameter, γ^* and the adjustment parameter, ψ^* are smaller.

Table 10.1: Parameter estimates - countries

Parameter	Czech Republic	Hungary	Poland	Slovakia
ϑ	0.734	0.658	0.625	0.682
	(0.653 - 0.819)	(0.565 - 0.755)	(0.524 - 0.728)	(0.585 - 0.782)
ϕ_h	0.896	0.977	0.691	0.881
	(0.614 - 1.184)	(0.671 - 1.292)	(0.459 - 0.921)	(0.585 - 1.163)
η	0.572	0.462	0.438	0.744
	(0.458 - 0.688)	(0.389 - 0.533)	(0.397 - 0.480)	(0.559 - 0.926)
Labour market - elasticities				
ξ	0.385	0.102	0.278	0.225
	(0.233 - 0.536)	(0.006 - 0.203)	(0.161 - 0.396)	(0.001 - 0.433)
ν	0.699	0.735	0.376	0.608
	(0.614 - 0.785)	(0.532 - 0.939)	(0.131 - 0.622)	(0.330 - 0.892)
e	1.486	1.944	1.694	1.718
	(1.278 - 1.694)	(1.542 - 2.341)	(1.567 - 1.822)	(1.276 - 2.162)
Price and wage setting				
γ_H	0.819	0.780	0.830	0.786
	(0.704 - 0.934)	(0.647 - 0.914)	(0.718 - 0.942)	(0.655 - 0.924)
γ_F	0.783	0.808	0.701	0.782
	(0.642 - 0.929)	(0.683 - 0.938)	(0.532 - 0.875)	(0.646 - 0.923)
γ_W	0.557	0.618	0.716	0.591
	(0.364 - 0.748)	(0.431 - 0.817)	(0.570 - 0.866)	(0.400 - 0.779)
ψ_H	58.405	54.440	107.658	62.405
	(39.177 - 76.682)	(34.690 - 72.984)	(79.355 - 135.945)	(38.531 - 87.266)
ψ_F	65.096	58.278	74.436	48.240
	(41.176 - 88.074)	(39.012 - 77.305)	(49.590 - 98.592)	(27.281 - 69.715)
ψ_W	86.945	83.187	88.816	56.805
	(58.275 - 116.291)	(57.287 - 110.320)	(60.105 - 117.170)	(34.230 - 80.220)
Monetary policy				
ρ_r	0.817	0.635	0.712	0.732
	(0.780 - 0.852)	(0.565 - 0.710)	(0.658 - 0.768)	(0.675 - 0.786)
ρ_π	1.552	1.576	1.687	1.536
	(1.384 - 1.714)	(1.400 - 1.743)	(1.518 - 1.863)	(1.376 - 1.699)
ρ_y	0.351	0.346	0.396	0.265
	(0.254 - 0.454)	(0.203 - 0.482)	(0.269 - 0.531)	(0.166 - 0.360)
$\rho_{\Delta y}$	0.291	0.253	0.174	0.336
	(0.146 - 0.438)	(0.097 - 0.409)	(0.008 - 0.332)	(0.190 - 0.474)
$\rho_{\Delta ner}$	0.211	0.369	-0.040	0.395
	(0.101 - 0.321)	(0.241 - 0.498)	(-0.107 - 0.025)	(0.256 - 0.537)
Foreign sector				
ϑ^*	0.870	0.879	0.875	0.902
	(0.822 - 0.918)	(0.833 - 0.928)	(0.828 - 0.924)	(0.862 - 0.941)
ρ_{r^*}	0.718	0.722	0.719	0.720
	(0.673 - 0.763)	(0.678 - 0.768)	(0.676 - 0.765)	(0.678 - 0.763)
ρ_{π^*}	1.478	1.480	1.483	1.481
	(1.314 - 1.641)	(1.321 - 1.630)	(1.312 - 1.642)	(1.320 - 1.643)
ρ_{y^*}	0.534	0.541	0.543	0.570
	(0.430 - 0.636)	(0.437 - 0.643)	(0.440 - 0.648)	(0.473 - 0.664)
$\rho_{\Delta y^*}$	0.306	0.295	0.293	0.277
	(0.151 - 0.463)	(0.137 - 0.451)	(0.137 - 0.451)	(0.135 - 0.430)
γ^*	0.520	0.521	0.514	0.513
	(0.372 - 0.666)	(0.378 - 0.663)	(0.368 - 0.653)	(0.367 - 0.660)
ψ^*	41.484	41.280	43.279	41.009
	(19.950 - 62.002)	(20.332 - 61.873)	(25.423 - 60.275)	(20.360 - 60.990)
κ^y	0.181	0.172	0.184	0.149
	(0.051 - 0.303)	(0.054 - 0.289)	(0.072 - 0.290)	(0.046 - 0.263)

Note: Posterior means and highest posterior density intervals (in parentheses).

10.2 Dynamical characteristics of economies

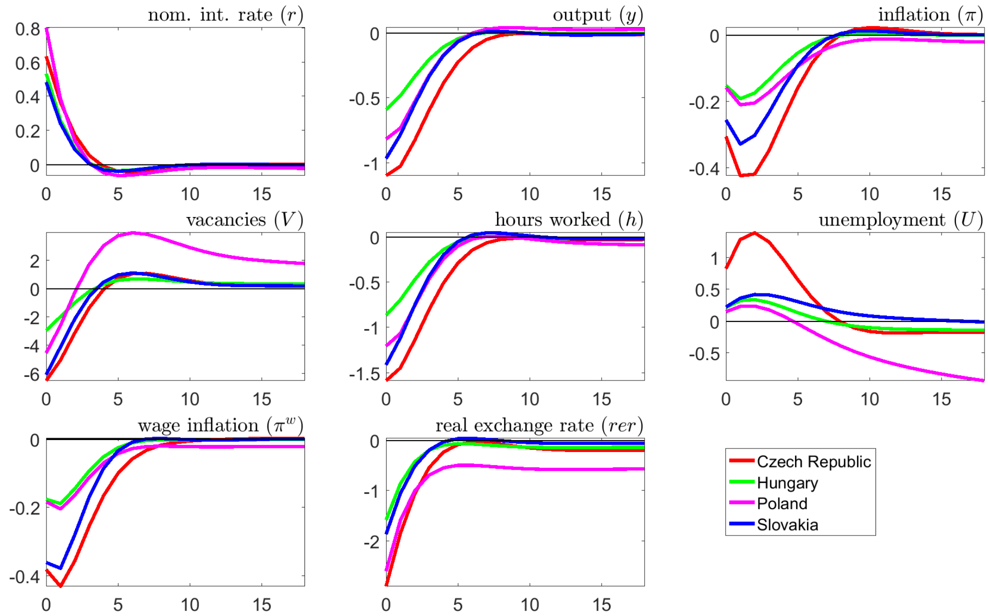
Figures 10.1 and 10.2 present the reactions of the 8 observed domestic variables to the monetary and technology shock respectively. Although the direction of reactions is quite similar, there are noticeable differences in the magnitude of influences. The results of Slovakia originate from the model of the whole period with the *switch*.

10.2.1 Monetary shock

The transmission mechanism of the monetary policy is described in the previous chapters and holds for each country. However, the degree to which it affects the economies is vastly different. The reaction of nominal interest rate to a standard deviation of monetary shock is the highest in Poland and lowest in Slovakia. The increased interest rate causes a drop in the product. This decline of output is twice as big as the increase of interest rates in Slovakia and the Czech Republic. There is a one-to-one ratio for this change in Hungary and Poland. This suggests that the central banks of the former two countries have a more influential monetary policy than the latter two economies. If they want to change the level of output, they need to adjust the interest rate to a smaller degree to achieve a change of the same magnitude. The reaction of inflation differs even more. While in the Czech Republic and Slovakia, the CPI inflation decreases half as much as the interest rate increases, the decline in Hungary is one third and in Poland one fifth. These changes also increase the real interest rate which in turn causes the appreciation of real exchange rate. The appreciation is the most significant in the Czech Republic and Poland.

The drop in output reduces the marginal value of a worker for the firm. The producers react to this by reducing the amount of posted vacancies. The initial decrease of vacancies is six times higher than the change of output in each economy. Due to the decline of product and prices the firms have lower profits. To decrease their expenses, the firms lower the employment. The decline of hours is similar throughout the economies and is 1.5 times higher than the drop of output. The increase of unemployment is the most significant in the Czech Republic while in the other economies it is almost the same. Slovak central bank could achieve the same change of unemployment with a smaller adjustment of nominal interest rate. The decreasing labour market tightness allows the firms to re-optimize their prices significantly lower levels in the Czech and Slovak economies than in Hungary and Poland.

