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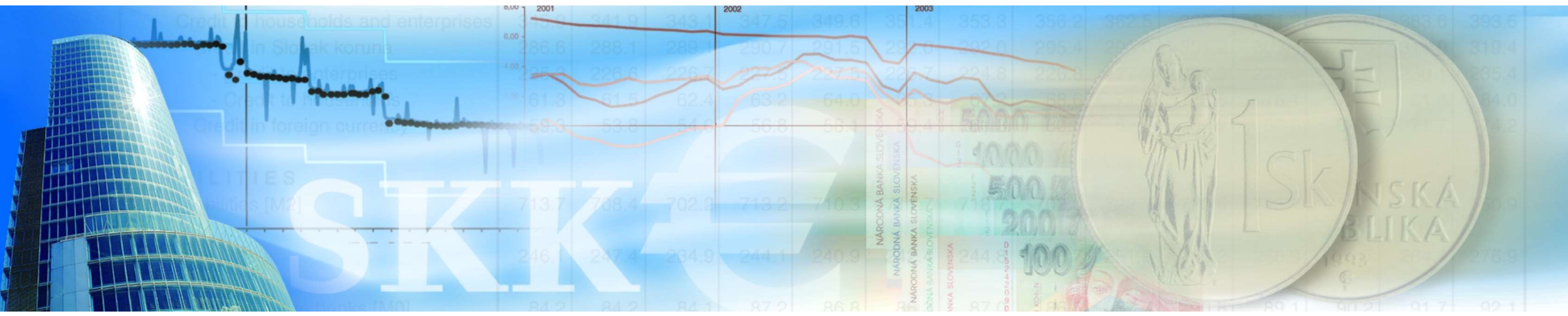
EFFECTS OF MONETARY POLICY SHOCKS IN SLOVAKIA



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EFFECTS OF MONETARY POLICY SHOCKS IN SLOVAKIA[1]

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Abstract

This paper presents the results of empirical investigation into Slovak monetary policy shocks' impacts on the economy. For estimating purposes, structural VAR based impulse responses of output, prices, exchange rates and short-term interest rates on structural disturbances selected by sign restrictions are studied. In most cases, to improve the quality of monetary policy shock definition, additional identification of historical shocks is provided. As a conclusion, unanticipated 50 basis points increase of the key interest rate lowers prices by up to 0.4% against the baseline. As expected, peak response is reached about one year after the shock at the latest. However, the effect on output is conflicting, suggesting that variations in monetary policy account for little variation in output.

Keywords: Structural Shocks, Monetary Policy Transmission Mechanism, Sign Restrictions
JEL classification: E52, C32, C51

Reviewed by: Roman Horváth (Czech National Bank)
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1 Introduction

For monetary policymaker, who attempts to ensure price stability, the most important question is how interest rate hike or cut by a given amount influences the economy, mainly prices, but also other indicators as output or exchange rates. In emerging small open economies, the monetary transmission mechanism is generally thought to be less straightforward. Existing literature on functioning of the channels of the mechanism in Central and Eastern Europe is summarized in a surveying paper of Coricelli et al. (2006). However, the paper reveals that in comparison with Hungary, Poland or the Czech Republic, Slovakia remains to be relatively less explored.

The structural vector autoregression (VAR) techniques show very good abilities to study economic fluctuations. It is a popular and well suited approach for the empirical analysis of the behaviour of endogenous variables in response to economic innovations. The method ensures a relatively precise definition of an independent shock, characterized from theoretical evidence. Moreover, with impulse response functions, the procedure allows to follow the dynamic development of variables in a given time horizon as a reaction to a shock. In other words, while exploring the transmission mechanism of the monetary policy, the advantage of structural VAR approach is that it allows identifying monetary policy shocks by characterizing their dynamic effects on economic indicators.

As already mentioned, literature on Slovak monetary policy effects, especially within a structural VAR framework, is rather limited. For example, Jarociński (2008) compares impulse responses to monetary policy shocks in two panels, five euro area countries and four of the New Member States from central-eastern Europe, exclusive of Slovakia. He argues that market interest rates in Slovakia fluctuate strongly and independently of the central bank interest rates, suggesting that the identification of monetary policy shocks in a model, where the central bank manages market interest rates by setting its instrument interest rate, might not be appropriate.

Nevertheless, there are some papers utilizing the method for Slovakia. For example, Kuijs (2002) provides a VAR model with restrictions based on estimated ECM equations and inspects impulse responses of variables on M2, real interest rate and exchange rate shocks. He concludes that the main direct determinants of inflation are foreign prices, the exchange rate and wage costs, with some additional impact from aggregate demand, but the impact of monetary policy on prices is indirect via the impact of interest rates on the exchange rate and aggregate demand and the impact of broad money on wage costs.

Ganev et al. (2002) use generalized impulse responses to analyze the exchange rate and interest rate transmission channel. The method is based on subjecting a selected equation to a one-standard-deviation forecast error shock, and simultaneously all other equations proportionally to correlation of residuals in a selected equation and other equations. The main advantage of the approach is that it does not require orthogonalization of shocks and is invariant to the ordering of the variables. The authors find that for Slovakia, a rise in short-term interest rate dampens output in the short run, brings about initial depreciation followed by appreciation of the currency, but raises inflation persistently which leads to higher inflation even after 3 years following the shock.

The VAR analysis in the EFN Report (2004) concludes that in the Slovak Republic, there is clear evidence of an exchange rate channel, while the interest rate channel of monetary policy seems to be blocked.

Elbourne and de Haan (2006) analyze responses to a shock of one hundred basis points to the domestic short-term interest rate identified by imposing short-term restrictions in structural VAR models for the most of 2004 and 2007 accession countries. They find that for the Slovak Republic, there is a positive, however statistically insignificant initial industrial production response, followed by a negative peak after 28 months. Further, the price level responds with a negative peak after 5 months. Finally, the exchange rate appreciates immediately markedly, but the interest rate responses with another significant cca. 150 basis points increase after 8 months.

Héricourt (2006) apply Cholesky and generalized impulse responses to estimate the effects of interest rate, exchange rate, money and domestic credit shocks in eight CEE countries. The results for Slovakia suggest that a monetary policy tightening leads to the expected but less significant contraction of output and appreciation of the exchange rate. However, price puzzle is also present at the beginning of the response period.

Horváth and Rusnák (2009) investigate the effects of domestic and Euro area monetary policy shocks in Slovakia, based on a block-restriction VAR model. To avoid the problem of price puzzle, they use output gap instead of GDP. According to their model, the monetary transmission mechanism functions relatively well: the price level drops, the output decreases and the nominal exchange rate appreciates after a domestic monetary tightening. Further, they find that the effect of the ECB's monetary policy shock on prices is larger than the effect of the corresponding NBS monetary policy shock. However, the large effect of the ECB's monetary policy shock doesn't prove to appear in the rest of the variables' responses. Anyway, the paper counts among the most relevant literature on the topic of estimating the effects of monetary policy shocks on the Slovak economy in a structural VAR framework, where the shock identification is based on a Cholesky recursive scheme. The contribution of present paper to the related literature is that we impose restrictions on signs of the responses in selected periods, instead of restricting them to fixed values in short- or long run, which may be in some sense arbitrary.

