COMENIUS UNIVERSITY IN BRATISLAVA

FACULTY OF MATHEMATICS, PHYSICS AND INFORMATICS

Mathematical Analysis of the Transmission Mechanism of Monetary Policy of the National Bank of Slovakia

DISSERTATION THESIS

2013 **RNDr. Ján Klacso**

COMENIUS UNIVERSITY IN BRATISLAVA

FACULTY OF MATHEMATICS, PHYSICS AND INFORMATICS

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Abstract

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In this thesis, we focus on the monetary policy and the transmission mechanism of the monetary policy of the National Bank of Slovakia from the period of the adoption of qualitative monetary policy in 2000 to the end of 2008 when Slovakia joined the euro area. First we estimate a small macroeconomic VEC model using a Bayesian Mixed Frequency estimator. We interpret the estimated cointegrating vector as the monetary policy reaction function. Based on estimation results it is the core inflation, the level of the EUR/SKK exchange rate, the real growth of the GDP and the balance of trade that entered the reaction function of the NBS. Next we build up a New Keynesian Macroeconomic Model for the Slovak economy. We show a possible way how investments into residential properties can be separated from consumption in the IS curve. The model consisting of the IS curve, the Phillips curve, the reaction function of the NBS and a simple equation describing the development of the property prices is estimated using the method of FIML. Estimation results show that the output gap was mainly affected by the development of the property prices and the expected development of the output gap; the inflation was affected to a great extent by the inflation of euro area and by regulated prices. Property prices followed the expected development of the property prices and the policy rate. In case of the reaction function, the positive development of the domestic inflation allowed the NBS to gradually harmonize its policy rate to those of the ECB in the process of preparation for the euro adoption. Based on the two models we conclude that an independent monetary policy should not dampen the negative impact of the global economic downturn on the Slovak economy in 2009.

Keywords: monetary policy, Bayesian Mixed Frequency VEC, New Keynesian Macroeconomic Models, FIML

Abstrakt

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Práca sa zaoberá štúdiom menovej politiky a transmisného mechanizmu menovej politiky Národnej banky Slovenska v období od zavedenia kvalitatívnej menovej politiky v roku 2000 do konca roka 2008, kedy Slovensko vstúpilo do eurozóny. Odhadujeme malý makroekonomický VEC model pomocou Bayesovskej metódy, ktorá nám umožňuje použiť endogénne premenné pozorované so zmiešanou frekvenciou. Odhadnutý kointegračný vektor interpretujeme ako reakčnú funkciu menovej politiky. Na základe odhadov vstupovala do reakčnej funkcie NBS jadrová inflácia, úroveň výmenného kurzu slovenskej koruny voči euru, reálny rast hrubého domáceho produktu a obchodná bilancia. Následne navrhneme Neokeynesiánsky Makroekonomický Model pre slovenskú ekonomiku. Načrtneme možný spôsob ako oddeliť investície do rezidenčných nehnuteľností od spotreby v IS krivke. Model pozostávajúci z IS krivky, Phillipsovej krivky, reakčnej funkcie NBS a jednoduchej rovnice popisujúcej vývoj cien nehnuteľností odhadujeme pomocou metódy FIML. Na základe odhadnutých parametrov modelu bola produkčná medzera ovplyvnená vývojom cien nehnuteľností a očakávaným vývojom produkčnej medzery, inflácia bola do veľkej miery ovplyvnená infláciou eurozóny a vývojom regulovaných cien. Ceny nehnuteľností nasledovali očakávaný vývoj cien nehnuteľností a základnej sadzby NBS. V prípade reakčnej funkcie sa ukazuje, že priaznivý vývoj domácej inflácie umožnil NBS postupne harmonizovať svoju základnú sadzbu s kľúčovou sadzbou ECB v rámci procesu prípravy zavedenia eura. Na základe uvedených dvoch modelov sa dá usúdiť, že prípadná nezávislá menová politika NBS by nebola schopná zmierniť negatívny dopad globálnej ekonomickej recesie na slovenskú ekonomiku v roku 2009 vo výraznej miere.

Kľúčové slová: menová politika, Bayesovský VEC model so zmiešanou frekvenciou, Neokeynesiánsky makroekonomický model, FIML

Preface

I focused on the monetary policy in more details first during my master studies at the Comenius University in Bratislava, when I analyzed the transmission of the changes in the key rate of the NBS into the Slovak interbank rates. There are several reasons I've decided to continue my research in this field.

While there is a broad literature focusing on the monetary policy and the impact of monetary policy decisions and shocks on the real economy, results are still ambiguous in case of small and open economies. In addition, the topic of monetary policy is gaining more and more attention after the onset of the global financial crisis and the sovereign crisis in the euro area. Beside the traditional goal of price stability, the importance of financial stability is growing. Also, there is now a brisk discussion among researchers about the nexus between monetary policy and macro-prudential policies and about the interactions of different policy measures.

While Slovakia joined the euro area in 2009, it is still important to understand the way how monetary policy of NBS affected the real economy during years before the euro adoption. On the one hand, it can help in understanding the effects of the monetary policy decisions of the ECB. On the other hand, it can help to answer the question, whether an independent monetary policy in 2009 would help in mitigating the negative impact of the global economic recession on the Slovak economy.

There are, however, several challenges when addressing the issue of monetary policy in Slovakia. NBS started to conduct qualitative monetary policy in 2000, which means there is a relatively short time period that is relevant for the analysis of the monetary policy. Moreover, the effects of monetary policy were probably affected by the changing structure of the financial sector and the domestic economy in the period under review.

In this thesis, we analyze the effects of the monetary policy and the reaction function of the NBS using the VEC framework and based on a New Keynesian Macroeconomic Model. As the time period is relatively short, it is better to use monthly observations rather then quarterly when estimating a VEC model. However, there are variables, like the GDP, that are not observed with a monthly frequency. While there are several techniques how to deal with this issue, none of these techniques are superior to others. Therefore, this thesis has the ambition to broaden the toolkit of possible methods that can be used in such cases. We introduce a modified version of a Bayesian estimator initially developed for estimating VAR models, that can be used for the estimation of VEC models and that enables the inclusion of endogenous variable observed with mixed frequencies.

As loans granted for house purchase have a significant share in the amount of total bank loans and their volume increased markedly during the period under review, an interesting question is to what extent the development of the monetary policy affected residential property prices in Slovakia. To address this question, we show a possible way how investments into residential properties can be separated from consumption when deriving the IS curve by maximizing the representative household's utility function. Subsequently, we estimate a structural model of the Slovak economy based on the theoretical model using the method of Full Information Maximum Likelihood.

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Introduction

One of the main tasks of central banks is to maintain price stability. Actually most of them have adopted a regime of explicit inflation targeting, which means they explicitly announce the targeted value of the inflation. The structural framework and the list of instruments the central bank is using to achieve its goals are called monetary policy. Majority of the central banks is using qualitative monetary policy, so they set key policy rates to affect the demand for money and, consequently, the output and inflation. The list of instruments, that forms the operational framework to implement the monetary policy, consists, inter alia, of open market operations, standing facilities and minimum reserves. All of these instruments help the central bank in steering market interest rates and managing interbank liquidity.

While the central bank cannot directly affect the inflation and the output, there are several channels how the monetary policy decisions are transmitted to the real economy. The mechanism of the transmission of the monetary decisions through these channels to the real economy is called the monetary policy transmission mechanism. There have to be fulfilled several conditions in order for the central bank to be able to affect the real economy: no privately issued securities can perfectly substitute the monetary base and nominal prices cannot react immediately to the nominal changes of the monetary base.

In general, there are five transmission channels studied in the literature. The most basic and well known is the interest rate channel. Others are the exchange rate channel that is particularly important for small and open economies, the asset price channel, the credit channel that underlines the relevance of the financial intermediaries and the channel of expectations that emphasizes that it is important for the central banks to gain credibility as it can increase the effectiveness of their monetary policy.

The transmission channels are not functioning separately but are mutually amplifying their effects. The functioning of the monetary policy and the respective transmission channels depends on the characteristics and current stance of the given economy and financial system, e.g. on the openness of the economy or on the liquidity and solvency position of firms, banks and households. As it is of vital importance for the central banks to know the structure of the real economy and the financial system and their reaction to the monetary policy decisions as deeply as possible, there is a broad field of literature dealing with monetary policy.

The literature can be summarized in line of the so called Lucas program, described by, e.g. in Christiano et al (1999): "…

- First, one isolates monetary policy shocks in actual economies and characterizes the nature of the corresponding monetary policy experiments.
- Second, one characterizes the actual economy's response to these monetary experiments.
- Third, one performs the same experiments in the model economies to be evaluated and compares the outcomes with actual economies' responses to the corresponding experiments." (p. 3-4)

Based on this "program", it is important to study the effects of monetary policy shocks, as these studies can help in understanding the transmission mechanism and can be used as benchmarks when assessing structural models. The most widespread are VAR/VEC models in analyzing the effects of monetary policy shocks. One of the first studies arguing in favor of the VAR methodology is Sims (1986). On the other hand, structural models can help providing a better insight into the structural part of the transmission mechanism. This property is, as argued in McCallum (1999), essential because it seems that shocks account only for a very small portion of the key policy rate variability.

In this thesis, we focus on the monetary policy and the transmission mechanism of the monetary policy of the National Bank of Slovakia from the period of the adoption of qualitative monetary policy in 2000 to the end of 2008 when Slovakia joined the euro area. While even in this short period there where several structural changes and a gradual harmonization of the monetary policy with those of the European Central Bank, it is important to understand the functioning of the transmission mechanism. On the one hand, this can help to predict the effects of the monetary policy decisions of the ECB on the Slovak economy. On the other hand, it can help to answer the question, whether an independent monetary policy would help to mitigate the negative consequences of the global financial crisis and economic downturn on the Slovak economy in 2009.

The thesis is organized as follows: In the first chapter, we give a brief theoretical description of the monetary policy and the transmission mechanism of the monetary policy. The second chapter contains a short overview of the relevant literature dealing with monetary policy. In the third chapter we summarize the economic development in Slovakia and the monetary policy in the period before the qualitative monetary policy and in the period under consideration.

In the next chapter we analyze the transmission mechanism of monetary policy shocks and the possible form of the reaction function of the NBS using VEC framework. As the time period is relatively short, in order to use data with monthly frequencies we introduce a modified version of the BMF estimator published in Citu et al (2011). This modified BMF estimator allows us to estimate VEC models including endogenous variables observed at mixed frequencies. At the end of the chapter we also analyze possible effects of an independent monetary policy in the period of 2009 and 2010 using conditional forecasts of the endogenous variables.

The fifth chapter consists of the analysis of the monetary policy and the transmission mechanism based on a New Keynesian Macroeconomic Model derived for a small open economy. First, we show a possible way how investments into properties can be separated from consumption within the utility function of households and consequently derive the IS curve assuming that the representative household is maximizing its utility function. This separation allows us to show the possible effects of the monetary policy on the property price inflation which is not part of the CPI or HICP inflation; and consequently to analyze possible effects of the property prices/property price inflation on the output gap. Second, based on the theoretical model consisting of the IS curve, a general form of the Phillips curve and the reaction function of the NBS and a simple equation describing the development of property prices we estimate a structural model of the Slovak economy using the method of Full Information Maximum Likelihood (FIML). A discussion of the possible effects of an independent monetary policy based on the estimation results is also part of the chapter.

Results are summarized in the last chapter of the dissertation thesis.

Goals of the thesis

The main goals of the thesis can be summarized in the following points:

- To analyze the transmission mechanism of the monetary policy of the NBS using the VEC framework and to propose a feasible estimation method that can be used in case of variables available at different frequencies.
- To build up a theoretical structural model based on the estimation results of the VEC model and to estimate a structural model of the Slovak economy based on the theoretical model.
- To analyze the possible impact of an independent monetary policy of the NBS on the Slovak economy in 2009, when the global economic recession transmitted into a sharp decrease of the domestic GDP.

1. Monetary policy and the transmission mechanism of the monetary policy

1.1. Monetary policy

The structural framework (rules and actions) and the list of instruments the central bank is using to transmit its decisions into the financial sector and, consequently, into the real economy, is called monetary policy.

Central banks usually choose the regime of their monetary policy according to the structure and the current stance of the economy. The regime or the framework provides the structure of the monetary policy decision-making process and also makes it easier to communicate these decisions to the public. The basic monetary policy regimes are[1]:

- a regime with implicit nominal anchor: within this regime, the central bank targets an explicit nominal variable only internally without explicitly announcing it to the public. This regime requires a high credibility of the central bank so that it can reach the desired changes in, e.g., the inflation without explicit targets.
- money targeting: under this regime the central banks targets the desired value of the growth rate of a chosen monetary aggregate. As in the long term, price growth is affected by money supply growth, in this way the central bank can control the monetary base and the inflation.
- exchange rate targeting: this regime means the central bank targets nominal exchange rate stability against the currency of a chosen country (the so called anchor country). Maintaining exchange rate stability requires ensuring low inflation differential against the anchor country, sufficient level of international reserves and the maintenance of the country's competitiveness and credibility.
- inflation targeting: under this regime the central bank explicitly announces the targeted value of the inflation (or an inflation band).

[1] http://www.cnb.cz/en/faq/what_are_the_regimes_of_monetary_policy.html

Many central banks define as a goal of their monetary policy price stability, explicit or implicit. Price stability is the main goal, e.g., of the ECB. However, beside price stability, the Eurosystem shall also "support the general economic policies in the Union with a view to contributing to the achievement of the objectives of the Union". These include inter alia "full employment" and "balanced economic growth".[2]

As it is explained in Ireland (2005), the liabilities of the central bank include cash and bank reserves, therefore the bank is able to control monetary base (e.g. through open market operations, i.e. through the purchase and sale of securities in the open market by the central bank). However, in order for the central bank to be able to effectively use its instruments and to affect the real economy, some assumptions have to hold:

- no privately issued securities can perfectly substitute the monetary base. This assumption can be achieved, e.g., by legal restrictions.
- nominal prices cannot react immediately to the nominal changes of the monetary base in order to achieve a real change of the monetary base

As it is further explained by the author, if the components of the monetary base don't pay interest rate, or, pay interest rate which is lower than the market rate on other highly liquid assets (e.g. short-term government bonds or T-bills), the private agents' demand for real base money M / P can be described as a decreasing function of the interest rate i: $M / P = L(i)$. This function explains how the increase of the nominal interest rate leads to an increased demand for other highly liquid assets and affects the demand for currency (in case of households and firms) and the holdings of reserves (in case of banks). Assuming that the price level cannot adjust fully in the short run, the central banks is able thus to influence the short-term nominal interest rate by changing the quantity of the base money (the so called quantitative monetary policy), or inversely, to influence the demand for the base money by changing the short-term nominal interest rate (qualitative monetary policy). However, based on the analysis of Poole (1970) it can be supposed that the targeting of the nominal interest rate leads to lower disturbances of the output and prices in the reaction to monetary policy decisions than in case of a money targeting.

[2] http://www.ecb.int/mopo/intro/objective/html/index.en.html

The central bank uses its instruments to reach the targeted value of the chosen variable. These instruments in general include open market operations, minimum reserves and the nominal interest rates associated with these instruments. In case of the ECB, there are three types of instruments[3]:

- open market operations, that play an important role in steering interest rates, managing the liquidity situation in the market and signaling the monetary policy stance.
- standing facilities, that aim to provide and absorb overnight liquidity, signal the general monetary policy stance and bound overnight market interest rates.
- minimum reserves, that are used to pursue the aims of stabilizing money market interest rates, creating (or enlarging) a structural liquidity shortage and possibly contributing to the control of monetary expansion.

1.2. The transmission mechanism of the monetary policy

Ireland (2005) introduces the monetary policy transmission as a mechanism that "describes how policy-induced changes in the nominal money stock or the short-term nominal interest rate impact real variables such as aggregate output and employment…" (p. 1). Consequently, the changes of these real variables than affect the price level in the economy.

Monetary policy decisions affect the real economy through various channels. A detailed description of these channels is presented in Mishkin (1995), where the author discusses the following channels:

- Interest rate channel
- Exchange rate channel
- Asset price channel
- Credit channel

A fifth, separate channel called the channel of expectations is discussed, e.g., in Loayza and Schmidt-Hebbel (2002).

[3] http://www.ecb.int/mopo/implement/intro/html/index.en.html

Interest rate channel

This channel is one of the basic and most well-known channels of the transmission mechanism of the traditional Keynesian model. Within this channel, monetary policy decisions affect short-term nominal interest rate and, through sticky prices and rational expectations, also the long-term nominal interest rate, at least temporarily. In case of a monetary restriction, short-term, and consequently, also long-term interest rates increase. Assuming temporary stickiness of prices this transmits into an increase of the real interest rates. Higher real interest rates, through the higher cost of funds, lead to a decline in investments (business fixed investments, residential housing investments and inventory investments) and consumption that transmits into a decline of aggregate output and, consequently, to the decline of inflation.

There are several factors impacting the efficiency of this channel. As primary reactions to the changes in monetary policy are expected in case of the interbank interest rates followed by changes of the client interest rates (interest rates on loans and deposits of non-financial corporations and households), the financial sector (especially the banking sector) has to be liberalized and developed enough to be able to transmit the changes of monetary policy into the real economy, see, e.g. Mukherjee and Bhattacharya (2011). Another assumption is that the real sector has to rely on funds (at least partially), the cost of which can be affected by the monetary policy. These assumptions can be disrupted, or weak, mainly in case of small and open economies[4]. The reaction of the targeted variables to monetary policy changes depends on the structure of the real economy, like the interest rate sensitivity of the consumption and investments, or the marginal propensity to consume.

Exchange rate channel

With growing internationalization of the economies throughout the world and flexible exchange rate regimes the importance of the exchange rate channel has gradually increased. This channel is particularly important for open economies, as discussed by Batini et al (2001). Within this channel, in case the nominal interest rate rises relative to the foreign interest rate, equilibrium in the foreign exchange market requires that the domestic currency gradually depreciate. This expected future depreciation requires an initial appreciation of the domestic

[4] An example of a country with weak interest rate channel is Belarus due to the high degree of dollarization, see, e.g. Horváth and Maino (2006).

currency as discussed by Ireland (2005). Assuming sticky prices, this appreciation transmits into the increase of the prices of domestically produced goods relative to the foreign-produced goods. This implies a fall of net exports that causes a drop also in domestic output and employment. Through this channel also the development of the foreign inflation can affect the domestic inflation, as described by Nell (2004).

Asset price channel

There are several ways, how monetary policy affects the target variables through the asset price channel. A proper mechanism can be provided using Tobin's *q* theory. Tobin (1969) defines *q* as the market value of firms divided by the replacement cost of capital. In case of a monetary policy contraction, increasing interest rates imply falling bond prices. Lower prices of bonds make them more attractive compared to equities, thus causing their prices to fall also. According to Tobin's theory, lower equity prices decrease *q* and lower *q* transmits into lower investment spending and lower aggregate output.

Another way how the asset price channel functions can be explained using the life-cycle model introduced in Modigliani (1971). According to this theory, consumption spending is determined by the lifetime resources of consumers. These resources include, inter alia, financial wealth the major component of which is common stocks. Falling stock prices caused by contractionary monetary policy thus lead to falling financial wealth that transmits into decreasing lifetime resources and contracting consumption.

Meltzer (1995) points to the fact that monetary policy can also have an important impact on the target variables through its effect on lend and property prices. A contractionary monetary policy, e.g., causes the prices to fall, that transmits into a decreasing households' wealth and a consequent decrease in consumption and aggregate output.

Credit channel

The main components of the credit channel, as described by Bernanke and Gertler (1995) are the bank lending channel and the balance sheet channel. The bank lending channel emphasizes the important role of banks as financial intermediaries, as they are suited to deal with certain type of borrowers, like small and medium enterprises and households, where the problem of asymmetric information arises. According to this theory, an increase in interest rates that leads to a contraction in bank reserves and bank deposits transmits into a contraction of intermediated credit. Thus, the reduction in the supply of bank credit, relative to other forms of credit, should increase the external finance premium and contract real activity.

The balance sheet channel works through the net worth of business firms and the present value of loan collateral. Contractionary monetary policy transmits into a decreasing net worth of firms, so the lenders have less collateral for the loans. It means losses from the adverse selection are higher. Beyond the adverse selection problem, the falling net worth of firms lowers the owners' equity stake in their firms giving them more incentives to engage in risky investment projects. This increases the so called moral hazard problem. These problems cause a decrease in the loan supply and thus a decrease in aggregate output. Except the effect on the net worth of firms/collateral, increasing interest rates can transmit also into higher debt burden (in case of loans with floating interest rates). Higher debt burden or lower cash flow of firms and households is mirrored in decreasing investments and consumption and thus in aggregate output.

The channel of expectations

Within this channel, the expected future values of macroeconomic variables are linked with their current and past values. In case of this mechanism, agents (firms or households) form their expectations based on the past monetary policy decisions and the development of macroeconomic factors. Assuming that these agents are optimizing their current and future investments and consumption, expectations are affecting also their actual investment and consumption and thus aggregate output. As this channel means expectations play an important role within the transmission mechanism, it is necessary for the central bank to gain credibility to be able to influence these expectations by its policy decisions.

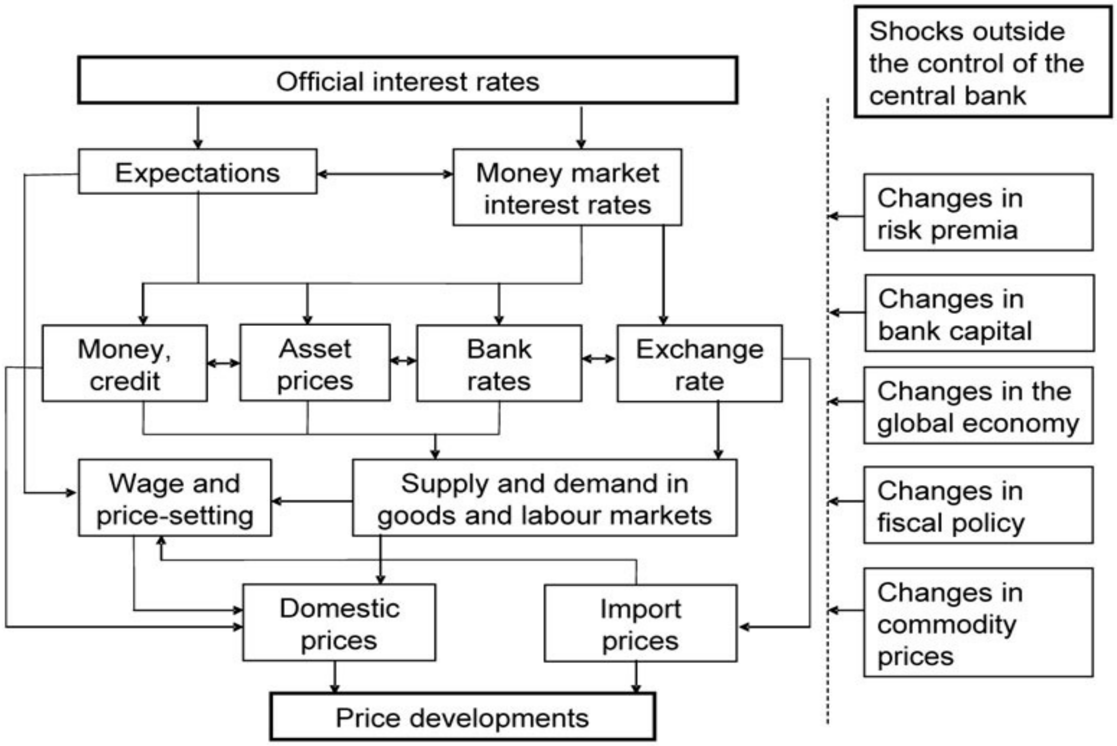


Figure 1 Scheme of the monetary policy transmission mechanism
Source: European Central Bank

Separating the channels of the monetary policy transmission mechanism helps to better understand, which financial aggregates are affected by the monetary policy and how is the financial and real sector interconnected. Central banks can thus have more proper estimates of future changes of the macroeconomic variables which can contribute to a more effective conduction of monetary policy. However, the identified transmission channels are not functioning separately but are mutually amplifying their effects. The functioning of the monetary policy and the respective transmission channels depends on the characteristics and current stance of the given economy and financial system, e.g. on the openness of the economy or on the liquidity and solvency position of firms, banks and households. The more diversified the financial market is, the higher is the competitiveness, the faster and stronger will be the transmission of monetary policy decisions and the stronger is the interest rate and asset price channel. Similarly, the more is the economy opened and dependent on foreign markets, the more important is the exchange rate channel. Lastly, the smaller are financial constraints of firms and households, the more stronger and flexible are their reactions to changes in market interest rates and prices. Thus, understanding the current stance of the economy and the financial system and identifying relative importance of the respective channels helps the central bank to concentrate on the most important transmission channels and gain a more realistic picture about the functioning of the monetary policy and about the future changes in targeted variables in response to monetary policy decisions.

2. Literature review

The importance of understanding the monetary policy transmission, the consequences of the chosen monetary policy framework and the reaction of the real economy to monetary policy decisions and monetary policy shocks has led to a broad field of studies concentrating on these issues. The approaches of different studies related to the monetary policy transmission mechanism can be, in general, separated into two main classes. First, a large number of studies use for the analysis of monetary policy shocks the VAR (VEC) framework. Sims (1986) argues in favor of the VAR framework, as he shows with the help of a simple VAR model using six macroeconomic variables describing the US economy in the period from the first quarter of 1948 up to the third quarter of 1979 that such models can provide useful information for the monetary authority. The second class of the studies related to monetary policy transmission can be denoted as the class of "structural models", it means models that, in general, aim at giving an analytical representation of monetary policy behavior and its effects on different macroeconomic variables, such as the output, output gap, inflation or exchange rate. Arguments in favor of the structural models can be found in McCallum (1999). In his paper, the author supports this view by arguing that "more emphasis should be given to the systematic portion of policy behavior and correspondingly less to random shocks – basically because shocks account for a very small fraction of policy-instrument variability" (McCallum, 1999, p. 33). As an example, the author points to the results of Clarida et al (1998), where it is found that in case of the baseline estimation of the reaction function of the Bundesbank, Bank of Japan and the Federal Reserve the portion of the policy instrument variability that is not explained by systemic determinants is only 1.9, 3.0 and 1.6% respectively. Based on Rotemberg and Woodford (1997) and McCallum and Nelson (1998), it is just about 5% of the policy instrument variability in case of the US that is not explained by systemic determinants. All papers deal with period roughly from 1979. However, as it is pointed out in Sims (1986), the structural models and VAR models in general face limitations that are different in nature but conceptually similar. Therefore, when analyzing monetary policy and monetary policy transmission mechanism, both classes of models should be taken into consideration, as there is a tradeoff between these types of models rather than a hierarchy of them.

Another way how the investigation of the impact of monetary policy shocks on different macroeconomic variables and structural models are linked is outlined by Lucas (1980) and in the literature that builds on his suggestion about the structural models, when he says that economists

"…need to test them (models) as useful imitations of reality by subjecting them to shocks for which we are fairly certain how actual economies or parts of economies would react. The more dimensions on which the model mimics the answers actual economies give to simple questions, the more we trust its answers to harder questions." (p. 696-697)

As it can be found, e.g. in Christiano et al (1999), the so called Lucas program using the abovementioned approach consists of three steps: "…

- First, one isolates monetary policy shocks in actual economies and characterizes the nature of the corresponding monetary policy experiments.
- Second, one characterizes the actual economy's response to these monetary experiments.
- Third, one performs the same experiments in the model economies to be evaluated and compares the outcomes with actual economies' responses to the corresponding experiments." (p. 3-4)

2.1. Monetary policy shock analysis using VAR/VEC framework

It means that an important application of VAR (VEC) models is that they can be used also as benchmarks when evaluating the performance of structural models. So, as outlined below, a widespread use of the VAR methodology is to identify monetary policy shocks and to study the effects of these shocks on the real economy. There are different ways how monetary policy shocks can be interpreted. Chritiano et al (1999) gives as one of the interpretations that these shocks are exogenous shocks to the preferences of the central bank (monetary authority). Ball (1995) argues that the exogenous source of variation of the monetary policy can be explained possibly by the monetary authority's efforts to avoid the social costs of disappointing private agents' expectations. Finally, Bernanke and Mihov (1995) point to a problem of the measurement error in the preliminary data available to the central bank at the time it makes the decisions about monetary policy.

However, neither the identification of monetary policy shocks, nor the estimation of their impact is straightforward. As discussed in Christiano et al (1999), there are in general three different approaches for isolating monetary policy shocks.

- The first involves making enough identifying assumptions to be able to estimate the central bank's feedback rule, or reaction function.
- The second approach is finding for data that purportedly signal exogenous monetary policy actions.
- The third approach uses an assumption that monetary policy shocks do not affect economic activity in the long run

In the last two cases, the central bank's reaction function is not modeled explicitly. As the first approach is the most widespread, our focus is mainly on this one. The second and third approach is applied, e.g., in Romer and Romer (1989), resp. in Faust and Leeper (1997).

One of the main problems when using VAR models for the identification of monetary policy shocks is that only the restricted form of the VAR system can be estimated. It means, in order to identify the structural shocks, some identifying restrictions (assumptions) have to be imposed on the parameters. The restricted form of VAR for a *k*-dimensional vector of variables, Z_t is given by:

$$Z_t = B_1 Z_{t-1} + B_2 Z_{t-2} + \ldots + B_q Z_{t-q} + u_t, E\left(u_u u_t^T\right) = V \quad (2.1)$$

where q refers to the number of lags included in the model and u_t is uncorrelated with variables dated $t-1$ and earlier. Here, u_t refers to the one period ahead forecast error in Z_t and, in general, each element of u_t reflects the effects off all structural shocks/structural innovations to the economy. To isolate the structural shocks, one has to reveal the structural form of the VAR system that has the form of

$$A_0 Z_t = A_1 Z_{t-1} + A_2 Z_{t-2} + \ldots + A_q Z_{t-q} + \varepsilon_t, E\left(\varepsilon_t \varepsilon_t^T\right) = D \quad (2.2)$$

where A_0 is an invertible, square matrix and D is a positively definite matrix and ε_t is the vector of structural innovations. Comparing (2.1) and (2.2) we obtain

$$B_i = A_0^{-1} A_i, i = 1, 2, \ldots, q \quad \text{and} \quad V = A_0^{-1} D \left(A_0^{-1}\right)^T$$

Let's define $\tilde{\gamma}_h$ as the solution to the difference equation of the form

$$\tilde{\gamma}_h = B_1\tilde{\gamma}_{h-1} + B_2\tilde{\gamma}_{h-2} + \ldots + B_q\tilde{\gamma}_{h-q}, h = 1, 2, \ldots$$

with initial conditions

$$\tilde{\gamma}_0 = I, \tilde{\gamma}_{-1} = \tilde{\gamma}_{-2} = \ldots = \tilde{\gamma}_{-q} = 0$$

Then,

$$\gamma_h = \tilde{\gamma}_h A_0^{-1}, h = 1, 2, \ldots$$

is the response of Z_{t+h} to a unit shock in ε_t, where the (i, j) element of γ_h is the response of the i^{th} component of Z_{t+h} to a unit shock in the j^{th} component of ε_t.