Figure 10.1: Impulse responses to monetary shock (% deviations from s.s.)



Note: The horizontal axis represents time periods. It holds that one time period is one quarter.

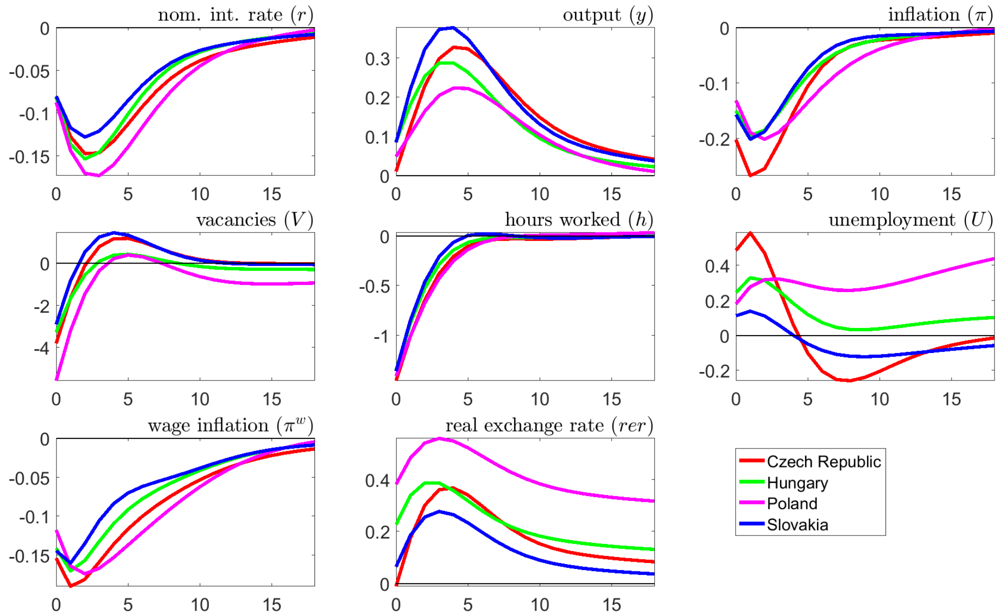
Majority of the variables return to their originating steady-states fairly quickly. The monetary shock has the most permanent impact on Polish economy, where the vacancy rate increases and the unemployment rate declines. The impulse responses to the monetary shock indicate that Slovak and Czech labour markets are more flexible than the other two.

10.2.2 Technology shock

The impulse responses to a productivity shock are portrayed in figure 10.2. The initial impact to output is relatively small in each economy. Due to the frictions it takes time for the technology shock to fully present itself. Over time, Slovak and Czech products increase the most. The monetary authority reacts to the increase of output by reducing the nominal interest rates. This reaction is the same in each country because of the similar parameter values of interest rate's reaction to output in the Taylor rule. The reaction of inflation is higher in the Czech Republic compared to the other countries, while the depreciation is the most substantial and permanent in case of Poland.

Looking at the labour market variables, the households supply less hours at lower wage inflation. The decrease of vacancies due to the increase of technologies is much higher in

Figure 10.2: Impulse responses to technology shock (% deviations from s.s.)



Note: The horizontal axis represents time periods. It holds that one time period is one quarter.

Poland. This is also the only country, where this decrease is permanent. Part of the work force that is replaced by more advanced technologies becomes unemployed. The decrease in employment is the most substantial in the Czech Republic. However, while in the more flexible labour markets of Czech and Slovak economies the unemployment returns to the steady-state, in the more sticky economies it remains permanently above the long term level.

10.3 Economic development and historical properties

By comparing the shock decompositions I find out which shocks are more important in each country. The foreign shocks play a much higher role in the explanation of output's dynamics in Slovakia than in Poland. This is given by the difference in the size and the openness of the two countries.

While in the case of the Czech unemployment the main influencing force is the bargaining shock due to the higher bargaining power of firms, the dominant driving force behind the volatility of this variable in Hungary and Poland comes from the matching shock. In Slovak economy, these two shocks participate evenly.

In the absence of the vacancy creation shock, the vacancies do not have a defining factor in Hungary. However, in the Czech Republic and Slovakia they are mainly governed by the bargaining shock while Polish vacancies are influenced by matching shock the most. The latter is given by the higher elasticity of the matching function with respect to the vacant job positions.

The wages are influenced by bargaining shock only in the Czech Republic while in other countries cost-push and UIP shocks appear instead. However, the dis-utility from labour plays a significant role in each economy. This is given by higher values of the Frisch elasticity parameter of labour supply.

10.4 Chapter's summary

This, final chapter collects the results described in the previous four chapters to allow comparison among economies. First, the structural properties of the examined economies are presented. I find the Hungarian and Polish economies to experience higher degrees of stickiness. On the other hand, the Czech and Slovak economies contain the least amount of rigidities. These different degrees of frictions define the different reactions of variables to examined socks in the next part. Finally, the historical shock decomposition is compared.

Chapter 11

Conclusion

My thesis concerns the examination of the structural and dynamical characteristics of four economies. The focus lies mainly in the examination of labour market frictions. To achieve my aims, I first outlined the existing literature to set a baseline for my approach. Next, I described the estimated model along with the executed modifications to introduce the mechanisms and information flows which are present in the economy. The following part contained the data and data transformation process together with the parameter calibration to present the model with the needed information. The next chapter presented the applied estimation techniques. The rest of the thesis contains the results of my examination.

Since the previous chapter already concluded in a way that it compared the results of different countries, in this final section I address the examined topic by answering the research questions set in section 1.2. The main aim of this thesis is to examine the labour market frictions in the countries of the Visegrad Group.

To find *the structural characteristics of the labour markets of the examined economies* and to examine whether the *structure of these markets is stable or time-varying, or whether it depends on the specification of the model* I investigated the parameter estimates of different model specifications on different time periods for different economies. I found that the structural characteristics of the labour markets do not depend on the model specification. Four different estimation were conducted for each country and each yielded similar results. Furthermore, by dividing the observed period into two equal parts (with the separation made at the arrival of the Great Recession in 2009) I compared the current economic situation with the one before the crisis. The estimations of the two shorter periods also evinced similar results which could be explained by the expiration of the recession's effects. The estimation results are quite robust to changes in model specifications and to changes in observed time period's length. However, the model is able to capture the structural and dynamical differences among the examined economies.

The results of estimations helped me to find, *which rigidities are present in the economy and to what degree.* The results indicate that each country faces substantial price frictions. They are the highest in the largest of the examined economies. Poland also has the most rigid wages, while the wages in other countries are quite flexible. The Bargaining power of firms is low in each country. High negotiating power of workers indicate higher frictions because the firms get less from the generated surplus. With the lowest bargaining power of firms in Hungary, the matching rate reacts the most to the changes in unemployment in this country. Furthermore, each country faces increasing vacancy posting costs which prevents firms from posting excessive amounts of new job positions. This is another form of a real rigidity that is present in each economy and is the most substantial in Hungary. The stylized facts also indicate that the lowest frictions are present in the Czech Republic and the highest are in Hungary.

By examining the historical shock decompositions and the impulse response functions, *the connection between the dynamics of the labour market and the rest of the economy* can be discovered. While the effects of labour market shocks on the domestic output is limited and the unemployment is mainly defined by bargaining or matching shocks in each country, other labour market variables also depend on other than labour market shocks. The historical shock decompositions show that cost-push shocks, preference shocks and technology shocks also take part in the dynamics of vacancies, real wages and hours.

The impulse response functions show *how the monetary authority influences the unemployment and other real variables by setting the nominal interest rates.* The results show that the monetary authority is able to affect the real economy in each country. This influence is higher in the Czech Republic and Slovakia than it is in the other two economies. This is given by the higher flexibility of labour markets in these countries. On the other hand, in countries with higher stickiness, the effects are much smaller. However, even though the effects on the unemployment and vacancies are significantly different from zero, one or six percent changes from the steady-state are relatively small if the model definition of these variables is taken into consideration. The other variables are affected more distinctively.