Key stage at employing structural VAR approach is to choose right criteria for identifying the monetary policy shock. We do it through its expected effects on variables in the system. According to conventional knowledge, contractionary monetary policy shock results in higher interest rates, stronger exchange rate, lower prices and reduced output. While attempting to identify monetary policy shocks, we keep in mind these "rules". However, as is often the case in literature, the above definition cannot be empirically fully confirmed in case of Slovakia. Therefore, concerning the monetary policy shock identification, we must apply additional restrictions and interpret the results according to them.

The structure of the paper is the following. Section 2 provides theoretical overview of the structural VAR methodology, sign restrictions and the common view about the implications of monetary policy shock widely used in the literature. Section 3 specifies the baseline monthly model, while section 4 introduces empirical results. In section 5, outcomes from additional selection methods and from quarterly model are presented. Results from an alternative model using output gap are also included in this part. Slovak impulse responses are compared with other Central European countries in section 6. Section 7 concludes on the consequences of the empirical analysis.

2 The SVAR approach

2.1 Identification of Vector Autoregressions

Since Vector Autoregressions (VAR) take into account interdependencies between variables better than single equation models and are easier to estimate and use, they belong to most widely used tools in macroeconometric research. A reduced-form VAR is a regression of some vector of variables on its own lags. The estimates of parameters are obtained by applying ordinary least squares (OLS) equation by equation. Then the residuals could be considered as estimates of exogenous disturbances affecting the economy. However, there is no reason to assume that a residual series of any equation corresponds to a “meaningful” economic shock, for example a shock to monetary policy. Since the residuals of the reduced-form VAR are contemporaneously correlated, i.e. not orthogonal among each other, they constitute a linear combination of some “fundamental” or “structural” economic disturbances, mixing contemporaneous responses among endogenous variables. Each element of the residuals’ vector reflects the effects of all the fundamental economic shocks. The impulse responses of the unrestricted reduced-form VAR therefore might not have any economic explanation.

Consider the following reduced-form VAR system:

$$y_t = c + A_1 y_{t-1} + ... + A_p y_{t-p} + e_t \qquad e_t \sim (0, \Omega),$$

where y_t is a vector of n endogenous variables, $A_1 ... A_p$ are $n \times n$ coefficient matrices of lagged endogenous variables with p lags included, c stands for the constant terms, also can include deterministic trends and further exogenous variables, but they are unimportant while describing the model and the methodology. e_t is a vector of residuals - innovations of the system with variance-covariance matrix $E(e_t e_t') = \Omega$. If the innovations are contemporaneously uncorrelated, then the i-th innovation is simply a shock to the i-th endogenous variable, it does not appear in residuals of any other equation. However, innovations are usually correlated, thus they have common components, which cannot be associated with a specific variable. For example, in a 2-variable VAR with output and inflation, the residuals of first equation contain not only innovations to output, but also to inflation and vice versa. In order to obtain orthogonal residuals, the system has to be transformed as follows:

$$\mathrm{B}_0 y_t = c + \mathrm{B}_1 y_{t-1} + ... + \mathrm{B}_p y_{t-p} + \varepsilon_t \qquad \varepsilon_t \sim (0, D),$$

where $\mathrm{B}_j = \mathrm{B}_0 A_j, \varepsilon_t = \mathrm{B}_0 e_t$ and $E(\varepsilon_t \varepsilon_t') = D$ is a diagonal matrix with residual variances σ_i^2 on the diagonal[2]. B_0 can be interpreted as the contemporaneous interrelations between variables. Moreover, since ε_i-s are uncorrelated and $e_t = \mathrm{B}_0^{-1} \varepsilon_t$, B_0^{-1} can be viewed as containing contemporaneous impacts of structural disturbances on the variables. As

[2] This property of D ensures that the residuals are orthogonal.

$\Omega = E(e_t e_t') = \mathrm{B}_0^{-1} E(\varepsilon_t \varepsilon_t')\left(\mathrm{B}_0^{-1}\right)' = \mathrm{B}_0^{-1} D\left(\mathrm{B}_0^{-1}\right)'$, having identified B_0, the system's structural shocks and their dynamics can be found. For identification, both rank condition and order condition is required to be satisfied (Hamilton, 1994). Rank condition means that rank of $\mathrm{B}_0^{-1} D\left(\mathrm{B}_0^{-1}\right)'$ must equal the rank of Ω. The order condition is that B_0 and D have no more unknown parameters than Ω. Since the variance-covariance matrix is symmetric, there are $n(n+1)/2$ distinct values in Ω. It follows that $n(n-1)/2$ additional restrictions, which corresponds to the number of matrix elements above or under the diagonal, are needed to identify the structural system.

A general orthogonalization method which achieves the purpose is an eigenvalue-eigenvector decomposition of the form $\Omega = Q\Lambda Q'$ where Q is a matrix of eigenvectors, Λ is a diagonal matrix with eigenvalues on the main diagonal. From a matrix theory, since Ω is symmetric, the eigenvector basis Q is orthogonal ($QQ'=I=Q'Q$). Another example is the Cholesky decomposition, the most common approach used to achieve the orthogonalization of the shocks. It has a form of $\Omega = PP'$ where P is lower triangular. Consequently, $E(\varepsilon_t \varepsilon_t') = I$, implying that the variances, hence standard deviations of structural innovations equal one.

Although the above-mentioned orthogonalizations are correct and unambiguous, the shocks are still hard to be economically interpreted. In the case of Cholesky decomposition, the zero restrictions above the diagonal mean that variable i is assumed to be affected contemporaneously only by variables (shocks to variables) ordered from 1 to i-1 recursively[3]. Therefore the results are dependent on the ordering of the variables and such restrictions may not have any theoretical foundation. Of course, in cases of lower number of variables (2 or 3), finding the "right" ordering is not so difficult. For example, Stock and Watson (2001) describe a 3-variable recursive VAR. However, most authors use more variables to include as much information as possible, e. g. Sims (1980), Bernanke and Mihov (1998).

Having orthogonal disturbances allows us to distinguish between innovations associated with the particular variables. However, inspecting "output" or "inflation shocks" has not much sense, because they are determined by the model only, they do not appear in reality. More precisely, innovations in economic indicators are always driven by some exogenous deviations in behaviors of economic subjects. Thus, a lot more meaningful is to find structural shocks with economic interpretation, e.g. supply, demand, technology, or monetary shocks, etc. The basic idea of structural VARs is to identify shocks usually by imposing restrictions on impulse responses to the variables. The most popular identification approaches are to impose so-called short- and/or long-run restrictions. For example, it is assumed that monetary policy has no instantaneous impact on output and inflation (Bernanke and Blinder, 1992). On the other hand, although it is difficult to think of long-run restrictions that uniquely identify monetary policy shocks, it can be assumed that monetary policy can have no long-run effects on real variables such as real output, the real interest rate or the real money stock, as used in Keating (1992) and Walsh (1993). An overview of structural VAR methods is provided by Christiano, Eichenbaum and Vigfusson (2006).