It means that, in order to compute the impulse response functions (the γ_h's), we need to know A_0 and B_i's. In general, when studying monetary policy shocks a base assumption is that $D = I$ or, equally, that

$$V = A_0^{-1}\left(A_0^{-1}\right)^T$$

which means that structural innovations are uncorrelated.

The second common assumption is that the diagonal elements of A_0 are strictly positive. Then, a usual practice is to pose $l \geq k(k-1)/2$ restriction on the matrix A_0 in a way to achieve a restricted matrix with full rank. A common way is assuming that A_0 is a lower triangular matrix.

In the above cited Christiano et al (1999), authors compare different specifications and identification methods used for the identification of the monetary policy shock based on the described short-run restriction. They main focus is on the "Recursive Assumption", it means on the assumption that monetary policy shocks are orthogonal to the information set of the monetary authority. In terms of the notation in (2.1), the assumption of recursiveness means that the ordering of the variables, Z_t is as follows:

$$Z_t = \begin{pmatrix} X_{1t} \\ S_t \\ X_{2t} \end{pmatrix}$$

where the k_1 variables X_{1t} are those that appear contemporaneously in the reaction function of the central bank, S_t is the instrument of the central bank, the k_2 variables X_{2t} appear in the reaction function only with a lag and $k = k_1 + k_2 + 1$ is the dimension of Z_t. They show in the paper that applying a lower triangular form of A_0 leads to the same response of all of the variables to the monetary policy shock (i.e. to the $(k_1+1)^{th}$ element of ε_t) regardless the ordering of the variables in X_{1t} and, in X_{1t} respectively.

In the benchmark specification, the Z_t consists of the log real GDP, the log of the implicit GDP deflator, the smoothed change in an index of sensitive commodity prices, the federal funds rate, the log of total reserves, the log of nonborrowed reserves plus extended credit and the log of either M1 or M2, respectively. All data refers to the US economy and are quarterly observations from the third quarter of 1965 to the second quarter of 1995. The impulse responses show that a contractionary monetary policy shock can be characterized by a persistent rise in the federal funds rate, a persistent drop in nonborrowed reserves, a fall in total reserves and a sustained decline in real GDP. They also try to exclude current output and prices from the reaction function, but as there is no clear interpretation of an initial increase of the GDP before falling, they find these assumptions as implausible. Moreover, they conclude that there is an impact of the time period considered, as there is some evidence that the variance of the monetary policy shock is larger in the early 1980's than in the periods before or after. Comparing to a large set of different identifying assumptions, they conclude that the described effects of the monetary policy shocks are robust across a huge variety of identifying assumptions.

From the benchmark specification it is clear that in this case the US economy is considered to be a close economy. There are several papers dealing with the effects of the monetary policy shocks also on the exchange rate, i.e. identifying the effects of the monetary policy shocks in an open economy. Eichenbaum and Evans (1995) consider, among others, a similar monetary policy shock measure as described above, including also some foreign variables into the Fed's reaction function (countries considered are Japan, Germany, Italy, France and the Great Britain). They assume that the Fed does not respond to the contemporaneous changes in the foreign interest rate or the exchange rate. They find that a contractionary shock to the U.S. monetary policy causes a persistent and significant appreciation in U.S. nominal and real exchange rates, a persistent decrease in the spread between the U.S. and foreign interest rates and a significant, persistent deviation from uncovered interest rate parity in favor of U.S. investments.

Grilli and Roubini (1995) consider monetary policy shock specifications for non-U.S. G7 countries similar to the measures in the previous study. They find that a contractionary shock to a foreign country's monetary policy causes an initial depreciation in the foreign country's currency. They argue that this reflects that the measures of monetary policy shocks are influenced by the systemic reaction of foreign monetary policy to U.S. monetary policy and expected inflation. Therefore, they consider another monetary policy shock measure based on the recursiveness assumption with a measure of the monetary policy tool equal to the spread between foreign short term and long term interest rates. Results show a temporary appreciation in the foreign exchange rate and a temporary fall in output as a reaction to the contractionary shock to foreign monetary policy.

Another, interesting approach for identifying monetary policy shocks is presented in Uhlig (2005). Instead of restricting the components of matrix A_0 in (2.2), the sign of the reaction of the endogenous variables to the monetary policy shock is predetermined. These sign restrictions, based on the methodology presented in Darvas (2006), are used also in Jurašeková Kucserová (2009).

Again, as in (2.2), we assume

$$E\left(u_t u_t^T\right) = V$$

The variance-covariance matrix of the one period ahead prediction errors can be decomposed as

$$V = \Gamma L \Gamma^T$$

where Γ is the matrix consisting of the eigenvectors of V and L is a diagonal matrix with the eigenvalues of matrix V on the main diagonal. Let

$$Q(\theta) = \Pi_{m,n} Q_{m,n}(\theta) \quad (2.3)$$

where

$$Q_{m,n}(\theta)=\begin{bmatrix}1 & 0 & . & 0 & . & . & . & 0\\ 0 & 1 & . & 0 & . & . & . & 0\\ : & : & : & : & : & : & : & :\\ 0 & 0 & . & \cos\theta & . & -\sin\theta & . & 0\\ : & : & : & : & 1 & : & : & :\\ 0 & 0 & . & \sin\theta & . & \cos\theta & . & 0\\ : & : & : & : & : & : & : & :\\ 0 & 0 & . & 0 & . & 0 & . & 1\end{bmatrix}$$

such that

$$Q(\theta)Q(\theta)^T = I$$

Matrix $Q_{m,n}(\theta)$ is a rotation matrix that rotates rows m and n by θ degrees. For the rotation matrix $Q_{m,n}(\theta)=Q_{m,n}(\theta+2\pi)$ holds. By splitting the interval $[0,2\pi)$ into M subintervals we can define M rotation matrices. Multiplying both sides of the equation in (2.3) with $\left(\Gamma L^{1/2}Q(\theta)\right)\left(\Gamma L^{1/2}Q(\theta)\right)^{-1}$, where $L^{1/2}$ is a matrix with the square roots of the eigenvalues on the main diagonal we get:

$$Z_t = B_1 Z_{t-1} + B_2 Z_{t-2} + \dots + B_q Z_{t-q} + \left(\Gamma L^{1/2} Q(\theta)\right)\tilde{\varepsilon}_t$$

$$\tilde{\varepsilon}_t = \left(\Gamma L^{1/2} Q(\theta)\right)^{-1} u_t$$

$$E\left(\tilde{\varepsilon}_t \tilde{\varepsilon}_t^T\right) = I$$

It means that $\tilde{\varepsilon}_t$ can be interpreted as structural innovations. Impulse response functions are calculated for each rotation matrix and in case responses fulfill the predetermined sign restrictions there are maintained otherwise there are dropped from the set of acceptable impulse responses.

Jurašeková Kucserová (2009) studies the effects of a contractionary monetary policy shock on the Slovak economy. The main findings include a drop in consumer prices and a rise of short term interest rate after a monetary policy tightening. The response of the nominal effective exchange rate is not so clear, there seems to be an initial depreciation followed by an appreciation, however smaller in size. The negative effect on output is obtained after a prior technology shock filter or the inclusion of output gap instead of real GDP.

While most of the studies described above are focused on the US economy and monetary policy transmission, the field of interest is wider and questions are arising also in connection with other economies. The natural question after 1999 has became the possible asymmetric reaction of different member state of the euro area to the monetary policy shocks of ECB and the overall reaction of the member states to monetary policy shock. A good overview can be found in Angeloni et al (2003). In case of the VAR approach, they refer to the paper of Peersman and Smets (2001) and Mojon and Peersman (2001). In the first paper, authors find that an interest rate increase reduces output for the euro area countries for a few quarters with the recovery starting after one and a half year, while the price level gradually falls. In general, the results are comparable to those for the US economy in Christiano et al (1999). The second paper is focused on individual euro area countries. While the comparison of quantitative results can be problematic, a qualitative comparison reveals that a monetary tightening results in a reduction in output and inflation in almost all euro area countries, while nearly in all cases the peak in the response of output is earlier than the peak in the response of inflation.

The issue of a possible asymmetric reaction of the member states is also investigated, with the focus on the role of national financial systems, in Putkuri (2003). Using panel data she concludes that there is some support in favor of the bank lending channel of the transmission mechanism and asymmetric responses across countries. According to the results, a larger size of the domestic banking sector relative to the total size of the economy strengthens the impact of the interest rate channel, while a smaller and better capitalized sector can better absorb monetary policy shocks. However, as it is pointed out in the paper, as the time series consist mainly of data before 1999, it is hard to assess the possible changes due to the adoption of the common currency.

The question of heterogeneity of the member countries of the euro area is also the focal point in Ciccarelli and Rebucci (2002). They apply a Bayesian time-varying panel VAR[5] model for the analysis focusing on the four largest member states, Germany, France, Italy and Spain. The results suggest there are some differences in the transmission mechanism, but these differences are rather in the timing than in the magnitude. The cumulative impact of country specific monetary shocks after two years is comparable in case of Germany, France and Italy. It is also shown that the transmission mechanism of monetary policy was changing over time

[5] For a deeper description of the Bayesian VAR models, we refer the reader to Ciccarelli and Rebucci (2003)

in the second part of the 1990s without a decrease of the existing heterogeneity. Another result is that the transmission mechanism might become faster in the second part of 1990s.

There is also a broad range of literature examining transmission mechanism in open economies. The effects of the monetary policy on the economy in Czech Republic are investigated in Borys and Horváth (2008). They use a VAR, Structural VAR and Factor-Augmented VAR framework to study the monetary policy transmission. They include data about the GDP, real-time output gap, a price index, the nominal EUR/CZK exchange rate, three month interbank interest rate (PRIBOR), the 1 year EURIBOR, a commodity price index and forwards on interbank rates that are closely related to the policy rate. Data are from the period of January 1998 to May 2006. Monthly data about the GDP and output gap are estimated using quadratic-match average interpolation. Results point to a well-functioning transmission mechanism similar to the euro area countries. A contractionary monetary policy shock has a negative effect on the degree of economic activity and the price level, with a peak of the response after about one year. They also document a persistent appreciation of the Czech crown after monetary policy tightening with a gradual depreciation afterwards.

A Bayesian VAR approach is used to examine the monetary policy in Australia in Joiner (2001). As the author notes, such a framework is well suited for modeling small open economies. An assumption of a block exogenity of the foreign (in this case, U.S.) economy is applied. The author restricts the effects of the policy instrument (the cash rate) on output, inflation and labor market variables in the first lag. With this specification, the results are supported by economic theory. For example, after cash shock, a decrease of the GDP and an increase of unemployment are recorded. However, the inflation decreased just after an initial increase. The exchange rate is initially appreciating and depreciating afterwards.

The effects of monetary policy shocks on the economy of New Zealand are studied in Citu (2003) using the VAR approach. Based on the results, the exchange rate channel plays an important role in the transmission mechanism and in explaining deviations of real GDP from its trend. Interest rates respond in accordance with the expectations – short term interest rates more than long term rates. Finally, house prices respond relatively slowly to the temporary rise of the short term rates after an initial drop.

A related issue, house prices in relation to the monetary policy in the U.S. is studied in Jarociňsky and Smets (2008). They use a Bayesian VAR technique to answer several questions. First, they find that the strong rise in house prices in 2000 and the peak of the house price increases in 2006 cannot be explained just using nominal and real GDP developments. The information about the development in the federal funds rate and long term interest rate helps in forecasting the housing boom. Second, they results suggest that monetary policy has significant effects on residential investment and house prices. The easy monetary policy in 2002 to 2004 has added to the housing market boom in 2004 to 2005. However, the impact of the boom on the overall economy was limited.

As in a lot of cases the stationarity of the time series used for the analysis of the monetary policy transmission is questionable, there is a broad field of literature incorporating also the possible existence of cointegrating relationship of the variables into the models. Holtemöller (2003) estimates a vector error correction model of the euro area to study monetary policy using money, prices, output, long term interest rate and short term interest rate. He finds that euro area money and prices are integrated of order two and identifies three cointegrating relationships. In the estimated VEC model, the short term interest rate is interpreted as the monetary policy instrument and the equation for the change in the short term interest rate as monetary policy reaction function that includes the deviation of output from trend as the main explanatory variable. Major interest rate changes of the ECB in the period of 1999 – 2002 can be explained by this equation. It is also shown that interest rate changes affect real growth for about six quarters and inflation after six quarters.

VEC model is used to evaluate the German monetary policy during the pre-euro area period of 1975 – 1998 in Eleftheriou (2009). The author concludes that the cointegrating relationship between the policy rate, the domestic rate of inflation and the measure of the economic activity can be interpreted as the interest rate rule of the Bundesbank. The inclusion of the federal funds rate to capture the foreign factors influencing the monetary policy helps to explain the movements in the policy rate and the effects of the inflation and output remains virtually unaffected.

The transmission mechanism of monetary policy in Central and Eastern Europe using cointegration analysis is investigated in Ganev et al (2002). They focus on Bulgaria, Czech

Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia and Slovenia. The study is focusing on the exchange rate channel and interest rate channel and their pass – through on inflation and output. A cointegrating relationship of the 4 variables can be found in all cases except Estonia and Slovenia. For most countries, the inflation was dampened by the increase of interest rate and boosted by exchange rate depreciation. Output was boosted by depreciation; other responses strongly vary by country.

A comparison of the performance of VEC and VAR models based on U.S. data can be found in Jang and Ogaki (2004). They find that estimates of impulse responses are sensitive to the choice of restrictions. There is an evidence of an immediate appreciation in the U.S. dollar followed by a gradual depreciation with long run restrictions in the VEC model but no such evidence can be revealed using short run restrictions in the VEC model or in levels VAR. The "price puzzle" is also resolved using long run restriction in the VEC model, which is usually found in level VARs models.

2.2. New Keynesian Macroeconomic models

A brief overview of one of the newest and wide-spread class of structural models, the New Keynesian Macroeconomic models, can be found in Ireland (2005). Within this class of models, the assumption of nominal price and wage rigidity is combined with the assumption of rational expectations. The equations describing the macro variables are derived from the optimizing behavior of the households and enterprises facing some constraints. These models usually consist of three basic equations; an example is given by Ireland (2005):

$$y_t = E_t\{y_{t+1}\} - \sigma\left(i_t - E_t\{\pi_{t+1}\}\right) \tag{2.4}$$

$$\pi_t = \beta E_t\{\pi_{t+1}\} + \gamma y_t \tag{2.5}$$

$$i_t = \alpha\pi_t + \psi y_t \tag{2.6}$$

Equation (2.4), the IS curve, links output today to its expected future value and to the real interest rates, computed as nominal interest rates minus the expected rate of inflation. This equation is derived from the log-linearized version of the Euler equation linking the optimizing representative household's intertemporal marginal rate of substitution to the inflation-adjusted return on bonds.

Equation (2.5) is the Phillips curve that uses the log-linearized first-order condition describing the behavior of optimizing monopolistically competitive firms. These firms face explicit costs of nominal price adjustments, as in Rotemberg (1982), or set nominal prices in randomly staggered way, as assumed in Calvo (1983).

Equation (2.6) represents the interest rate rule of the monetary policy authority. This form of interest rate rule was presented first by Taylor (1993) and is one of the milestones for the analysis of the monetary policy behavior and the monetary policy transmission. This equation links the adjustments of the policy rate to the movements in inflation and output, so uses the assumption that the central bank conducts qualitative monetary policy. As it is shown on the U.S. data in Taylor (1999), such equation can be a useful tool for monetary policy analysis in different policy regimes.

Within this framework, monetary policy is transmitted to the real economy through the interest rate channel. A monetary tightening in form of rising short term nominal interest rates causes also a rise in the real interest rates assuming nominal price rigidities. Higher real interest rates force households to lower spending, which translates into lower output as outlined in equation (2.4). Finally, a drop in output transmits into a gradual adjustment of prices, captured by equation (2.5). The quantitative effects of the monetary policy are to a large extent affected also by the expectations, depending on whether the decisions of the central bank are expected or not by the real sector.

As an implication, the credibility of the central bank is very important. This aspect is, inter alia, evaluated in Clarida et al (1999), who use a simple closed economy model similar to that described by equations (2.4) – (2.6) to analyze the monetary policy design problem. While the IS curve and the Phillips curve are introduced in their usual form, the reaction function of the central bank is derived from the objective function or the loss function of the central bank. In their baseline representation, the loss function of the central bank takes the form

$$\max -\frac{1}{2} E_t \left\{ \sum_{i=0}^{\infty} \left[\alpha x_{t+i}^2 + \pi_{t+i}^2 \right] \right\}$$

where x_t is the output gap, π_t is the inflation and α is the relative weight on output deviations. They show, how the reaction function differs in case of a central bank operating under discretion, i.e. when the central bank is reoptimizing every period and in case of a central bank that uses a rule, i.e. it chooses a plan for the path of the interest rates that it sticks forever. As they explain, "The plan may call for adjusting the interest rate in response to the state of the economy but both the nature and size of the response are etched in stone" (p. 19). As they show in the paper, the trade-off between the output and inflation is highly sensitive to the degree and nature of the persistence in inflation. They also point to the fact that such models usually end up with a much more volatile policy rate than what is observed in the realty; therefore existing models may characterize the constraints of the central bank just inadequately.

While in these papers theoretical work is focused on a closed economy, there are also studies that extent the framework to the open-economy case. An overview of the work done in the field of New Keynesian open-economy models can be found in Bowman and Doyle (2003). The base model in the overview is that of Obstfeld and Rogoff (1996). They introduce a two-country model including households and governments. They assume competitive labor market and flexible wages and that each firm is a monopolistic competitor setting prices one period in advance, than a one-time unforeseen monetary policy shock is introduced. In their model, a positive monetary policy shock leads to an increased aggregate consumption of the domestic households, to a depreciation of the exchange rate and an increase in net domestic claims on foreigners, while all of these changes are largely permanent.

There are also some extensions of their model in other studies. A home bias, assuming that domestic households prefer more domestically produced goods, is introduced in Warnock (1998). As an implication, a domestic monetary policy shock has a higher effect on domestic welfare than foreign welfare and also the exchange rate will, in contrast to the benchmark model, overshoot. Corsetti and Pesenti (2001), or Chari et al (2002) assume that the elasticity of substitution between domestic and foreign goods does not have to be the same as the elasticity of substitution between different domestic goods. The assumption that the law of one price holds for all goods, is relaxed in some studies. The law of one price assumes that

$$P(i) = \varepsilon P^F(i)$$

where $P(i)$ ($P^F(i)$) is the price of good i in domestic (foreign) currency and ε is the exchange rate. As the deviation from the low of one price for traded goods appears to explain a high portion of the exchange rate fluctuation, there are also some alternative pricing models. Betts and Devereux (1996), e.g., assume that a fraction of firms set price in the buyer's currency (LCP – Local Currency Pricing). Full LCP implies that short term movements in nominal and real exchange rates will be perfectly correlated. Also, this assumption tends to produce greater variability in the nominal exchange rate. As it is argued, e.g., Obstfeld and Rogoff (2000), sticky wages and flexible prices are closer to realty as the opposite assumed in the benchmark model, so they work with this assumption. There are, however, applications where these assumptions don't matter. While these assumption or changes in assumptions refer to the benchmark model in Obstfeld and Rogoff (1996), they can be transformed to be applied also in other types of macroeconomic models.

A small open economy version of the Calvo sticky price model is laid down in Galí and Monacelli (2005). They show how the equilibrium dynamics can be reduced to a simple representation in inflation and the output gap, using a canonical representation similar that of equations (2.4) and (2.5). The model is based on households maximizing their utility function and firms setting prices. They model a small open economy, while it is assumed that this economy is one of the continuum of economies, so that the monetary policy and the behavior of agents of this economy cannot alter significantly the development of the world economy. As they show, the natural levels of output and interest rates in the small open economy are a function not just of the domestic, but also of the foreign factors. They point to the presence of a trade-off between the stabilization of the nominal exchange rate and the balance of trade and also between the stabilization of the output gap and the domestic inflation. As the calibrated model shows, a policy of domestic inflation targeting stabilizes both domestic prices and the output gap but results in a larger volatility of the nominal exchange rate and the terms of trade relative to the exchange rate peg. A CPI based Taylor rule results in a dynamics of the variables that is somewhere between a domestic inflation based Taylor rule and an exchange rate peg.

2.3. Empirical studies of the Monetary Policy of the NBS

While the literature studying monetary policy and the transmission of the monetary policy is very broad and exhaustive, research has still remained constrained in case of Slovakia. The two most relevant papers in estimating the effects of monetary policy shocks on the Slovak economy are the abovementioned Jurašeková Kucserová (2009) and Horváth and Rusnák

(2009). In the first paper, sign restrictions are used to identify monetary policy shocks. The main findings include a drop in consumer prices and a rise of short term interest rate after a monetary policy tightening. The response of the nominal effective exchange rate is not so clear, there seems to be an initial depreciation followed by an appreciation, however smaller in size. The negative effect on output is obtained after a prior technology shock filter or the inclusion of output gap instead of real GDP. The underlying VAR includes real output, a price index (net inflation without fuel), nominal effective exchange rate and a short term interest rate (3 month BRIBOR). The author works with monthly data, monthly GDP is constructed based on the dependence of the quarterly GDP on quarterly receipts in selected branches of economy, while the estimated dependence was used to construct monthly data of GDP based on monthly receipts in these branches.

In the second paper, authors investigate the effects of domestic and euro area monetary policy shocks on the Slovak economy using a block-restricted VAR model. The monetary policy in the paper is characterized by a Taylor-type policy rule including the domestic output gap, inflation and the output gap, inflation and policy rate of the rest of the world. A smoothing parameter is also included in the monetary policy reaction function. According to their results, the monetary transmission mechanism functions as should be expected. After a domestic monetary policy tightening the inflation and the output decreases and the nominal exchange rate appreciates. They also conclude that the ECB's monetary policy shock affects the development of prices more than that of the NBS. This result doesn't appear in the response of the rest of the variables.

Also a Taylor-type monetary policy reaction function is estimated for six central and eastern European countries, including Slovakia, in Frömmel et al (2009). The Taylor rule applied by the authors includes the equilibrium real interest rate, the inflation and the deviation of the inflation from its target rate, the output gap and the exchange rate. However, the results for Slovakia are quite puzzling as there are no realistic inflation coefficients and the R-square is relatively low. Therefore the authors conclude that the specification may not match the real figures for Slovakia. Another conclusion is that changes of the central parity of the exchange rate while the country was in the ERM2 period caused that also the impact of the exchange rate on the reaction function are questionable.

These results are somewhat in contrast to the findings in Paez-Farrell (2007), where the author analyzes six different Taylor-type monetary policy rules for the Visegrad four countries. The basic Taylor rule and its non-linear extensions perform poorly in case of Slovakia. The preferred model results in an insignificant coefficient on output and a low response to the inflation, but a strong response to the exchange rate.

The basic Taylor rule for different central European countries including the inflation and the output gap is estimated also in Polovková (2009) using VEC modeling framework. The coefficients for the inflation and the output gap are of expected sign, however their value does not match the expectations and there is no adjustment of the policy rate that yields to the possibility of a misspecification of the policy rule.

As it can be concluded from this brief overview, the results are rather mixed, which is natural in case of an emerging small open economy. This outcome of the review can be related, e.g. to the different methodologies, but also to the different time period the authors worked with.

3. Monetary policy of the NBS with regard to the economic development in Slovakia

3.1. Development in 1993 – 1999

Year 1993 was the first year of the existence of the independent central bank. The main goal of the monetary policy was to maintain a sustainable level of inflation and the internal convertibility of the currency. There were several factors influencing the monetary policy, like the consequences of the split of the ČSFR, the common currency used until the beginning of February, new tax system, price liberalization, the overall economic development and the development of the balance of payments, in particular the development of the current account. NBS (1994)

During 1994 the NBS continued in conducting its monetary policy in a quantitative way, it means in controlling the money supply by controlling the M2 monetary aggregate indirectly by controlling the monetary base, which represents the consolidated balance of the NBS. The NBS used mainly transactions in Treasury bills and bills of exchange and the minimum reserve requirements. During the year, the NBS managed to lower the inflation rate (CPI inflation) from 25.1 % in 1993 to 10 - 13.2 % in 1994. NBS (1995)

In 1995, NBS continued in quantitative monetary policy with the main objective of maintaining internal and external stability of the domestic currency and supporting economic growth. Internal stability meant keeping consumer price dynamics within the limits of 8 – 10 % while the external stability was defined by the fixed exchange rate of the Slovak crown against a basket of currencies[6]. The fall in CPI inflation (which reached 7.2 % at the end of the year) enabled the bank to gradually lower its discount rate. NBS (1996)

Year 1996 was the third consecutive year of economic growth in Slovakia, with real GDP increasing by 6.9 % (in 1993 prices), CPI inflation falling from 6.4 % in January to 5.4 % in December and unemployment decreasing to 12.6 %. Although monetary policy was changing during the year, it may be characterized as expansive. Despite decreasing inflation and

[6] The basket of currencies consisted mainly of DEM and USD

growing domestic economy, the trade balance (as well as the balance of payments on current account) worsened and reached a level exceeding 10 % of GDP. NBS (1997)

Monetary policy in 1997 can be characterized as restrictive, with the aim of reducing the deficit of trade by regulating domestic demand through its impact on bank lending. The environment where the monetary policy took place can be characterized by growing GDP, although the pace of growth slowed down when compared to 1996; by upward trend in unemployment; by inflation with an upward trend, caused, inter alia, by increased import surcharge and by attack on the exchange rate of Slovak crown in May. The NBS managed to slow down the dynamics of bank lending to the real economy, to maintain the stability of the currency and to decrease the current account deficit. NBS (1998)

In 1998, economic development was influenced by several negative trends. Y-o-y GDP growth slowed down to 4.4 %, external imbalances increased, financial and non-financial institutions recorded a drop in profit compared to the previous year exceeding more than 50 % and the negative trends in the unemployment continued. Inflation reached 5.6 % in December. Increasing internal and external macroeconomic imbalances, the financial crisis in Russia and the fear of currency devaluation during the run-up to the parliamentary elections caused negative pressure on the domestic currency. The NBS decided, to keep the convertibility of the currency, to replace the fixed exchange rate regime by floating. The deutschmark, and, from 1999 the euro, had became the reference currency for monitoring and setting the exchange rate. NBS (1999)

Year 1999 can be characterized by conflicting tendencies of the economic development. As a result of the negative trends in the previous years and measures adopted by the Government to support economic recovery, GDP growth dropped to 1.9 %, inflation increased to 14.2 % in December and the unemployment reached 19.2 % at the end of the year. On the other hand, the deficit of trade decreased by more than 50 %. Monetary policy was influenced by the measures of the Government and the development of the domestic currency that reacted sensitively to signals from the real economy. The NBS intervened on the foreign exchange markets throughout the year several times to prevent the exchange rate from excessive volatility. The goal of the monetary policy was to eliminate secondary price infection in sectors with non-regulated prices. The development of the exchange rate and the trade balance enabled a policy aiming a decrease of the interest rates. NBS (2000)

3.2. Development in 2000 – 2008

In 2000, the NBS conducted its monetary policy in an environment of slowing price dynamics, increasing rate of economic growth and improving balance of current account as well as fiscal deficit. These circumstances allowed the NBS to shift from quantitative to qualitative monetary policy framework as a part of the harmonization of its monetary policy tools with those of the ECB. NBS started to set interest rates for overnight transactions with commercial banks in February and limit rates for two-week REPO tenders (the key rate) from May. The abovementioned positive development of key macroeconomic indicators allowed the NBS to gradually cut the interest rates during the year. The reduced ratio of required reserves, interventions on the foreign exchange markets and other factors increased surplus liquidity and thus further supported lending activity of banks. NBS (2001)

The rate of inflation and the economic growth continued in their positive trends also in 2001. This led to a further monetary easing in the first quarter of the year. However, due to the deepening deficit of the public finance and the trade deficit, there were no further interest rate adjustments in the remaining quarters of the year. Year 2001 was also marked with the restructuring of selected banks, continued privatization of state property and a moderate appreciation with low volatility of the Slovak koruna against the euro, its reference currency. The harmonization of the monetary policy instruments with those of the ECB continued, inter alia, in form of lowering ratio of required reserves. NBS (2002)

In the first half of 2002 the NBS responded to the deepening external economic imbalance, mainly to the growing trade deficit, by increasing its key interest rates. In the second half, due to decreasing risks associated with the development of economic imbalances and the appreciation of the Slovak koruna against the euro caused mainly by non-economic and speculative factors, the NBS gradually decreased the interest rates. Similarly to the previous years, the focus of the Bank remained on sterilization because of the excess liquidity within the banking sector. NBS (2003)

Trade balance recorded a favorable trend in 2003, which also led to an increasing rate of economic growth. The NBS actively intervened in the foreign exchange markets to moderate the nominal appreciation of the EUR/SKK exchange rate. The pressures for the appreciation were partially related to the existing positive interest rate differential. Despite increasing price level, the Bank lowered its key interest rates in the second half of the year. This was due to the fact that the inflation was determined mainly by increasing regulated prices and indirect taxes. The NBS was of the view that there were no demand-based pressures and thus the decreased interest rates were aimed at supporting economic growth and eliminating potential risks, connected mainly to the excessive appreciation of the exchange rate. NBS (2004)

In 2004, the monetary policy reflected positive trends in the economic growth, inflation, unemployment rates, balance of trade and the appreciation of the EUR/SKK exchange rate. Furthermore, on 1 May the Slovak Republic became a member of the European Union and a participant in EMU as a member state with derogation. The National Bank of Slovakia became a member of the European System of Central Banks. The Bank Board approved the Monetary Programme of the NBS up to 2008. The monetary policy strategy had been defined as inflation targeting in the conditions of ERM II. The HICP inflation target was set below 2.5% for end-2006 and below 2% for end-2007 and end-2008. The overall positive macroeconomic conditions and the appreciating trend of the exchange rate allowed the Bank to gradually cut its key interest rates. NBS (2005)

Economic growth continued to increase in 2005. Beside falling unemployment rate and positive developments in public finances, the inflation started to accelerate in the third quarter as a result of the increase of regulated prices. From the beginning of the year the NBS started to monitor the Harmonized Index of Consumer Prices as its inflation target. In the first quarter the NBS reacted to the excessive appreciation of the Slovak koruna against the euro with direct foreign exchange market interventions and lowering its key interest rates. In the second half of the year, the NBS started to communicate a need for monetary policy tightening in light of the wage growth and inflation expectations. NBS (2006)