The historical shock decompositions also reveal that the Great Recession in 2009 substantially affected the labour markets. The unemployment rate increased while the vacancies, wages and hours plummeted. The parameter estimates reveal, whether *the impact of the financial crisis is still observable and to what degree it changed the frictions.* Even though the impacts of the crisis were substantial, the influence of it has already passed and the labour market variables retreated to their pre-crisis values. Furthermore, the current situation in countries like the Czech Republic and Slovakia is inclined towards the households. The firms post more and more vacancies, while the unemployment rate decreases or remains at low levels.

11.1 Contribution of thesis

My thesis provides a comprehensive look on the labour market frictions of the V4 economies. I have selected different model specifications and time periods to investigate whether these differences affect the results of estimation.

I found out through the investigation of labour market frictions, that their role in the real economy is not negligible and they need to be incorporated into a model that aims to examine the dynamics of macroeconomic variables. Other contribution of my thesis is the expansion of an existing DSGE model with a more complex foreign sector. I compared the estimation result of this model with other specifications and found this model to match the volatility of observed variables the best. I also compared two different filtration methods – one-sided and two-sided HP filter – to investigate which one of them gives more appropriate results. I found no decisive evidence to disregard the results of the two sided filter. The differences among the model specifications have not proven to be significant. This signalizes the robustness of the estimation results.

Furthermore, to account for the admission of Slovakia to the euro area, I implemented a switching mechanism which changes the monetary regime form autonomous to joint monetary policy.

In the provided comparison of two sub-samples divided by the global economic recession in 2009 I found that the crisis had no substantial long lasting effects and the majority of the structural parameters retreated to their pre-crisis values. In spite of the geographical closeness and historical similarities of the V4 economies, I found that there are differences among these countries. Overall I found that the Czech and Slovak labour markets are more flexible than the labour markets in Poland and Hungary.

11.2 Areas of future research

One of the main limitation of my thesis was caused by an unavailability of some observed variables – Polish and Hungarian hours and Hungarian vacancies. A possible improvement of my model would be either to remove these variables from the set of observables or to implement observation errors to these variables to account for their uncertainty. Furthermore, the model has a scanty ability to match the dynamics of some observed variables.

Another area that would be interesting to research is the short term impact of the crisis since the effects of the recession are almost unnoticeable after such long time. The estimation of shorter time periods, such as until 2010 or recursive estimations could reveal some structural changes in the examined countries.

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List of abbreviations

BUBOR Budapest Interbank Offered Rate
CNB Czech National Bank
CPI Consumer Price Index
CZSO Czech Statistical Office
DSGE Dynamic Stochastic General Equilibrium
EMU Economic and Monetary Union
GDP Gross Domestic Product
GMM Generalized Method of Moments
HP filter Hodrick-Prescott filter
IRF Impulse Response Function
KSH Central Statistical Office of Hungary (Központi Statisztikai Hivatal)
MC Marginal Cost
MH Metropolis-Hastings
MNB National Bank of Hungary (Magyar Nemzeti Bank)
NBER National Bureau of Economic Research
NBP National Bank of Poland
NBS National Bank of Slovakia
NKPC New-Keynesian Phillips Curve
OECD Organisation for Economic Co-operation and Development
OLS Ordinary Least Squares
SOE Small Open Economy
SVAR Structural Vector Autoregression
UIP Uncovered Interest Rate Parity
V4 Visegrad Four/Visegrad Group

Appendix A

Model variables, parameters and shocks

Table A.1: List of shocks

$\widehat{\varepsilon}_t^a$	domestic technology process
ξ_t	shock to bargaining process
$\widehat{\varepsilon}_t^\chi$	matching function process
κ_t^h	dis-utility from working process
$\widehat{\varepsilon}_t^{Y^*}$	foreign output process
$\widehat{\varepsilon}_t^{\pi^*}$	foreign inflation process
$\widehat{\varepsilon}_t^{r^*}$	foreign interest rate process
$\widehat{\varepsilon}^{rer_t}$	UIP process
$\widehat{\varepsilon}_t^c$	preference process
$\widehat{\varepsilon}_t^H$	cost-push process
$\widehat{\varepsilon}_t^m$	monetary process

Table A.2: List of innovations

Innovation	Description
ϵ^a	productivity shock
ϵ^m	monetary shock
ϵ^{rer}	UIP shock
ϵ^c	preference shock
ϵ^H	cost-push shock
ϵ^ξ	bargaining shock
ϵ^χ	matching shock
ϵ^h	dis-utility of work shock
ϵ^{y^*}	foreign output shock
ϵ^{r^*}	foreign interest rate shock
ϵ^{π^*}	foreign inflation shock

Table A.3: List of variables

Variable	Log-linear	Description
Labour market		
V_t	$\widehat{v}_t$	*vacancy rate
U_t	$\widehat{u}_t$	*unemployment rate
S_t	$\widehat{s}_t$	job seekers
K_t	$\widehat{k}_t$	vacancy filling rate
F_t	$\widehat{f}_t$	job finding rate
M_t	$\widehat{m}_t$	matches
H_t	$\widehat{h}_t$	*hours worked
N_t	$\widehat{n}_t$	employment
W_t	$\widehat{w}_t$	*real wage
Θ_t	$\widehat{\theta}_t$	labour market tightness
Goods market - firms and households		
Y_t	$\widehat{y}_t$	*domestic output per capita
MC_t	$\widehat{mc}_t$	marginal cost
B_t	$\widehat{b}_t$	bonds, assets
C_t	$\widehat{c}_t$	consumption
$C_{F,t}$	$\widehat{c}_{F,t}$	foreign goods consumption
$C_{H,t}$	$\widehat{c}_{H,t}$	domestic goods consumption
$C^*_{F,t}$	$\widehat{c}^*_{F,t}$	foreign consumption of domestic goods
μ_t	$\widehat{\mu}_t$	marg. value of employing a worker for the firm
φ_t	$\widehat{\varphi}_t$	marg. value of an employed worker to the household
Λ_t	$\widehat{\lambda}_t$	Lagrange mult. on the budget const. for the household
$\mu_t^{'w}$	$\widehat{\mu}_t^{'w}$	derivative of mu wrt. w
$\mu_t^{'h}$	$\widehat{\mu}_t^{'h}$	derivative of mu wrt. hm
$\varphi_t^{'h}$	$\widehat{\varphi}_t^{'h}$	derivative of varphi wrt. hm
Open economy, price relations and foreign sector		
RER_t	$\widehat{rer}_t$	*real exchange rate
ΔNER_t	$\Delta\widehat{ner}_t$	Nom. exch. rate growth
TOT_t	$\widehat{tot}_t$	terms of trade
LOP_t	$\widehat{lop}_t$	law of one price gap
$\Pi_{F,t}$	$\widehat{\pi}_{F,t}$	import inflation
$\Pi_{H,t}$	$\widehat{\pi}_{H,t}$	domestic inflation
Π_t	$\widehat{\pi}_t$	*CPI inflation
A^x_t	$\widehat{a}^x_t$	price index ratio
$\Pi_{W,t}$	$\widehat{\pi}_{W,t}$	wage inflation
R_t	$\widehat{r}_t$	*nominal interest rate
Y^*_t	$\widehat{y}^*_t$	*foreign output
Π^*_t	$\widehat{\pi}^*_t$	*foreign inflation
R^*_t	$\widehat{r}^*_t$	*foreign nominal interest rate

Note: the observed variables are marked with * in the description.