Imposing short-run restrictions is essentially a generalization of the Cholesky decomposition. The method consists in restriction of some elements of matrix B_0^{-1} as long as rank and order conditions are satisfied. Clearly, elements of B_0^{-1} need not be necessarily restricted to zero, if

[3] Hence, the decomposition is referred to as recursive identification.

some elasticity is to be captured. Non-recursive short-run identification is applied for example in Blanchard and Perotti (2002), Fatás and Mihov (1998), Gordon and Leeper (1994). Examples of non-zero restrictions are the articles Faust et al (2003) and Smets (1997).

While short-run assumptions take the form of direct restrictions on B_0^{-1}, long-run assumptions place indirect restrictions on B_0^{-1} that stem from restrictions on the long-run response of variables to shocks in elements of ε_t. Note that from the structural form of the VAR, $B_0 y_t = B_1 y_{t-1} + ... + B_p y_{t-p} + \varepsilon_t$, it follows that $(B_0 - B_1 L - B_2 L^2 - ... B_p L^p) y_t = \varepsilon_t$, where L is a lag operator. Thus, imposing long-run restrictions means restrictions on the matrix of long-run effects $B(1)^{-1} = (B_0 - B_1 - ... - B_p)^{-1}$. Again, to identify the structural system, one needs $n(n-1)/2$ long-run restrictions. The approach is exploited in seminal paper of Blanchard and Quah (1989) followed by many others[4].

Identifying shocks with a combination of short-run and long-run restrictions is also possible. Such an approach is applied in Gerlach and Smets (1995), Smets (1997), Peersman and Smets (2001).

However, it is apparent that each approach to identifying monetary policy shocks has its shortcomings. Faust (1998) describes situations when contemporaneous restrictions put forward tentatively may not hold in reality. Faust and Leeper (1997) see imposing long-run – hence infinite horizon - restrictions problematic, since the VAR is estimated with data from a finite sample and this imprecision is transformed to other parameters of the model. Further, they argue that the inferences as regards impulse responses are biased in all sample sizes.

2.2 Sign restrictions

An alternative way to identify shocks in the VAR system is to impose interval, sign or shape restrictions, instead of fixed values. The basic idea is to eliminate those elements of a set of orthogonalizations which do not satisfy the properties that are assumed for the effects of a particular shock. The approach was drafted out by Faust (1998), even if he originally intended to check the robustness of identifications which give reasonable impulse responses.

The method works as follows. First, it extracts orthogonal innovations from the reduced-form model, usually as described above, using Cholesky- or eigenvalue-eigenvector decomposition. The resulting shocks have no economic interpretation, which does not matter in this case, since the goal is to achieve contemporaneously and serially uncorrelated innovations. In a second stage, a set of orthogonal decompositions of Ω and hence a set of orthogonal innovations is generated according to some well-known algorithm. Subsequently, a subset of impulse responses originated from orthogonal shocks which satisfy the given restrictions are selected. Finally, the median of selected impulse responses is computed to investigate the information contained in structural shocks that we have identified and assign an interpretation to their effects on variables in the system.

The restrictions usually regard the signs of impulse responses of variables to an identified shock either immediately (Faust, 1998) or in a longer time horizon (Uhlig, 2005). Notice that

[4] See for example Clarida and Galí (1994), Fackler and McMillin (1998) or Galí (1999)

we may assume that the response of some variable is hump-shaped and dies out after a couple of months or quarters. Hence is the term "shape restriction".

The response of y_{t+h} to a unit shock in ε_t, γ_h, can be computed as follows[5].

$$\gamma_h = \tilde{\gamma}_h \mathrm{B}_0^{-1}, h = 0, 1, ...$$

where $\tilde{\gamma}_h$ is the solution of the following difference equation:

$$\tilde{\gamma}_h = A_1\tilde{\gamma}_{h-1} + ... + A_p\tilde{\gamma}_{h-p}, h = 1, 2, ...$$

with initial conditions

$$\tilde{\gamma}_0 = I, \tilde{\gamma}_{-1} = \tilde{\gamma}_{-2} = ... = \tilde{\gamma}_{-p} = 0.$$

Then, γ_h labels the impulse response function of the elements of y_t to the elements of ε_t after h periods: the (i, j) element of γ_h represents the response of the i^{th} component of y_{t+h} (i^{th} variable) to a unit shock in the j^{th} component of ε_t. Shocks are then identified by imposing restrictions on the signs of selected elements of γ_h for selected h.

Other literatures follow the approach of Canova and De Nicoló (2002), who identify monetary disturbances by imposing sign restrictions on the pairwise dynamic cross-correlations of variables in response to structural shocks. In other words, they search for joint comovements of variables' impulse responses (positive cross-correlation) or their movement in different directions (negative cross-correlation).

There exist several algorithms according to which the space of orthogonal decompositions is to be generated. The approach used in this paper is to generate a class of rotations of the orthogonal system, using rotation matrices H of $n \times n$. An isometric property of a rotation (i.e. it is a transformation that moves points without changing the distances between them) ensures that the impulse responses we focus on do not change their scale. In matrix theory, a rotation matrix is a special orthogonal matrix ($HH'=I=H'H$) the determinant of which is one (det H = +1). It can be easily shown that if H is a rotation matrix, H^{1} is a rotation matrix too. Thus, the following adjustment of the original decomposition of Ω is admissible: $\Omega = PP' = PHH'P' = \hat{P}\hat{P}'$. Then, $e_t = P\varepsilon_t = PHH'\varepsilon_t = \hat{P}\varepsilon_t^*$, hence $\varepsilon_t^* = \hat{P}^{-1}e_t = H^{-1}P^{-1}e_t$, so multiplying by H^{1}, a rotation of orthogonal innovations is received. This produces a new set of shocks and impulses but the shocks will be still orthogonal.