The GDP growth in 2006 reflected, inter alia, the increase in the production capacity of the economy and the positive contribution from net exports. The inflation expectations were formed in the environment of moderating rise in oil and energy prices on the global markets. The Regulatory Office for Network Industries decided to make adjustments to regulated prices. During the year the risk of rising inflation in 2007 increased, therefore the Bank decided to tighten the monetary policy by increasing its key interest rates. Falling inflation and the lack of demand-based inflationary pressures prepared the floor for changing monetary policy settings in 2007. NBS (2007)

The first three quarters of 2007 were marked by favorable development of the domestic economy and slowing rate of inflation. In this environment given the strong appreciation of the Slovak koruna against the euro the NBS decided to decrease the key interest rates. Interventions on foreign exchange market were also needed to cope with the volatility and appreciation pressures on the exchange rate. NBS (2008)

2008 was the last year when the NBS conducted its monetary policy independently from the ECB. The EUR/SKK exchange rate appreciated during the year. The central rate of the Slovak koruna in ERM II was revaluated in May by more than 17.6 %. Key interest rates were left basically unchanged during the year. Starting in October the Bank Board gradually conducted a monetary policy easing to match the level of ECB key interest rate for one-week refinancing tenders. At the second half of the year, however, GDP growth started to decrease while the inflation reached its peak in September. NBS (2009)

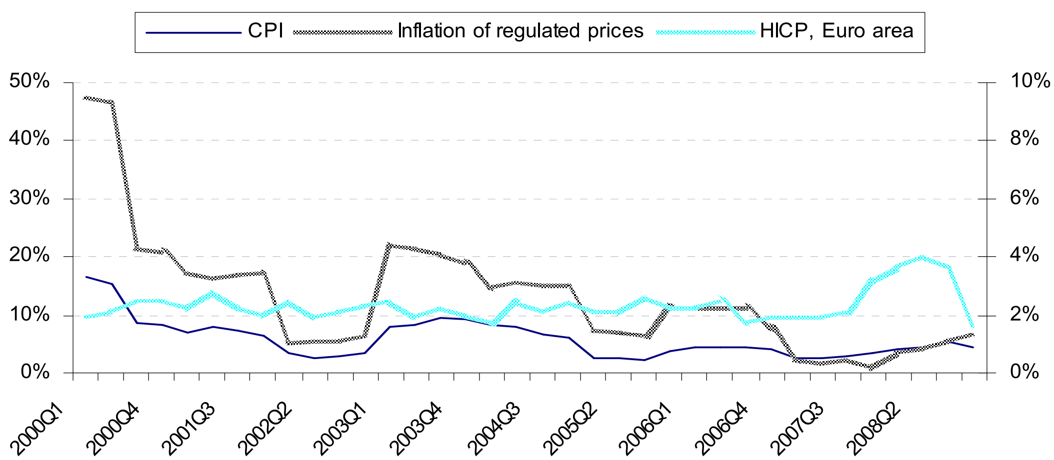


Figure 2 Inflation in Slovakia and the euro area
Source: Statistical Office of the Slovak Republic, Eurostat

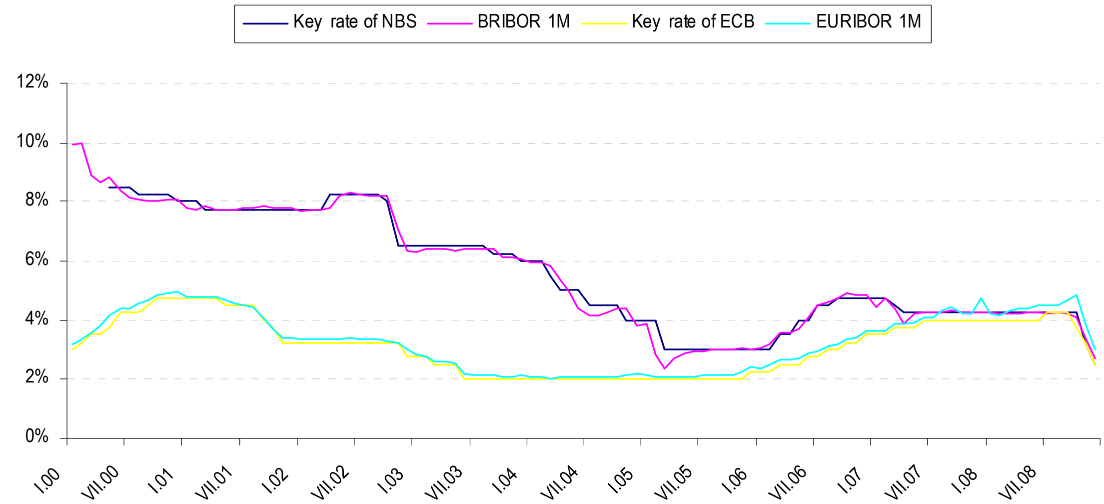


Figure 3 Key interest rates of the NBS and ECB and interbank interest rates of 1 month maturity
Source: National Bank of Slovakia, European Central Bank, www.euribor.org

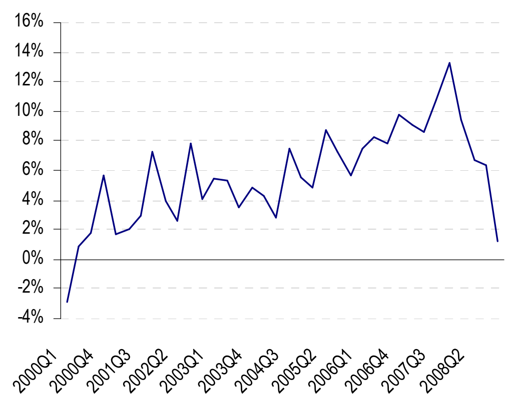


Figure 4 Real GDP growth of Slovakia
In constant prices of 2005, source: Statistical Office of the Slovak Republic

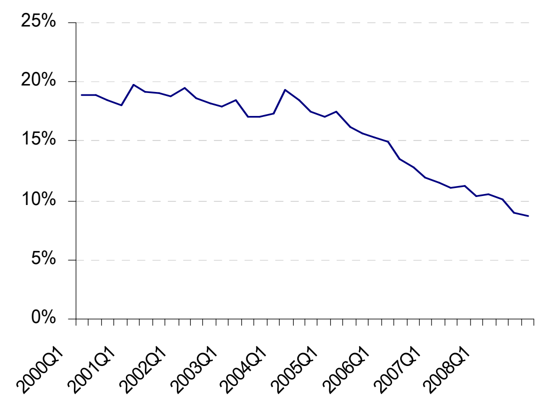


Figure 6 Unemployment rate in Slovakia
Source: Statistical Office of the Slovak Republic

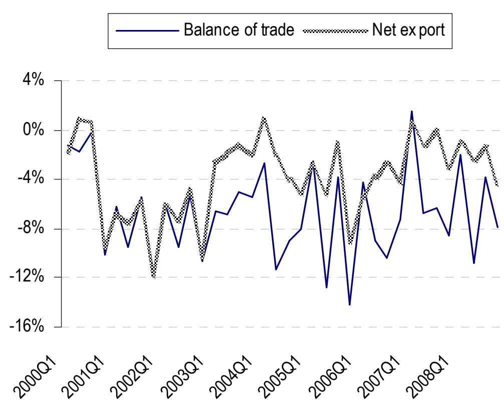


Figure 5 Balance of trade and net export as a percentage of GDP
Source: Statistical Office of the Slovak Republic

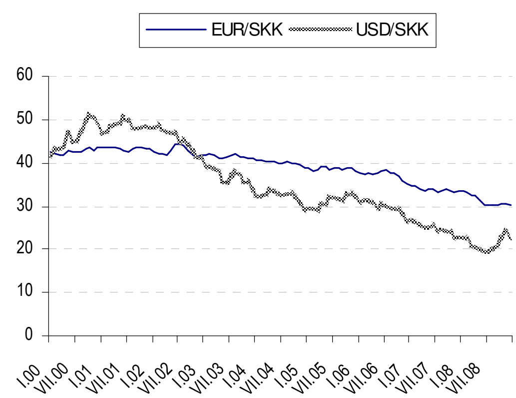


Figure 7 Exchange rate of the Slovak crown against the euro and the US dollar
Source: National Bank of Slovak

4. BVEC model of the monetary policy

4.1. Modeling framework and estimation methodology

For studying monetary policy transmission we use data from January 2000 up to December 2008. Our dataset includes domestic macroeconomic variables such as the inflation measured by CPI, the core inflation, real GDP growth, BRIBOR interbank rate of 1 month maturity, the EUR/SKK exchange rate, the current and capital account as a share in GDP and the balance of trade as a share in GDP; and different indicators of the global macroeconomic development such as the oil price index, S&P 500 stock index, EURIBOR interbank rate of 1 month maturity and the EUR/USD exchange rate.

There are several conditions stationary time series have to fulfill. One of the basic assumptions is that the series started sufficiently long ago to get near to their limiting mean value (see, e.g., Enders, 1995 or Gerlach-Kristen, 2003). As for Slovak macroeconomic time series there is no such a long history available, our assumption is that these series behave as non-stationary.

Table 1 Unit root tests of Slovak macroeconomic variables

	ADF		Phillips – Perron	
	Level	1st difference	Level	1st difference
BRIBOR 1M	0.562	0.000	0.001	0.000
CPI	0.123	0.000	0.115	0.000
CPI core	0.115	0.000	0.102	0.000
EUR/SKK y-o-y	0.037	0.000	0.131	0.000
log(EUR/SKK)	1.000	0.000	1.000	0.000
Balance of current and capital account	0.021	0.015	0.205	0.003
Balance of trade*	0.006	0.007	0.067	0.010
GDP growth*	0.696	0.000	0.151	0.134
GDP gap*	0.642	0.000	0.561	0.132
Balance of trade**	0.314	0.018	0.003	0.000
GDP growth**	0.081	0.000	0.081	0.000
GDP gap**	0.049	0.000	0.032	0.000

Respective p-values listed in table
In all cases an intercept was included into the test equation
* monthly data obtained by cubic interpolation
** quarterly data

This assumption is supported in nearly all cases also by unit root tests (Table 1), when at least one of the tests used does not reject the null hypothesis that the time series contain unit root. Therefore, mainly because of the short history, we dealt with the data as integrated of order 1 (This is also in line with the methodology used in Frömmel (2009)). There are two disputable cases, the GDP growth and the GDP gap, where the interpolated series are integrated at least of order two based on the results of the Phillips – Perron test. However, as they can be treated as integrated of order one based on the ADF test and they are integrated of order at most one using quarterly series (based on the results of both the ADF and PP test), we treat these data also as integrated of order 1.

When using non-stationary time series, it is reasonable to estimate VEC model first instead of VAR model as potential cointegrating relationships between the endogenous variables may contain important information the omitting of which can lead to misleading estimation results. Therefore, we chose to estimate a VEC model, the general form of which can be written as

$$\Delta y_t = A + \Pi y_{t-1} + \sum_{j=1}^{p} B_j \Delta y_{t-j} + Cexog_{t-1} + \varepsilon_t, t = 1,2,...,T \tag{4.1}$$

where y_t is an $n \times 1$ vector of endogenous variables, $exog_t$ is an $m \times 1$ vector of exogenous variables (trend and dummy variables may also included), A, B_i, Π and C are matrices of parameters to be estimated, $\varepsilon_t \sim N(0, \Sigma)$. For a better interpretation, the model can be written in a parameterized form:

$$\Delta y_t = A + \alpha \beta^T y_{t-1} + \sum_{j=1}^{p} B_j \Delta y_{t-j} + Cexog_{t-1} + \varepsilon_t \tag{4.2}$$

where α and β are $n \times r$ matrices of rank r. The rank refers to the number of cointegrating relationships between the endogenous variables, columns of matrix β represent the cointegrating vectors and the columns of matrix α are the adjustment parameters.

As there are only 9 years of observations when the NBS conducted qualitative monetary policy, it is convenient to use monthly data rather than quarterly. However, as there are time series that are available only with quarterly frequencies (GDP growth, balance of trade), we had to estimate/incorporate missing observations. As it was mentioned in Chapter 2, there are several approaches outlined how to deal with this problem in context of monetary policy analysis. A straightforward way is to interpolate data observed at lower frequencies, like in

Borys and Horváth (2008), where authors use quadratic interpolation. Bernanke et al (1997) uses a form of state space model to interpolate quarterly data of GDP. Jurášeková Kucserová (2009) constructs monthly GDP data based on the dependence of the quarterly data on quarterly receipts in selected branches of the economy.

We introduce a modified version of the Bayesian estimation method for mixed frequency VAR's (BMF estimator) published in Chiu et al (2011), that can be used to estimate VEC models with endogenous variables observed at mixed frequencies. In their paper, authors compare their method to the basic approach of using just the lowest frequency for the estimation (it means that in case of monthly and quarterly data quarterly observations are used for the estimation). They show that the BMF estimator produces more accurate estimates of model parameters. They also argue in favor of the BMF estimator compared to the Kalman filtering approach, as the former can perform better in case of irregular frequencies of the missing data. For further details, we refer to the paper.

This BMF estimator is an application of Bayesian Gibbs sampler that draws the parameters (the objects of interest) in every iteration from the conditional posterior distributions of these parameters given their initial value and prior distributions. In case of VEC model the parameters to be estimated (or the objects of interest) are the matrices $A, B_j, C, \alpha, \beta, \Sigma$ and the missing observations of the endogenous variables.

Let us denote $y_{o,t}$ the set of endogenous variables that are fully observed and $y_{u,t}$ the set of endogenous variables with missing observations, so

$$y_t = \begin{pmatrix} y_{o,t} \\ y_{u,t} \end{pmatrix}$$

For convenience, as it is also sufficient for the purposes of this paper, let's assume that there are only 2 frequencies the data are observed at (monthly and quarterly in our case). Let $\hat{y}_u$ denote the set of observed and sampled data, $\hat{y}_{u,\backslash t}$ all elements of $\hat{y}_u$ except of the t-th ones and $\hat{Y}^i$ the complete set of observed and sampled data at iteration *i*. Given the initial values of the parameters and their prior distributions, the *i*-th iteration consists of the following steps:

- Step 1: for $t = 1,...,T$, draw missing data $\hat{y}^i_{u,t}$ conditional on $y_o, \hat{y}^{i-1}_{u,\backslash t}, A^{i-1}, B^{i-1}_j, C^{i-1}, \alpha^{i-1}, \beta^{i-1}, \Sigma^{i-1}$, where $\hat{y}^{i-1}_{u,\backslash t}$ denote the set of the most recently updated missing variables. That is, if the missing variables are updated in a consecutive order, $\hat{y}_{u,\backslash t}^{i-1} = \left(\hat{y}_{u,1}^{i}, \hat{y}_{u,2}^{i}, ..., \hat{y}_{u,t-1}^{i}, \hat{y}_{u,t+1}^{i-1}, ..., \hat{y}_{u,T}^{i-1}\right)$. $A^{i-1}, B_j^{i-1}, C^{i-1}, \alpha^{i-1}, \beta^{i-1}, \Sigma^{i-1}$ are the latest draws of the parameter matrices.

- Step 2: draw β^i conditional on $\hat{Y}^i, A^{i-1}, B_j^{i-1}, C^{i-1}, \alpha^{i-1}, \Sigma^{i-1}$
- Step 3: draw $A^i, B_j^i, C^i, \alpha^i$ conditional on $\hat{Y}^i, \beta^i, \Sigma^{i-1}$
- Step 4: draw Σ^i conditional on $\hat{Y}^i, A^i, B_j^i, C^i, \alpha^i, \beta^i$

The detailed description of the drawing is as follows:

Step 1

We can rewrite (4.1) in the following form (for simplicity, let's assume p = 1):

$$\begin{pmatrix} \Delta y_{o,t} \\ \Delta y_{u,t} \end{pmatrix} = \begin{pmatrix} A_0 \\ A_u \end{pmatrix} + \begin{pmatrix} \Pi_{oo} & \Pi_{ou} \\ \Pi_{uo} & \Pi_{uu} \end{pmatrix} \begin{pmatrix} y_{o,t-1} \\ y_{u,t-1} \end{pmatrix} + \begin{pmatrix} B_{oo} & B_{ou} \\ B_{uo} & B_{uu} \end{pmatrix} \begin{pmatrix} \Delta y_{o,t-1} \\ \Delta y_{u,t-1} \end{pmatrix} + \begin{pmatrix} C_o \\ C_u \end{pmatrix} exog_{t-1} + \begin{pmatrix} \varepsilon_{o,t} \\ \varepsilon_{u,t} \end{pmatrix},$$

$$\begin{pmatrix} \varepsilon_{o,t} \\ \varepsilon_{u,t} \end{pmatrix} \sim N\left(0, \begin{pmatrix} \Sigma_{oo} & \Sigma_{ou} \\ \Sigma_{uo} & \Sigma_{uu} \end{pmatrix}\right), t = 1, 2, ..., T$$

Please recall that $\Pi = \alpha\beta^T$. Than, the conditional density for $\Delta y_{u,t}$ is multivariate normal of the form (see Appendix A for the detailed description):

$$p\left(\Delta y_{u,t} \middle| y_o, \hat{y}_{u,\backslash t}^{i-1}, \Theta^{i-1}\right) \sim N\left(V_1^{-1}V_2, V_2\right)$$

where Θ^{i-1} stands for all other variables and parameters except of $\Delta y_{u,t}, y_0, \hat{y}_{u,\backslash t}^{i-1}$,

$$V_1 = \Sigma^{uu} + B_{ou}^T \Sigma^{oo} B_{ou} + B_{ou}^T \Sigma^{ou} B_{uu} + B_{uu}^T \Sigma^{uo} B_{ou} + B_{uu}^T \Sigma^{uu} B_{uu} \quad (4.3)$$

$$\begin{aligned} V_2 = & -\Sigma^{uo}\left(\Delta y_{o,t} - A_o - \Pi_{oo} y_{o,t-1} - \Pi_{ou} y_{u,t-1} - B_{oo}\Delta y_{o,t-1} - B_{ou}\Delta y_{u,t-1} - C_o exog_{t-1}\right) \\ & + B_{ou}^T \Sigma^{oo}\left(\Delta y_{o,t-1} - A_o - \Pi_{oo} y_{o,t} - \Pi_{ou} y_{u,t} - B_{oo}\Delta y_{o,t} - C_o exog_t\right) \\ & + B_{ou}^T \Sigma^{ou}\left(\Delta y_{u,t+1} - A_u - \Pi_{uo} y_{o,t} - \Pi_{uu} y_{u,t} - B_{uo}\Delta y_{o,t} - C_u exog_t\right) \\ & + B_{uu}^T \Sigma^{uo}\left(\Delta y_{o,t+1} - A_o - \Pi_{oo} y_{o,t} - \Pi_{ou} y_{u,t} - B_{oo}\Delta y_{o,t} - C_o exog_t\right) \\ & + B_{uu}^T \Sigma^{uu}\left(\Delta y_{u,t+1} - A_u - \Pi_{uo} y_{o,t} - \Pi_{uu} y_{u,t} - B_{uo}\Delta y_{o,t} - C_u exog_t\right) \end{aligned} \quad (4.4)$$

$$\begin{pmatrix} \Sigma_{oo} & \Sigma_{ou} \\ \Sigma_{uo} & \Sigma_{uu} \end{pmatrix}^{-1} \equiv \begin{pmatrix} \Sigma^{oo} & \Sigma^{ou} \\ \Sigma^{uo} & \Sigma^{uu} \end{pmatrix}$$

It means that in each iteration, the unobserved data are sampled from a multivariate normal distribution. Sampling from normal distribution is straightforward, as algorithms are already available. In case of monthly and quarterly data, for the series with quarterly frequency we have observations in iteration i for $\hat{y}^i_{u,t}, t = 3l, l \in \mathrm{N}$. For $t \neq 3l$, we draw $\Delta\hat{y}^i_{u,t}$ and calculate $\hat{y}^i_{u,t}$ as

$$\hat{y}^i_{u,t} = \hat{y}^i_{u,t-1} + \Delta\hat{y}^i_{u,t}$$

for $t = 3l$ we calculate $\Delta\hat{y}^i_{u,t}$ simply as

$$\Delta\hat{y}^i_{u,t} = \hat{y}^i_{u,t} - \hat{y}^i_{u,t-1}$$

Step 2

For convenience, we can rewrite (4.2) in a condensed matrix format:

$$Y = X\Gamma + Z\beta\alpha^T + E \tag{4.5}$$

where Y, X, Z and E are $T \times n, T \times k, T \times n, T \times n$ matrices the *t*-th rows of which are given by (assuming p = 1): Δy^T_t, $(1, \Delta y^T_{t-1}, exog^T_{t-t})$, y^T_{t-1} and ε^T_t. In case an intercept is included in the cointegrating equation, than the *t*-th row of Z is given by $(y^T_{t-1}, 1)$. Γ, β and α are the respective parameters to be estimated. Let's suppose there is only one cointegrating equation, so that β is a vector ($n \times 1$ without and $n+1 \times 1$ with intercept). Cointegrating vector can be normalized for the first variable, so that $\beta_1 = 1$. In that case, the number of restrictions on the values of the cointegrating vector will be *r = 1*. Let's assume the prior density of the cointegrating vector has the form:

$p(\beta) \propto 1$

In this case, as it is shown in Bauwens and Lubrano (1994), the marginal posterior conditional distribution of the cointegrating vector has a form:

$$p(\beta | Y, X, Z) \propto \left|\beta^T W_0 \beta\right|^{l_0} / \left|\beta^T W_1 \beta\right|^{l_1}$$

where

$$M_X = I_T - X\left(X^T X\right)^{-1} X^T$$

$$W_0 = Z^T M_X Z$$

$$W_1 = Z^T M_X \left| I_T - Y\left(Y^T M_X Y\right)^1 Y^T \right| M_X Z$$

$$l_0 = (T - k - r - n)/2$$

$$l_1 = (T - k - r)/2$$

Given the assumption this is a kernel of a *1-1 poly-t* density that is "integrable and has finite moments of order equal to the order of overidentification of β" (Bauwens and Lubrano (1994), p.13).

In case the cointegrating vector contains an intercept, it is recommended that only the first n elements of β are estimated (except the first element which is restricted to 1). The last element corresponding to the intercept term can be calculated, e.g. as the mean value of the residuals from the cointegrating equation (and thus adjust the mean of the residuals to zero).

While the posterior conditional distribution of the cointegrating vector is known and is integrable drawing the elements of the cointegrating vector is not straightforward. Let denote the elements of β except of the *j*-th one as $\beta_{\backslash j}$. A possible way to draw the elements of the cointegrating vector is to estimate (calculate numerically) for each element of the vector its marginal posterior conditional distribution. We used in each iteration gridy Gibbs sampler to obtain $p\left(\beta_j^i \mid \beta_{\backslash j}^{i-1}, \hat{Y}^i, A^{i-1}, B_j^{i-1}, C^{i-1}, \alpha^{i-1}, \Sigma^{i-1}\right), j = 2,3,...,n$, where $\beta_{\backslash j}^{i-1}$ is the vector of the most recently updated coefficients, $\beta_{\backslash j}^{i-1} = \left(\beta_1^i, \beta_2^i, ..., \beta_{j-1}^i, \beta_{j+1}^{i-1}, ..., \beta_n^{i-1}\right)$. Having calculated the conditional posterior density it is possible to sample from this distribution using the cumulative distribution function and sampling from a uniform distribution on the unit interval.

Step 3

Let's take the equation for the *t*-th row of *Y* in (4.5):

$$Y_t = X_t \Gamma + Z_t \beta \alpha^T + \tilde{\varepsilon}_t \tag{4.6}$$

$$\tilde{\varepsilon}_t \sim N\left(0, \tilde{\Sigma}\right)$$

where

$$Y_t = \Delta y_t^T,\ X_t = \left(1, \Delta y_{t-1}^T, exog_{t-1}^T\right),\ Z_t = y_{t-1}^T,\ \tilde{\varepsilon}_t = \varepsilon_t^T.$$

When estimating coefficient matrices Γ and α and the variance-covariance matrix $\tilde{\Sigma}$, it is important to notice that conditional on the estimated values of β (4.6) becomes a linear model. It means, we can rewrite (4.6) as

$$Y_t = X_t\Gamma + \tilde{Z}_t\alpha^T + \tilde{\varepsilon}_t = \hat{X}_t\hat{B} + \tilde{\varepsilon}_t$$

where

$$\tilde{Z}_t = Z_t\beta, \hat{X}_t = \left(X_t, \tilde{Z}_t\right) \text{and } \hat{B} = \left(\Gamma^T, \alpha\right)^T \tag{4.7}$$

Finally, based on (4.7) we can rewrite (4.5) in a compact form as

$$Y_t = \tilde{X}_t\tilde{B} + \tilde{\varepsilon}_t, t = 1, 2, ..., T \tag{4.8}$$

where

$$\tilde{X}_t = I_n \otimes \hat{X}_t \quad \text{and } \tilde{B} = vec\left(\hat{B}\right),$$

$\tilde{X}_t$ is a $n \times n(1+n+r+h)$ matrix, where r is the rank of β and α, h is the number of exogenous variables included in the model and $\tilde{B}$ is a $n(1+n+r+h)\times 1$ vector of parameters. Let's assume an independent Normal-inverse Wishart prior for (4.8):

$$p\left(\tilde{B}\right) \sim N\left(\mu_\Omega, \Sigma_\Omega\right)$$

$$p\left(\tilde{\Sigma}\right) \sim iW\left(\Psi, m\right)$$

where Ψ is the mean and *m* is the degrees of freedom for the variance-covariance matrix. The conditional posterior distribution for $\tilde{B}$ than has the form (see, e.g., Chiu et al, 2011):

$$p\left(\tilde{B}\middle|Y, \tilde{X}, \tilde{\Sigma}\right) \sim N\left(\left(\Sigma_\Omega^{-1} + \sum_{t=1}^{T}\tilde{X}_t^T\tilde{\Sigma}^{-1}\tilde{X}_t\right)^{-1}\left(\Sigma_\Omega^{-1}\mu_\Omega + \sum_{t=1}^{T}\tilde{X}_t^T\tilde{\Sigma}^{-1}Y_t\right), \left(\Sigma_\Omega^{-1} + \sum_{t=1}^{T}\tilde{X}_t^T\tilde{\Sigma}^{-1}\tilde{X}_t\right)^{-1}\right)$$

As the conditional posterior of $\tilde{B}$ has also normal distribution, drawing from this distribution in *i*-th iteration is straightforward.

Step 4

Based on the prior described in Step 3 the posterior conditional distribution of the variance-covariance matrix has the form (see, e.g. Chiu et al (2011)):

$$p\left(\tilde{\Sigma}\middle|Y, \tilde{X}, \tilde{B}\right) \sim iW\left(\Psi + \sum_{t=1}^{T}\left(Y_t - \tilde{X}_t\tilde{B}\right)\left(Y_t - \tilde{X}_t\tilde{B}\right)^T, T + m\right) \tag{4.9}$$

The posterior conditional distribution is also inverse Wishart, and as algorithms for drawing from this distribution are already available, drawing from (4.9) is also straightforward.

4.2. Model specification and estimation results

In this section we build up a small macroeconomic VEC model for studying the monetary policy reaction function and the effects of monetary policy shocks. Rather then specifying an exact Taylor rule for describing the monetary policy of the NBS ex ante, we estimated different specifications and checked whether they are in line with the expectations and fulfill the conditions for the monetary policy reaction function.

Dataset

It is usually not straightforward to determine which macroeconomic variables to include when estimating the monetary policy reaction function. Based on the results in Polovková (2009) it seems that a standard Taylor rule does not fit the data. Results in Frömmel at all (2009) and Horváth and Rusnák (2009) suggest that beside the exchange rate there are also foreign factors that impact the setting of the key interest rates of the NBS. Following these papers and the available information about the monetary policy described in Chapter 3 our dataset includes domestic macroeconomic variables and variables describing the macroeconomic development potentially impacting also the Slovak economy.

As one of the goals is to estimate the reaction function, the NBS's policy rate should be included; however, when estimating a VAR or VEC model, it is better to use an approximation of this policy rate. A possible way is to approximate the policy rate by a short term interbank rate, as a strong reaction of the Slovak interbank rates of shorter maturity to the changes of the NBS key interest rate can be documented (see, e.g. Klacso, 2008 or NBS, 2008b). Therefore, we included the Slovak interbank rate of 1 month maturity ($BRIBOR1M_t$)[7]. The set of domestic endogenous variables consists also of the year-on-year percentage change of the real GDP (GDP_t), the output gap (GDP_gap_t) estimated by detrending the monthly approximation of the real GDP growth rate using HP filter (with $\lambda = 14\,400$), the consumer

[7] Another advantage of approximating the key policy rate by the interbank rate is that the expectations of the banking sector about the future development of the key rate and possible assimetric reactions to the increase or decrease of the policy rate are to some extent captured.

price index (*CPI_t*), the core inflation (*CPI_core_t*) and the inflation of regulated prices (*CPI_reg_t*) all as a year-on-year percentage change of the respective price index; the EUR/SKK[8] exchange rate (the year-on-year changes of the exchange rate in percentages, *EUR/SKK_ch_t* and also the natural logarithm of the exchange rate *EUR/SKK_ln_t*), the balance of trade as a share in nominal GDP (year-on-year changes in percentage points, *BTA_t*), and the balance of current and capital account as a share in nominal GDP (year-on-year changes in percentage points, *$BCCA_t$*).

The set of other variables, that represents the set of exogenous variables, includes EURIBOR interbank interest rate of 1 month maturity in percentages (*$EURIBOR1M_t$*) to capture the monetary policy decisions of the ECB and their impact on the Slovak economy, the EUR/USD exchange rate (year-on-year changes, *EUR/USD_ch_t* and natural logarithm, *EUR/USD_ln_t*), the index of Brent crude oil 1 month Forward per barrel (in natural logarithms, *OIL_t*) and the Standard & Poors 500 stock index (in natural logarithms, *$SP500_t$*) as an indicator of the global economic and fiscal cycle and thus the foreign demand. As the monetary and fiscal policy should be independent from each other and the aim of the paper is not to study the fiscal policy, the inflation of regulated prices is considered to be an exogenous variable that affects the inflation rate.

Data about the Slovak economy (GDP, balance of trade, balance of current and capital account and the price indices) were taken from the Statistical Office of the Slovak Republic, the BRIBOR interbank rate and the EUR/SKK and EUR/USD exchange rates were taken from the database of the National Bank of Slovakia, data about the EURIBOR interbank rate were taken from www.euribor.org, other indices were taken from Bloomberg, provided under the License agreement (2012). In case the year-on-year changes (in percentage or percentage points) enter the equation, data were not seasonally adjusted. In other cases, as the seasonally adjustment[9] of the data does not alter the results significantly and there is not a significant difference in the seasonally adjusted and seasonally not adjusted data, we present here just models with seasonally not adjusted data.

[8] While the standard notation for the exchange rate is EUR/SKK, it expresses how many Slovak crowns can be purchased for €1. It means, when the Slovak koruna appreciates the EUR/SKK exchange rate decreases.
[9] To seasonally adjust data we used Census X12 with additive method and the default seasonal and trend filter in EViews 7.