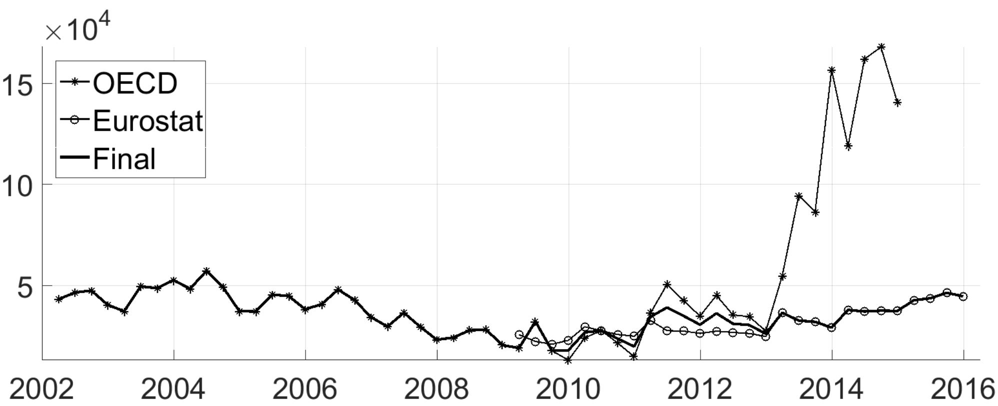
Table A.4: List of parametres

Name	Description
Structural parameters	
ϑ	deep-habit parameter
β	discount factor
α	import share on GDP
ϵ	elasticity of substitution
η	el. of substitution between domestic and foreign
ζ	share of labour in production
ϕ_h	inverse of Frisch elasticity
e	elasticity of vacancy creation
b^u	unemployment benefits
τ^b	elasticity of debt elastic risk premium
ν	elasticity of matching function
ρ^x	job separation rate
γ_H	weight of backward looking price (dom. goods)
γ_F	weight of backward looking price (for. goods)
γ_W	weight of backward looking wage
ψ_H	price adjustment cost (dom. goods)
ψ_F	price adjustment cost (for. goods)
ψ_W	wage adjustment cost
κ^v	scaling factor of vacancy creation cost
κ^h	work dis-utility parameter
ξ	elasticity of Nash bargaining
AR(1) persistence	
ρ_{rer}	UIP shock
ρ_H	cost-push shock
ρ_a	productivity shock
ρ_m	monetary shock
ρ_c	preference shock
ρ_ξ	bargaining shock
ρ_χ	matching shock
ρ_v	vacancy shock
ρ_h	dis-utility of work shock
ρ_{y^*}	development of exogenous foreign output
ρ_{r^*}	development of exogenous foreign interest rate
ρ_{π^*}	development of exogenous foreign inflation
$\rho_{\varepsilon^{Y^*}}$	foreign output shock
$\rho_{\varepsilon^{i^*}}$	foreign interest rate shock
$\rho_{\varepsilon^{\pi^*}}$	foreign inflation shock
Taylor-rule parameters	
ρ_i	interest rate smoothing parameter
ρ_π	weight of inflation in the monetary policy rule
ρ_Y	weight of output gap in the monetary policy rule
$\rho_{\Delta Y}$	weight of difference in output gap in the monetary policy rule
$\rho_{\Delta ner}$	weight of difference in nom. exchange rate gap in the monetary policy rule

Appendix B

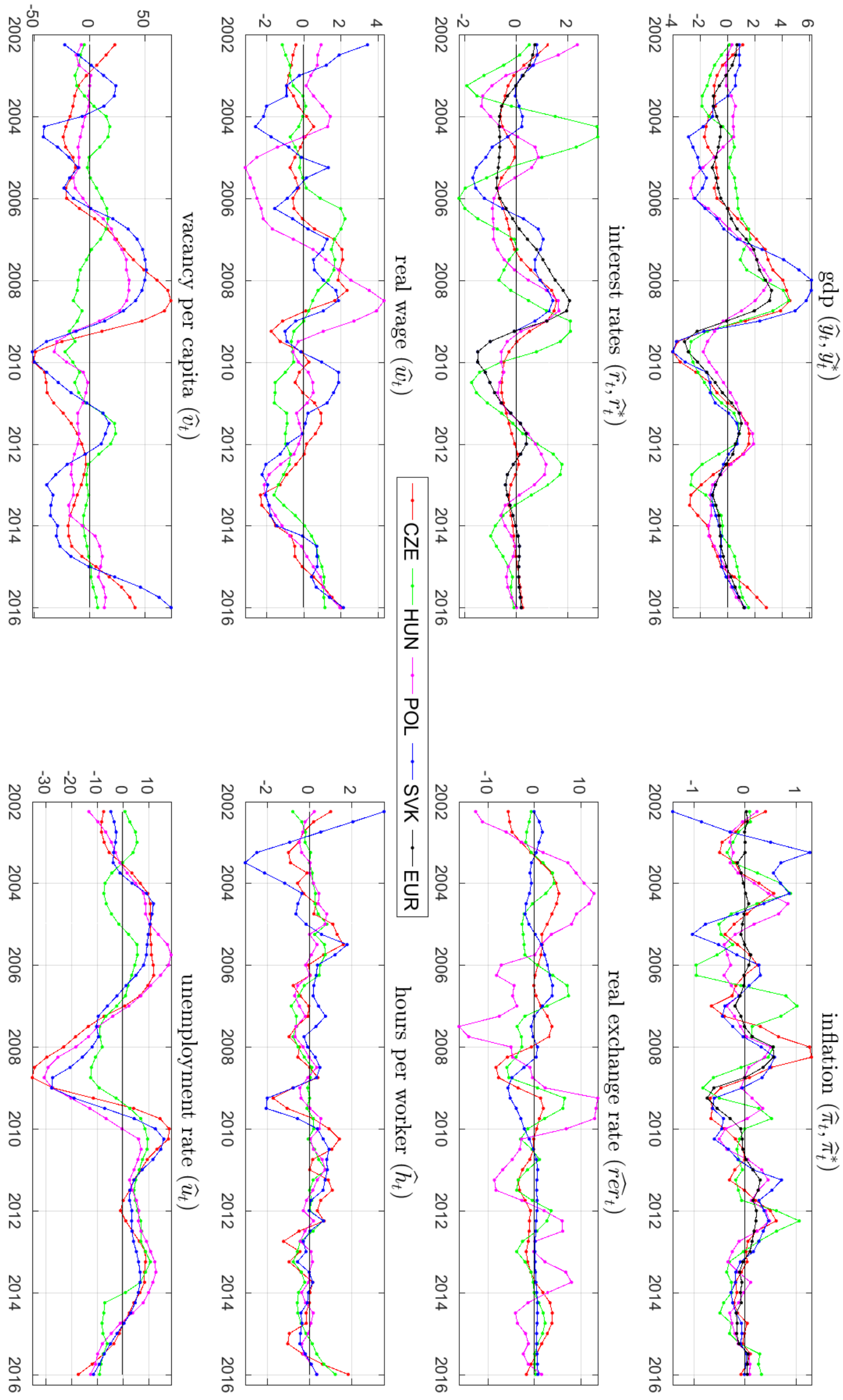
Data figures

Figure B.1: Vacancies of Hungary - combination of two sources of data



Source: data from OECD and Eurostat; author's processing.

Figure B.2: HP filtered input data - percentage deviations from steady state (%)



Source: data from OECD database; author's processing.

Appendix C

Figures of estimation results

Figure C.1: Shock decomposition of Czech consumption (deviations from s.s. in %)

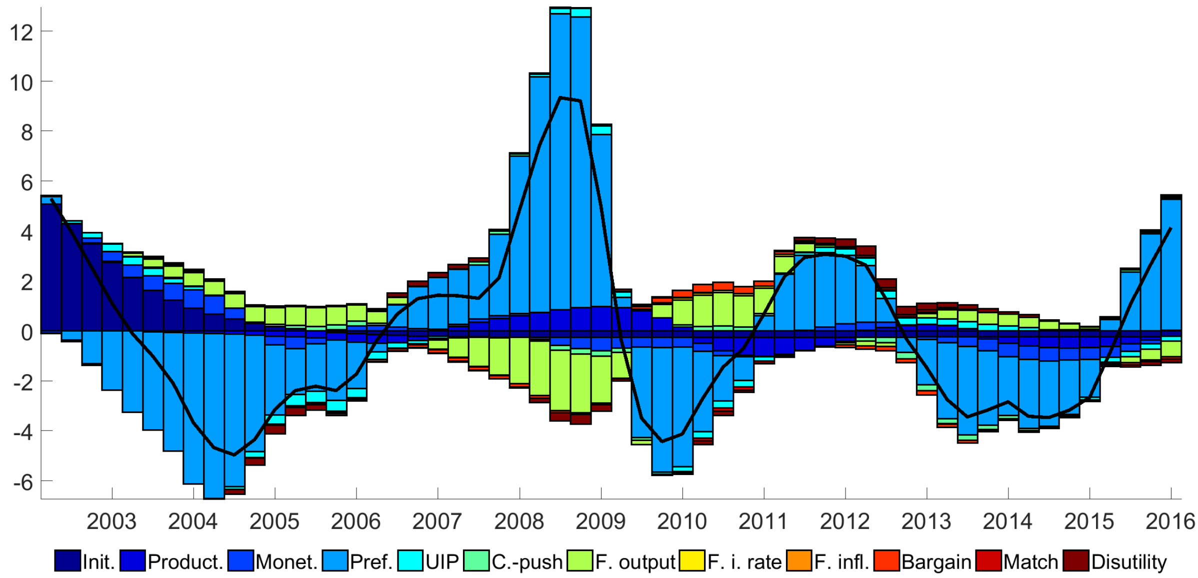


Figure C.2: Shock decomposition of Czech labour market tightness (dev. from s.s. in %)