For n=2, the general form of a rotation matrix is

$$H(\omega) = \begin{pmatrix} \cos(\omega) & -\sin(\omega) \\ \sin(\omega) & \cos(\omega) \end{pmatrix},$$

where varying $\omega \in [0,2\pi]$, the entire 2-dimensional space is covered. Although there is infinitely many ω's, the problem can be "discretized" by dividing the interval $[0,2\pi]$ with a relatively fine grid. To extend the dimension to n>2, the 2-dimensional rotation matrix $H(\omega)$ is combined with an identity matrix of $n \times n$, placing the elements of $H(\omega)$ to positions (i, i), (i, j), (j, i) and (j, j) of the identity matrix, i, j = 1, …, n, $i \neq j$, called as Givens matrix:

[5] Christiano, Eichenbaum and Evans (1998)

$$
H_{i,j}(\omega) = \begin{pmatrix} 1 & 0 & 0 & \dots & \dots & \dots & 0 & 0 \\ 0 & 1 & 0 & \dots & \dots & \dots & 0 & 0 \\ \dots & \dots & \ddots & \dots & \dots & \dots & \dots & \dots \\ 0 & 0 & \dots & \cos(\omega) & \dots & -\sin(\omega) & \dots & 0 \\ \vdots & \vdots & \vdots & \vdots & 1 & \vdots & \vdots & \vdots \\ 0 & 0 & \dots & \sin(\omega) & \dots & \cos(\omega) & \dots & 0 \\ \dots & \dots & \dots & \dots & \dots & \dots & \ddots & \dots \\ 0 & 0 & \dots & \dots & \dots & \dots & \dots & 1 \end{pmatrix}.
$$

The object is then rotated within the plane spanned by axes i and j. Since the product of two rotation matrices is a rotation matrix, the product of all possible Givens matrices (all combinations of i and j) with varying angles ω will cover the entire n-dimensional space. Depending on the dimension n and the number of grids g the interval $[0, 2\pi]$ is divided with, there are $g^{n(n-1)/2}$ possible rotations.

The use of rotation matrices is complicated in large scale systems, since there are many rotations one needs to consider. Alternative approach is to use a QR decomposition[6] of a random $n \times n$ matrix drawn from N(0,1) and restrict impulse responses computed from a Wold MA-representation of the VAR multiplied by Q.

Despite the fact that imposing sign restrictions seems to be less arbitrary than short- or long-run restrictions, as Fry and Pagan (2007) criticize, one cannot recover accurate quantitative message simply by the use of sign restrictions, since they are very weak information. Nonetheless, sign restriction identifying approach is an intuitive and useful technique for assessing impulse responses.

2.3 Positive monetary policy shock

The purpose of this paper is to identify monetary policy shocks to reveal its effects on the economy. It has to be done carefully in order to obtain credible results.

Via its effect on demand, monetary policy influences output: through increasing/decreasing instrumental interest rate it moderates/boosts demand, and stabilizes/strengthens production. This is possible, because in short-term horizon, prices and wages are rigid. As an answer, however, in order to stimulate demand to adapt to a new equilibrium, prices stabilize/rise - in the long run, prices and wages are completely flexible. Monetary policy thus can by no means contribute to permanently higher economic growth. On the other hand, price stability is the only feasible long-term objective for monetary policy.

Further, an increase in the policy rate usually[7] leads to a stronger exchange rate for two main reasons. First, in the short run, higher interest rates make domestic assets more attractive relative to investments in other currencies. Second, a monetary policy tightening implies a lower rate of inflation and this in time can be expected to lead to an appreciation of the exchange rate.

[6] Q is an orthogonal and R is a triangular matrix.
[7] If not affected by other factors.

A shock associated with an exogenous monetary policy tightening should thus for example more or less proportionally increase short-term interest rates (temporarily increase the real interest rate), decrease prices, appreciate the exchange rate and should not increase output. The effect on output is however not strongly supported in the literature. Uhlig (1995) concludes that the effect of monetary policy on real GDP is ambiguous. Other authors e.g. Faust (1998) or Bernanke and Mihov (1998) argue that most variation in output is due to non-monetary factors.

Since the output reaction to monetary policy shock is ambiguous and our purpose is to estimate the response of prices, we decided to follow Vonnák (2005) who identifies monetary policy shocks as imposing restrictions on short-term interest rate and on the nominal exchange rate, instead of imposing restrictions on output and prices. We assume that the unanticipated monetary policy tightening results in exchange rate appreciation and higher interest rates (both impulse responses are restricted to be positive). As the results suggest, however, another definition of monetary policy shock seems to be more intuitive. Consequently, for a second alternative, we abandon from restricting exchange rate and restrict prices to decline instead. The restriction on interest rates is maintained.

3 Specification

The underlying VAR is estimated with four variables: real output, price index, nominal effective exchange rate and short-term interest rates. Since the ability of identifying correctly the short-term pattern of an economic phenomenon increases with the frequency of the observations, we build our model on monthly data.

It means that for real output, an alternative to quarterly real GDP series is needed. One possibility is monthly industrial production, which is a standard proxy for monthly GDP. However, this indicator is for the most part formed of products value expressed in units in kind and most reasonably, in case of Slovakia, the fit with the GDP series is poor. Therefore we constructed monthly GDP series based on the idea of Chow and Lin (1971). For this purpose, monthly data of receipts for own and goods in selected branches of economy are used, which include all receipts for products, receipts from services sales and receipts for goods, which are conducted by an enterprise for all its activities. First, monthly data of receipts are converted to quarterly series, by taking the period average. Subsequently, quarterly GDP is estimated on quarterly series of receipts in industry and receipts in sectors other than industry (construction and services). Afterwards, monthly GDP series is constructed according to the estimated equation, using monthly data.

Since monetary policy cannot influence such volatile items as food and fuel prices, also regulated prices and the effect of indirect taxes, CPI adjusted of the above-mentioned effects (net inflation without fuel) is used as for prices. Nominal effective exchange rate is referred to 15 main trading partners of Slovakia. As short-term interest rates, 3-month BRIBOR rate enters the VAR as the fourth variable.

Although estimation results of a VAR are valid under condition of stationary input variables, we estimate the model in levels. The reason is that in small samples it is difficult to determine whether time series are stationary. Further, our goal is to investigate the effects of monetary policy shocks on output and price levels, and imposing restrictions inappropriately could possibly lead to incorrect inference. Finally, according to Sims et al. (1990), the usual practice of transforming the models to stationary form by difference or cointegrating operators whenever it appears likely that the data are integrated is often unnecessary.

GDP and price index series are needed to be seasonally adjusted. Further for better interpretation, except for the interest rate given in percentages, we work with logarithms of series. Data cover the period 1996:M12-2008:M3. The information criteria mostly suggest 1 lag in the baseline VAR, however to get serially uncorrelated residuals, 2 lags are included. Intercept and time trend are also contained in the VAR.

In our case of 4 variables, the rotation matrix is a product of 6 different rotation matrices, depending on the combination of two rows (or columns) with the sine and cosine functions. The rotation angles ω are obtained after dividing the interval $[0,2\pi]$ into 14 uniform sections. All possible combinations of matrices and angles give 14^6=7,53mil. rotations[8]. However, in our work, we choose randomly 2500 different rotations out of them. Thus, we construct 2500 different sets of orthogonal innovations and the impulse responses of all variables on all innovations at all 2500 rotations[9]. The sign restriction method then selects impulse responses satisfying the restrictions specific to a given shock. Moreover, if the impulse responses of a shock satisfy restrictions of opposite signs, their (-1)-multiples are selected as satisfying impulse responses.