Model specification

As one of the goals of the thesis is to study the possible impact of an independent monetary policy on the Slovak economy in the period 2009 and 2010 (when the global economic recession transmitted into a sharp decline of the Slovak economy), the monetary policy reaction function of the NBS has to be estimated. It is however not straightforward which macroeconomic variables entered the NBS's reaction function in the period 2000 – 2008. Therefore, we defined several specifications of the estimated VEC model where apart from the BRIBOR interbank rate (which represents the policy rate) different Slovak macroeconomic variables were included as endogenous variables (Table 2)[10]. These endogenous variables represent the set of the variables that potentially entered the reaction function.

Table 2 Model specification – endogenous variables

	y_t				
Model 1	$BRIBOR1M_t$	CPI_t	EUR/SKK_ch_t	BTA_t	GDP_t
Model 2	$BRIBOR1M_t$	CPI_t	EUR/SKK_ln_t	BTA_t	GDP_t
Model 3	$BRIBOR1M_t$	CPI_core_t	EUR/SKK_ch_t	BTA_t	GDP_t
Model 4	$BRIBOR1M_t$	CPI_core_t	EUR/SKK_ln_t	BTA_t	GDP_t
Model 5	$BRIBOR1M_t$	CPI_core_t	EUR/SKK_ch_t	$BCCA_t$	GDP_t
Model 6	$BRIBOR1M_t$	CPI_core_t	EUR/SKK_ln_t	$BCCA_t$	GDP_t
Model 7	$BRIBOR1M_t$	CPI_core_t	EUR/SKK_ch_t		GDP_t
Model 8	$BRIBOR1M_t$	CPI_core_t	EUR/SKK_ln_t		GDP_t
Model 9	$BRIBOR1M_t$	CPI_t			GDP_gap_t
Model 10	$BRIBOR1M_t$	CPI_core_t			GDP_gap_t
Model 11	$BRIBOR1M_t$	CPI_core_t	EUR/SKK_ln_t		GDP_gap_t
Model 12	$BRIBOR1M_t$	CPI_t	EUR/SKK_ln_t		GDP_gap_t
Model 13	$BRIBOR1M_t$	CPI_core_t	EUR/SKK_ln_t	BTA_t	GDP_gap_t
Model 14	$BRIBOR1M_t$	CPI_t	EUR/SKK_ln_t	BTA_t	GDP_gap_t
Model 15	$BRIBOR1M_t$	CPI_core_t	EUR/SKK_ch_t	BTA_t	GDP_gap_t
Model 16	$BRIBOR1M_t$	CPI_t	EUR/SKK_ch_t	BTA_t	GDP_gap_t
Model 17	$BRIBOR1M_t$	CPI_core_t	EUR/SKK_ch_t		GDP_gap_t
Model 18	$BRIBOR1M_t$	CPI_t	EUR/SKK_ch_t		GDP_gap_t

[10] The exogenous variables included in the model consist of the inflation of regulated prices, the EURIBOR interbank rate, the oil price index, the S&P 500 stock index and the EUR/USD exchange rate all with one lag (in case the CPI is included in the VEC model the regulated prices are included also with no lag as they have a direct impact on the inflation).

Johansen cointegration tests confirmed the existence of a cointegrating relationship between the endogenous variables, as in all cases at least one of the tests pointed to the existence of such a relationship (Table 3). Despite the fact that it is hard to decide the number of cointegrating vectors we assume one cointegrating relationship in all cases[11]. Following Eleftheriou (2009) we interpret this cointegrating relationship as the monetary policy reaction function that represents the optimal value of the policy rate in relation to the value of other endogenous variables. Therefore, in all models the cointegrating vector is normalized such that the coefficient for the interbank rate is equal to one.

Table 3 Johansen cointegration tests

	Trace test					Max eigenvalue test				
	None *	At most 1 *	At most 2	At most 3	At most 4	None *	At most 1 *	At most 2	At most 3	At most 4
Model 1	0.000	0.024	0.121	0.413	0.379	0.009	0.106	0.140	0.407	0.379
Model 2	0.001	0.038	0.339	0.855	0.734	0.010	0.047	0.184	0.811	0.734
Model 3	0.000	0.066	0.394	0.557	0.417	0.001	0.076	0.430	0.548	0.417
Model 4	0.002	0.048	0.383	0.748	0.589	0.016	0.053	0.285	0.709	0.589
Model 5	0.000	0.035	0.578	0.739	0.560	0.001	0.014	0.527	0.705	0.560
Model 6	0.004	0.056	0.519	0.693	0.275	0.040	0.036	0.488	0.763	0.275
Model 7	0.036	0.782	0.840	0.616		0.006	0.718	0.810	0.616	
Model 8	0.081	0.918	0.830	0.378		0.009	0.928	0.857	0.378	
Model 9	0.001	0.103	0.319			0.003	0.098	0.319		
Model 10	0.003	0.784	0.437			0.001	0.788	0.437		
Model 11	0.084	0.921	0.736	0.152		0.009	0.967	0.898	0.152	
Model 12	0.026	0.515	0.784	0.205		0.012	0.410	0.897	0.205	
Model 13	0.001	0.034	0.326	0.676	0.165	0.021	0.043	0.264	0.834	0.165
Model 14	0.000	0.006	0.193	0.785	0.216	0.015	0.011	0.098	0.891	0.216
Model 15	0.000	0.033	0.250	0.464	0.582	0.000	0.062	0.295	0.409	0.582
Model 16	0.000	0.004	0.021	0.361	0.448	0.008	0.090	0.020	0.333	0.448
Model 17	0.017	0.620	0.770	0.798		0.004	0.557	0.705	0.798	
Model 18	0.008	0.269	0.466	0.475		0.009	0.321	0.433	0.475	

Respective p-values listed in table
An intercept was included in the cointegrating equation and VAR in all cases
We included one lag of the endogenous variables in all cases

[11] In case of one cointegrating vector a possible interpretation is that the cointegrating relationship represents the monetary policy reaction function. In case we assume two cointegrating vectors the economic interpretation is more challenging. The possibility of two cointegrating vectors is not rejected in case the indicator of the economic imbalance is included in the model. Therefore, the potential interpretation could be that one vector represents the monetary policy reaction function without the indicator of the economic imbalance and the second vector represents the relationship between this indicator and the other endogenous variables.

The set of endogenous variables potentially entering the monetary policy reaction function includes the inflation (CPI or the core inflation), the indicator of the economic development (GDP or the GDP gap), the EUR/SKK exchange rate (in levels or the year-on-year changes capturing the dynamics of the exchange rate) and the indicator of the economic imbalances (the balance of trade or the current and capital account).

Monetary policy easing should take place in an environment of decreasing inflation, appreciating currency and improving trade balance or balance of current and capital account (see Chapter 3). Therefore, we expect a negative sign of the coefficient for the inflation and the exchange rate and positive sign of the coefficient for the trade balance and current and capital account. If the GDP growth is in line with the expectations, a positive growth can be followed by monetary policy easing, however a potential overheating or extensive GDP growth can be followed by monetary policy tightening. Therefore, we expect a negative sign for the output gap while for the growth rate of the GDP there are no ex ante expectations regarding the sign of the coefficient[12]. To interpret the cointegrating equation as the monetary policy reaction function it is necessary for the adjustment coefficient for the interbank rate to have the right sign, so that if there is a deviation from the cointegrating relation the policy rate reacts in the expected way.

Estimation results

The estimated coefficients of the cointegrating vectors and the related adjustment coefficients are summarized in Table 4 and table 5[13]. As we are interested also in the possible impact of an independent monetary policy on the Slovak economy, in the first eight specifications it is the real GDP growth rate that enters the monetary policy reaction function.

In the first four specifications all of the possible endogenous variables are included in the model (and thus in the reaction function). As the adjustment coefficient for the interbank rate is negative in all cases, it is indeed possible to interpret the cointegrating equation as the monetary policy reaction function. Comparing the estimated coefficients of vector β for the two price indices it seems that it is more the core inflation than the CPI that entered the

[12] The expected signs are for the cointegrating vector β in form such that $\beta^T y = 0$.
[13] For the estimation we used 20 000 iterations with the first 10 000 iterations having as burn-in. The parameters for the prior distributions were taken from a ML estimation of the VEC models using monthly approximation of quarterly data calculated by cubic interpolation. The initial estimations were conducted in EViews, all other estimations were conducted in MATLAB®

reaction function in the period under review, having an opposite sign for the coefficients in case of the CPI inflation than expected. The exchange rate enters the reaction function with the expected sign in all cases (both using the level or the year-on-year change of exchange rate). The balance of trade enters the cointegrating equation with the expected sign only in case of Model 3.

When using the current and capital account as an indicator of economic imbalance instead of the balance of trade the estimations are worse (Model 5 and 6). In both cases the adjustment coefficient for the interbank rate has opposite sign than expected. Moreover, in Model 5 neither the coefficient for the inflation nor the coefficient for the exchange rate enters the cointegrating equation with the expected sign.

In specification 7 and 8 only the inflation, the exchange rate and the GDP growth rate enters the cointergating equation, so it is a more standard form of the reaction function not considering the possible impact of the development of the economic imbalance on the base rate of the NBS. In both specifications all of the endogenous variables enter the reaction function with the expected sign, but the adjustment coefficient for the interbank rate has the expected sign only Model 8. Therefore, it seems that these models are sensitive to the specification of the exchange rate.

In the remaining specifications (Model 9 – Model 18) it is the output gap that enters the monetary policy reaction function. This specification is more in line with the literature estimating a Taylor-type monetary policy rule.

Specifications 9 and 10 represent the basic Taylor rule with only the inflation and the output gap entering the reaction function. In both cases the coefficients of the cointergrating vectors for the macroeconomic variables have the expected sign, but the adjustment coefficient for the interbank rate is negative only in Model 10. It supports the findings of the previous models that it is more likely that the core inflation entered the reaction function instead of the inflation measured by CPI.

Models 11, 12 and 17 and 18 are similar to Models 7 and 8 using the output gap instead of the GDP growth and considering also the CPI (not just the core inflation). In all cases the variables enter the reaction function with the expected sign (except the exchange rate in Model 18). Also the adjustment coefficient for the interbank rate has a negative value in all cases but Model 18.

Table 4 Estimated coefficients of cointegrating vectors

	BRIBOR1M	*CPI*	*CPI_core*	*EUR/SKK_ch*	*EUR/SKK_ln*	*BTA*	*BCCA*	*GDP*	*GDP_gap*
Model 1	1.0000	21.3659		-0.1393		-3.5734		19.0678	
Model 2	1.0000	19.2609			-1.4290	-3.6960		19.2726	
Model 3	1.0000		-0.1692	-0.1739		0.0530		0.2997	
Model 4	1.0000		-1.0428		-17.5903	-0.0822		-0.2326	
Model 5	1.0000		0.2198	0.1195			0.6697	0.4364	
Model 6	1.0000		-1.0040		-18.5601		-0.4069	-0.1566	
Model 7	1.0000		-0.6551	-0.5058				-0.0460	
Model 8	1.0000		-1.3273		-17.2139			-0.4617	
Model 9	1.0000	-0.8791							-1.1412
Model 10	1.0000		-0.2934						-0.8306
Model 11	1.0000		-0.7926		-7.9981				-0.8077
Model 12	1.0000	-0.5814			-2.4400				-0.8238
Model 13	1.0000		-0.7868		-12.7371	-0.1150			-0.4161
Model 14	1.0000	-0.6907			0.8432	0.1352			-1.0494
Model 15	1.0000		-0.7672	-0.5538		-0.3572			-0.3234
Model 16	1.0000	-0.5937		-0.1932		-0.1315			-0.9046
Model 17	1.0000		-0.5780	-0.3607					-0.6841
Model 18	1.0000	-0.7170		0.0275					-0.8774

Table 5 Estimated adjustment coefficients

	BRIBOR1M	*CPI*	*CPI_core*	*EUR/SKK_ch*	*EUR/SKK_ln*	*BTA*	*BCCA*	*GDP*	*GDP_gap*
Model 1	-0.0011	0.0011		-0.0055		0.0019		-0.0721	
Model 2	-0.0002	0.0012			-0.0001	-0.0074		-0.0547	
Model 3	-0.0008		-0.0018	0.0051		0.0088		0.0132	
Model 4	-0.0149		0.0026		0.0005	0.1162		0.1352	
Model 5	0.0025		-0.0011	0.0109			0.1910	0.0255	
Model 6	0.0021		0.0186		-0.0003		0.3892	0.1320	
Model 7	0.0009		0.0019	0.0038				-0.0371	
Model 8	-0.0080		-0.0226		-0.0013			0.1184	
Model 9	0.0000	-0.0015							0.1068
Model 10	-0.0033		-0.0058						0.0629
Model 11	-0.0052		-0.0032		0.0001				0.0701
Model 12	-0.0003	-0.0005			0.0001				0.0718
Model 13	-0.0061		-0.0031		0.0002	0.1612			0.1528
Model 14	0.0203	0.0256			-0.0001	0.0140			0.0298
Model 15	0.0372		0.0078	-0.1328		0.1973			-0.0026
Model 16	0.0020	0.0152		0.0007		-0.0098			0.0701
Model 17	-0.0018		-0.0033	-0.0079					0.0469
Model 18	0.0021	0.0004		-0.0303					0.0745

Models 13 – 16 are a modified version of Models 1 – 4 using the output gap instead of the GDP growth. The inflation, exchange rate and the output gap enter the reaction function with the expected sign nearly in all cases; the coefficient for the balance of trade has a positive value just in Model 14. However, the adjustment coefficient for the interbank rate is negative only in case of Model 13.

To sum up, the estimated coefficients of cointegrating vectors and the related adjustment coefficients point to a relatively robust result: the negative sign of the adjustment coefficient for the interbank rate confirms the interpretation of the cointegrating vector as the monetary policy reaction function and it seems that it is more the core inflation than the inflation measured by the CPI that entered the monetary policy reaction function. Including the exchange rate improves the estimations, especially when the CPI instead of the core inflation enters the cointegrating equation. When the GDP growth is included into the reaction function, the indicator of economic imbalances seems to improve the estimation. When the output gap is used instead of the GDP growth rate, this indicator seems to be unnecessary. A potential interpretation of this result can be that the output gap contains some information about the development of the economic imbalance and so there is no need to include another variable to capture this development.

Another way to evaluate the estimated models is to compare the sum of squared residuals and thus the ability of the models to capture the development of the endogenous variables in the period of 2000 – 2008 (Figure 8). The results don't point to a single model shoving better performance than the others.

The sum of squared residuals for the interbank rate are comparable across all specifications, which means that including the output gap instead of the GDP growth rate does not improve the estimation. An interesting result is that the development of the yearly change of the exchange rate is captured better in case the GDP growth is included. The development of the GDP is captured better when the CPI is included instead of the core inflation. A possible interpretation is that the CPI includes more information about the development of the real economy than the core information. However, in case of the output gap there is no significant difference between the specifications including CPI and core inflation. An interesting result is that in Models 14 and 15 the development of the output gap is captured better than in other specifications. Therefore, it seems that while the indicators of the economic imbalances are not able to improve the interpretation of the reaction function including the output gap, they can improve the ability of the model to capture the development of the output gap.

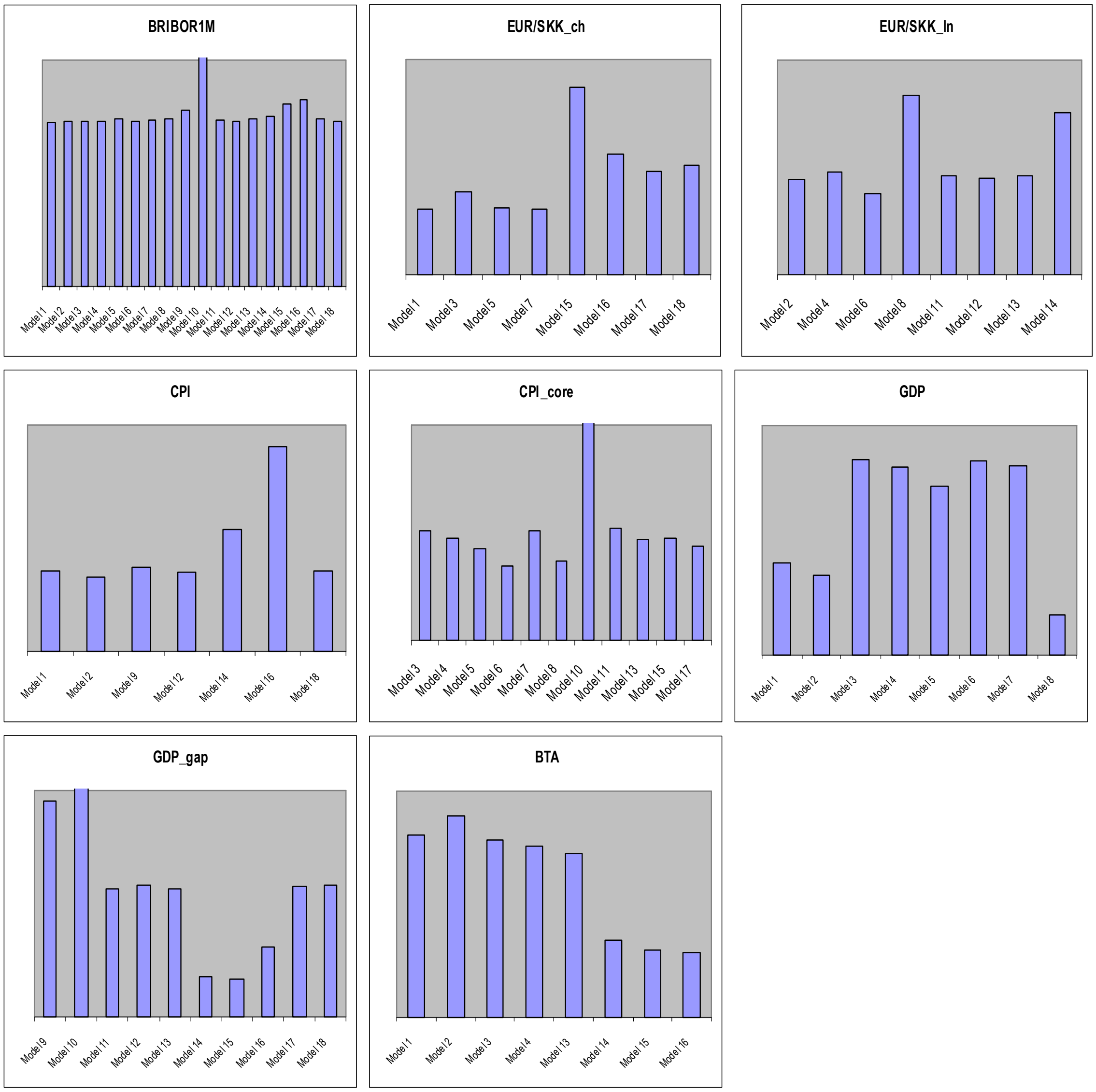


Figure 8 Sum of squared residuals

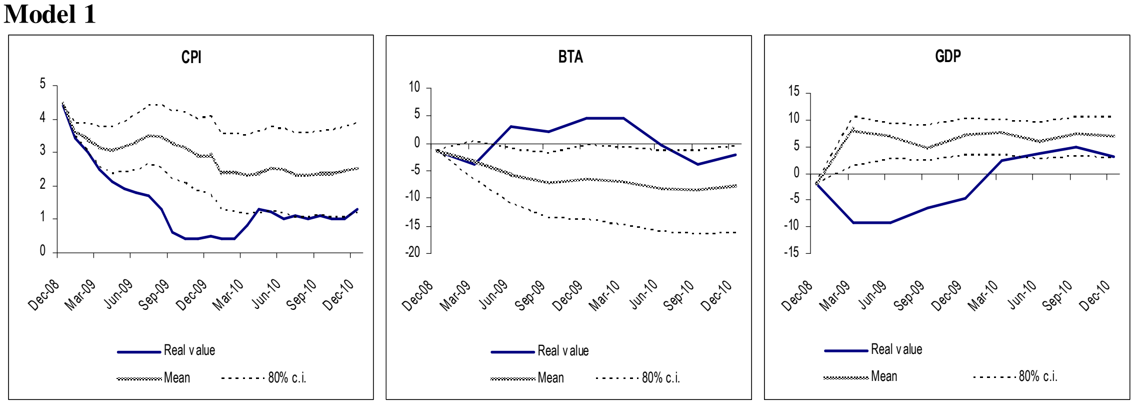
The results are more interesting when comparing the forecasting ability of the models (Figure 9)[14]. As Slovakia became a member of the euro area from the beginning of 2009, the monetary policy decisions were delegated to the ECB and the euro became the domestic currency of the country. Therefore, we estimated only the rate of inflation, the indicator of the economic imbalance and the GDP growth, while the interbank interest rate was replaced by the EURIBOR interbank rate and the EUR/SKK exchange rate was kept constant and equal to

[14] For simplicity, the forecasts are shown only for models where the cointegrating equation can be interpreted as the monetary policy reaction function, it means where the adjustment coefficient for the interbank rate is negative.

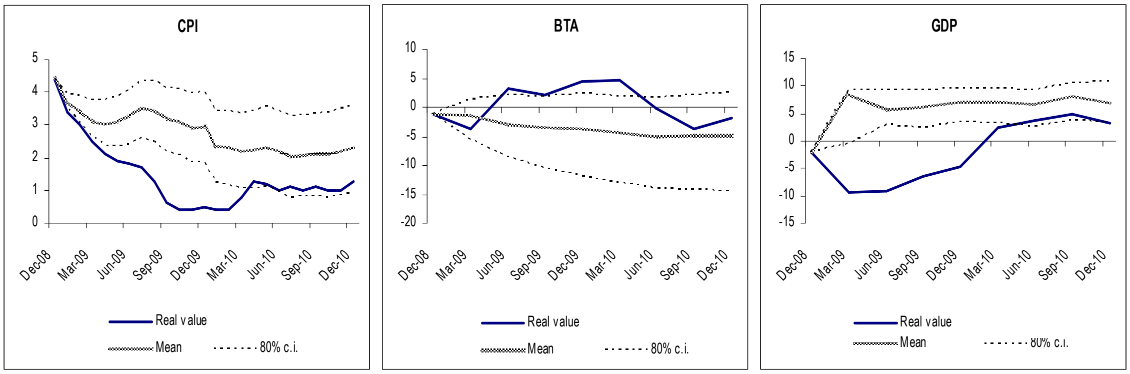
its value at the end of 2008. We estimated the development of the remaining 3 endogenous variables for years 2009 and 2010, when the impact of the economic recession culminated in Slovakia. A basic result of the forecasts is that all of the models overestimate the inflation up to March 2010. It seems that during this period the inflation was on its historically low levels due to external factors that are not included in the models (see, e.g., NBS, 2010). Regarding the other two variables, the best estimates are clearly given by Model 4. In all other cases the real values of the variables were out of the coverage intervals or the coverage intervals were to wide/unclear. In case of Model 4, not just the development of the balance of trade in 2009 and 2010 is predicted relatively well, but also the drop of the GDP at the beginning of the period and the gradual increase from the second half of 2009 is captured. The drop of the GDP or the output gap is captured nearly in all specifications, supporting the inclusion of the oil price index and the stock index as a possible indicator of the external demand. Comparison of Models 3 and 4 points to a conclusion that it is more the level of the exchange rates (the EUR/SKK and the EUR/USD) that can help to predict the development of the domestic economy than its dynamics. The increase of the output gap is also captured in the models (Model 10, 11, 12 and 13) to a given extent, but the coverage intervals point in favor of Model 4.

To sum up, based on the estimated cointegrating vectors, the adjustment coefficients, the sum of squared residuals and the forecasting ability of the models, it seems that Model 4 outperforms other specifications. It means we assume that it was the core inflation, the level of the EUR/SKK exchange rate, the balance of trade and the real growth rate of the GDP that affected the monetary policy the most (from the set of endogenous domestic variables) in 2000 – 2008.Therefore, in the remaining parts of the chapter the results are based on Model 4.

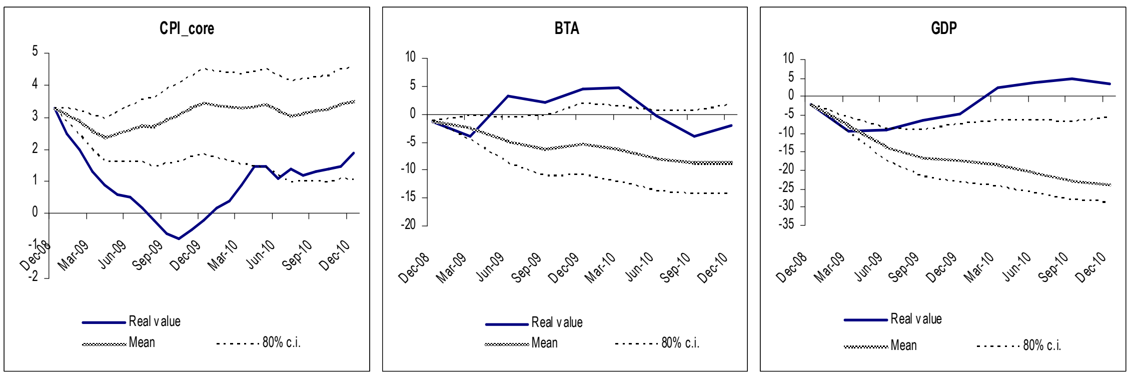
Model 1



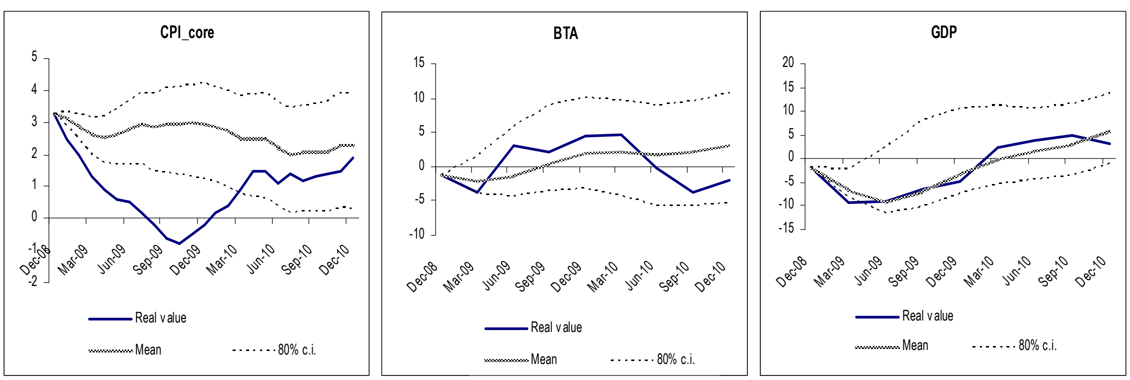
Model 2



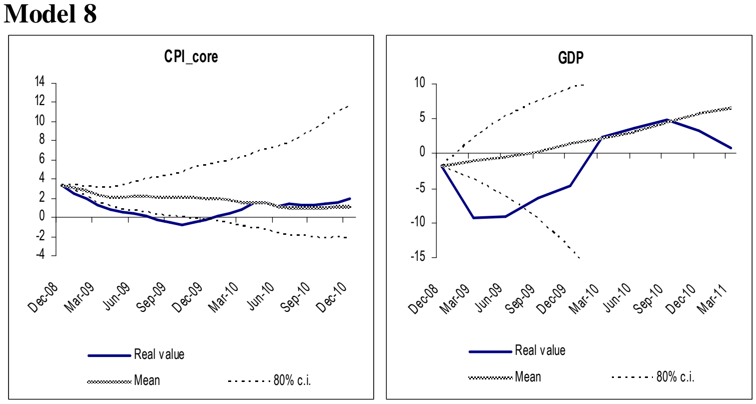
Model 3



Model 4



Model 8



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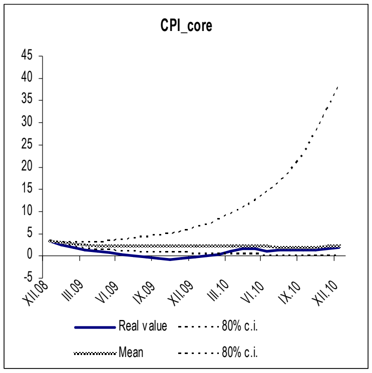

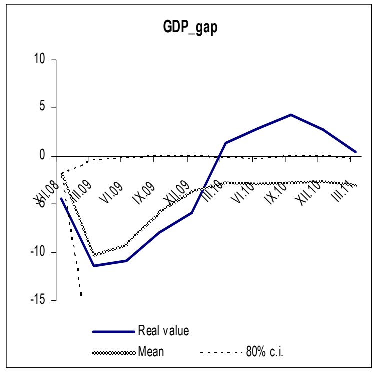

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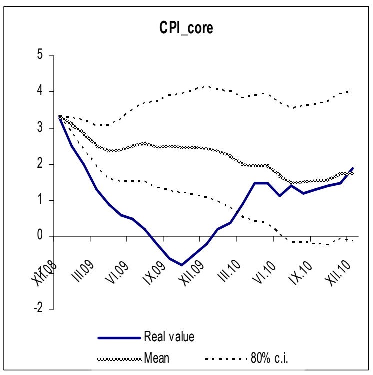

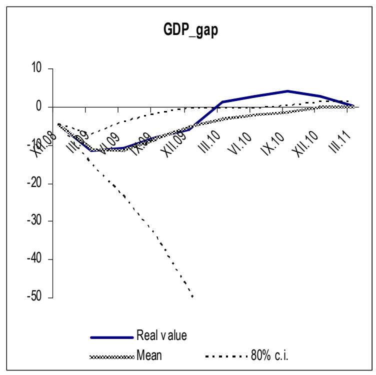

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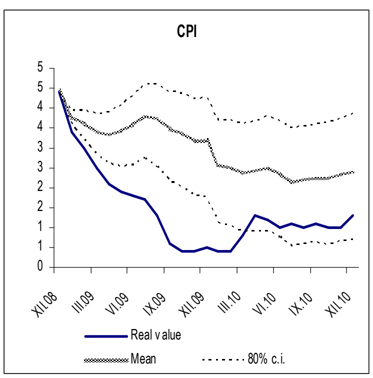