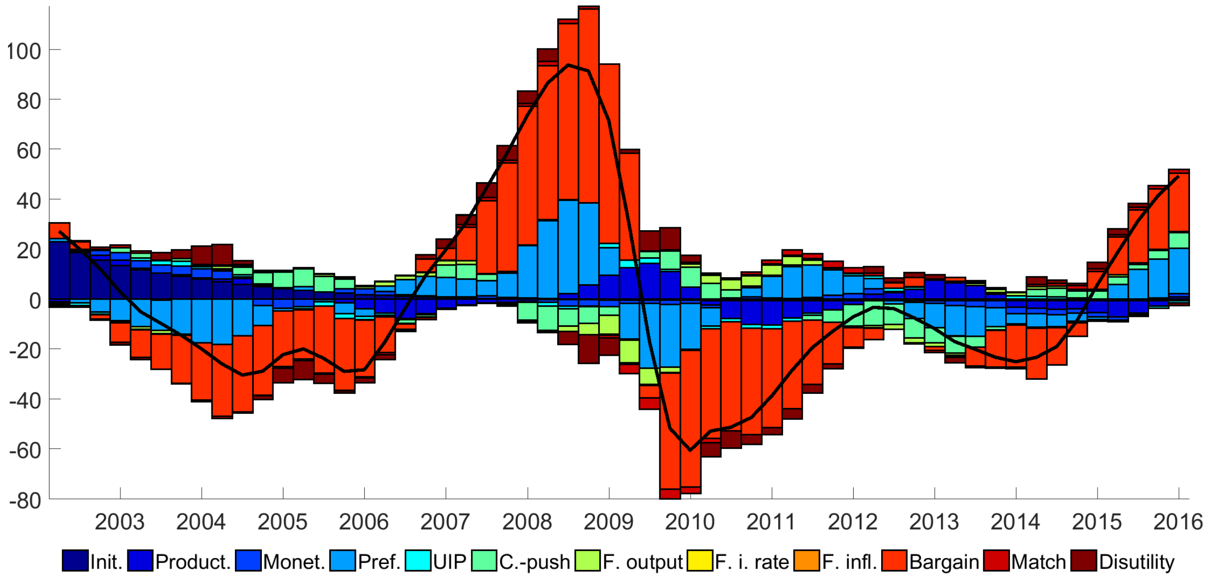


Figure C.3: Shock decomposition of Czech real wages (deviations from s.s. in %)

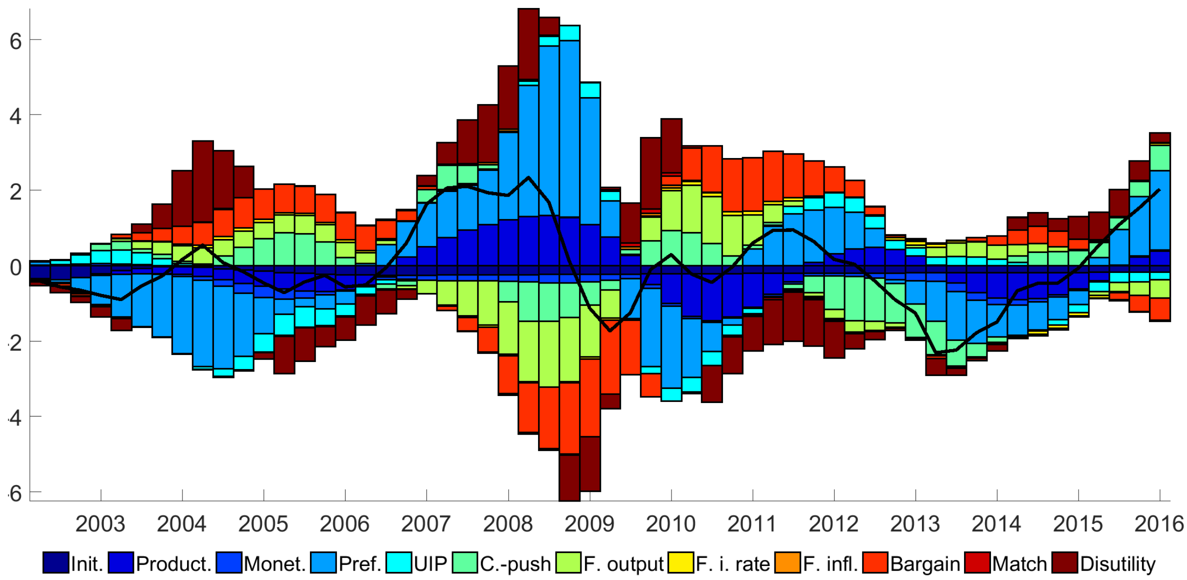


Figure C.4: Shock decomposition of Czech hours worked (deviations from s.s. in %)

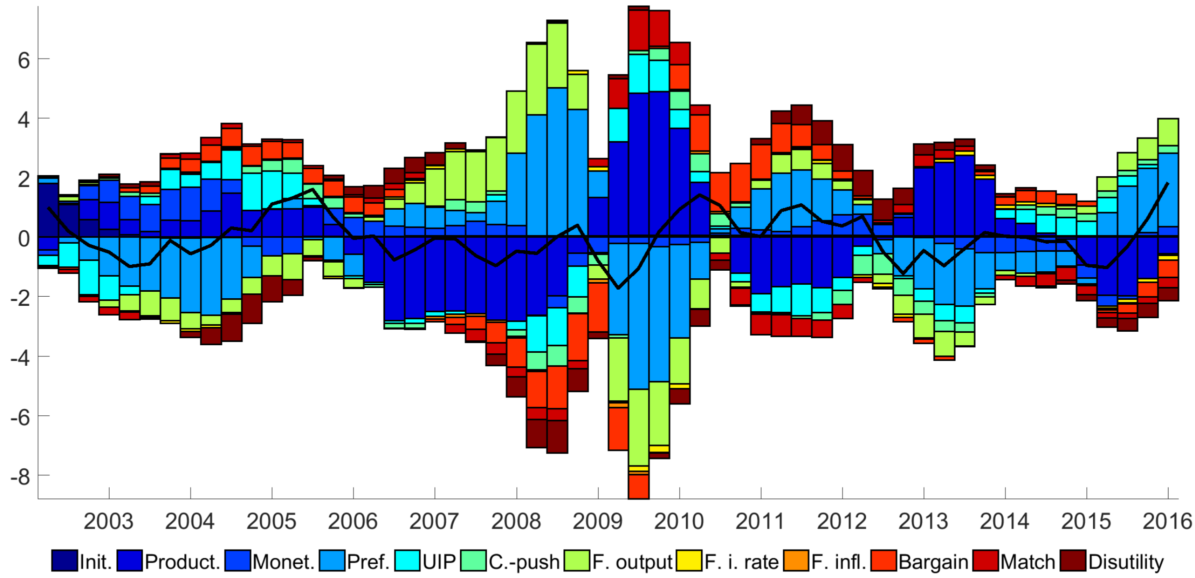


Figure C.5: Shock decomposition of Hungarian consumption (deviations from s.s. in %)

