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

na získanie vedecko-akademickej hodnosti philosophiae doctor
v odbore doktorandského štúdia: 9.1.9. Aplikovaná matematika

Bratislava 2013

Dizertačná práca bola vypracovaná v externej forme doktorandského štúdia na Katedre aplikovanej matematiky a štatistiky Fakulty matematiky, fyziky a informatiky, Univerzity Komenského v Bratislave

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1. 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.

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.

2. 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.

3. Results

3.1. BVEC model of the monetary policy

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. This assumption is supported also by unit root tests.

Therefore, we chose to estimate a VEC model, the general form of which can be written as

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

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:

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

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.

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. 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, 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, $\hat{y}^{i-1}_{u,\backslash t} = \left(\hat{y}^i_{u,1}, \hat{y}^i_{u,2},..., \hat{y}^i_{u,t-1}, \hat{y}^{i-1}_{u,t+1},..., \hat{y}^{i-1}_{u,T}\right)$. $A^{i-1}, B^{i-1}_j, C^{i-1}, \alpha^{i-1}, \beta^{i-1}, \Sigma^{i-1}$ are the latest draws of the parameter matrices.
- Step 2: draw β^i conditional on $\hat{Y}^i, A^{i-1}, B^{i-1}_j, C^{i-1}, \alpha^{i-1}, \Sigma^{i-1}$
- Step 3: draw $A^i, B^i_j, C^i, \alpha^i$ conditional on $\hat{Y}^i, \beta^i, \Sigma^{i-1}$
- Step 4: draw Σ^i conditional on $\hat{Y}^i, A^i, B^i_j, C^i, \alpha^i, \beta^i$

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 1). These endogenous variables represent the set of (domestic) variables that potentially entered the reaction function.

Table 1 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

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

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.

Table 2 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 3 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

We studied 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.

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. 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.

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. A possible explanation is 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.

We also analyzed 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.

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.

3.2. A structural model of the Slovak 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.

As one of the results of the BVEC model is that monetary policy of NBS didn't affected domestic inflation in a significant way, we wanted to test our hypothesis that monetary policy decisions affected, and were transmitted to the development of the, property prices. To test this hypothesis, we first derived the IS curve where we separated investments into properties from consumption. We assumed 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. The model is based on the model presented in Galí and Monacelli (2005).

We derived the IS curve using an assumption that the households are maximizing their utility function. We specified two versions of the utility function, first with backward-looking property prices and the second with forward-looking property prices. The utility function with backward-looking property prices has the form

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

and the utility function with forward-looking property prices has the form

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

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. The first and the last expression within the utility function 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. In case of the utility function with backward-looking property prices we assumed that households are forming their expectations based on the past development of property prices. Rising prices are than transmitted into expectations about future increase of property prices. In case of the utility function with forward-looking property prices we assumed that households have rational expectations about the future development of property prices.

We assumed that the price of the properties (expressed, e.g., in m^2) follows the following simple rule:

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

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 can rewrite this equation in a log-linearized form:

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

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

Based on the optimizing households and together with some other assumptions it is possible to show that investments into properties can be described by an Euler equation of the form

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

in case of the backward-looking property prices in the utility function, where $\pi_t^a \equiv a_t - a_{t-1}$ is the inflation of the property prices and $b_t \equiv \ln(B_t)$. The expression relates the current amount of investment into properties positively 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). In case of the utility function with forward-looking property prices the equation has the form

$$b_t = E_t\{b_{t+1}\} - \left(r_t + \rho E_t\{r_{t+1}\} - (\rho+1)E_t\{\pi_{t+1}^a\}\right)$$

The difference 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.

Based on this equation, on the Euler equation that can be derived for the consumption and together with other assumptions it is possible to derive the IS curve of the form

$$y_t = E_t\{y_{t+1}\} + \beta_{y,1} + \beta_{y,2} r_t + \beta_{y,3} E_t\{\pi_{t+1}\} + \beta_{y,4}\pi_t^a + \beta_{y,5} E_t\{\Delta e_{t+1}\} + \beta_{y,6} E_t\{\pi_{t+1}^F\}$$

using the utility function with backward-looking property prices, 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

$$x_t \equiv y_t - \overline{y}_t \tag{0.1}$$

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):

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

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 means 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.

Using the utility function with forward-looking property prices the IS curve has the form

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

$$+\beta_{x,5} E_t\{\Delta e_{t+1}\} + \beta_{x,6} E_t\{\pi_{t+1}^F\} + \beta_{x,7} E_t\{r_{t+1}\} + E_t\{\Delta\overline{y}_{t+1}\}$$

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.

We assumed that the central bank of the small open-economy seeks to maximize a loss function of the form:

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

where $\bar{e}_t$ 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

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

Together with the IS curve, the uncovered interest rate parity and the Phillips curve, for which we assumed a general form similarly to Vašíček (2009), it is possible to derive the reaction function of the central bank. We also show that, 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 rather than to the development of these key variables.

Based on the theoretical model we estimated a structural model of the Slovak economy. 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. As there are expectations entering the model, based on the findings of Danišková (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

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

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 (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). 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, 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.

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.

Estimation results for the benchmark theoretical model are relatively poor. 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.

Estimation results are very similar comparing specifications using detrended data and first differences. 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 of the

BVEC model 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, 2009). 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.

4. 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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