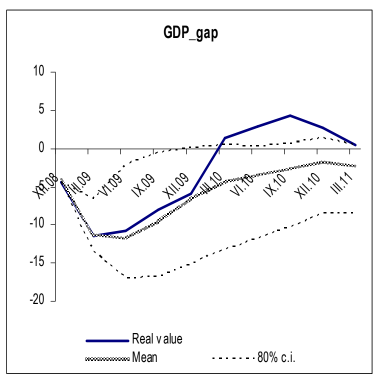

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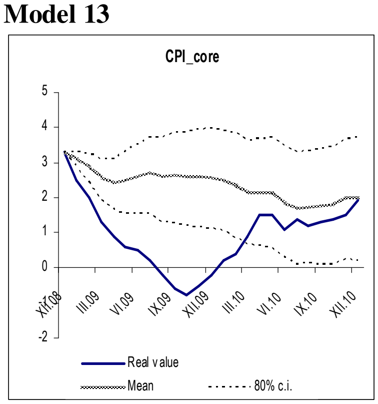
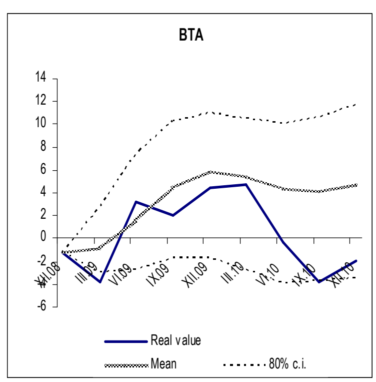
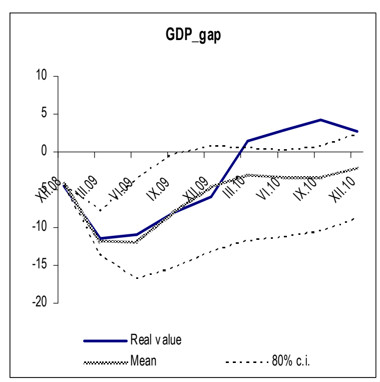






Model 17

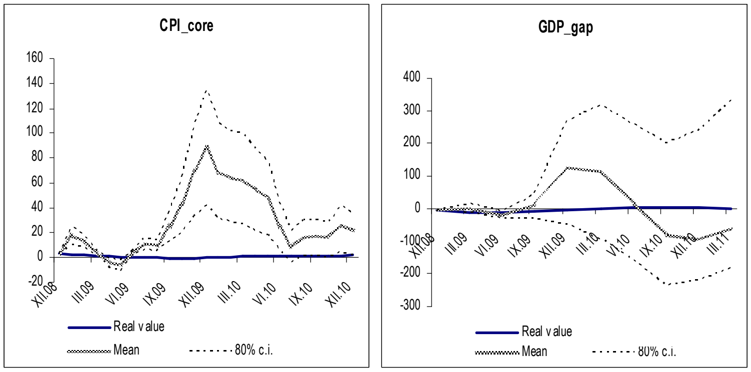


Figure 9 Forecasts of endogenous variables

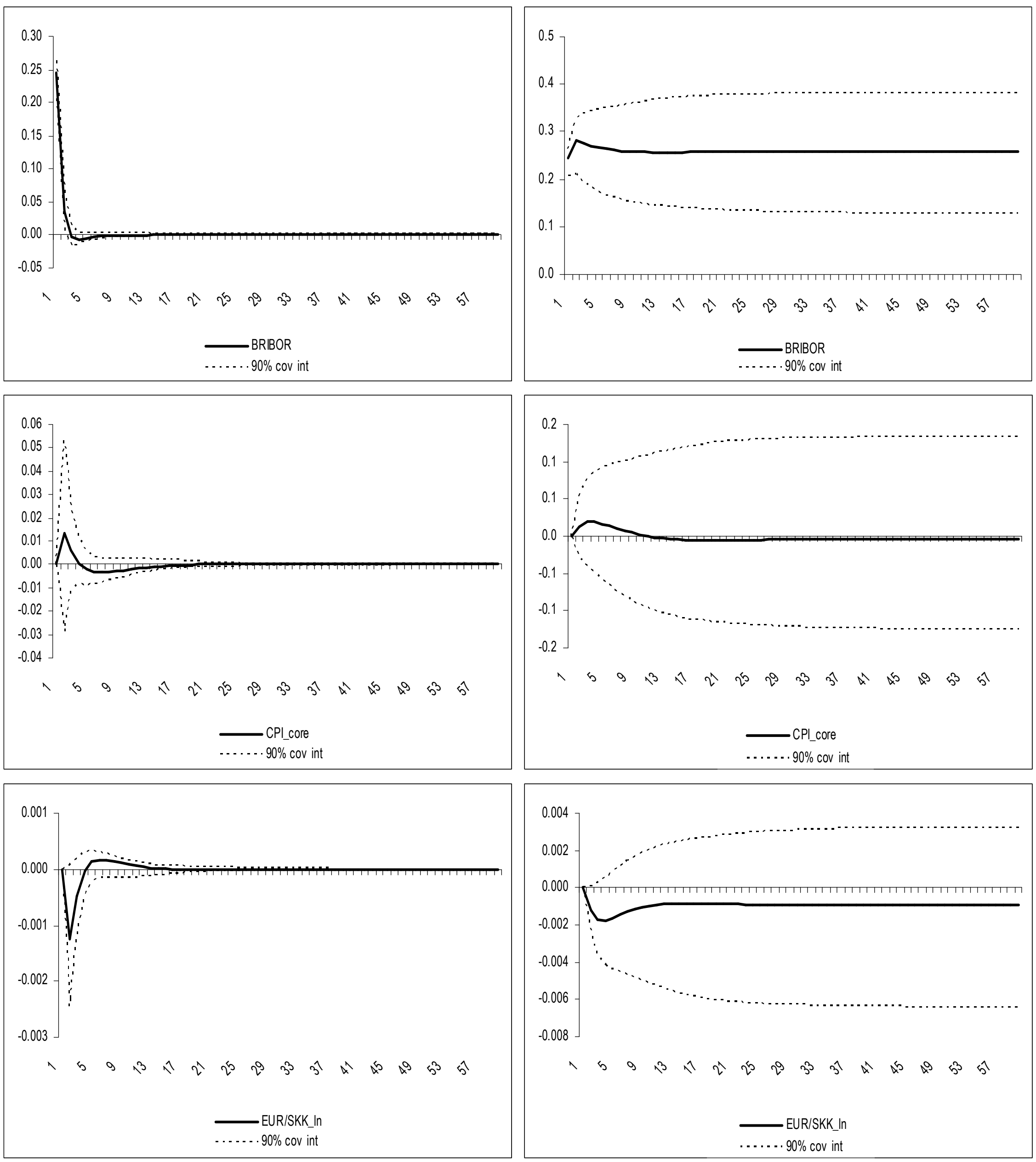
Impulse responses

In this section we analyze the dynamics of the estimated VEC model using impulse response functions. We focused on the reaction of the endogenous variables to a contractionary monetary policy shock. For the identification of the shock we used the benchmark recursive assumption used also in Christiano et al (1999), it means we assumed that the monetary policy shocks are orthogonal to the information set of the central bank and used a Cholesky decomposition of the variance-covariance matrix of the residuals. The order of the endogenous variables is: GDP, the core inflation, the exchange rate, the balance of trade and the interbank rate. The interbak rate is on the last place to ensure the assumption of the orthogonality, so that the monetary policy shock has no contemporaneous effects on the rest of the variables. As it is shown in the abovementioned study, the ordering of these variables doesn't alter their responses to the monetary policy shock.

As expected, the reaction of the interbank interest rate is immediate and fast. A contractionary monetary policy shock transmits into an increase of the short term interest rate, while the peak of the response is after 2 months (Figure 10). This result supports the functioning of the first stage of the transmission mechanism, that is, the strong reaction of the interbank interest rates to the changes in the policy rates of the NBS.

The result is more confusing in case of the response of the core inflation. The contractionary monetary policy shock is followed by an immediate increase of the core inflation, the reaction turns to negative after approximately 4 months while the cumulative response is negative after one year. It means that the price puzzle is present in the dynamics of the core inflation. This reaction seems to be, however, of a negligible size and the result can be viewed as not significant based on the 90 % coverage interval. As during the period under review monetary policy tightening took place in case of an expected acceleration of the price dynamics, the outcome can reflect the fact that generally the monetary policy tightening was really followed by an increase of the inflation. Another explanation of the insignificant result can be that during the period from 2000 to 2008 monetary policy worked mainly through its systemic impact on the economy and monetary policy shocks were just of a minor relevance.

Changes **Cumulative responses**



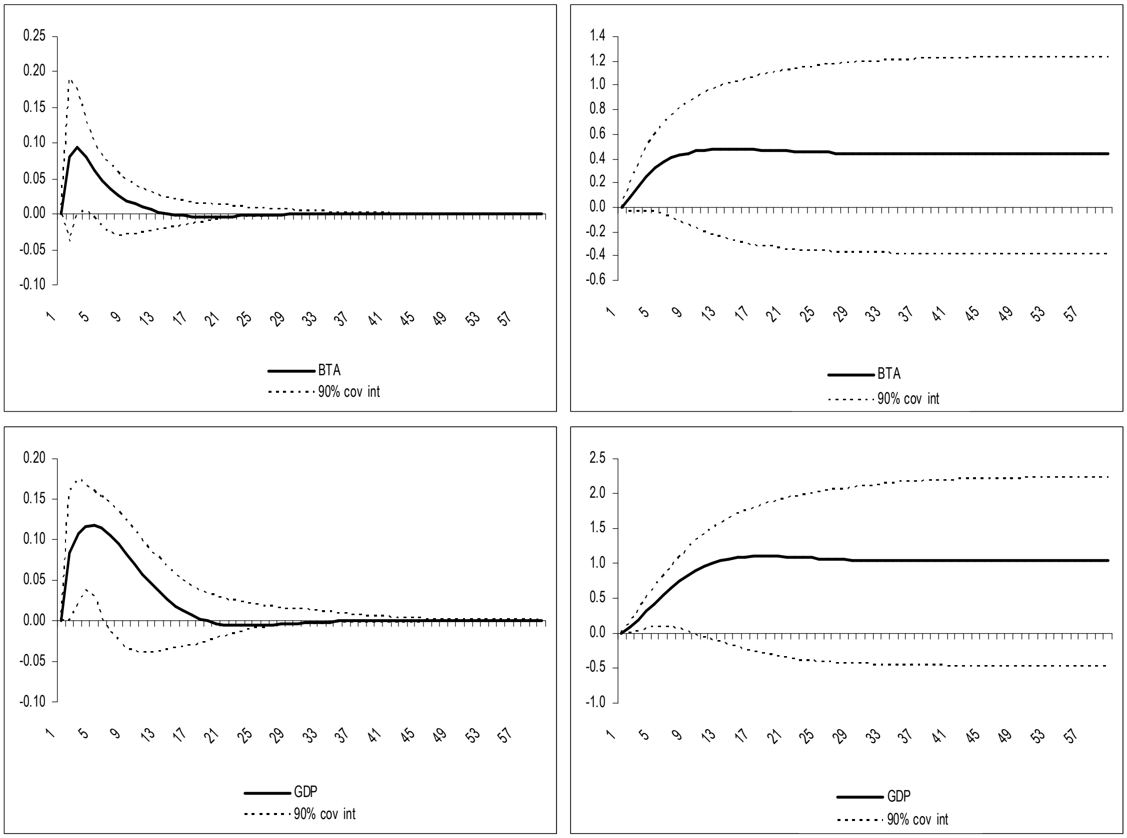


Figure 10 Impulse response functions

In case of the exchange rate there is an initial appreciation followed by a gradual depreciation. This result is in line with, e.g., the findings in Borys and Horváth (2008) for the Czech economy. However, in contrast to their results, there is a cumulative appreciation of the exchange rate in the long run. Similarly to the core inflation, these results are rather ambiguous based on the 90 % coverage intervals.

The response of the balance of trade is in line with the expectations, as after a contractionary monetary policy shock there is an increase of the trade balance. It means that after an increase of the key interest rates there is a positive development of economic imbalances. This result seems to be relatively significant, the shock is diminishing approximately after one year.

The response of the GDP is in line with the appreciating exchange rate, increasing inflation and the positive development of the trade balance. On the other hand, the results are in contradiction with the expected effect of a restrictionary monetary policy shock. It is increasing with the peak after approximately one quarter. While the coverage intervals are relatively wide in this case, too, the responses are more significant than in the case of the exchange rate or inflation. Based on the impulse response functions however, the relevance of monetary policy shocks for the Slovak economy in the period under review can be questionable.

4.3. Possible effects of an independent monetary policy

In this section we try to answer the question of whether an independent monetary policy during 2009 – 2010 would help to mitigate the effects of the financial crisis and the global economic downturn on the Slovak economy. More precisely, we conducted several counterfactual forecasting experiments and we compared the forecasts of the endogenous variables, mainly the forecasts of the GDP and the inflation. While there are several papers focusing on the importance of different channels in transmitting the effects of a monetary policy shock to the real economy (see, e.g., Citu, 2003, who investigates the importance of the exchange rate channel in New Zealand) or try to isolate the impact of a monetary policy shock from the impact of different kind of real economy shocks (see, e.g., Bernanke et al, 1997, where the authors try to answer, what is the role of endogenous monetary policy shocks in the postwar U.S. economy after an oil price shock in the economic downturn that usually followed oil price shocks), instead of focusing on the effects of monetary policy shocks we tried to forecast the overall development of the endogenous variables included in the VEC model. There are two reasons of this approach. First, based on the impulse response functions it seems that it is relatively hard to identify the impact of a monetary policy shock based on data from the period under consideration. Second, as we interpret the cointegrating equation as the policy rule, we can try to forecast also the "systemic" part of the monetary policy and not just the reaction of the variables to unanticipated policy shocks.

When forecasting, we assumed that external shocks to the real economy are captured in the development of the exogenous variables/are transmitted into the endogenous variables through the exogenous variables (the inflation of regulated prices, EURIBOR interbank rate, EUR/USD exchange rate, oil price index and the index of stock prices), therefore we did not pose any additional structural shocks into the model. Alternative forecasting exercises were conducted by fixing the development of the respective endogenous variables (it means we treated them as exogenous variables during the forecasting period while we assumed that they enter the equations of the remaining endogenous variables with the estimated coefficients), while the remaining endogenous variables were forecasted conditional on the predetermined values of these variables. We estimated the development of the variables again for years 2009 and 2010. Our focus was mainly on the possible impact of the monetary policy on the development of the GDP.

Naturally, the Lucas critique (Lucas, 1976) holds also for these experiments, as it is hard to incorporate rational expectations into VAR or VEC models. It can be argued, similarly than in Bernanke et al (1997), that the Lucas critique seems to be stronger in case of financial markets and less significant for real economy variables such as output and prices. Also, as pointed out above, using the interbank rate instead of the policy rate means to a given extent rational expectations on the interbank market are incorporated into the model. Despite these arguments, the experiments can be viewed more as a starting point of the debate about the possible effects of an independent monetary policy and not as a clear answer and there is definitely a need for a structural model to incorporate rational expectations to a greater extent.

The benchmark specification

To capture the errors related to the parameter estimations and the model specification, we took as a benchmark the forecast described in the previous section. It means that in the benchmark specification we forecasted the development of the GDP, the inflation and the balance of trade conditional on the predetermined values of the BRIBOR interbank rate (the value of which was set equal to the respective value of the EURIBOR interbank rate) and the EUR/SKK exchange rate (in each month set to be equal to the converse course 30.126 SKK per 1 EUR).

The effects of an independent monetary policy

When estimating the effects of an independent monetary policy, the natural starting point is to estimate the development of the endogenous variables without posing any restrictions on them. Thus, in the second specification we assumed that the NBS is going to conduct its monetary policy in line with the reaction function estimated in the previous section and that the exchange rate is going to react in a similar way than in years 2000 – 2008, so that all five endogenous variables were forecasted conditional just on the development of the exogenous variables. The estimation (Figure 11, marked as Forecast – free BRIBOR, free FX rate) shows a much higher interbank interest rate during the predicted period than its real value. This higher interbank interest rate can be related to the higher level of inflation, which doesn't differ significantly from the forecasted inflation in the previous section (marked as Forecast) and also to the fact that the reaction of the ECB to the financial crisis in 2009 was relatively fast and unprecedented. The outcome for the inflation is in line with the findings in the previous section, that is the monetary policy has just a small impact on it and that the price dynamics is driven mainly by other, domestic and external factors. The model expects a gradual appreciation of the exchange rate, which is obviously driven by the strong appreciation trend observed in the years before Slovakia became a member of the euro area. The drop in the GDP affected mainly the dynamics of the appreciation, as it fastened to some extent in the second half of 2009 when the GDP growth became positive again.

Based on the estimation results, it seems that the drop in the GDP in the first half of 2009 couldn't be dampened by an independent monetary policy. The monetary policy in form of gradually decreasing interest rates is affecting the economic development mainly during its recovery phase. It means that, based on the estimations in these two specifications, an independent monetary policy is not able to prevent the economy from the drop caused by mainly external factors, however it can help the economy to reveal faster from the recession. An interesting result is that the GDP is growing faster compared to the benchmark forecast despite higher interest rates. We explain this development by the fact that in the benchmark forecast the interest rates drop significantly during the highest impact of the external shock, while during the recovery phase there is no space for further monetary policy easing. While the low interest rates do not prevent the economy from recession, monetary easing during the recovery can have a more significant impact.

Possible effects of an alternative monetary policy and the importance of the exchange rate channel

The next questions are whether the quick drop in the interest rates could have a stronger effect on the GDP having not fixed the exchange rate, and to what extent is the stronger recovery related to the exchange rate channel. Therefore, we estimated the development of the endogenous variables with two more specifications: with the interbank interest rates fixed at their true values (marked as fixed BRIBOR, free FX rate) and with the exchange rate fixed at its value at the end of 2008 (marked as free BRIBOR, fixed FX rate). In the first specification, we tested the impact of a monetary policy different than could be expected based on the estimated reaction function. Comparing this specification with the benchmark specification and the “free BRIBOR, fixed FX rate” specification with the “free BRIBOR, free FX rate” specification we can assess the importance of the exchange rate channel.

The results of the forecasts underline the weak impact of the interest rates on the inflation, as with both specifications the estimated development of the price level does not differ significantly from the previous two specifications. In case of the GDP, the results suggest that the external shock affected the Slovak economy to such extent that even a much quicker reaction of the monetary policy would not be able to dampen the impact significantly. As it is described above, the economy is recovering faster in case of the “free BRIBOR, free FX rate” specification than in the benchmark specification (with fixed BRIBOR and fixed FX rate). As the “free BRIBOR, fixed FX rate” specification gives a forecast of the GDP growth that is similar to the “free BRIBOR, free FX rate” specification and the “fixed BRIBOR, free FX rate” specification gives a forecast that is similar to the benchmark specification, it seems that it is more the interest rate channel that can support the recovery than the exchange rate channel. As the interest rate channel does not work through its impact on the inflation, a possible explanation is that the monetary policy decisions affect the GDP mainly through their impact on the Slovak government bond yields and through the impact of the increased demand and supply for loans because of decreased interest rates. As the model predicts an appreciation of the exchange rate, the weaker impact of the exchange rate channel can be explained by the worsening competitive power of the export oriented sector due to this appreciation.

Forecasts with fixed inflation

As a robust result of all the specifications is that the inflation is affected just to a negligible extent, we present here also forecasts based on two more specifications. The first assumes a fixed inflation at its true values through the forecasted horizon (marked as fixed inflation), while the second one assumes also fixed interbank rates (marked as fixed inflation, fixed BRIBOR). In the first specification we tested the reaction of the NBS based on the estimated reaction function while in the second we tested the impact of a more pronounced monetary policy on the GDP with inflation lower than predicted by the model.

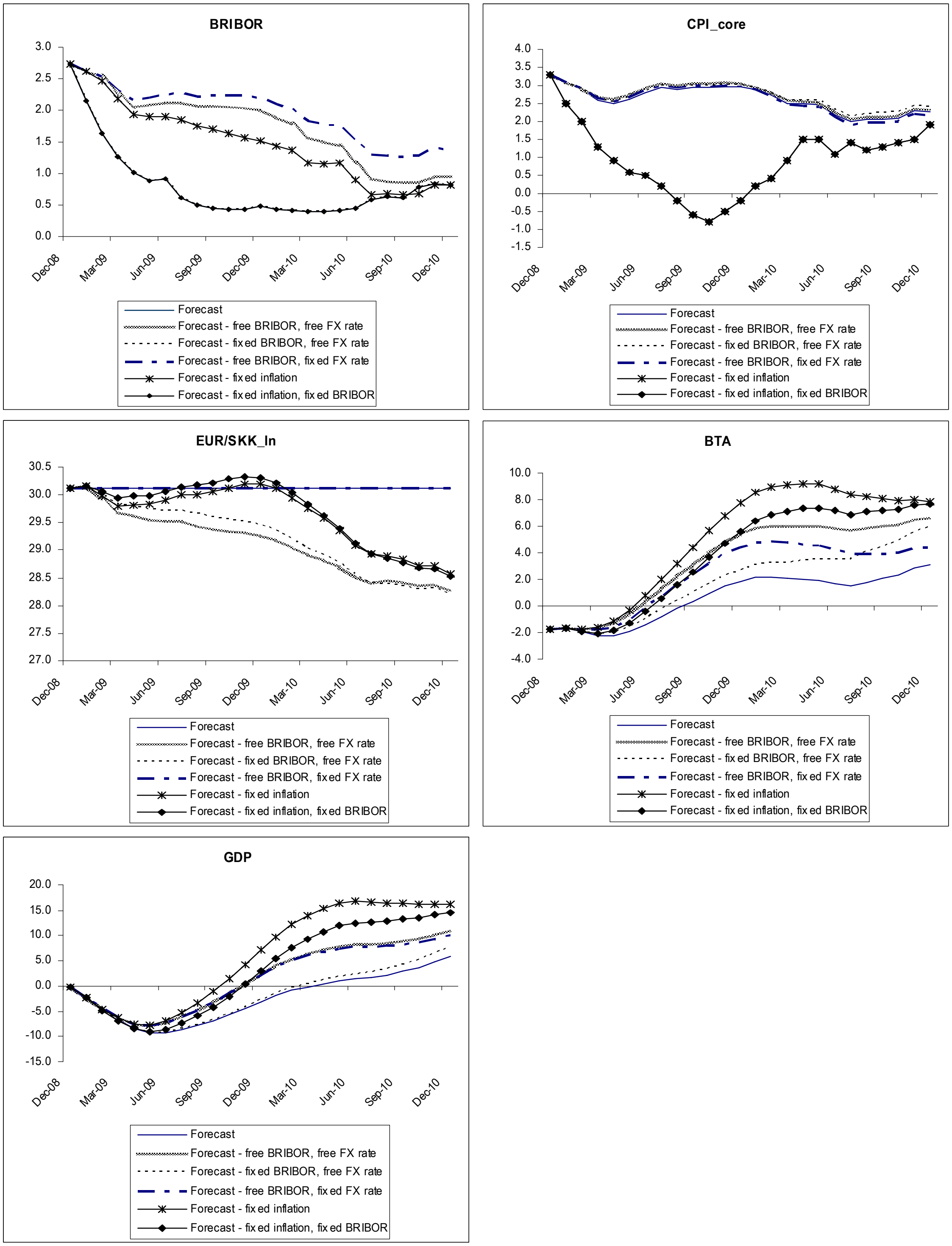


Figure 11 Forecasts of endogenous variables

In both specifications we get a much slower appreciation/depreciation of the exchange rate up to the end of 2009. Also in the first specification we get a gradually decreasing interest rate that is lower than in the previous specifications. In line with the previous specifications, the drop of the GDP in 2009 wouldn't be dampened by the monetary policy. On the other hand, we get a stronger recovery in both cases. This stronger recovery can be related partially to the weaker exchange rate. The stronger effect of gradually decreasing interest rates is also supported.

To sum up, a robust result is that the impact of the monetary policy on inflation is rather weak. The results also suggest that it is mainly the recovery phase of the GDP growth that could be affected by monetary policy decisions. This impact is, however, gradually diminishing as towards the end of the forecasting horizon the differences between respective specifications are lower than in the course of years 2009 and 2010. The recovery could be accelerated by depreciating exchange rate and gradually decreasing interest rates affecting the supply and demand for loans and the yields on Slovak government bonds. However, the fact that the sovereign risk increased during the period after 2008 for most of the countries (see, e.g. Šesták (2012)) and thus the reaction of the government bond yields could be weaker is not taken into account in the model. Also the weaker demand and more cautious behavior of the banks due to the high uncertainty related to the global economic development could disturb the transmission channel of the monetary policy. These possibilities are also hard to incorporate into the model.

4.4. Concluding remarks

In this chapter, we built up a small macroeconomic VEC model for the Slovak economy to study the effects of monetary policy shocks, to estimate the monetary policy reaction function and to study the possible effects of an independent monetary policy during the period of marked decrease of the economic activity in Slovakia.

Based on the estimation results, we conclude that it is able to find a reaction function, that describes to a given extent monetary policy in the period 2000 – 2008. A robust result is that it is more the core inflation than the inflation measured by the CPI that entered the reaction function. The results suggest that it is more the level of the exchange rate than its dynamics that affected monetary policy decisions of the NBS. The GDP and the indicators of economic imbalance seem to play just a secondary role in the reaction function.

Based on impulse response functions and on forecasts a robust result is the weak reaction of the inflation to the monetary policy decisions. A possible interpretation is that up to 2004 the overall amount of loans granted to the real economy by banks was relatively small and the banking sector underwent significant changes and thus interest rate changes on client loans and deposits were not able to affect the inflation. After 2004 we suggest that interest rate movements affected other parts of the economy that was not transmitted to the inflation. A possible explanation is that interest rate movements impacted more the development of residential real prices. Therefore, we conclude that the qualitative monetary policy in 2000 – 2008 was conducted in a period of overall positive macroeconomic development that allowed the NBS to gradually harmonize its tools with those of the ECB and thus prepare for the entry to the European Union and to the euro area.

Another robust result is that an independent monetary policy wouldn't be able to mitigate the impact of the global economic recession that transmitted into a significant drop of the domestic economic activity. It is more the recovery phase that could be affected by an independent monetary policy, where a depreciating exchange rate and gradually decreasing interest rates could lead to a more pronounced increase of the GDP.

5. A structural model of the Slovak economy

As one of the results of the previous chapter is that monetary policy of NBS didn't affected domestic inflation in a significant way, in this chapter, inter alia, we test our hypothesis that monetary policy decisions affected, and were transmitted to the development of the, property prices. Therefore, in the first part of the chapter we focus on the IS curve and show a possible way how to involve property prices/property price inflation into the IS curve. Together with the Phillips curve, the uncovered interest rate parity, a simple equation describing the development of property prices and an assumed form of the loss function of the central bank we derive the reaction function of the central bank. We show that the central bank should react to the development of the variables affecting the key variables entering into the loss function rather than to the development of these key variables.

Based on the theoretical model, in the second part of the chapter we estimate a structural model for the Slovak Republic. As the theoretical assumptions are not valid in all cases and for all economies, we used the FIML method to estimate the underlying parameters of the model rather than to calibrate them. To get reasonable estimations, we also augmented the model with other variables not used in the first part.

5.1. New Keynesian Macroeconomic Model for a Small Open Economy

Structural macroeconomic models are broadly used to study the reaction function of the monetary policy and the way how monetary policy affects the real economy through the transmission mechanism. As it is argued in McCallum (1999), an advantage of the structural models, compared to VAR models, is that they can be used to study the systemic part of the transmission mechanism, i.e. the propagation of shocks and changes in the instruments of monetary policy. One of the newest class of structural models is the so called New Keynesian macroeconomic models. This class differs from the traditional Keynesian models in that it involves imperfect competition and nominal rigidities (Galí and Monacelli, 2005) and the equations evolve explicitly from optimization by households and firms (Clarida et al, 1999). An interesting feature of these models is that there is an important role of expectations in the process of price settings and consumption decisions. These models in general consist of an IS curve that relates the output gap to the real interest rate, a Phillips curve that relates inflation to the output gap and the loss function of the central bank that is used to derive the monetary policy reaction function. In case of an open economy model there can be also an equation describing the development of the exchange rate, where usually it is assumed that the uncovered interest rate parity holds for the exchange rate.

The IS curve is usually derived by maximizing the household utility function given a budget constraint. It is in general assumed that the household can decide how many hours to work and how much to consume, while there is an income of the household in form of wages and/or dividends (it is also possible to assume that instead of dividends the household can decide to take a loan that can increase its current income). What is, however, in general missed in these models is the differentiation between the consumption of goods and investment into properties. Properties are one of the continuum of goods the consumption of which is determined to a great extent by their price. However, there are several reasons, why investment into properties should gain special attention also in these models:

- investment into (residential) properties is usually a life-time investment (for living) or a long-time investment (e.g. for renting)
- in contrast to other goods, the price of properties is significantly larger that also makes "consumption" of properties more like an investment
- the development of property prices is not a part of the CPI or HICP inflation, so standard inflation measures that are used in these models are not able to capture the effect of property price inflation on the real economy
- construction of buildings enters the output in a different way than consumption: in the expenditure (consumption) method of the calculation of the GDP the consumption enters the GDP through the final consumption while the construction of buildings enters the GDP through gross capital formation
- the price setting of the properties can differ significantly from the price setting of other goods used for consumption. In general, there is not yet a common way of understanding, what are the factors driving the development of property prices.

There is a broad literature dealing with the estimation of property prices and the phenomenon of property price bubbles and their consequences to the real economy. One of the basic theoretical models is presented in Poterba (1984). The model is based on a representative investor, who maximizes its utility function which is increased by a rise in the amount of investments into properties and decreased by the costs of living. As of Holly and Jones (1997), equilibrium house prices can be derived from the optimizing behavior of the representative household, who chooses between consumption and investments into properties. Leither and Mesonnier (2005) discuss two possible ways to calculate equilibrium property prices. The first is based on the discounted values of expected future cash flows – rents. The second is the structural approach that determines house prices by defining supply and demand equations for housing. An empirical analysis of the factors behind the development of residential property prices in Slovakia is available, e.g., in NBS (2008c). An overview and a discussion on the relationship of asset prices bubbles and financial crisis is published in Reinhart and Rogoff (2008).

There is, however, less attention in the literature on the importance of the property markets and property price inflation for the monetary policy and for the transmission mechanism.

5.1.1. Deriving the IS curve

In this part we show a possible way how investments into properties can be differentiated from consumption within the utility function of households and consequently derive the IS curve assuming that the households are maximizing their utility function. This section is based on the model presented in Galí and Monacelli (2005).

Let's assume there are two countries making up the world economy. One country (the home country) has a small open economy exporting and importing to the second country (foreign country). We assumed that the foreign country is significantly larger than the home country so that the monetary policy decisions of the home country don't affect the monetary policy decisions of the foreign country.