4 Empirical results

Assuming that a positive monetary policy shock (monetary policy tightening) results in exchange rate appreciation and higher short-term interest rate, both impulse responses are restricted to be positive. Further, we suppose that interest rate responds to the shock immediately and the positive response lasts at least 6 months. We admit that exchange rate reacts with a lag of 3 months and its response remains positive at least until the 6th month after the shock has arisen. The opposites of impulse responses of a shock, where both exchange rate and interest rate reacts negatively, are also selected.

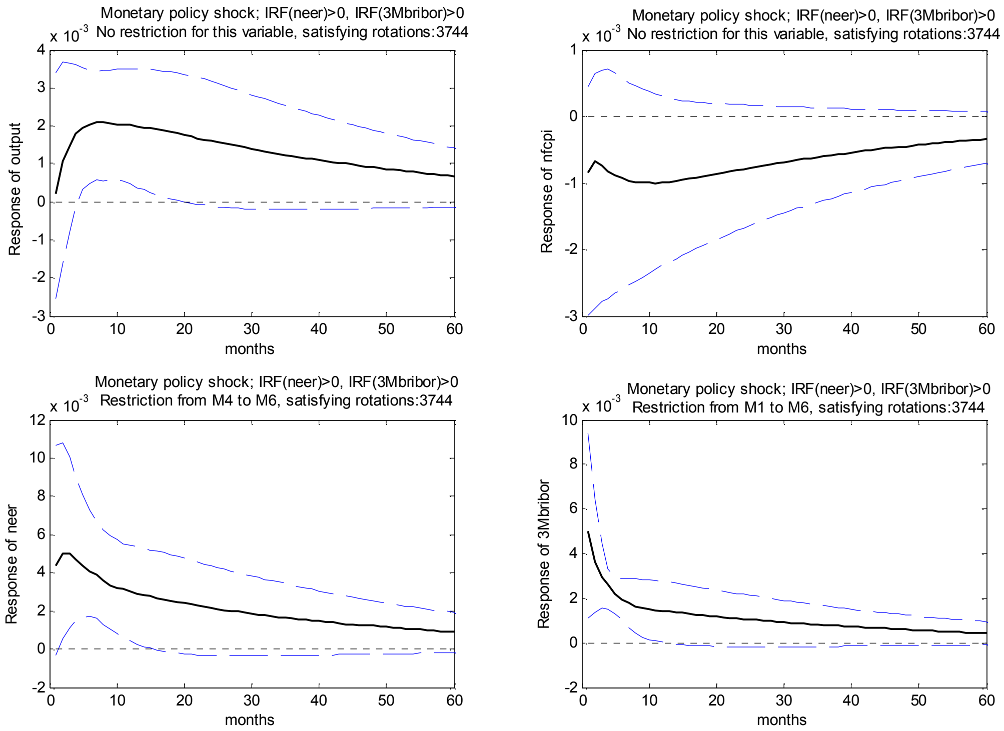
Despite the fact that the interest rate pass-through between the policy and market rates may be incomplete, to make the size of the shock imaginable, the 50 basis points basic interest rate hike is supposed to fully transfer to an immediate short-term interest rate increase. Thus, the impulse responses are normalized as the initial increase of 3-month BRIBOR to be 50 basis points.

Figure 1 shows the effects of positive monetary shocks defined as above. The effect on the interest rate fades out relatively quickly, there remains only 14 points above the baseline after 12 months. The exchange rate appreciates by 0.5% during the first few months, than slows back to 0.3% response after 12 months and 0.2% after two years.

The impact on price level shows a typical hump-shape, suggesting that a 50 basis point monetary policy tightening lowers prices in the first months by 0.07% against the baseline and reaches its biggest effect after 11 months, where the price level is 0.1% below the baseline.

[8] It can be shown that in fact, a part of rotation matrices will generate the same vectors.
[9] That is, in summary, there are $4 \times 2500 = 10\ 000$ impulse responses for each variable.

Figure 1: Impulse responses to 50 points basis point monetary policy tightening, satisfying positive sign restrictions on NEER and 3M Bribor
Solid line indicates median values, 16% and 84% quantiles are represented by dashed lines.

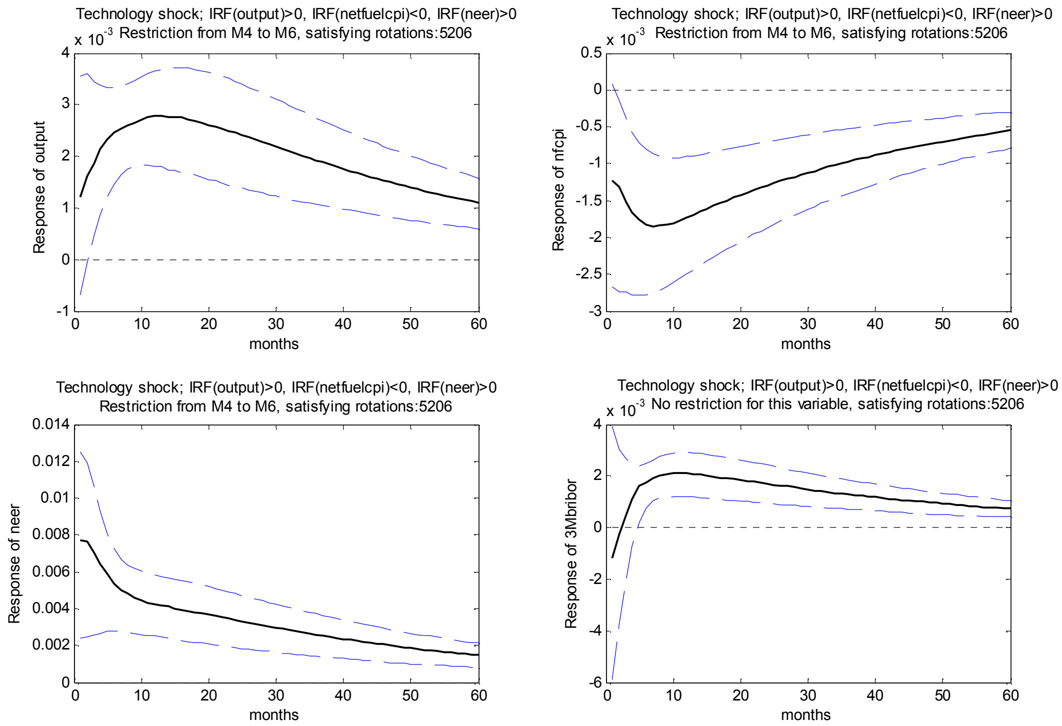


Source: author's own calculations

The most unclear effect is that on the real GDP: the conventional view is that interest rate tightening should not result in increase of output. In contrary, as the results show, the median of the selected monetary shock impulse responses of the output have positive values, peaking in 7 to 9 months after the shock at 0.21%. Moreover, the shock appears to be relatively persistent, since after 4 years the response is still almost 0.1%. One could argue that in most of the period, the output impulse responses do not significantly differ from zero, but still the peak effect is significantly positive. On the other hand, as the price responses suggest, monetary policy has no significant effect neither on prices.