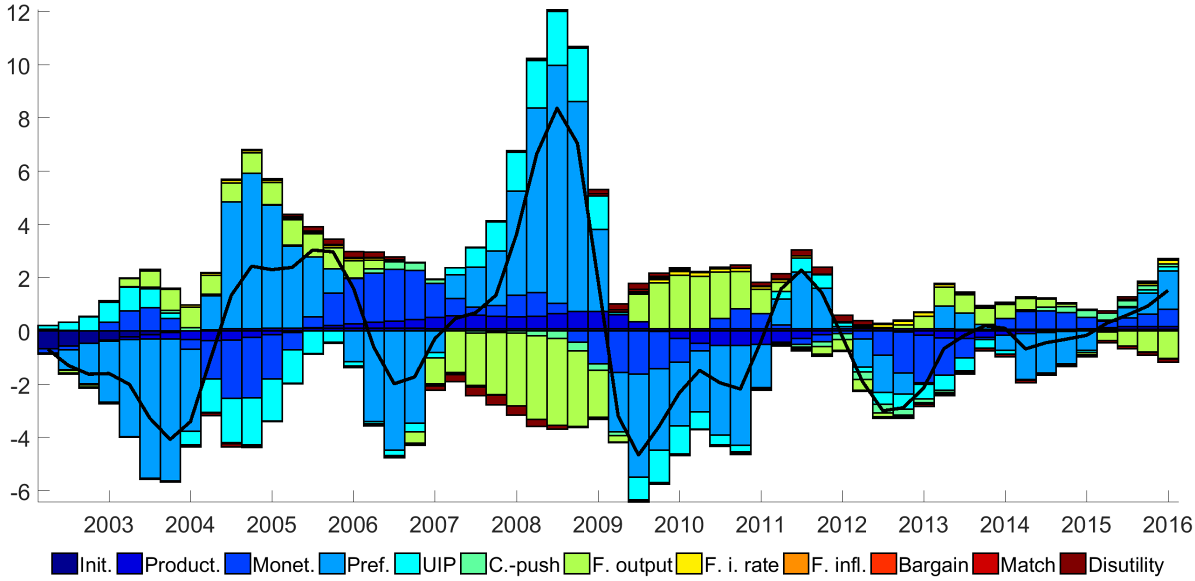


Figure C.6: Shock decomposition of Hungarian labour market tightness (deviations from s.s. in %)

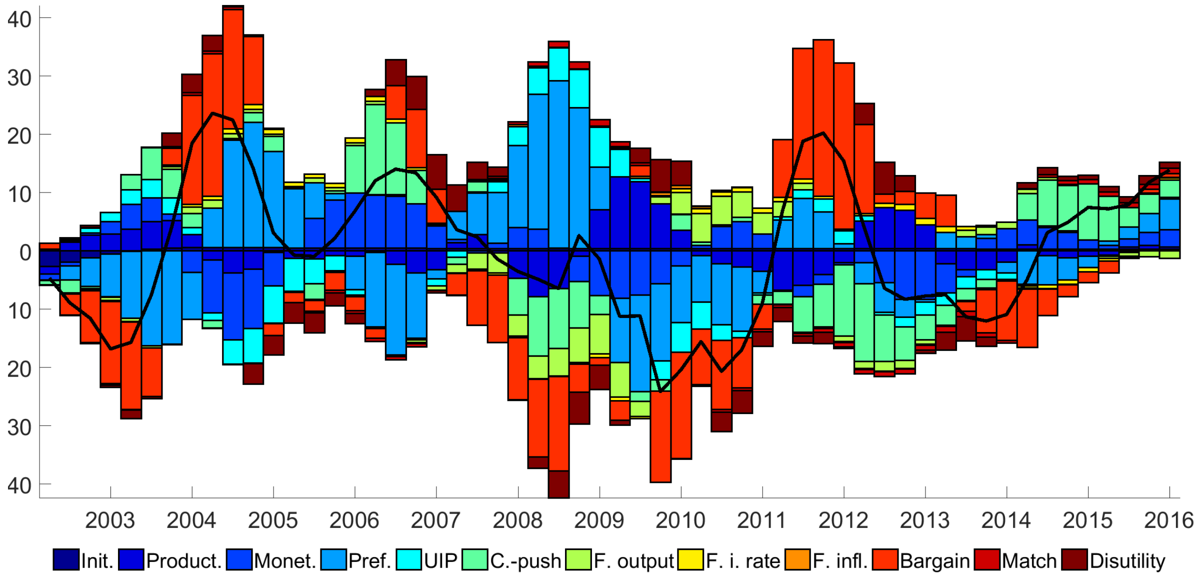


Figure C.7: Shock decomposition of Hungarian real wages (deviations from s.s. in %)

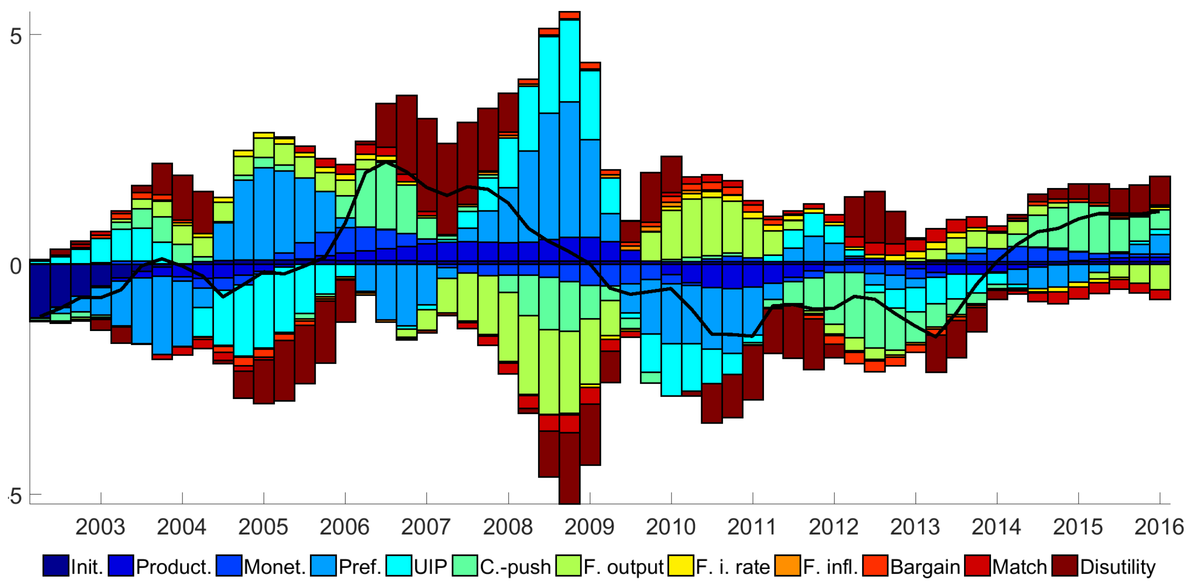


Figure C.8: Shock decomposition of Hungarian hours worked (deviations from s.s. in %)

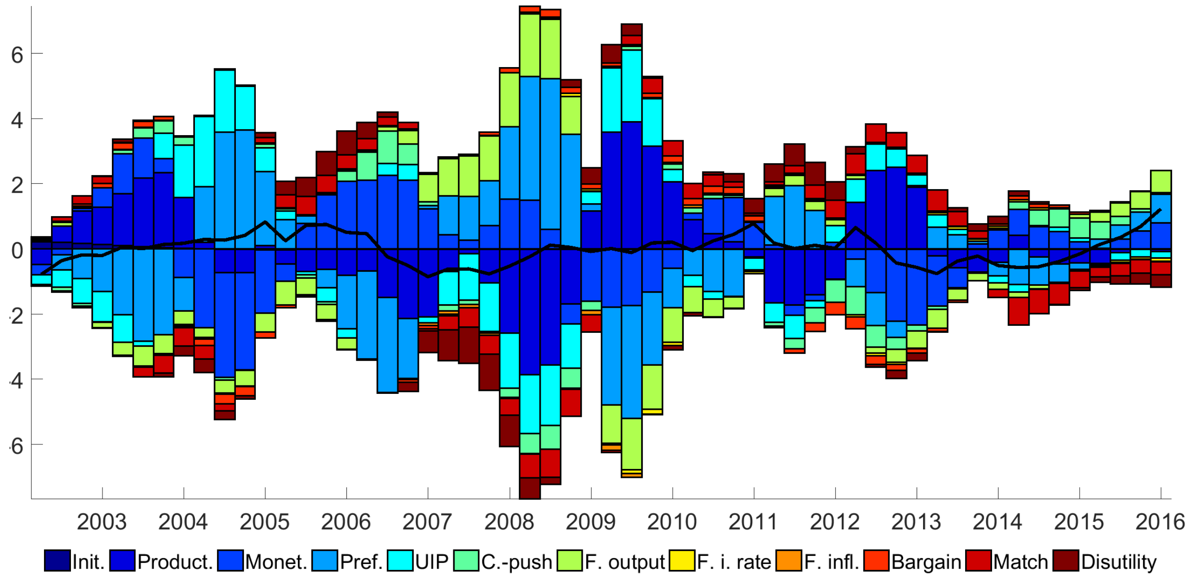


Figure C.9: Shock decomposition of Polish consumption (deviations from s.s. in %)