We assumed that the home economy is inhabited by a representative household that seeks to maximize its utility function of the form[15]

[15] Please note that as we wanted to maintain standard notation used in the literature to the extent possible, there is some overlap of the notations in Chapter 4 and Chapter 5.

$$E_0\left\{\sum_{t=0}^{\infty}\beta^t U\left(C_t, N_t, B_t\right)\right\} \tag{5.1}$$

where $0<\beta<1$ is the discount factor, B_t denotes investments into new properties, N_t hours of labor and C_t is a composite consumption index defined by:

$$C_t \equiv \left[(1-\alpha)^{1/\eta} C_{H,t}^{(\eta-1)/\eta} + \alpha^{1/\eta} C_{F,t}^{(\eta-1)/\eta}\right]^{\eta/(\eta-1)}$$

where $\alpha \in [0,1]$ is the degree of home bias (the smaller is α, the greater is the preferences for domestic goods), $\eta > 1$ is the elasticity, $C_{H,t}$ is an index of consumption of domestic goods and $C_{F,t}$ is an index of consumption of foreign/imported goods. The indexes are given by the CES function:

$$C_{H,t} \equiv \left(\int_0^1 C_{H,t}(j)^{(\varepsilon-1)/\varepsilon} dj\right)^{\varepsilon/(\varepsilon-1)}, C_{F,t} \equiv \left(\int_0^1 C_{F,t}(j)^{(\varepsilon-1)/\varepsilon} dj\right)^{\varepsilon/(\varepsilon-1)}$$

where $\varepsilon > 1$ is the elasticity of substitution.

The price of the domestic good j and the imported good j (expressed in domestic currency) is $P_{H,t}(j)$ and $P_{F,t}(j)$, respectively. The domestic price index and the price index for imported goods are defined as:

$$P_{H,t} \equiv \left(\int_0^1 P_{H,t}(j)^{1-\varepsilon}\right)^{1/(1-\varepsilon)} \text{ and } P_{F,t} \equiv \left(\int_0^1 P_{F,t}(j)^{1-\varepsilon}\right)^{1/(1-\varepsilon)} \tag{5.2}$$

The optimal allocation of any given expenditure within each category of goods yields:

$$C_{H,t}(j) = \left(\frac{P_{H,t}(j)}{P_{H,t}}\right)^{-\varepsilon} C_{H,t} \text{ and } C_{F,t}(j) = \left(\frac{P_{F,t}(j)}{P_{F,t}}\right)^{-\varepsilon} C_{F,t} \tag{5.3}$$

It follows from (5.3) that

$$\int_0^1 P_{H,T}(j) C_{H,t}(j) dj = P_{H,t} C_{H,t} \text{ and } \int_0^1 P_{F,T}(j) C_{F,t}(j) dj = P_{F,t} C_{\mathrm{F},t}$$

Finally, the optimal allocation of expenditures between domestic and imported goods is given by

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

where the consumer price index is defined as:

$$P_t \equiv \left[(1-\alpha) P_{H,t}^{1-\eta} + \alpha P_{F,t}^{1-\eta} \right]^{1/(1-\eta)}$$

The total consumption expenditures by domestic households are than given by

$$P_{H,t} C_{H,t} + P_{F,t} C_{F,t} = P_t C_t$$

As described above, we assumed that households are either consuming or investing into (new)[16] properties. Let's assume that the total volume of investments (expressed, e.g., in m^2) at time *t* is B_t and the price of the properties (expressed, e.g., in m^2) follows the following simple rule:

$$A_t = E_t \left\{ \frac{A_{t+1}}{R_{t,t+1}} \right\} \tag{5.4}$$

where $R_{t,t+1}$ is the one period ahead discount factor at time t. It means we assumed that the price of properties at time t is the discounted future expected price (expected price in *t+1*). We assumed that the discount factor is the central bank's policy rate because of two reasons:

- when the household has the resources to invest into properties, it can choose between the investment into the property or alternatively deposit the money into a bank using a sight account/term account the interest rate on which is assumed to be determined by the central bank's policy rate
- when the household does not have the full resources it can borrow from a bank. We assumed that the interest rate on the house purchase loans is also determined by the central bank's policy rate

We can rewrite (5.4) in a log-linearized form:

$$a_t = E_t \{ a_{t+1} \} - r_t \tag{5.5}$$

where $r_t \approx \ln(R_{t,t+1})$[17] and $a_t \equiv \ln(A_t)$.

Let's assume that the budget constraint for the representative household at time *t* takes the form:

[16] We assumed that the investments into old properties are used again (by the seller) for consumption or for investments into new properties. Therefore, when modeling the total output we took into account only investments into new properties. This assumption is also in line with the methodology of the calculation of GDP.

[17] Assuming that the discount factor can be expressed as $R_{t,t+1} = 1 + r_t$, where r_t is the interest rate set at time *t* and valid until *t+1* we get $\ln(R_{t,t+1}) = \ln(1 + r_t) \approx r_t$.

$$A_t B_t + P_t C_t + D_t \leq W_t N_t + E_t \left\{ \frac{D_{t+1}}{R_{t,t+1}} \right\} \tag{5.6}$$

where D_t is debt (maturing at time *t*), W_t are wages and N_t is the number of hours worked. It means that the household can consume or invest into properties and use for these purposes its income or borrow from a bank. For simplicity, we assumed that the maturity of the debt is one period.

In the following part we define the utility function of the household. We defined two versions of the utility function, the first we denoted as the utility function with backward-looking property prices and the second with forward-looking property prices.

Utility function with backward-looking property prices

Let's assume that the utility function of the representative household defined generally in (5.1) takes the form:

$$E_0 \left\{ \sum_{t=0}^{\infty} \beta^t U(C_t, N_t, B_t) \right\} = E_0 \left\{ \sum_{t=0}^{\infty} \beta^t \left\{ \frac{C_t^{1-\sigma}}{1-\sigma} + \left(\frac{A_t}{A_{t-1}} \right)^{\rho} \ln(B_t) - \frac{N_t^{1+\varphi}}{1+\varphi} \right\} \right\}$$

The first and the last expression is a standard part of the utility function that is rising in the consumption and decreasing in the number of hours worked. However, we also added to the utility function a third term, that catches the effects of property investments on the household utility. The difference is that while the marginal increase of the utility depends only on the elasticity σ and φ in case of the consumption and the number of hours worked, it also depends on the inflation of property prices in case of property investments. We opted for such a different approach to underline the assumed difference in the way how households decide the amount of consumption and investment into properties. While in case of consumption it is always better to consume more, in case of the properties the more are prices rising the higher is the utility from investing into properties. The reason is that in this case we assumed that households are forming their expectations based on the past development of property prices[18].

[18] Note that the expectations of households can be different from the expectation used to derive actual property prices, as we assumed that house prices are stated on the property market where there are also other agents that can form their expectations and behave differently than households.

Rising prices are than transmitted into expectations about future increase of property prices. These expectations than lead to higher investments due to the following reasons:

- in case the household invests into new property for living purposes, expected future higher prices force the household to increase its current investments with lower property prices,
- in case the household invests into property for pure investment purposes (it means the household invests to sell the property in the future) the higher is the expected property price inflation the higher is the expected future gain from the investment.

Therefore, we also assumed that the elasticity, ρ, is positive.

The household maximizes its utility function subject to the budget constraint, which means that the Lagrangian takes the form:

$$L = E_0 \sum_{t=0}^{\infty} \beta^t \left\{ \left(\frac{C_t^{1-\sigma}}{1-\sigma} + \left(\frac{A_t}{A_{t-1}} \right)^{\rho} \ln\left(B_t\right) - \frac{N_t^{1+\varphi}}{1+\varphi} \right) + \lambda_t \left(A_t B_t + P_t C_t + D_t - W_t N_t - E_t \left\{ \frac{D_{t+1}}{R_{t,t+1}} \right\} \right) \right\}$$

The intratemporal first-order conditions take the form:

$$\frac{\partial L}{\partial C_t} = 0 \Rightarrow C_t^{-\sigma} + \lambda_t P_t = 0 \Rightarrow \lambda_t = -\frac{C_t^{-\sigma}}{P_t} \tag{5.7}$$

$$\frac{\partial L}{\partial N_t} = 0 \Rightarrow -N_t^{-\varphi} - \lambda_t W_t = 0 \Rightarrow \lambda_t = -\frac{N_t^{-\varphi}}{W} \tag{5.8}$$

$$\frac{\partial L}{\partial B_t} = 0 \Rightarrow B_t^{-1} \left(\frac{A_t}{A_{t-1}} \right)^{\rho} + \lambda_t A_t = 0 \Rightarrow \lambda_t = -B_t^{-1} \left(\frac{A_t^{\rho-1}}{A_{t-1}^{\rho}} \right) \tag{5.9}$$

The intertemporal first-order condition takes the form:

$$\frac{\partial L}{\partial D_t} = 0 \Rightarrow E_t \left\{ \frac{\lambda_t}{R_{t,t+1}} \right\} = \beta \lambda_{t+1} \tag{5.10}$$

Substituting (5.9) into (5.10) we obtain:

$$B_t^{-1} \frac{A_t^{\rho-1}}{A_{t-1}^{\rho}} \frac{1}{R_{t,t+1}} = \beta B_{t+1}^{-1} \frac{A_{t+1}^{\rho-1}}{A_t^{\rho}}$$

or, taking conditional expectations and rearranging:

$$E_t \left\{ \frac{B_t}{B_{t+1}} \frac{A_{t+1}^{\rho-1}}{A_t^{\rho}} \frac{A_{t-1}^{\rho}}{A_t^{\rho-1}} \beta R_{t,t+1} \right\} = 1 \tag{5.11}$$

Expressing (5.11) in log-linearized form we get:

$$b_t = \beta^* + E_t\{b_{t+1}\} - r_t + (2\rho - 1)a_t - \rho a_{t-1} - (\rho - 1)E_t\{a_{t+1}\} =$$

$$= \beta^* + E_t\{b_{t+1}\} - \rho r_t + (2\rho - 1)a_t - \rho a_{t-1} - (\rho - 1)a_t =$$

$$= \beta^* + E_t\{b_{t+1}\} - \rho\left(r_t - (a_t - a_{t-1})\right) = \beta^* + E_t\{b_{t+1}\} - \rho\left(r_t - \pi_t^a\right) \tag{5.12}$$

where $\pi_t^a \equiv a_t - a_{t-1}$ is the inflation of the property prices, $b_t \equiv \ln(B_t)$ and the second row is obtained using (5.5). The expression derived for the investments into properties is an Euler equation that can be compared to the standard Euler equation describing consumption. It means that the current amount of investment into properties is positively related to the amount of expected future investments and negatively to the real interest rate (in this case the nominal interest rate lowered by the property price inflation).

Substituting (5.7) into (5.10) we obtain:

$$\frac{C_t^{-\sigma}}{P_t}\frac{1}{R_{t,t+1}} = \beta\frac{C_{t+1}^{-\sigma}}{P_{t+1}}$$

Taking conditional expectations and rearranging:

$$E_t\left\{\left(\frac{C_{t+1}}{C_t}\right)^{-\sigma}\beta R_{t,t+1}\frac{P_t}{P_{t+1}}\right\} = 1 \tag{5.13}$$

Expressing (5.13) in log-linearized form we get:

$$c_t = E_t\{c_{t+1}\} - \frac{1}{\sigma}\left(r_t - E_t\{p_{t+1} - p_t\} - \varsigma\right) = E_t\{c_{t+1}\} - \frac{1}{\sigma}\left(r_t - E_t\{\pi_{t+1}\} - \varsigma\right) \tag{5.14}$$

where $\pi_t \equiv p_t - p_{t-1} \equiv \ln(P_t) - \ln(P_{t-1})$ is the CPI inflation. (5.14) is the standard Euler equation relating the current consumption to the expected future consumption and to the real interest rate (nominal interest rate lowered by the CPI inflation).

We defined the bilateral (or in this case also effective) terms of trade between the home country and the foreign country (F) as the price of country F's good expressed in terms of home good:

$$S_t \equiv \frac{P_{F,t}}{P_{H,t}} \text{ and } s_t \equiv \ln(S_t) \tag{5.15}$$

Using (5.15) we get for the CPI inflation:

$$p_t \equiv (1-\alpha)\, p_{H,t} + \alpha p_{F,t} = p_{H,t} + \alpha\left(p_{F,t} - p_{H,t}\right) = p_{H,t} + \alpha s_t$$

Defining domestic inflation as

$$\pi_{H,t} \equiv p_{H,t} - p_{H,t-1} = \ln\left(P_{H,t}\right) - \ln\left(P_{H,t-1}\right)$$

we obtain:

$$\pi_t = p_t - p_{t-1} = \left(p_{H,t} + \alpha s_t\right) - \left(p_{H,t-1} + \alpha s_{t-1}\right) = \pi_{H,t} + \alpha \Delta s_t$$

We assumed the law of one price, i.e. that

$$P_{F,t}(j) = \varepsilon_t P^F_{F,t}(j) \tag{5.16}$$

holds for all $j \in [0,1]$, where ε_t is the nominal exchange rate (the price of country F's currency in terms of domestic currency) and $P^F_{F,t}(j)$ is the price of country F's good j expressed in country F's currency.

Substituting (5.16) into the price indices (5.2) we obtain

$$P_{F,t} = \varepsilon_t P^F_{F,t} \text{ or } p_{F,t} = e_t + p^F_{F,t} \tag{5.17}$$

Substituting (5.17) into the terms of trade (5.15):

$$s_t = p_{F,t} - p_{H,t} = e_t + p^F_{F,t} - p_{H,t}$$

We defined the bilateral (effective) real exchange rate as

$$Q_t \equiv \frac{\varepsilon_t P^F_t}{P_t}$$

i.e. the ratio of the two countries CPI inflations expressed in domestic currency. For the logarithm of the real exchange rate we get

$$q_t = e_t + p^F_t - p_t = s_t + p_{H,t} - p_t = (1-\alpha)\, s_t$$

where the last expression is obtained by log-linearization around a symmetric steady state value[19].

We assumed that for the domestic country and country F the uncovered interest parity holds, i.e.

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[19] We assumed that in steady state $P_{H,t} = P^*_H = P^*_F = P_{F,t}$

$$E_t\left\{\frac{\varepsilon_{t+1}}{\varepsilon_t}\right\}=\frac{R_{t,t+1}}{R^F_{t,t+1}} \tag{5.18}$$

where $R^F_{t,t+1}$ is the foreign country's discount rate. In log-linearized form:

$$E_t\left\{\Delta e_{t+1}\right\}=r_t-r^F_t \tag{5.19}$$

The next assumption was that (5.13) holds also for the foreign country, i.e. that

$$E_t\left\{\left(\frac{C^F_{t+1}}{C^F_t}\right)^{-\sigma}\beta R^F_{t,t+1}\frac{P^F_t}{P^F_{t+1}}\right\}=1 \tag{5.20}$$

Substituting (5.18) into (5.20) we get

$$E_t\left\{\left(\frac{C^F_{t+1}}{C^F_t}\right)^{-\sigma}\beta R_{t,t+1}\frac{P^F_t}{P^F_{t+1}}\frac{\varepsilon_t}{\varepsilon_{t+1}}\right\}=1 \tag{5.21}$$

Combining (5.13) and (5.21) we get, similarly as in Gali and Monacelli (2005):

$$C_t=\vartheta_F C^F_t Q_t^{1/\sigma}$$

where ϑ_F is a positive constant.

Also, we assumed that the aggregate domestic output consists of output for consumption (domestic and foreign) and the construction of new properties[20]:

$$Y_t=Y^C_t+B_t \tag{5.22}$$

where

$$Y^C_t\equiv\left[\int_0^1\left\{Y^C_t\left(j\right)\right\}^{(\varepsilon-1)/\varepsilon}dj\right]^{\varepsilon/(\varepsilon-1)} \tag{5.23}$$

We assume that the production of good *j* in the home country has to be equal to the consumption of that good (produced in the home country) in the home country and to the export to country F:

$$Y^C_t\left(j\right)=C_{H,t}\left(j\right)+C^F_{H,t}\left(j\right)=\left(1-\alpha\right)\left(\frac{P_{H,t}}{P_t}\right)^{-\eta}\left(\frac{P_{H,t}\left(j\right)}{P_{H,t}}\right)^{-\varepsilon}C_t+\alpha\left(\frac{P^F_{F,t}}{P^F_t}\right)^{-\eta}\left(\frac{P_{F,t}\left(j\right)}{P_{F,t}}\right)^{-\varepsilon}C^F_t \tag{5.24}$$

[20] Note that this approach is in line with the methodology of the calculation of GDP (by expenditure components), where output for consumption enters the GDP through final consumption and net export and the construction of new buildings through the gross capital formation.

Substituting (5.24) into (5.23) we obtain:

$$Y_t^C = (1-\alpha)\left(\frac{P_{H,t}}{P_t}\right)^{-\eta} C_t + \alpha\left(\frac{P_{F,t}^F}{P_t^F}\right)^{-\eta} C_t^F = (1-\alpha)\left(\frac{P_{H,t}}{P_t}\right)^{-\eta} C_t + \alpha\left(\frac{P_t}{P_t^F \varepsilon_t}\frac{\varepsilon_t P_{F,t}^F}{P_t}\right)^{-\eta} C_t^F =$$

$$= (1-\alpha)\left(\frac{P_{H,t}}{P_t}\right)^{-\eta} C_t + \alpha Q_t^{\eta}\left(\frac{P_{F,t}}{P_t}\right)^{-\eta} C_t^F = (1-\alpha)\left(\frac{P_{H,t}}{P_t}\right)^{-\eta} C_t + \alpha Q_t^{\eta}\left(\frac{P_{F,t}}{P_{H,t}}\frac{P_{H,t}}{P_t}\right)^{-\eta} C_t^F =$$

$$= (1-\alpha)\left(\frac{P_{H,t}}{P_t}\right)^{-\eta} C_t + \alpha Q_t^{\eta} S_t^{-\eta}\left(\frac{P_{H,t}}{P_t}\right)^{-\eta} C_t^F = \left(\frac{P_{H,t}}{P_t}\right)^{-\eta} C_t\left[(1-\alpha) + \alpha \vartheta_F S_t^{-\eta} Q_t^{\eta-1/\sigma}\right]$$

(5.25)

If we assume that the degree of home bias is different in the home country and the foreign country (with the home bias of the foreign country being significantly larger, i.e. $\alpha_F << \alpha$), we can rewrite (5.25) as:

$$Y_t^C = \left(\frac{P_{H,t}}{P_t}\right)^{-\eta} C_t\left[(1-\alpha) + \alpha_F \vartheta_F S_t^{-\eta} Q_t^{\eta-1/\sigma}\right] \tag{5.26}$$

Substituting (5.26) into (5.22) we get for the aggregate domestic output:

$$Y_t = \left(\frac{P_{H,t}}{P_t}\right)^{-\eta} C_t\left[(1-\alpha) + \alpha_F \vartheta_F S_t^{-\eta} Q_t^{\eta-1/\sigma}\right] + B_t \tag{5.27}$$

Log-linearization of (5.27) around a symmetric steady state value yields to (for the detailed derivation see Appendix B):

$$y_t = \frac{y^*}{Y^*} + \left[(1-\alpha) + \alpha_F \vartheta_F\right]\frac{C^*}{Y^*}\left(c_t - c^*\right) + \frac{B^*}{Y^*}\left(b_t - b^*\right) + \left[\eta\alpha - \frac{1}{\sigma}\alpha_F \vartheta_F\right]\frac{C^*}{Y^*} q_t =$$

$$= konst + \left[(1-\alpha) + \alpha_F \vartheta_F\right]\frac{C^*}{Y^*} c_t + \frac{B^*}{Y^*} b_t + \left[\eta\alpha - \frac{1}{\sigma}\alpha_F \vartheta_F\right]\frac{C^*}{Y^*} q_t =$$

$$= konst + \left[(1-\alpha) + \alpha_F \vartheta_F\right]\frac{C^*}{Y^*} E_t\{c_{t+1}\} + \frac{B^*}{Y^*} E_t\{b_{t+1}\} + \left[\eta\alpha - \frac{1}{\sigma}\alpha_F \vartheta_F\right]\frac{C^*}{Y^*} E_t\{q_{t+1}\} -$$

$$-\left[(1-\alpha) + \alpha_F \vartheta_F\right]\frac{C^*}{Y^*}\frac{1}{\sigma}\left(r_t - E_t\{\pi_{t+1}\} - \varsigma\right) + \frac{B^*}{Y^*}\left(\beta^* - \rho\{r_t - \pi_t^a\}\right) + \left[\frac{1}{\sigma}\alpha_F \vartheta_F - \eta\alpha\right]\frac{C^*}{Y^*} E_t\{\Delta q_{t+1}\} =$$

$$= konst + \left[(1-\alpha) + \alpha_F \vartheta_F\right]\frac{C^*}{Y^*} E_t\{c_{t+1}\} + \frac{B^*}{Y^*} E_t\{b_{t+1}\} + \left[\eta\alpha - \frac{1}{\sigma}\alpha_F \vartheta_F\right]\frac{C^*}{Y^*} E_t\{q_{t+1}\} -$$

$$-\left[(1-\alpha) + \alpha_F \vartheta_F\right]\frac{C^*}{Y^*}\frac{1}{\sigma}\left(r_t - E_t\{\pi_{t+1}\} - \varsigma\right) + \frac{B^*}{Y^*}\left(\beta^* - \rho\{r_t - \pi_t^a\}\right) +$$

$$+\left[\frac{1}{\sigma}\alpha_F\vartheta_F-\eta\alpha\right]\frac{C^*}{Y^*}E_t\left\{\Delta e_{t+1}+\pi^F_{t+1}-\pi_{t+1}\right\} \tag{5.28}$$

Rearranging (5.28) we obtain the IS curve:

$$y_t=E_t\left\{y_{t+1}\right\}+\beta_{y,1}+\beta_{y,2}r_t+\beta_{y,3}E_t\left\{\pi_{t+1}\right\}+\beta_{y,4}\pi^a_t+\beta_{y,5}E_t\left\{\Delta e_{t+1}\right\}+\beta_{y,6}E_t\left\{\pi^F_{t+1}\right\} \tag{5.29}$$

where

$$\beta_{y,2}=-\left[(1-\alpha)+\alpha_F\vartheta_F\right]\frac{C^*}{Y^*}\frac{1}{\sigma}-\frac{B^*}{Y^*}\beta^*\rho<0,$$

$$\beta_{y,3}=\left[\frac{1}{\sigma}(1-\alpha)+\eta\alpha\right]\frac{C^*}{Y^*}>0,$$

$$\beta_{y,4}=\frac{B^*}{Y^*}>0,$$

$$\beta_{y,5}=\beta_{y,6}=\left[\frac{1}{\sigma}\alpha_F\vartheta_F-\eta\alpha\right]\frac{C^*}{Y^*}.$$

Defining the output gap as

$$x_t\equiv y_t-\overline{y}_t \tag{5.30}$$

where $\overline{y}_t$ is the potential/natural level of output we can rewrite the IS curve in its canonical representation (i.e. in terms of output gap):

$$x_t=E_t\left\{x_{t+1}\right\}+\beta_{x,1}+\beta_{x,2}r_t+\beta_{x,3}E_t\left\{\pi_{t+1}\right\}+\beta_{x,4}\pi^a_t+\beta_{x,5}E_t\left\{\Delta e_{t+1}\right\}+\beta_{x,6}E_t\left\{\pi^F_{t+1}\right\}+E_t\left\{\Delta\overline{y}_{t+1}\right\} \tag{5.31}$$

It means we assumed that the output gap depends on the expected output gap, the monetary policy interest rate, the expected domestic and foreign CPI inflation and on the expectations about the development of the exchange rate and the potential output. In contrast to similar models, the output gap depends not just on the CPI inflation, but also on the inflation of the property price/ on the development of the property prices. This possible effect of the property prices on the output/ output gap is usually neglected in the literature, however in light of the effects of property price booms and busts on the real economy it is reasonable to involve it to the IS curve. In case of the expected output gap and the expected potential output it is straightforward from (5.31) that we expected a positive impact on the actual output gap. In case of the expected domestic CPI and property price inflation we also expected positive impact, which means that higher inflation should increase the output gap. In case of the policy rate we expected negative impact, so that monetary tightening should result in a decreasing output gap. In case of the exchange rate and the foreign inflation the sign of the coefficient depends on the actual values of the underlying parameters. However, as Slovakia has a small export oriented open economy it is reasonable to assume that a depreciating exchange rate will increase the output gap, which means that $\beta_{x,5}$ is positive. It means that $\beta_{x,6}$ is also positive, so that an increasing foreign inflation affects domestic output gap positively, too.

Utility function with forward-looking property prices

In the previous part we expected that it is the actual inflation of property prices that enters the utility function of the representative household. The reason of such an assumption was that households are forming their expectations based on the past/actual inflation of property price. However, it is reasonable to assume that it is not the actual inflation, but the expected inflation of the property prices that enters the utility function, or that the expectations are not just solely based on the past inflation, but can be also rational (so that the expected property prices are in line with the future property prices). In this case, the utility function takes the form:

$$E_0\left\{\sum_{t=0}^{\infty}\beta^t U(C_t,N_t,B_t)\right\} = E_0\left\{\sum_{t=0}^{\infty}\beta^t\left\{\frac{C_t^{1-\sigma}}{1-\sigma}+\left(\frac{A_{t+1}}{A_t}\right)^{\rho}\ln(B_t)-\frac{N_t^{1+\varphi}}{1+\varphi}\right\}\right\} \tag{5.32}$$

Combining (5.32) with the budget constraint, (5.6) we get the Lagrangian:

$$L = E_0\sum_{t=0}^{\infty}\beta^t\left\{\left(\frac{C_t^{1-\sigma}}{1-\sigma}+\left(\frac{A_{t+1}}{A_t}\right)^{\rho}\ln(B_t)-\frac{N_t^{1+\varphi}}{1+\varphi}\right)+\lambda_t\left(A_tB_t+P_tC_t+D_t-W_tN_t-E_t\left\{\frac{D_{t+1}}{R_{t,t+1}}\right\}\right)\right\}$$

The intratemporal first-order condition than takes the form:

$$\frac{\partial L}{\partial B_t}=0\Rightarrow B_t^{-1}E_t\left\{\left(\frac{A_{t+1}}{A_t}\right)^{\rho}\right\}+\lambda_tA_t=0\Rightarrow\lambda_t=-B_t^{-1}E_t\left\{\left(\frac{A_{t+1}^{\rho}}{A_t^{\rho+1}}\right)\right\}$$

which yields to the following expression for the investments into properties:

$$E_t\left\{\frac{B_t}{B_{t+1}}\frac{A_t^{\rho+1}}{A_{t+1}^{\rho}}\frac{A_{t+2}^{\rho}}{A_{t+1}^{\rho+1}}\beta R_{t,t+1}\right\}=1$$

or, in log-linearized form:

$$b_t = E_t\{b_{t+1}\}-r_t-(\rho+1)a_t-\rho E_t\{a_{t+2}\}+(2\rho+1)E_t\{a_{t+1}\}+\beta^* =$$

$$= E_t\{b_{t+1}\} - r_t - (\rho+1)a_t - \rho E_t\{a_{t+1} + r_{t+1}\} + (2\rho+1)E_t\{a_{t+1}\} + \beta^* =$$

$$= E_t\{b_{t+1}\} - \left(r_t + \rho E_t\{r_{t+1}\} - (\rho+1)E_t\{\pi^a_{t+1}\}\right) \tag{5.33}$$

The difference between (5.33) and (5.12) is that in this case it is not just the actual but also the expected policy rate and not the actual but the expected property price inflation that determines the amount of property investments.

The derivation of the IS curve is straightforward and similar as in the previous part. The expression for the output gap takes the form:

$$x_t = E_t\{x_{t+1}\} + \beta_{x,1} + \beta_{x,2}r_t + \beta_{x,3}E_t\{\pi_{t+1}\} + \beta_{x,4}E_t\{\pi^a_{t+1}\} +$$

$$+\beta_{x,5}E_t\{\Delta e_{t+1}\} + \beta_{x,6}E_t\{\pi^F_{t+1}\} + \beta_{x,7}E_t\{r_{t+1}\} + E_t\{\Delta\bar{y}_{t+1}\} \tag{5.34}$$

The difference is that in this case it is also the expected monetary policy rate and the expected property price inflation that enters the IS curve. The sign of the coefficients is similar as described in the previous case.

5.1.2. Deriving the reaction function of the central bank

In the previous part we derived the dynamic IS equation for the small open-economy in terms of output gap. Here we show how can be the IS curve together with a given form of the Philips curve, the assumed equation describing the development of the property prices and the uncovered interest rate parity used to derive the monetary policy reaction function from the loss function of the central bank. We mainly focused on showing that without any further assumptions about the underlying parameters of the model all of the variables entering the equations have to be taken into consideration by the central bank when setting the monetary policy interest rate.

The IS equation based on the utility function with backward looking property prices is described by (5.31), the property prices follow a simple rule described by (5.5) and the uncovered interest rate parity is given by (5.19).

The Phillips curve, similarly to Vašíček (2009) takes here a general form

$$\pi_t = \beta_{\pi,1} + \beta_{\pi,2}\pi_{t-1} + \beta_{\pi,3}E_t\{\pi_{t+1}\} + \beta_{\pi,4}x_{t-1} + \beta_{\pi,5}\pi^F_t + \beta_{\pi,6}e_{t-1} \tag{5.35}$$

where π_t^F is the inflation in the foreign country, and that the central bank of the small open-economy seeks to maximize a loss function of the form:

$$-\frac{1}{2}E_t\left\{\sum_{i=0}^{\infty}\beta_{CB}^i\left[\left(1-k_\pi-k_e\right)x_{t+i}^2+k_\pi\pi_{t+1+i}^2+k_e\left(e_{t+1+i}-\overline{e}_{t+1+i}\right)^2\right]\right\} \tag{5.36}$$

where $\overline{e}_t$ is the natural level of the exchange rate, k_π and k_e is the weight of the central bank on the inflation and the exchange rate, where $k_\pi, k_e > 0$ and $k_\pi + k_e < 1$. It means we assumed that it is not just the output gap and the inflation that enters the loss function of the central bank but it is also the exchange rate (the deviation of the exchange rate from its potential level), which is assumed to play an important role in a small open economy.

We assumed that the central bank at each period t sets its key rate (r_t) to maximize the loss function at period *t*, i.e. the central bank maximizes

$$\max -\frac{1}{2}\left[\left(1-k_\pi-k_e\right)x_t^2+k_\pi E_t\left\{\pi_{t+1}^2\right\}+k_e E_t\left\{e_{t+1}-\overline{e}_{t+1}\right\}^2\right] \tag{5.37}$$

constrained to (5.31), (5.19) and (5.35).