Possible explanation of this puzzle is that the procedure cannot distinguish monetary shock from technology shock. Positive technology shock arises when a new technology or know-how enters the production in a given economy. It increases output and consumption on impact and reduces inflation. Exchange rate appreciation is a consequence of the increasing productivity. Finally, an increase in consumption implies short-term nominal interest rates increase. That is, regarding exchange rate and interest rate impacts, a positive monetary policy shock looks similar to a positive technology shock. To avoid this problem, we can first eliminate technology shocks from the system, see Figure 2.

Figure 2: Impulse responses to technology shock, satisfying positive sign restrictions on output and NEER, as well as negative sign restriction on net fuel CPI
Solid line indicates median values, 16% and 84% quantiles are represented by dashed lines.



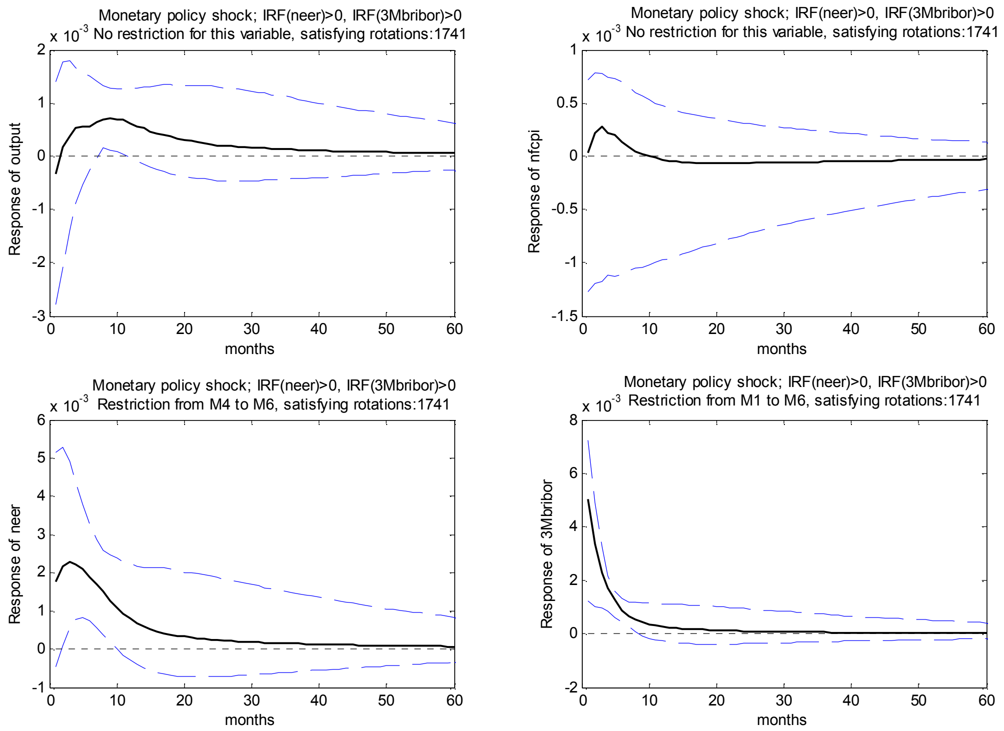
Source: author's own calculations

Figure 3 depicts the effects of a positive monetary policy shock selected from the remaining shocks after elimination of technology shocks.

This step helped to find shocks where the median of the impulse responses of output show less questionable results. The median effect on output is still positive, but smaller in size and less persistent. The problem in this case is the impact on inflation: monetary policy tightening results in a temporary increase of prices. This effect is the so-called price puzzle: monetary policy would tighten in response to a supply shock but not by enough to prevent inflation from rising.

To avoid the puzzle, we can restrict the price level to respond negatively to contractionary monetary policy shock and as for our aim, study the size of the price response only. On the other hand, the restriction of the exchange rate appreciation as a response to monetary policy tightening is doubtful as well. The theory of uncovered interest-rate parity claims that a country that raises interest rates encounters a currency appreciation. This is because rational expectations suggest that the currency will depreciate back to its original (real) exchange rate afterwards. So an increase of interest rates is expected to lead to an appreciation followed by a quick depreciation. However, as for example Blinder (2006) argues, empirically, it does not happen, on average, the uncovered interest rate parity fails. Kim and Roubini (2000) provide some explanations for the so-called exchange rate puzzle. Thus, applying restriction on exchange rate to appreciate in order to identify contractionary monetary policy may be misleading.

Figure 3: Impulse responses to 50 points basis point monetary policy tightening, satisfying positive sign restrictions on NEER and 3M Bribor, after a prior selection of technology shock
Solid line indicates median values, 16% and 84% quantiles are represented by dashed lines.



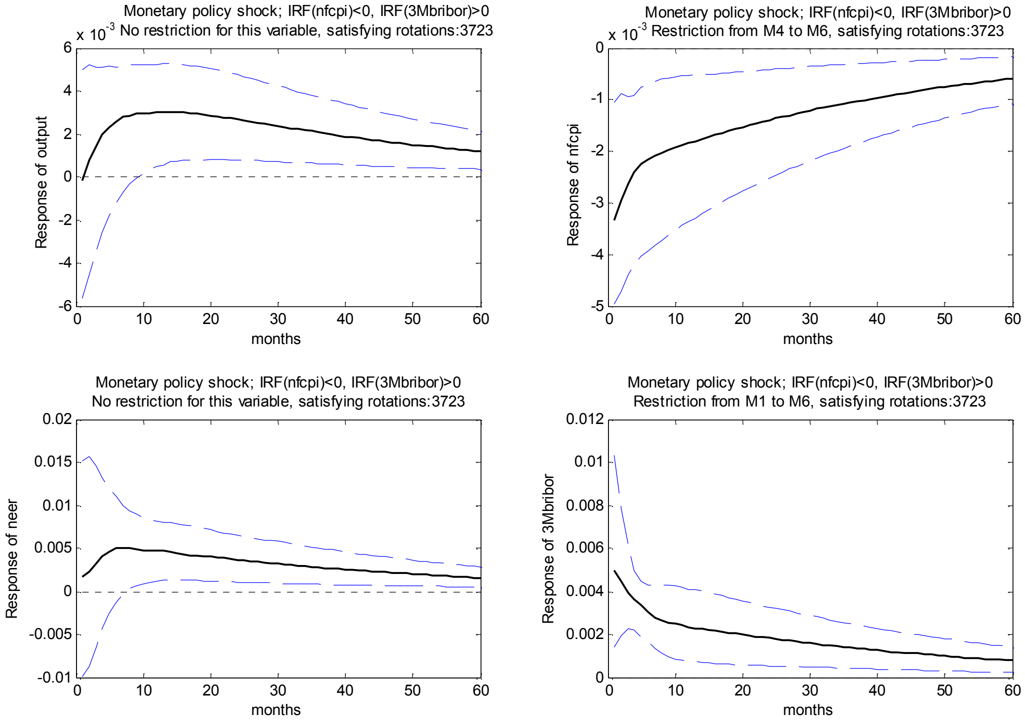
Source: author‘s own calculations

Instead, as another definition of monetary policy shock, in addition to short-term interest rate condition, we restrict prices to react negatively to monetary policy tightening. Again, we allow prices to respond with a 3-months lag until the end of a half-year. Results are captured in Figure 4.