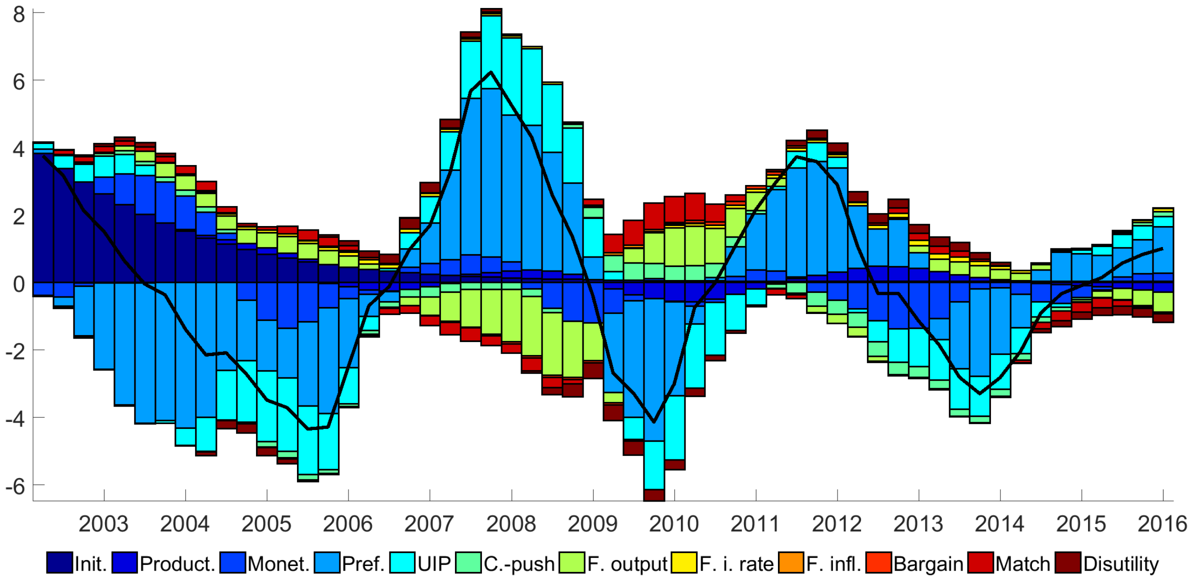


Figure C.10: Shock decomposition of Polish labour market tightness (deviations from s.s. in %)

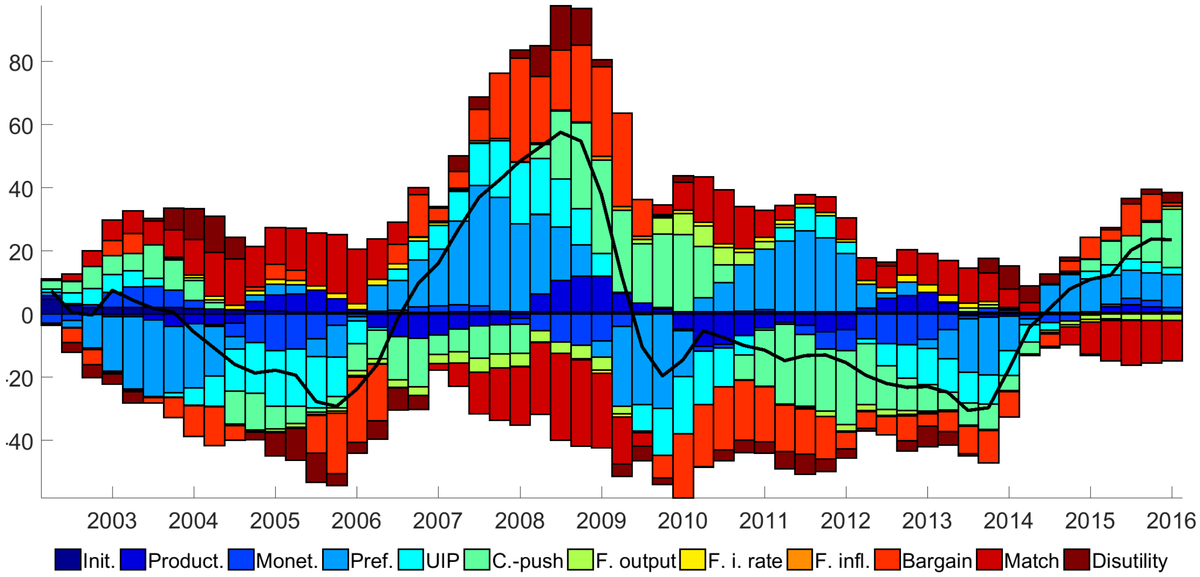


Figure C.11: Shock decomposition of Polish real wages (deviations from s.s. in %)

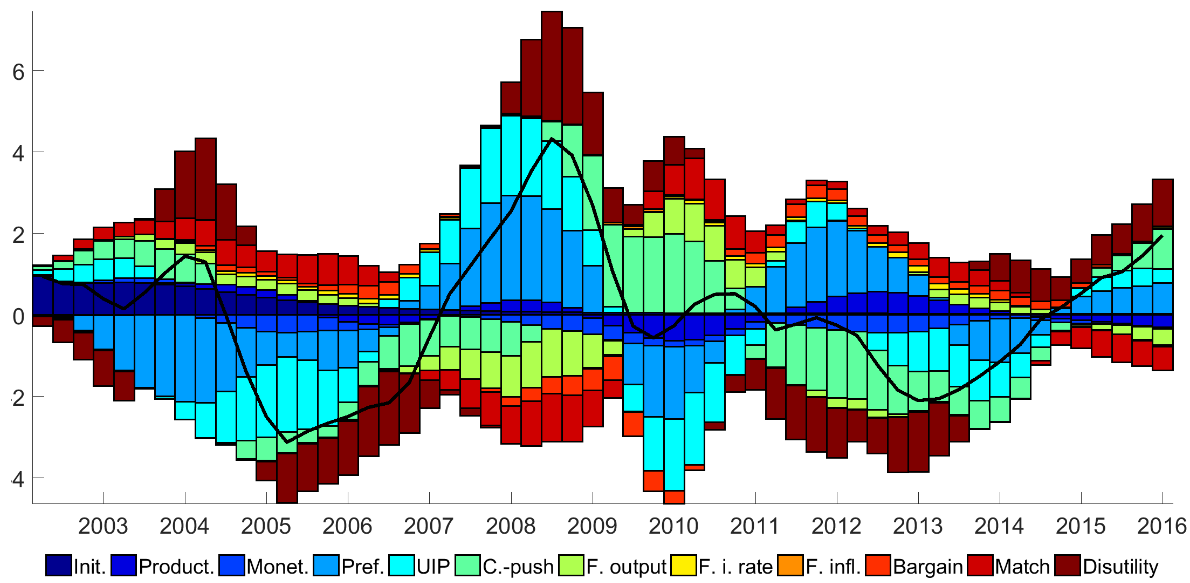


Figure C.12: Shock decomposition of Polish hours worked (deviations from s.s. in %)