As it is shown in Appendix C, when setting the policy rate the central bank has to adjust its rate to all of the parameters influencing the output gap, inflation and the exchange rate, so the monetary policy reaction function takes the form:

$$\begin{aligned} r_t = {} & \beta_{r,1}+\beta_{r,2}E_t\left\{x_{t+1}\right\}+\beta_{r,3}\pi_t^a+\beta_{r,4}e_t+\beta_{r,5}E_t\left\{\pi_{t+1}^F\right\}+\beta_{r,6}E_t\left\{\Delta\overline{y}_{t+1}\right\}+\beta_{r,7}\overline{e}_{t+1} \\ & +\beta_{r,8}\pi_t+\beta_{r,9}E_t\left\{\pi_{t+2}\right\}+\beta_{r,10}E_t\left\{\pi_{t+1}^F\right\}+\beta_{r,11}r_t^F \end{aligned} \tag{5.38}$$

It is also straightforward to show that in case of the forward-looking utility function the monetary policy reaction function changes to:

$$\begin{aligned} r_t = {} & \beta_{r,1}+\beta_{r,2}E_t\left\{x_{t+1}\right\}+\beta_{r,3}E_t\left\{\pi_{t+1}^a\right\}+\beta_{r,4}e_t+\beta_{r,5}E_t\left\{\pi_{t+1}^F\right\}+\beta_{r,6}E_t\left\{\Delta\overline{y}_{t+1}\right\}+ \\ & +\beta_{r,7}\overline{e}_{t+1}+\beta_{r,8}\pi_t+\beta_{r,9}E_t\left\{\pi_{t+2}\right\}+\beta_{r,10}E_t\left\{\pi_{t+1}^F\right\}+\beta_{r,11}r_t^F+\beta_{r,12}E_t\left\{r_{t+1}\right\} \end{aligned} \tag{5.39}$$

5.2. Estimating a structural model for Slovakia

In the previous part we derived the IS curve for a small open economy that includes the property price inflation. Together with the Phillips curve, the equation representing the uncovered interest rate parity and the loss function of the central bank we showed that in order to reach the optimal value of the macroeconomic variables entering the loss function the central bank has to react to the factors affecting those macroeconomic variables.

In this part we estimate a structural model of the Slovak economy based on the theoretical model derived in the previous part[21]. There are usually two methods how to derive the values of the underlying coefficients, to calibrate the model and to estimate it. However, as the theoretical model does not have to fit the economy of the given country in each case, rather than to calibrate we decided to estimate a structural model that is based on the theoretical model showed in the previous part.

As there are expectations entering the model, based on the findings of Daništková (2012), who estimated the Phillips curve for the Czech Republic, we used the method of full information maximum likelihood (FIML). We assume that the expectations are rational

$$z_{t+1} = E_t\left\{z_{t+1}\right\} + v_t \tag{5.40}$$

where v_t is assumed to be a white noise.

Our dataset consists of quarterly data from the first quarter of 2000 until the fourth quarter of 2008. The dataset includes: the output gap, the seasonally adjusted harmonized index of consumer prices (HICP, q-o-q changes), seasonally adjusted regulated prices (q-o-q changes, π_t^{reg}), EUR/SKK exchange rate (in natural logarithm) and the potential/natural level of the exchange rate, the key rate of NBS as the policy rate (or alternatively the BRIBOR interest rate with 1 month maturity), property prices[22] (in natural logarithm) and the inflation (q-o-q changes) of property prices in Slovakia, the key rate of the ECB as the foreign policy rate (or alternatively the EURIBOR interest rate with 1 month maturity), HICP (q-o-q changes) and the output gap of the euro area $\left(x_t^F\right)$.

The potential level of the GDP (for Slovakia and the euro area) was calculated using HP filter (with $\lambda = 1600$) and the seasonally adjusted quarterly real GDP (in natural logarithm).

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[21] Estimations were conducted in EViews.

[22] Property prices (in €/m^2) are published at www.nbs.sk from 2002 with yearly frequency and from 2005 with quarterly frequency. We approximated property prices in 2000 and 2001 using published data about the number of finished properties, average size of those properties in m^2 and the value of gross capital formation published at www.statistics.sk. Yearly data were transformed to quarterly using quadratic interpolation (to match average values).

The potential level of the exchange rate was also calculated using HP filter (with $\lambda = 1600$) using the EUR/SKK exchange rate in natural logarithm.

Data about the key rate of the ECB were taken from the website of ECB; data about the output and inflation of the euro area were taken from EUROSTAT.

Based on the results of unit root tests (Table 6), the inflation rates and the measures of the output gap (for Slovakia and the euro area) can be treated as stationary series while other variables are integrated of order one. It means that for the estimation of the structural model using FIML method we cannot use data in levels. Therefore, we used two specifications. In the first, following, e.g., Joiner (2001), we estimated the model using detrended interest rates, exchange rate and property prices. Data were detrended using HP filter with $\lambda = 1600$. In the second specification, we used first differences of the data.

Table 6 Unit root tests of the macroeconomic variables

	ADF		Phillips-Perron	
	Level	1st difference	Level	1st difference
CPI (s.a.)	0.002	0.000	0.001	0.000
CPI reg (s.a.)	0.000	0.000	0.000	0.000
HICP EA	0.000	0.000	0.000	0.000
NBS key rate	0.804	0.007	0.780	0.007
NBS key rate detrended	0.060	0.000	0.036	0.000
BRIBOR1M	0.687	0.000	0.682	0.000
BRIBOR1M detrended	0.038	0.000	0.025	0.000
ECB key rate	0.262	0.002	0.638	0.003
ECB key rate detrended	0.010	0.000	0.025	0.000
EURIBOR1M	0.184	0.008	0.631	0.006
EURIBOR1M detrended	0.006	0.000	0.024	0.000
Output gap	0.025	0.000	0.023	0.000
Output gap EA	0.006	0.000	0.023	0.000
EUR/SKK	0.971	0.000	0.971	0.000
EUR/SKK detrended	0.001	0.000	0.001	0.000
Property prices	0.475	0.017	0.218	0.016
Property prices detrended	0.003	0.001	0.015	0.000
Real property prices	0.473	0.005	0.303	0.005
Real property prices detrended	0.039	0.000	0.110	0.000

The model consists of four equation, the IS curve, the Phillips curve, the equation for the property prices and the reaction function of the NBS. We included also the uncovered interest rate parity into the model, however the estimations hadn't showed that this equation held for the exchange rate in the period of 2000Q1 2008Q4. As in case of first differences estimated coefficients (including also the uncovered interest rate parity) were not unique, we present an example using only detrended data (Table 12).

5.2.1. Estimation results using detrended data

As the baseline specification, we estimated the IS curve, the Phillips curve and the property prices based on the theoretical findings using the backward looking utility function (equations (5.31), (5.35) and (5.5)) and a standard form of the reaction function for an open economy including inflation, expected value of the output gap (in the next period), the deviation of the EUR/SKK exchange rate from its potential level (e_gap, in this case it is the detrended exchange rate that enters also the other equations), expected value of the foreign (euro area) inflation and the policy rate of the ECB as explaining variables. We used two specifications, one with the key rate of the NBS and ECB (Model 19) and one with the BRIBOR and EURIBOR of 1 month maturity as an approximation of the policy rate (Model 20). We included also a dummy variable to take into account the changes in the methodology of the calculation of the property prices in all specifications (also in specifications presented later on). As property prices are in nominal terms and output gap is calculated from the real output, in case of the IS curve we adjusted the property prices (or the property price inflation) in all models described below by the GDP deflator to include real property prices[23].

Estimation results (Table 7, Table 8, Table 9 and Table 10) are relatively poor. There are no significant coefficients in any of the estimated equations and also the values of the aR^2 are very low.

In case of the IS curve, the expected value of the output gap, the expected value of the home and the eurozone inflation and the property price inflation enters the equation with positive coefficient. This is in line with the expectations, as it is usually assumed that an increase of inflation and an increase of the expected future output gap raise economic activity. The exchange rate enters the equation also with positive coefficient, which means that a depreciation of the Slovak koruna against the euro increases the output gap. The expected

[23] Real property prices (or the detrended real property prices) are calculated as $A_t / Defl_t$, where $Defl_t$ is the GDP deflator calculated by dividing nominal GDP with real. As it is the log of the property prices entering the estimated equations, the adjusted property prices are calculated as $a_t - defl_t$, where $defl_t = \ln(Defl_t)$

change of the potential level of the GDP enters the equation with negative and the interest rate with positive sign. The sign of the later coefficient is opposite to the expected, as it is usually assumed that a restrictive monetary policy in form of increased interest rate lowers output gap. However, the high value of the standard errors makes the possible impact of the explanatory variables relatively unclear.

In case of the Phillips curve, only the past and the expected inflation enter the equation with positive coefficient both in case of Model 19 and Model 20. While the low and insignificant coefficient for the output gap is in line, the low and insignificant coefficient for the past inflation is in contradiction with the findings of Danišková (2012) for the Phillips curve estimated for the Czech Republic. Only the coefficient for the expected inflation is relatively high, however, based on the standard errors it is not possible to draw any conclusions neither in this case.

Table 7 Estimation results for the IS curve

	Model 19	Model 20	Model 21	Model 22	Model 23	Model 24	Model 25	Model 26
c	-20.415 *(305.150)*	-22.585 *(173.940)*	0.949 *(1.093)*	0.905 *(0.984)*	0.441 *(1.672)*	1.069 *(2.078)*	1.807 *(1.608)*	1.237 *(1.695)*
x_{t+1}	2.756 *(16.736)*	2.770 *(9.765)*	0.448*** *(0.155)*	0.452*** *(0.159)*	0.707** *(0.314)*			
x_t^f						1.048** *(0.485)*	0.574 *(0.434)*	0.924** *(0.416)*
a_t^r			0.091* *(0.048)*	0.088** *(0.042)*	0.077 *(0.076)*	0.119* *(0.062)*	0.146** *(0.063)*	0.128** *(0.056)*
r_t	269.144 *(430.981)*	275.419 *(206.310)*						
r_{t-1}			0.677 *(0.649)*	0.622 *(0.498)*			0.994 *(0.829)*	
r_{t+1}								0.326 *(0.934)*
π_{t+1}	16.617 *(105.104)*	17.021 *(77.575)*						
π_t^a	0.170 *(0.251)*	0.159 *(0.344)*						
π_{t+1}^f	6.447 *(51.337)*	6.410 *(48.374)*						
Δe_{t+1}	0.056 *(0.581)*	0.051 *(0.553)*						
$\Delta \bar{y}_{t+1}$	-3.524 *(22.207)*	-0.838 *(15.946)*						
aR^2	-819027%	-955993%	91.43%	91.60%	83.34%	75.76%	77.53%	75.20%

* significance at 10%, ** significance at 5%, *** significance at 1%
Standard errors in parenthesis

Estimation results for the property prices are, similarly to the results of the IS curve estimation, relatively poor. The positive coefficient for the expected value of the future property prices is in line, while the estimated positive value for the interest rate is in contradiction with our expectations. However, also in this case, none of the explanatory variables enter the equation with significant coefficient.

Table 8 Estimation results for the Phillips curve

	Model 19	Model 20	Model 21	Model 22	Model 23	Model 24	Model 25	Model 26
c	0.866 *(1.868)*	0.870 *(1.837)*	0.097 *(0.335)*	0.116 *(0.347)*	0.126 *(0.364)*	0.133 *(0.455)*	0.088 *(0.333)*	0.126 *(0.439)*
π_t^f	-0.007 *(0.045)*	-0.007 *(0.039)*	0.829** *(0.382)*	0.791* *(0.425)*	0.781* *(0.455)*	0.771 *(0.617)*	0.875* *(0.513)*	0.792 *(0.549)*
π_t^{reg}			0.267*** *(0.063)*	0.267*** *(0.058)*	0.267*** *(0.063)*	0.266*** *(0.066)*	0.260*** *(0.071)*	0.264*** *(0.057)*
π_{t-1}	0.003 *(0.023)*	0.001 *(0.022)*						
π_{t+1}	0.323 *(1.412)*	0.322 *(1.258)*						
x_{t-1}	-0.011 *(0.063)*	-0.011 *(0.068)*						
e_{t-1}	-0.002 *(0.021)*	-0.001 *(0.013)*						
aR^2	2.35%	2.22%	73.18%	73.29%	73.32%	73.35%	73.05%	73.34%

* significance at 10%, ** significance at 5%, *** significance at 1%
Standard errors in parenthesis

While the value of the aR^2 is relatively high for the reaction function compared to the other equations, only the positive coefficient for the interest rate of the ECB enters the equation with the expected positive sign, even if the value of the coefficient is relatively low. While the coefficient for the exchange rate is not significantly different from zero, the inflation, both domestic and foreign, and the expected output gap enters the equation with negative sign. It means that, opposite to the usual assumptions, the central bank should react to the increasing inflation and overheating economy with decreasing its policy rates.

There can be different reasons of the poor estimation results. If a part of the estimated system of equations is misspecified, it can have impact on the remaining part of the system in case of the FIML method. Also, the relatively large number of the coefficients compared to the time period under consideration results in a relatively low degree of freedom that can influence negatively the estimation results.

Therefore, we estimated also different specifications of the system derived from the baseline theoretical model. We tried to lower the number of explanatory variables in the system to increase the degrees of freedom and also augmented the system with different variables not included in the baseline model: the property prices instead of the inflation of the property prices, the output gap of the euro area in case of the IS curve and the inflation of the regulated prices in case of the Phillips curve.

Table 9 Estimation results for the property prices

	Model 19	Model 20	Model 21	Model 22	Model 23	Model 24	Model 25	Model 26
c	-0.654	-0.155	-0.798	-0.781	-0.807	-0.807	-0.787	-0.810
	(51.841)	*(49.362)*	*(0.935)*	*(0.905)*	*(0.840)*	*(1.443)*	*(1.006)*	*(1.172)*
a_{t+1}	1.069	1.056	0.999***	0.990***	1.006***	1.010***	0.993***	1.012***
	(0.729)	*(0.565)*	*(0.130)*	*(0.146)*	*(0.080)*	*(0.090)*	*(0.099)*	*(0.089)*
r_{t+1}			-2.018*	-1.670	-2.069**	-1.984**	-1.970*	-2.132
			(1.158)	*(1.446)*	*(1.010)*	*(0.988)*	*(1.117)*	*(1.455)*
r_t	69.701	68.755						
	(386.490)	*(265.838)*						
aR^2	-3234%	-3529%	92.21%	92.35%	92.19%	92.23%	92.22%	92.13%

* significance at 10%, ** significance at 5%, *** significance at 1%
Standard errors in parenthesis

Due to the fact that there are a large number of possible specifications we present only the models with the best estimation results (Model 21 – Model 26 with estimation results in Table 7, Table 8, Table 9 and Table 10).

A common feature of those models is that the goodness of fit (measured by aR^2) increased significantly in all cases. Also, most of the variables enter the model with coefficient significant at least at the 10% significance level.

As in the presented specifications altering the key rate of NBS to the 1 month BRIBOR interbank interest rate does not change significantly the results, we present only the models including the key rate.

It is the expected output gap that enters the IS curve in Model 21, 22 and 23, in Model 24, 25 and 26 it is replaced by the actual output gap of the euro area. Lagged policy rate enters the equation in Model 21, 22 and 25; in Model 26 the equation includes the expected policy rate. Property prices enter the equation in all specifications.

Inflation is explained by the inflation of regulated prices and the HICP inflation in the euro area in all cases. The equation for the property prices is also the same in all models and includes the expected value of property prices and the policy rate.

The reaction function of the central bank includes the lagged value of the policy rate, the output gap and the actual value of the exchange rate in all specifications. To capture the fact that the central bank in case of the development of the domestic inflation takes into account also the impact of the changes in regulated prices (as described in Chapter 3), we included into the reaction function an adjusted value of the domestic inflation. The value of the CPI inflation is lowered by the inflation of the regulated prices, using the same coefficient as estimated in the Phillips curve. This adjusted inflation is included in all models except of Model 22.

Table 10 Estimation results for the reaction function of the NBS

	Model 19	Model 20	Model 21	Model 22	Model 23	Model 24	Model 25	Model 26
c	0.268 *(1.536)*	0.261 *(1.081)*	-0.097 *(0.193)*	-0.015 *(0.126)*	-0.099 *(0.186)*	-0.098 *(0.167)*	-0.095 *(0.162)*	-0.103 *(0.178)*
r_{t-1}			0.744*** *(0.171)*	0.813*** *(0.157)*	0.732*** *(0.158)*	0.735*** *(0.169)*	0.750*** *(0.211)*	0.734*** *(0.161)*
π_t	-0.198 *(0.913)*	-0.198 *(1.037)*						
π_{t+2}^{adj}			0.150 *(0.264)*		0.155 *(0.263)*	0.152 *(0.258)*	0.146 *(0.256)*	0.159 *(0.250)*
x_{t-1}			0.064* *(0.038)*	0.049 *(0.089)*	0.066* *(0.039)*	0.066 *(0.041)*	0.061 *(0.041)*	0.068* *(0.040)*
x_{t+1}	-0.010 *(0.059)*	-0.011 *(0.035)*						
e_gap_t	0.000 *(0.003)*	0.000 *(0.003)*	0.095* *(0.055)*	0.113** *(0.049)*	0.096* *(0.054)*	0.098** *(0.047)*	0.096* *(0.054)*	0.096* *(0.053)*
π_{t+1}^{f}	-0.024 *(0.179)*	-0.022 *(0.164)*						
r_t^{f}	0.001 *(0.021)*	0.004 *(0.015)*						
aR^2	35.05%	33.32%	74.18%	74.65%	73.93%	74.02%	74.27%	73.92%

* significance at 10%, ** significance at 5%, *** significance at 1%
Standard errors in parenthesis

Estimation results show a significant impact of the expected value of the output gap and the actual value of the real property prices nearly in all specifications. In line with the expectations, both variables enter the equation with positive coefficient, which means that the expected increase of the output gap and the actual increase of the property prices increase the output gap. An interesting result is that the policy rate enters the equation in all cases (when the policy rate is included) with positive and insignificant coefficient. A possible explanation is that an increasing policy rate reflects the development of other macroeconomic variables having an upward pressure on the output gap (such as the increasing inflation). It means that the contractuary monetary policy does not have a significant negative impact on the output gap expected in the theoretical model. A possible explanation of the insignificant coefficient is that the development of the economy reflected in the movements of the policy rate impact also the expected value of the output gap, while the impact on the actual output gap is stronger through this channel. On the other hand, the exclusion of the policy rate from the IS curve decreases the overall fit of the model and the coefficient for the property prices becomes insignificant (Model 21 vs. Model 23).

As Slovakia has a small and open economy, we also replaced the expected value of the output gap by the output gap of the euro area. This replacement caused a decrease of the goodness of fit (Model 21 to 23 vs. model 24 to 26). A possible explanation is that the value of the output gap of the euro area enters the first three specifications through its impact on the expected value of the domestic output gap, while the expected value of the gap contains even more information giving thus better estimation results. An interesting result is that based on the specification of the policy rate it is either the coefficient for the euro area output gap in the IS curve or the coefficient for the inflation in the euro area in the Phillips curve that enters the equation with insignificant coefficient.

In case of the Phillips curve the estimation results improved significantly. The value of aR^2 increased from less than 3 % up to more than 70 % in all specifications. Both the inflation of the eurozone and the inflation of regulated priced enter the equations with positive and significant coefficients. The only exceptions are Model 24 and 26, as described above.

In case of property prices estimation results also improved significantly. The coefficient for the expected value of property prices is significant and close to one in all specifications and the aR^2 increased to values more than 90 %. The hypothesis that the coefficient of the expected value of property prices is equal to one, or that the expected property prices are fully transmitted into the current prices, cannot be rejected by the Wald coefficient test (Table 11). An important and positive change compared to the first two specifications is that the coefficient of the interest rate became negative and significant and the standard errors decreased significantly.

If we connect this results to the estimation results of the IS curve, we see that the increase of the interest rate affects the output gap negatively and significantly through its negative impact on the property prices.

Table 11 Wald test results – Equation describing property prices

Specification	Test statistic	Value	p-value
Model 21	Chi-square	0.006	0.940
Model 22		0.011	0.918
Model 23		0.010	0.937
Model 24		0.013	0.908
Model 25		0.005	0.946
Model 26		0.020	0.889

The value of aR^2 increased in case of the reaction function to more than 73 % in all cases. Estimation results show a strong impact of the past value of the policy rate on the current value as the coefficients are relatively high and significant in all cases. This outcome is partially in line with the findings of Marušiak (2009), who also finds an evidence of strong inertia in case of the policy rate of the NBS. The coefficient for the output gap, the adjusted rate of the expected inflation and the exchange rate enters the equation in all cases with positive value. It means that in case of an expected increase of the inflation and an increased output gap the model predicts restrictive monetary policy. In case of the exchange rate the positive coefficient means that an excessive depreciation of the exchange rate against the euro is followed by an increase of the policy rate; or oppositely, an excessive appreciation of the exchange rate is followed by a decreased policy rate. While the coefficient for the exchange rate is significant in all cases, the adjusted rate of inflation is not entering the equation with significant coefficient. On the other hand, the exclusion of this variable makes the coefficient for the output gap insignificant and, interestingly, also the coefficient for the interest rate in case of the property prices becomes insignificant (Model 21 vs. 22).

Table 12 Estimation results of Model 21 including the uncovered interest rate parity

	x_t	π_t	a_t	r_t	Δe_t
c	0.995 (1366.135)	0.085 (375.046)	-0.792 (4114.831)	-0.096 (943.704)	0.020 (667.402)
x_{t+1}	0.527 (484.481)				
a_t^r	0.103 (498.648)				
r_{t-1}	0.606 (2723.838)				
π_t^f		0.851 (581.415)			
π_t^{reg}		0.266 (227.188)			
a_{t+1}			0.997 (1142.754)		
r_{t+1}			-2.0167 (293.903)		
π_{t+2}^{adj}				0.153 (901.885)	
r_{t-1}				0.745 (1391.163)	
x_{t-1}				0.062 (40.880)	
e_gap_t				0.091 (148.907)	
$r_{t-1} - r_{t-1}^f$					-0.345 (4381.197)
aR^2	83.53%	73.10%	92.20%	74.16%	-1.10%

* significance at 10%, ** significance at 5%, *** significance at 1%
Standard errors in parenthesis

5.2.2. Estimation results using first differences

As a first step, we estimated also in this case the equations based on the theoretical model and estimated in the previous part (Model 19 and 20 using detrended data, Model 27 and 28 using first differences). We estimated two specifications – first using the key rate of the NBS and ECB (Model 27), second using 1 month BRIBOR and EURIBOR (Model 28). Estimation results are comparable in terms that using first differences the estimated coefficients are not significant in any of the equations and the values of aR^2 are very low.

In case of the IS curve, the estimated coefficients are a bit different using the key rate and using interbank rate. In both cases, an increase of the expected output gap and an increase of the (actual) property price inflation results in an increase of the actual output gap while, contrary to our expectations, the increase of the expected inflation in both cases results in a lower output gap. While in line with the expectations an increasing key rate results in decreasing output gap, the rise of the interbank rate increases output gap. Coefficients are opposite also in case of the expected inflation of the euro area, the exchange rate and the potential output. However, as in case of the detrended data, standard errors are too high to make conclusions based on the estimated coefficients.

Table 13 Estimation results for the IS curve

	Model 27	Model 28	Model 29	Model 30	Model 31	Model 32	Model 33	Model 34
c	-2.079 *(42.912)*	0.558 *(184.462)*	-0.393 *(0.439)*	-0.399 *(0.414)*	-0.513 *(0.428)*	-0.395 *(0.483)*	-0.343 *(0.405)*	-0.346 *(0.330)*
x_{t+1}	0.447 *(2.753)*	0.225 *(6.373)*	0.300** *(0.148)*	0.280* *(0.146)*	0.273** *(0.132)*	0.298** *(0.150)*	0.298** *(0.148)*	
x_{t+1}^{f}								0.032 *(0.748)*
a_t^r			0.271*** *(0.090)*	0.276*** *(0.088)*	0.296*** *(0.080)*	0.272*** *(0.093)*	0.262*** *(0.087)*	0.285*** *(0.084)*
r_t	-1.905 *(13.500)*	0.128 *(19.937)*				0.252 *(0.359)*		
r_{t+1}					-0.508 *(1.136)*			
π_{t+1}	-0.367 *(9.825)*	-0.243 *(24.003)*						
π_t^a	0.102 *(0.959)*	0.067 *(2.503)*						
π_{t+1}^{f}	-0.425 *(14.678)*	0.078 *(8.738)*						
Δe_{t+1}	-0.042 *(0.842)*	0.055 *(1.497)*						
$\Delta \bar{y}_{t+1}$	1.195 *(31.737)*	-0.383 *(133.344)*						
aR^2	-163.71%	-54.63%	79.57%	79.69%	79.63%	79.68%	79.57%	74.16%

* significance at 10%, ** significance at 5%, *** significance at 1%
Standard errors in parenthesis

Estimation results of Model 27 and 28 are more comparable in case of the Phillips curve. The increase of the foreign inflation, the expected inflation and the output gap results in an increased actual inflation. Opposite to the expectations, an increased lagged inflation decreases the actual inflation and a depreciating exchange rate also decreases inflation. Similarly to the IS curve, high standard errors and low aR^2 makes it hard to draw any conclusions.

Estimation results for the property prices, similarly to the detrended data, showed a positive effect of the expected property prices and negative effect of the interest rate both in case of Model 27 and 28. However, aR^2 is very low and the standard errors are too high also in this case.

Table 14 Estimation results for the Phillips curve

	Model 27	Model 28	Model 29	Model 30	Model 31	Model 32	Model 33	Model 34
c	-0.013 *(2.673)*	-0.026 *(3.234)*	-0.004 *(0.100)*	-0.004 *(0.097)*	-0.004 *(0.108)*	-0.004 *(0.101)*	-0.004 *(0.100)*	-0.005 *(0.109)*
π_t^f	0.445 *(6.123)*	0.445 *(7.106)*	0.654** *(0.276)*	0.654** *(0.264)*	0.656** *(0.284)*	0.659** *(0.288)*	0.654** *(0.276)*	0.655** *(0.273)*
π_t^{reg}			0.221*** *(0.028)*	0.220*** *(0.033)*	0.221*** *(0.030)*	0.221*** *(0.038)*	0.221*** *(0.028)*	0.220*** *(0.029)*
π_{t-1}	-0.878 *(4.667)*	-0.898 *(6.923)*						
π_{t+1}	1.988 *(12.668)*	2.122 *(17.414)*						
x_{t-1}	0.081 *(3.412)*	0.113 *(5.631)*						
e_{t-1}	-0.053 *(1.506)*	-0.071 *(1.143)*						
aR^2	-567.15%	-643.22%	74.27%	74.26%	74.28%	74.27%	74.27%	74.26%

* significance at 10%, ** significance at 5%, *** significance at 1%
Standard errors in parenthesis

The goodness of the fit is the highest, similarly to the detrended data, in case of the reaction function with the aR^2 being more than 35% and 22% in case of Model 27 and 28, respectively. While the coefficient for the actual inflation is positive in case of Model 27 and negative in case of Model 28, the coefficient for the expected output gap, the exchange rate and the policy rate of the euro area are all positive. It means that, in line with the expectations, a potential overheating of the economy, a depreciating exchange rate (a weaker exchange rate than its potential level) and an increasing euro area policy rate should be followed by a contractionary monetary policy. On the other hand, an increase of the expected foreign inflation results in a decreasing domestic policy rate.

To improve estimation results, we augmented the model similarly as in the previous part. Because of the high number of possible specifications, we present in the following part only those with the best estimation results (Model 29 to 34 in Table 13, Table 14, Table 15 and Table 17).

Table 15 Estimation results for the property prices

	Model 27	Model 28	Model 29	Model 30	Model 31	Model 32	Model 33	Model 34
c	0.714	0.655	0.106	0.121	0.233	0.095	0.106	0.105
	(6.218)	*(11.650)*	*(0.725)*	*(0.657)*	*(0.721)*	*(0.695)*	*(0.725)*	*(0.762)*
a_{t+1}	0.869	0.894	1.032***	1.024***	1.020***	1.030***	1.032***	1.027***
	(0.834)	*(2.371)*	*(0.163)*	*(0.148)*	*(0.148)*	*(0.139)*	*(0.163)*	*(0.164)*
r_{t+1}			-1.305*	-1.451*	-0.803	-1.386	-1.305*	-1.242*
			(0.777)	*(0.778)*	*(0.723)*	*(0.849)*	*(0.779)*	*(0.727)*
r_t	-0.340	-0.329						
	(43.808)	*(20.886)*						
aR^2	2.42%	0.11%	79.86%	80.35%	80.45%	80.06%	79.86%	79.76%

* significance at 10%, ** significance at 5%, *** significance at 1%
Standard errors in parenthesis

In case of the IS curve, the expected output gap and the property price inflation (the first difference of the log property prices) enters the equation with positive and significant coefficient. Results are very similar using the key rate or the interbank rate (Model 29 and Model 30, respectively). Similarly as in case of detrended data, also the aR^2 increased significantly and reached levels above 70 %. Inclusion of other variables did not improve estimation results. Model 31 and 32 presents estimation results with the policy rate included in the IS curve[24]. The sign of the coefficient depends on the specification; the coefficient is positive using actual interest rate (Model 31) and negative using the expected interest rate (Model 32). In both cases, however, the coefficient is not significant and the value of aR^2 does not improve. Interestingly, including the policy rate into the IS curve the coefficient for the interest rate became insignificant in the equation for the property prices. We also tried to include into the model foreign output gap, or replace expected output gap by foreign gap. An example is given in Model 34. However, using foreign output gap, similarly as in the previous part, does not improve estimation results. Furthermore, the coefficient for the foreign output gap is not significant.

Estimation results for the Phillips curve showed significant positive effects of the foreign inflation and the inflation of regulated prices also using first differences. Similarly to the IS curve, the value of aR^2 exceeded 70 %.

In case of the property prices, the impact of the expected value is, similarly to the detrended data, very strong and near to 1. We tested the hypothesis of full transmission of the

[24] As results are similar using the base rate or the interbank rate, we present only the results of the former specification.

expected value of the property prices to the actual value also in this case. Similarly to the detrended data, we cannot reject this hypothesis based on the coefficient tests (Table 16). The coefficient for the interest rate is significantly negative, which means that, in line with the expectations, an expected restrictionary monetary policy affects property prices negatively.

Table 16 Wald test results – Equation describing property prices

Specification	Test statistic	Value	p-value
Model 29	Chi-square	0.087	0.768
Model 30		0.038	0.846
Model 31		0.035	0.852
Model 32		0.073	0.787
Model 33		0.074	0.785
Model 34		0.020	0.888

Estimation results for the reaction function showed a significant impact of the expected inflation, the exchange rate and the foreign interest rate. The signs of the coefficients are in line with the expectations for all of these variables. An expected increase of the inflation, an increase of the foreign interest rate and a depreciation of the exchange rate result in a restrictionary monetary policy. The lagged value of the interest rate enters the equation with positive but not significant coefficient. The inflation of regulated prices (actual using the key rate and expected using the interbank rate) enters the equation with negative coefficient. It can be explained by the fact that the monetary authority has no impact on the regulated prices and the effect of regulated prices on the overall inflation was reflected also in the decisions of the NBS. It means that if the inflation was high due to the development of regulated prices, the NBS usually did not adjust its monetary policy to this higher inflation (as described in further details in Chapter 3). Interestingly, while most of the coefficients are significant in case of Model 29 and 30, the value of the aR^2 does not increased significantly and remained at a level of nearly 37 % using the key rate and 28 % using interbank rate. While the coefficient for the lagged interbank rate and the inflation of regulated prices is not significant, exclusion of these variables worsens the estimation results. As an example we present in Model 33 a specification without the lagged value of the key rate[25]. Compared to Model 29, the coefficient for the expected inflation became insignificant and also the value of the aR^2 decreases.