Now the median effect on inflation is immediate, prices lower 0.3% against the baseline in the first two months and the effect gradually dies out. It is -0.2% eight months after the shock, and -0.1% after three years. This shape, in a way contradicts with the expected effect of a monetary policy shock. We can reasonably expect that the impulse response of prices to an effective monetary policy is hump-shaped, that is the biggest impact is reached after a couple of months only. On the other hand, as compared to figure 1, where 11 months after the shock the peak of the price response is at -0.1%, this last case suggests -0.18% at the same period.

Nevertheless, the positive effect on output suggests that again, the specification of the monetary shock might be not precise. The median response peaks at 0.3% in months 10 to 17, which is the biggest positive effect among the different approaches we made. One might think that the problem could be solved simply by restricting the output to be negative, but a neutral or slightly positive response is just as good too. Moreover, we concentrate on the median effect only. So in order to obtain credible results, the identification of monetary policy shocks using restrictions on short-term interest rates and prices should be completed with some additional selection.

Figure 4: Impulse responses to 50 points basis point monetary policy tightening, satisfying negative sign restriction on net fuel CPI and positive sign restriction on 3M Bribor
Solid line indicates median values, 16% and 84% quantiles are represented by dashed lines.



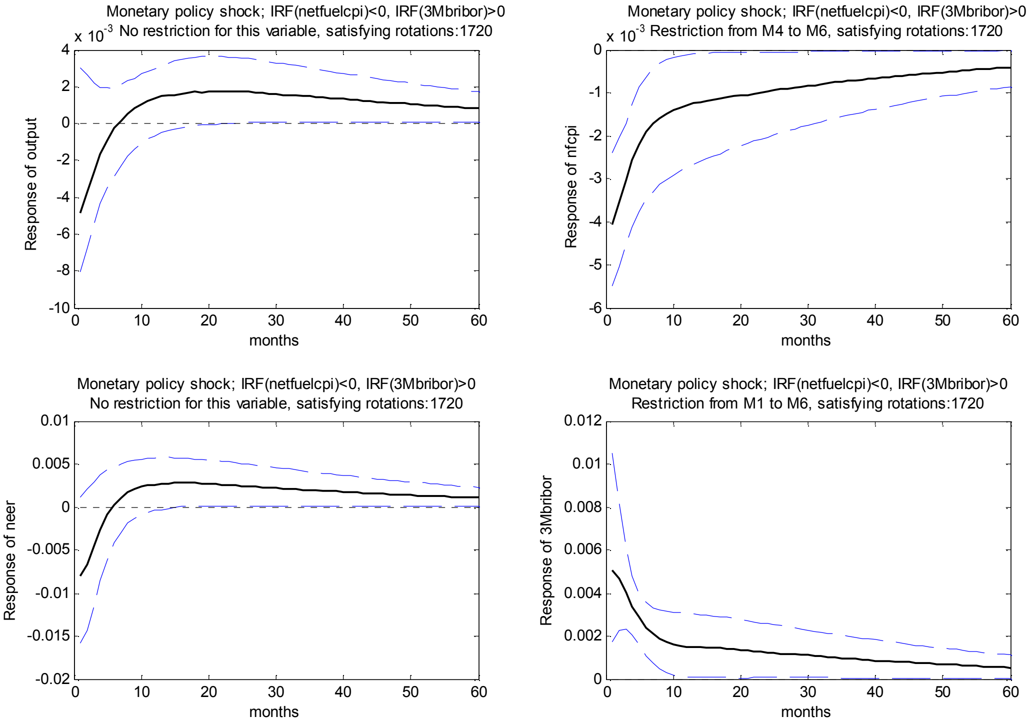
Source: author's own calculations

One possibility is the already applied pre-separation of technology shocks (Fig. 2). After that, interest rate and price restrictions are imposed on the remaining impulse responses. Results are presented in Figure 5.

The advantage of this approach is that the output response is negative in first six months. The immediate effect is -0.5% and when the response of 3-months Bribor falls to 20 basis points, the lower pressure on interest rates allows the effect on output to achieve positive values. The peak is reached 17 to 28 months after the shock at 0.17%. As the exchange rate is not restricted in this case, the initial response is a depreciation (by 0.8%), possibly as a result of worsening expectations concerning the economy due to the interest rate hike. As the effect of the tightening declines, the impact on currency turns into a slight appreciation after 6 months.

The impact on prices is similar as in the previous case of monetary policy shock identification without prior technology shock filtering. Prices decrease 0.4% against the baseline immediately, but the effect fades out more rapidly. The impact lowers to -0.3% in the third month and to -0.2% in the sixth one. -0.1% remains already after less than two years (compared to three years in the previous case).

Figure 5: Impulse responses to 50 points basis point monetary policy tightening, satisfying negative sign restriction on net fuel CPI and positive sign restriction on 3M Bribor, after a prior selection of technology shock
Solid line indicates median values, 16% and 84% quantiles are represented by dashed lines.