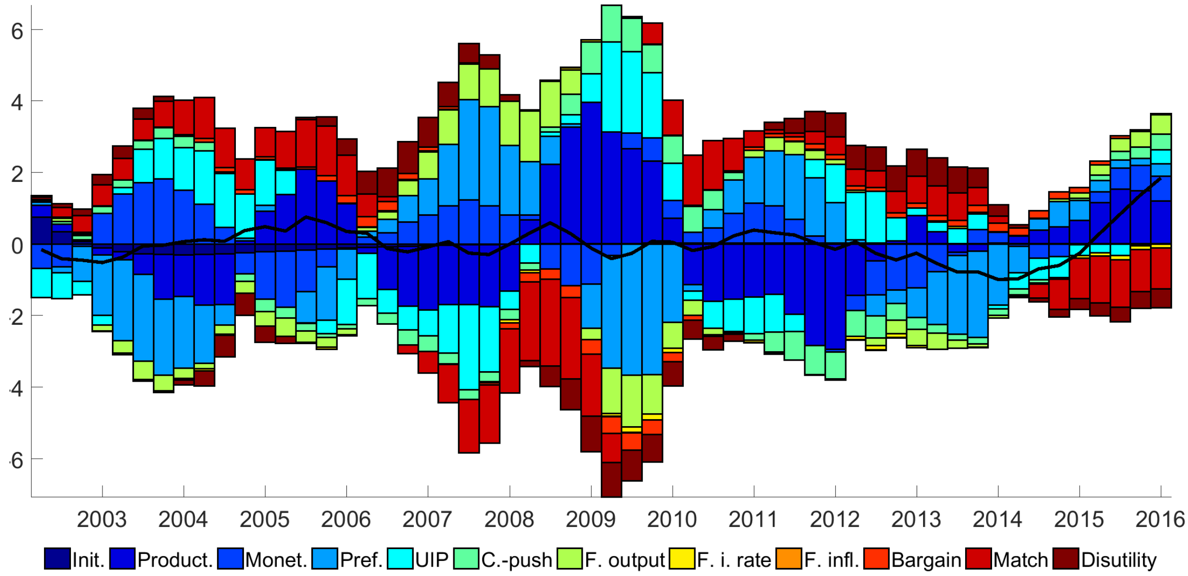


Figure C.13: Shock decomposition of Slovak consumption (deviations from s.s. in %)

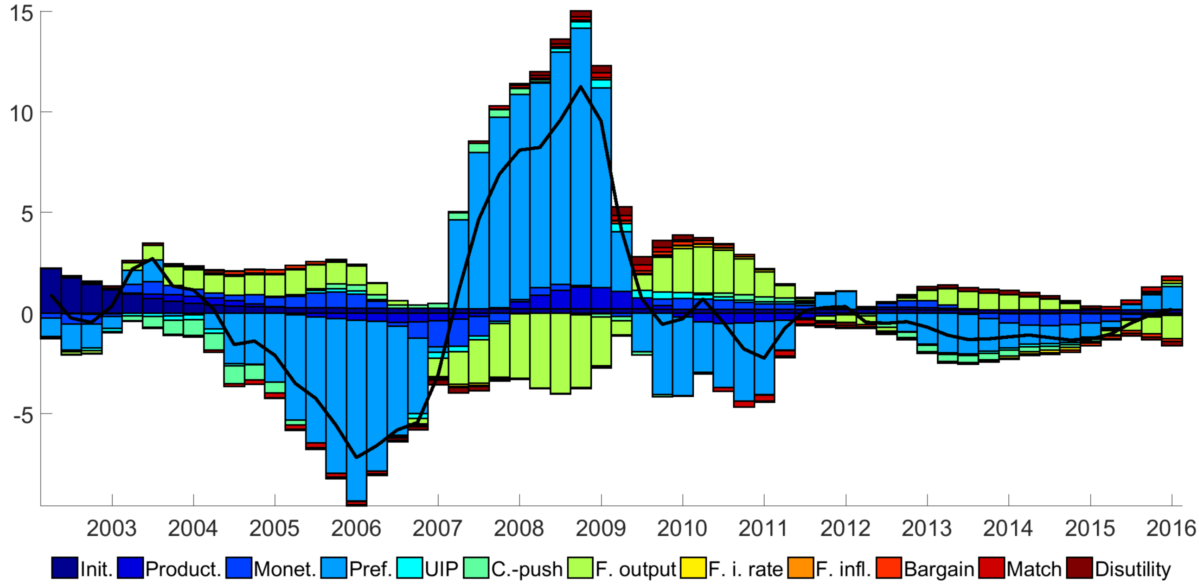


Figure C.14: Shock decomposition of Slovak labour market tightness (dev. from s.s. in %)

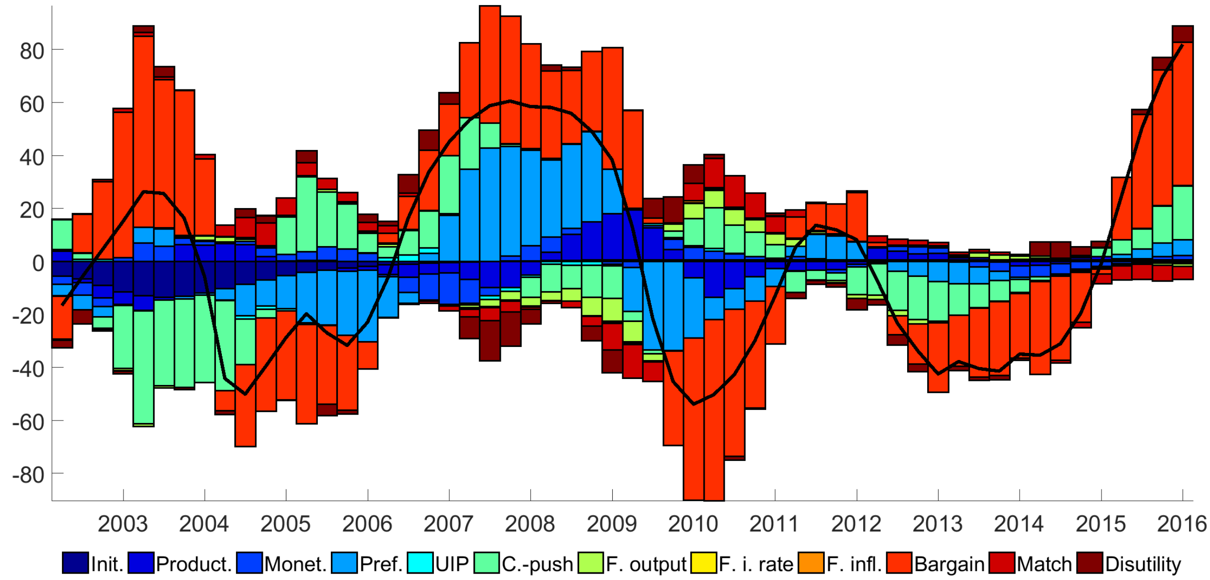


Figure C.15: Shock decomposition of Slovak real wages (deviations from s.s. in %)

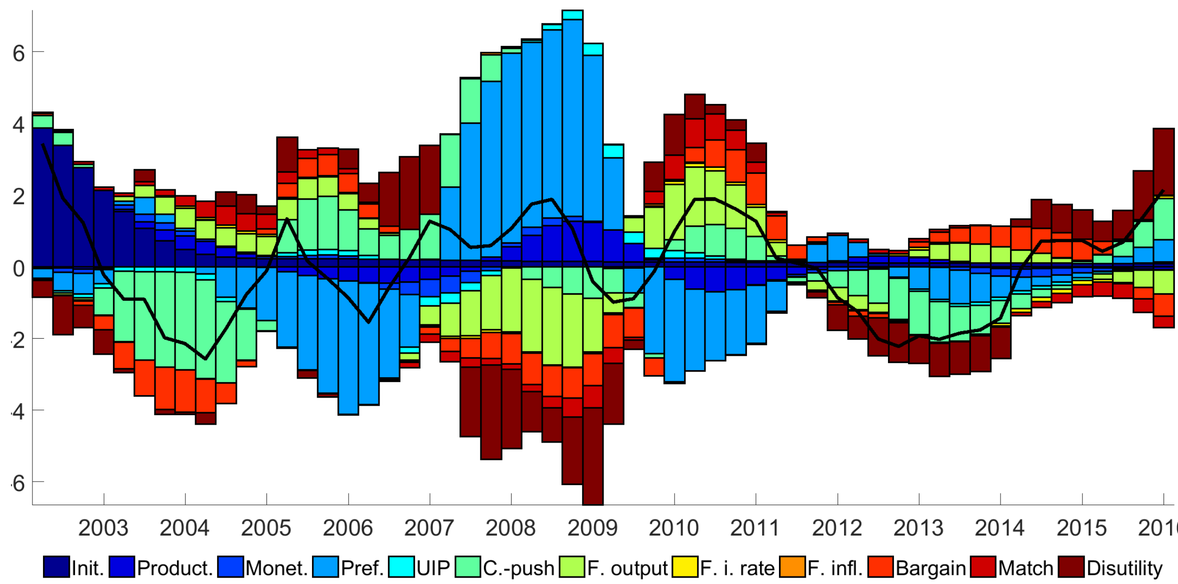


Figure C.16: Shock decomposition of Slovak hours worked (deviations from s.s. in %)