[25] The effects are similar using the interbank rate as a proxy for the policy rate; therefore this specification is not presented here.

Table 17 Estimation results for the reaction function of the NBS

	Model 27	Model 28	Model 29	Model 30	Model 31	Model 32	Model 33	Model 34
c	-0.161 (0.713)	-0.172 (1.745)	-0.041 (0.103)	-0.043 (0.122)	-0.041 (0.103)	-0.039 (0.104)	-0.130 (0.100)	-0.041 (0.103)
r_{t-1}			0.185 (0.157)	0.097 (0.220)	0.185 (0.157)	0.184 (0.160)		0.185 (0.157)
π_t	-0.023 (0.258)	0.006 (1.103)						
π_{t+2}			0.127* (0.077)	0.366* (0.211)	0.127* (0.077)	0.127* (0.080)	0.110 (0.082)	0.127* (0.077)
π_t^{reg}			-0.019 (0.035)		-0.019 (0.035)	-0.019 (0.034)	-0.003 (0.031)	-0.019 (0.034)
π_{t+2}^{reg}				-0.058 (0.052)				
e_t			0.118** (0.047)	0.131** (0.066)	0.118** (0.047)	0.118** (0.047)	0.072* (0.043)	0.117** (0.047)
x_{t+1}	0.053 (0.528)	0.018 (2.798)						
e_gap_t	0.074 (0.369)	0.108 (0.914)						
π_{t+1}^f	-0.090 (1.672)	-0.073 (5.100)						
r_t^f	0.555 (2.150)	0.475 (19.004)	0.717*** (0.143)	0.584*** (0.196)	0.717*** (0.144)	0.717*** (0.144)	0.610*** (0.132)	0.717*** (0.144)
aR^2	35.64%	22.45%	36.72%	27.64%	36.72%	36.69%	25.91%	36.72%

* significance at 10%, ** significance at 5%, *** significance at 1%
Standard errors in parenthesis

5.3. Concluding remarks

In this chapter we introduced a theoretical background that allowed us to reflect the impact of property prices on the output and the output gap in the IS curve. Based on the theoretical model we estimated a structural model of the Slovak economy using the IS curve, the Phillips curve, an equation describing property prices and the reaction function. To show that the general theoretical model can have drawbacks and that the relationship of the macroeconomic variables can differ from the assumptions, we estimated the model using the FIML method rather than calibrated the underlying coefficients. Also, we augmented the baseline theoretical model with variables not included in it, like the foreign output gap or the inflation of regulated prices. As non-stationarity of some of the variables cannot be excluded, we estimated the model using detrended variables and also first differences.

Estimation results are very similar comparing these specifications. In case of the IS curve the expected value of the output gap and the property prices have significant impact on the actual output gap. As the equation for property prices showed a significant positive impact of the expectations and a negative impact of the policy rate, in our specifications the monetary policy has its impact on the output gap through its effects on the expectations and through its negative impact on the property prices. Based on the estimation results the inflation is strongly influenced by the inflation of regulated prices and the inflation of eurozone.

Estimation results are a little bit different in case of the reaction function. In general, in both cases macroeconomic variables enter the equation with the expected sign. Also in both cases, the exchange rate has significant impact on the policy rate. On the other hand, while in case of the detrended data it is the output gap and the lagged policy rate that enters the equation with significant coefficient, in case of first differences it is the foreign policy rate and the inflation. A possible explanation is that during the period under consideration, NBS gradually adjusted its policy rate to the policy rate of the ECB while the decreasing trend of the inflation allowed this adjustment. It means that, while the monetary authority reacted also to other macroeconomic variables, the trend of the policy rate followed, in general, the trend of the foreign policy rate and domestic inflation. While this information is not contained in the detrended data, its impact is significant using first differences.

While there are available estimation techniques to provide conditional forecasts in case expectations are also part of the model, we discuss the possible effects of an independent monetary policy based solely on the estimation results. On the one hand, the estimated structural model allows us to make conclusions relying just on the estimation results. On the other hand, it is relatively hard to quantify possible changes in the formation of expectations after a change in the framework of monetary policy.

Estimation results of the Phillips curve showed that monetary policy did not have a direct significant impact on the development of the inflation. Therefore, in line with the results discussed in Chapter 4 we can conclude that an independent monetary policy different from those of the ECB shouldn't have any significant impact on the development of the domestic inflation in 2009 and 2010.

Monetary policy had significant indirect effect on the output gap through its impact on the property prices and possibly through its impact on the expectations about the future development of the output gap. Property prices declined throughout year 2009 despite decreasing policy rates and the consequent decrease of the interest rates on loans for customers (NBS, 2010). As the trend in the development of property prices started already in 2008, before the euro adoption, it can be concluded that negative expectations had such a significant impact that there was no room for an independent monetary policy to mitigate significantly the negative development of the property prices. While the impact of an independent monetary policy on the expectations about the output gap and the real output is hard to quantify, it seems that it was mainly the expected negative development of the economies of the main export partners of Slovakia that caused expectations about declining trend of the domestic economy (NBS, 2009b). This also allows us to conclude that there was just a little floor for the monetary policy to mitigate the negative effects of the financial crisis and the global economic downturn. This conclusion is also in line with the results presented in Chapter 4. An open question, however, remains the possible effect of the exchange rate channel, as based on the estimation results this channel does not have a direct significant effect on the output gap. Here, also relying on the results presented in Chapter 4 and the negative expectations it seems that neither this channel would significantly alter the development of the domestic economy during 2009.

6. Summary

In the thesis we focused on the analysis of the monetary policy and the transmission mechanism of the monetary policy of the NBS from the adoption of qualitative monetary policy in 2000 to the end of 2008, when Slovakia joined the euro area. The analysis was conducted based on the VEC framework and also using a New Keynesian Macroeconomic Model.

As the time period is relatively short, we introduced a Bayesian VEC estimator that allowed us to estimate the model using endogenous variables observed at mixed frequencies, in our case variables observed monthly and quarterly. Within the VEC model, we focused on the domestic macroeconomic variables that could potentially enter the reaction function of the NBS in the period under review. Foreign macroeconomic variables and international financial indicators enter the model as exogenous variables.

Based on the estimation results we can interpret the cointegrating equation as the reaction function of the NBS. A robust result is that it is more the core inflation than the inflation measured by the CPI that entered the reaction function. Results suggest that it is more the level of the exchange rate than its dynamics that affected monetary policy decisions of the NBS. The GDP and the indicators of economic imbalance seem to play just a secondary role in the reaction function. Based on impulse response functions and on conditional forecasts a robust result is the weak reaction of the inflation to monetary policy shocks.

We studied possible impacts of an independent monetary policy in 2009 and 2010 by conducting several counterfactual forecasting experiments. We conclude that it is mainly the recovery phase that could be affected by an independent monetary policy, while it seems that there was no potential for mitigating the sharp downturn of the domestic economy in 2009.

Based on the results of the VEC model, we estimated a structural model of the Slovak economy using the method of FIML. The model consists of the IS curve, the Phillips curve, a simple equation describing property prices and the reaction function of the NBS. In case of the IS curve, we showed a possible way how can investments into residential properties be separated from the consumption of households in the theoretical model. This separation allowed us to study the possible effects of the monetary policy on the output gap through its impact on the property prices. We estimated the model using detrended data and first differences of the data.

Estimation results are to a great extent in line with the results of the VEC model. Based on the estimation results, we conclude that the output gap was mainly affected by the expected development of the domestic output gap and/or by the expected development of the output gap in the euro area, and by the development of the residential property prices. As property prices moved in line with the expected future (increase of) prices and were corrected by the expected movements of the policy rate, we can conclude that the credit channel was present in the given period. Domestic inflation showed a significant dependence on the development of foreign (euro area) inflation and on the inflation of regulated prices. In line with the VEC model, we haven't found a significant direct impact of the monetary policy.

Estimation results in case of the reaction function are a bit different using detrended data and first differences. It seems that while the trend was influenced by the development of the domestic inflation and the policy rate of the ECB, fluctuations around the trend were caused by reactions to the development of the output gap and the SKK/EUR exchange rate. Based on this outcome we conclude that the positive development of the domestic inflation allowed the NBS to gradually harmonize its policy rate to those of the ECB in the process of preparation for the euro adoption.

Based on the estimation results of the structural model we conclude also in this case that the downturn was affected to such a large extent by negative expectations and by the negative development of the economies of the main export partners that there was no room for an independent monetary policy to significantly mitigate the sharp deterioration of the domestic economy in 2009.

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Appendix A Conditional distribution of the unobserved data

The conditional distribution of the unobserved data,

$$p\left(\Delta y_{u,t} \middle| y_0, \hat{\mathrm{y}}_{u,\backslash t}, \Theta\right)$$

is proportional to the product of densities of the changes in endogenous variables between *t+1* and *t* given data at *t*, $p\left(\Delta y_{o,t+1}, \Delta y_{u,t+1} \middle| \Delta y_{o,t}, \Delta y_{u,t}, y_{o,t}, y_{u,t}, \Theta\right)$ and the changes in endogenous variables between *t* and *t-1*, $p\left(\Delta y_{o,t}, \Delta y_{u,t} \middle| \Delta y_{o,t-1}, \Delta y_{u,t-1}, y_{o,t-1}, y_{u,t-1}, \Theta\right)$:

$$p\left(\Delta y_{u,t} \middle| y_0, \hat{\mathrm{y}}_{u,\backslash t}, \Theta\right) \propto$$

$$p\left(\Delta y_{o,t+1}, \Delta y_{u,t+1} \middle| \Delta y_{o,t}, \Delta y_{u,t}, y_{o,t}, y_{u,t}, \Theta\right) p\left(\Delta y_{o,t}, \Delta y_{u,t} \middle| \Delta y_{o,t-1}, \Delta y_{u,t-1}, y_{o,t-1}, y_{u,t-1}, \Theta\right)$$

The densities are conditionally normal:

$$p\left(\Delta y_{o,t+1}, \Delta y_{u,t+1} \middle| \Delta y_{o,t}, \Delta y_{u,t}, y_{o,t}, y_{u,t}, \Theta\right) \propto \exp\left\{-\frac{1}{2}\begin{bmatrix} v_{1,t+1} \\ v_{2,t+1} \end{bmatrix}^T \begin{bmatrix} \Sigma^{oo} & \Sigma^{ou} \\ \Sigma^{uo} & \Sigma^{uu} \end{bmatrix} \begin{bmatrix} v_{1,t+1} \\ v_{2,t+1} \end{bmatrix}\right\} \tag{A.1}$$

where

$$v_{1,t+1} = \Delta y_{o,t+1} - A_o - \Pi_{oo} y_{o,t} - \Pi_{ou} y_{u,t} - B_{oo}\Delta y_{o,t} - B_{ou}\Delta y_{u,t} - C_o exog_t$$

$$v_{2,t+1} = \Delta y_{u,t+1} - A_u - \Pi_{uo} y_{o,t} - \Pi_{uu} y_{u,t} - B_{uo}\Delta y_{o,t} - B_{uu}\Delta y_{u,t} - C_u exog_t$$

$$p\left(\Delta y_{o,t}, \Delta y_{u,t} \middle| \Delta y_{o,t-1}, \Delta y_{u,t-1}, y_{o,t-1}, y_{u,t-1}, \Theta\right) \propto \exp\left\{-\frac{1}{2}\begin{bmatrix} v_{1,t} \\ v_{2,t} \end{bmatrix}^T \begin{bmatrix} \Sigma^{oo} & \Sigma^{ou} \\ \Sigma^{uo} & \Sigma^{uu} \end{bmatrix} \begin{bmatrix} v_{1,t} \\ v_{2,t} \end{bmatrix}\right\} \tag{A.2}$$

where

$$v_{1,t} = \Delta y_{o,t} - A_o - \Pi_{oo} y_{o,t-1} - \Pi_{ou} y_{u,t-1} - B_{oo}\Delta y_{o,t-1} - B_{ou}\Delta y_{u,t-1} - C_o exog_{t-1}$$

$$v_{2,t} = \Delta y_{u,t} - A_u - \Pi_{uo} y_{o,t-1} - \Pi_{uu} y_{u,t-1} - B_{uo}\Delta y_{o,t-1} - B_{uu}\Delta y_{u,t-1} - C_u exog_{t-1}$$

Multiplying (A.1) and (A.2) gives

$$p\left(\Delta y_{u,t} \middle| y_0, \hat{\mathrm{y}}_{u,\backslash t}, \Theta\right) = \exp\left\{-\frac{1}{2}\begin{bmatrix} v_{1,t+1} \\ v_{2,t+1} \end{bmatrix}^T \begin{bmatrix} \Sigma^{oo} & \Sigma^{ou} \\ \Sigma^{uo} & \Sigma^{uu} \end{bmatrix} \begin{bmatrix} v_{1,t+1} \\ v_{2,t+1} \end{bmatrix} - \frac{1}{2}\begin{bmatrix} v_{1,t} \\ v_{2,t} \end{bmatrix}^T \begin{bmatrix} \Sigma^{oo} & \Sigma^{ou} \\ \Sigma^{uo} & \Sigma^{uu} \end{bmatrix} \begin{bmatrix} v_{1,t} \\ v_{2,t} \end{bmatrix}\right\}$$

$$= \exp\left\{-\frac{1}{2}\Big[v_{1,t+1}^T \Sigma^{oo} v_{1,t+1} + v_{1,t+1}^T \Sigma^{ou} v_{2,t+1} + v_{2,t+1}^T \Sigma^{uo} v_{1,t+1} + v_{2,t+1}^T \Sigma^{uu} v_{2,t+1} + \right.$$

$$\left. + v_{1,t}^T \Sigma^{oo} v_{1,t} + v_{1,t}^T \Sigma^{ou} v_{2,t} + v_{2,t}^T \Sigma^{uo} v_{1,t} + v_{2,t}^T \Sigma^{uu} v_{2,t} \Big]\right\} \propto$$

$$\propto \exp\left\{-\frac{1}{2}\Big[v_{1,t+1}^T \Sigma^{oo} v_{1,t+1} + v_{1,t+1}^T \Sigma^{ou} v_{2,t+1} + v_{2,t+1}^T \Sigma^{uo} v_{1,t+1} + v_{2,t+1}^T \Sigma^{uu} v_{2,t+1} + \right.$$

$$\left. + v_{1,t}^T \Sigma^{ou} v_{2,t} + v_{2,t}^T \Sigma^{uo} v_{1,t} + v_{2,t}^T \Sigma^{uu} v_{2,t} \Big]\right\} = \exp\left\{-\frac{1}{2}\Big[\Delta y_{u,\mathrm{t}}^T V_1 \Delta y_{u,t} - \Delta y_{u,t}^T V_2 - V_2^T \Delta y_{u,t}\Big]\right\} \propto$$

$$\propto \exp\left\{-\frac{1}{2}\left[\Delta y_{u,\mathrm{t}}^T V_1 \Delta y_{u,t} - \Delta y_{u,t}^T V_2 - V_2^T \left(V_1^{-1}\right)^T V_1 \Delta y_{u,t} + V_2^T \left(V_1^{-1}\right)^T V_2\right]\right\} =$$

$$\propto \exp\left\{-\frac{1}{2}\left[\Delta y_{u,\mathrm{t}}^T V_1 \Delta y_{u,t} - \Delta y_{u,t}^T V_1 V_1^{-1} V_2 - \left(V_1^{-1} V_2\right)^T V_1 \Delta y_{u,t} + \left(V_1^{-1} V_2\right)^T V_1 V_1^{-1} V_2\right]\right\} =$$

$$= \exp\left\{-\frac{1}{2}\left(\Delta y_{u,t} - V_1^{-1} V_2\right)^T V_1 \left(\Delta y_{u,t} - V_1^{-1} V_2\right)\right\},$$

where V_1 and V_2 are defined in (4.3) and (4.4). In the derivation we made use of the fact that V_1 is a symmetric matrix.

Appendix B Log-linearization of the IS curve

We log-linearize the expression

$$Y_t = \left(\frac{P_{H,t}}{P_t}\right)^{-\eta} C_t\left[(1-\alpha)+\alpha_F \vartheta_F S_t^{-\eta} Q_t^{\eta-1/\sigma}\right]+B_T$$

around a symmetric steady-state value, where:

$$Y_t = Y^*, C_t = C^*, B_t = B^*, P_{H,t} = P_t = P^*, S_t = Q_{F,\mathrm{t}} = 1$$

As it is described in more detail in, e.g., DeJong and Dave (2007) , log-linearization of an equation

$g(Y_t) = f(X_{1,t}, X_{2,t},..., X_{n,t}); n \in N$ around a steady-state value $Y, X_1, X_2,..., X_n$ yields to the following expression:

$$g'(Y)Y(\ln Y_t - \ln Y) = f_{X_1}(X_1, X_2,..., X_n)X_1(\ln X_{1,t} - \ln X_1)+$$

$$+f_{X_2}(X_1, X_2,..., X_n)X_2(\ln X_{2,t} - \ln X_2)+...+f_{X_n}(X_1, X_2,..., X_n)X_n(\ln X_{n,t} - \ln X_n) \quad \text{(B.1)}$$

For the total output we have

$$g(Y_t) = Y_t$$

$$f(P_{H,t}, P_t, C_t, S_t, Q_t, B_t) = \left(\frac{P_{H,t}}{P_t}\right)^{-\eta} C_t\left[(1-\alpha)+\alpha_F \vartheta_F S_t^{-\eta} Q_t^{\eta-1/\sigma}\right]+B_T$$

The first derivations take the form:

$$g'(Y^*) = 1$$

$$f_{P_{H,t}}(P^*, C^*, 1, 1, B^*) = -\eta C^*\left[(1-\alpha)+\alpha_F \vartheta_F\right]\frac{1}{P^*}$$

$$f_{P_t}(P^*, C^*, 1, 1, B^*) = \eta C^*\left[(1-\alpha)+\alpha_F \vartheta_F\right]\frac{1}{P^*}$$

$$f_{C_t}(P^*, C^*, 1, 1, B^*) = \left[(1-\alpha)+\alpha_F \vartheta_F\right]$$

$$f_{S_t}(P^*, C^*, 1, 1, B^*) = -\eta \alpha_F \vartheta_F C^*$$

$$f_{Q_t}(P^*, C^*, 1, 1, B^*) = \left(\eta - \frac{1}{\sigma}\right)\alpha_F \vartheta_F C^*$$

$$f_{B_t}(P^*, C^*, 1, 1, B^*) = 1$$

Substituting into (B.1):

$$Y^*\left(y_t - y^*\right) = -\eta C^*\left[(1-\alpha)+\alpha_F\vartheta_F\right]\left(p_{H,t} - p^*\right) + \eta C^*\left[(1-\alpha)+\alpha_F\vartheta_F\right]\left(p_t - p^*\right) +$$

$$+\left[(1-\alpha)+\alpha_F\vartheta_F\right]C^*\left(c_t - c^*\right) - \eta\alpha_F\vartheta_F C^* s_t + \left(\eta - \frac{1}{\sigma}\right)\alpha_F\vartheta_F C^* q_t + B^*\left(b_t - b^*\right) =$$

$$= \eta C^*\left[(1-\alpha)+\alpha_F\vartheta_F\right]\left(p_t - p_{H,t}\right) + \left[(1-\alpha)+\alpha_F\vartheta_F\right]C^*\left(c_t - c^*\right) - \eta\alpha_F\vartheta_F C^* s_t +$$

$$+\left(\eta - \frac{1}{\sigma}\right)\alpha_F\vartheta_F C^* q_t + B^*\left(b_t - b^*\right) \qquad \text{(B.2)}$$

where

$y^* = \ln\left(Y^*\right), y_t = \ln\left(Y_t\right), c^* = \ln\left(C^*\right), c_t = \ln\left(C_t\right), p^* = \ln\left(P^*\right), b^* = \ln\left(B^*\right), b_t = \ln\left(B_t\right)$.

As $p_t - p_{H,t} = \alpha s_t$ and $q_t = (1-\alpha)s_t$, we can rewrite (B.2) as:

$$Y^*\left(y_t - y^*\right) = \eta C^*\left[(1-\alpha)+\alpha_F\vartheta_F\right]\frac{\alpha}{1-\alpha}q_t + \left[(1-\alpha)+\alpha_F\vartheta_F\right]C^*\left(c_t - c^*\right) -$$

$$-\eta\alpha_F\vartheta_F C^*\frac{1}{1-\alpha}q_t + \left(\eta - \frac{1}{\sigma}\right)\alpha_F\vartheta_F C^* q_t + B^*\left(b_t - b^*\right) =$$

$$= \left[(1-\alpha)+\alpha_F\vartheta_F\right]C^*\left(c_t - c^*\right) + B^*\left(b_t - b^*\right) + \left[\alpha\eta - \frac{1}{\sigma}\alpha_F\vartheta_F\right]C^* q_t \qquad \text{(B.3)}$$

Dividing (B.3) by Y^* and adding y^* we obtain

$$y_t = \frac{y^*}{Y^*} + \left[(1-\alpha)+\alpha_F\vartheta_F\right]\frac{C^*}{Y^*}\left(c_t - c^*\right) + \frac{B^*}{Y^*}\left(b_t - b^*\right) + \left[\alpha\eta - \frac{1}{\sigma}\alpha_F\vartheta_F\right]\frac{C^*}{Y^*}q_t .$$

Appendix C Derivation of the reaction function

We can use (5.37), (5.31) and (5.35) to form the Lagrangian and derive the optimal value of the output gap, inflation and the exchange rate and (5.19) to derive the optimal value for the monetary policy rate.

The Lagrangian takes the form:

$$L\left(x_t, E_t\{\pi_{t+1}\}, E_t\{e_{t+1}\}, \lambda_1, \lambda_2\right) - \frac{1}{2}\left[\left(1-k_\pi-k_e\right)x_t^2 + k_\pi E_t\left\{\pi_{t+1}^2\right\} + k_e E_t\{e_{t+1}-\overline{e}_{t+1}\}^2\right] -$$

$$-\lambda_1\left(x_t - E_t\{x_{t+1}\} - \beta_{x,1} - \beta_{x,2}r_t - \beta_{x,3}E_t\{\pi_{t+1}\} - \beta_{x,4}\pi_t^a - \beta_{x,5}E_t\{\Delta e_{t+1}\} - \beta_{x,6}E_t\left\{\pi_{t+1}^F\right\} - E_t\{\Delta\overline{y}_{t+1}\}\right) -$$

$$-\lambda_2\left(E_t\{\pi_{t+1}\} - \beta_{\pi,1} - \beta_{\pi,2}\pi_t - \beta_{\pi,3}E_t\{\pi_{t+2}\} - \beta_{\pi,4}x_t - \beta_{\pi,5}E_t\left\{\pi_{t+1}^F\right\} - \beta_{\pi,6}e_t\right)$$

The first order conditions take the form:

$$\frac{\partial L}{\partial x_t} = -\left(1-k_\pi-k_e\right)x_t - \lambda_1 + \beta_{\pi,4}\lambda_2 = 0 \qquad \text{(C.1)}$$

$$\frac{\partial L}{\partial E_t\{\pi_{t+1}\}} = -k_\pi E_t\{\pi_{t+1}\} + \beta_{x,3}\lambda_1 - \lambda_2 = 0 \qquad \text{(C.2)}$$

$$\frac{\partial L}{\partial E_t\{e_{t+1}\}} = -k_e E_t\{e_{t+1}-\overline{e}_{t+1}\} + \beta_{x,5}\lambda_1 = 0 \qquad \text{(C.3)}$$

Multiplying (C.1) by $\beta_{x,5}$ and adding to (C.3) yields to

$$-\beta_{x,5}\left(1-k_\pi-k_e\right)x_t + \beta_{\pi,4}\beta_{x,5}\lambda_2 - k_e E_t\{e_{t+1}-\overline{e}_{t+1}\} = 0 \qquad \text{(C.4)}$$

Multiplying (C.2) by $-\beta_{x,5}$, (C.3) by $\beta_{x,3}$ and adding to each other yields to

$$k_\pi\beta_{x,5}E_t\{\pi_{t+1}\} + \beta_{x,5}\lambda_2 - k_e\beta_{x,3}E_t\{e_{t+1}-\overline{e}_{t+1}\} = 0 \qquad \text{(C.5)}$$

Multiplying (C.5) by $-\beta_{\pi,4}$ and adding to (C.4) yields to

$$-\beta_{x,5}\left(1-k_\pi-k_e\right)x_t + k_e\left(\beta_{\pi,4}\beta_{x,3}-1\right)E_t\{e_{t+1}-\overline{e}_{t+1}\} - \beta_{\pi,4}\beta_{x,5}k_\pi E_t\{\pi_{t+1}\} = 0$$

or, multiplying by -1 and together with the IS and the Phillips curve:

$$\beta_{x,5}\left(1-k_\pi-k_e\right)x_t + k_e\left(1-\beta_{\pi,4}\beta_{x,3}\right)E_t\{e_{t+1}-\overline{e}_{t+1}\} + \beta_{\pi,4}\beta_{x,5}k_\pi E_t\{\pi_{t+1}\} = 0 \qquad \text{(C.6)}$$

$$x_t = E_t\{x_{t+1}\} + \beta_{x,1} + \beta_{x,2}r_t + \beta_{x,3}E_t\{\pi_{t+1}\} + \beta_{x,4}\pi_t^a + \beta_{x,5}E_t\{\Delta e_{t+1}\} + \beta_{x,6}E_t\left\{\pi_{t+1}^F\right\} + E_t\{\Delta\overline{y}_{t+1}\}$$

(C.7)

$$E_t\{\pi_{t+1}\} = \beta_{\pi,1} + \beta_{\pi,2}\pi_t + \beta_{\pi,3}E_t\{\pi_{t+2}\} + \beta_{\pi,4}x_t + \beta_{\pi,5}E_t\left\{\pi_{t+1}^F\right\} + \beta_{\pi,6}e_t \qquad \text{(C.8)}$$

Multiplying (C.7) by $-\beta_{x,5}(1-k_\pi-k_e)$ and adding to (C.6):

$$\beta_{x,5}\left(\beta_{\pi,4}k_\pi+\beta_{x,3}\left(1-k_\pi-k_e\right)\right)E_t\left\{\pi_{t+1}\right\}+\left(k_e\left(1-\beta_{\pi,4}\beta_{x,3}\right)+\beta_{x,5}^2\left(1-k_\pi-k_e\right)\right)E_t\left\{e_{t+1}\right\}+$$
$$+\beta_{x,5}\left(1-k_\pi-k_e\right)\left(E_t\left\{x_{t+1}\right\}+\beta_{x,1}+\beta_{x,2}r_t+\beta_{x,4}\pi_t^a-\beta_{x,5}e_t+\beta_{x,6}E_t\left\{\pi_{t+1}^F\right\}+E_t\left\{\Delta\overline{y}_{t+1}\right\}\right)-$$
$$-k_e\left(1-\beta_{\pi,4}\beta_{x,3}\right)\overline{e}_{t+1}=0 \qquad \text{(C.9)}$$

Multiplying the (C.7) by $\beta_{\pi,4}$ and adding to (C.8):

$$\left(1-\beta_{\pi,4}\beta_{x,3}\right)E_t\left\{\pi_{t+1}\right\}-\beta_{\pi,4}\beta_{x,5}E_t\left\{e_{t+1}\right\}-\beta_{\pi,4}\left(E_t\left\{x_{t+1}\right\}+\beta_{x,1}+\beta_{x,2}r_t+\beta_{x,4}\pi_t^a-\beta_{x,5}e_t+\right.$$
$$\left.+\beta_{x,6}E_t\left\{\pi_{t+1}^F\right\}+E_t\left\{\Delta\overline{y}_{t+1}\right\}\right)-\beta_{\pi,1}-\beta_{\pi,2}\pi_t-\beta_{\pi,3}E_t\left\{\pi_{t+2}\right\}-\beta_{\pi,5}E_t\left\{\pi_{t+1}^F\right\}-\beta_{\pi,6}e_t=0$$
$$\text{(C.10)}$$

Multiplying (C.9) by $-\left(1-\beta_{\pi,4}\beta_{x,3}\right)$, (C.10) by $\beta_{x,5}\left(\beta_{\pi,4}k_\pi+\beta_{x,3}\left(1-k_\pi-k_e\right)\right)$ and adding together we get for the expected value of the exchange rate:

$$\left[-\beta_{\pi,4}\beta_{x,5}^2\left(\beta_{\pi,4}k_\pi+\beta_{x,3}\left(1-k_\pi-k_e\right)\right)-\left(1-\beta_{\pi,4}\beta_{\pi,3}\right)\left(k_e\left(1-\beta_{\pi,4}\beta_{\pi,3}\right)+\beta_{x,5}^2\left(1-k_\pi-k_e\right)\right)\right]E_t\left\{e_{t+1}\right\}=$$
$$=\left(\left(1-\beta_{\pi,4}\beta_{x,3}\right)\beta_{x,5}\left(1-k_\pi-k_e\right)+\beta_{\pi,4}\beta_{\pi,5}\left(\beta_{\pi,4}k_\pi+\beta_{x,3}\left(1-k_\pi-k_e\right)\right)\right)\left(E_t\left\{x_{t+1}\right\}+\beta_{x,1}+\beta_{x,2}r_t+\right.$$
$$\left.+\beta_{x,4}\pi_t^a-\beta_{x,5}e_t+\beta_{x,6}E_t\left\{\pi_{t+1}^F\right\}+E_t\left\{\Delta\overline{y}_{t+1}\right\}\right)-k_e\left(1-\beta_{\pi,4}\beta_{x,3}\right)^2\overline{e}_{t+1}+\beta_{x,5}\left(\beta_{\pi,4}k_\pi+\right.$$
$$\left.+\beta_{x,3}\left(1-k_\pi-k_e\right)\right)\left(\beta_{\pi,1}+\beta_{\pi,2}\pi_t+\beta_{\pi,3}E_t\left\{\pi_{t+2}\right\}+\beta_{\pi,5}E_t\left\{\pi_{t+1}^F\right\}+\beta_{\pi,6}e_t\right) \qquad \text{(C.11)}$$

Substituting (C.11) into (5.19) and re-marking the parameters we obtain for the policy rate:

$$r_t=\beta_{r,1}+\beta_{r,2}E_t\left\{x_{t+1}\right\}+\beta_{r,3}\pi_t^a+\beta_{r,4}e_t+\beta_{r,5}E_t\left\{\pi_{t+1}^F\right\}+\beta_{r,6}E_t\left\{\Delta\overline{y}_{t+1}\right\}+\beta_{r,7}\overline{e}_{t+1}$$
$$+\beta_{r,8}\pi_t+\beta_{r,9}E_t\left\{\pi_{t+2}\right\}+\beta_{r,10}E_t\left\{\pi_{t+1}^F\right\}+\beta_{r,11}r_t^F$$