Source: author's own calculations

5 Alternative approaches

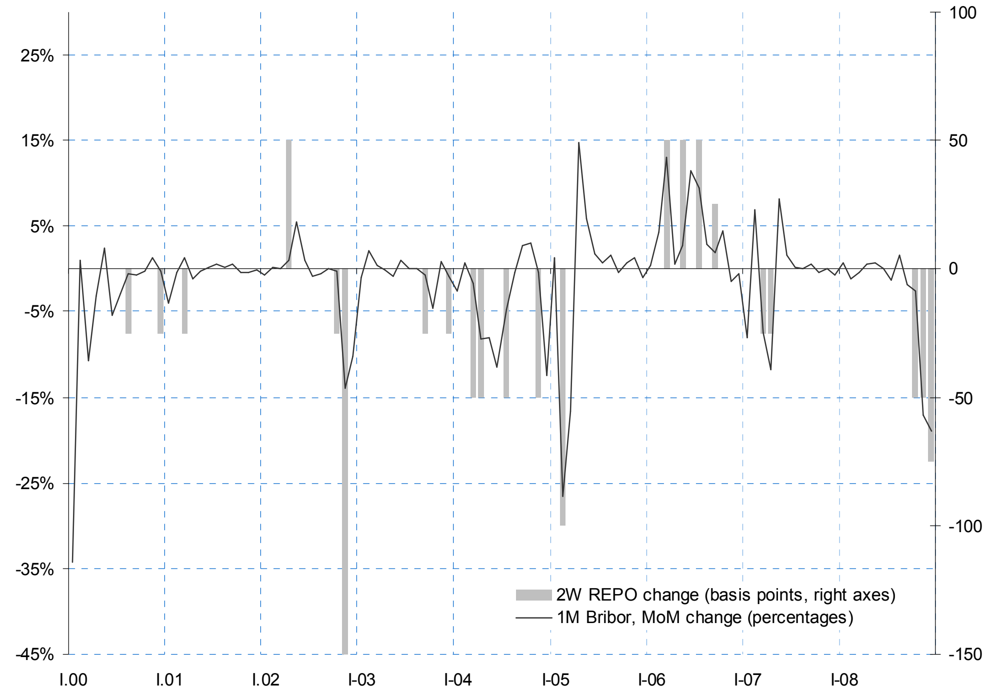
5.1 Historical shocks

Another strategy of supplementary monetary policy shocks identification is to use additional information from the historical development of shocks. The method is inspired by the so-called narrative approach (Romer and Romer, 1989) and employed in the manner as applied in Vonnák (2005). However, in order to avoid identifying a monetary policy shock mixed with several other shocks resulting from sign restriction selection, we utilize the information from historical shocks on the top of sign restrictions, not separately.

The aim is to choose impulse responses of monetary policy shocks with highest and lowest values at given dates of monetary contractions and easenings respectively, known from the history. The identification works as follows. We go through the sets of rotated shocks ($\varepsilon_t^* = H^{-1}\varepsilon_t$) and record the maximum (minimum) value of every shock series. If the period when the maximum (minimum) shock occurs, coincides with a period when a surprise monetary contraction (easening) took place, the shock can be considered as a monetary policy shock. Note that monetary policy decisions are usually made at the end of the month, so as for the date of a monetary policy change as a shock, is assumed to be the next month. We choose one date of a monetary policy contraction and one of a monetary policy easening with a most frequent occurrence or most intuitive results.

Figure 6 depicts the change of the basic interest rates of the NBS, the two week repo tender limit rate (in basis points) and the monthly percentage change of 1-month Bribor rate, as it is assumed to react to monetary policy changes even faster than the 3-months rate, confirming a monetary policy shock in the economy. The figure serves for checking whether the economy responds to monetary policy change as a shock. Worth to mention is that the model need not necessarily evaluate the biggest monetary policy easenings in November 2002 and February 2005 as the biggest monetary policy shocks, since as both supporting interventions against the koruna appreciation, they were not unanticipated.

Figure 6: Historical basic key interest rate hikes and cuts, in comparison with 1-month Bribor MoM percentage change



Source: National Bank of Slovakia

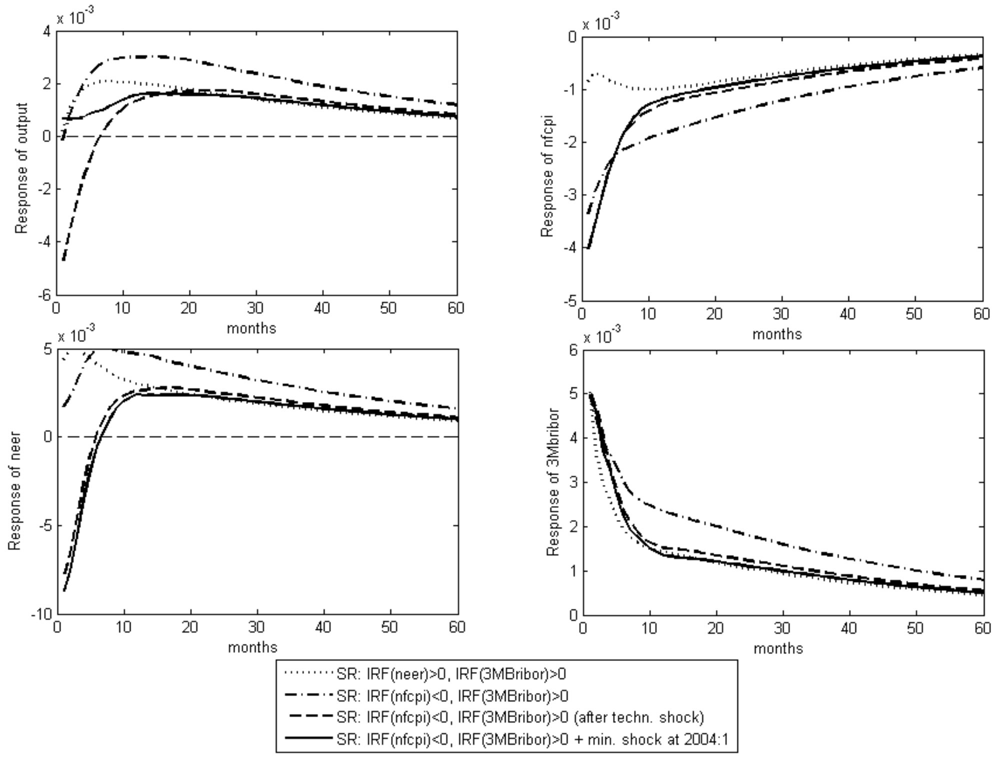
We apply the method of detecting historical monetary policy shocks on innovations with variable impulse responses selected by sign restrictions on prices and interest rate[10]. Since the key interest rate of NBS as monetary policy tool has been introduced in 2000, we study the shock series from that period only. As Figure 6 shows, monetary policy contractions have been realized in end of April 2002 (as already mentioned, with an effect in May 2002) and several times in 2006. However, no maximal shock happened in the above mentioned periods and the procedure did not select any impulse responses. As for the minimal shocks, the only one corresponding to a monetary policy easening is January 2004.

The Bank Board of the NBS decreased the key interest rates by 25 basis points in December 2003. In that time, the economic and monetary development was expected to further influenced by the increased regulated prices and indirect taxes[11] impact on the development of real wages and final consumption of households. This, together with falling

[10] Historical shocks in addition to sign restrictions on exchange rate and interest rate do not offer an improvement of the results.
[11] Their share in headline inflation was 77% in 2003 and 75% in 2004.

investment demand and expected decrease in the fiscal deficit implied the lack of demand pressures in the economy and convinced policymakers to act dovishly.

Figure 7: Comparison of median impulse responses according to selected identification criteria



Source: author‘s own calculations

Results from the historical shock selection after sign restriction, in comparison with the previous results, are in Figure 7. The impulse responses are similar to those in the case of technology shock pre-identification, except for output. However, not shown on the graph, output impulse responses do not significantly differ from zero and the median is relatively close to zero in first months, so the results are acceptable.

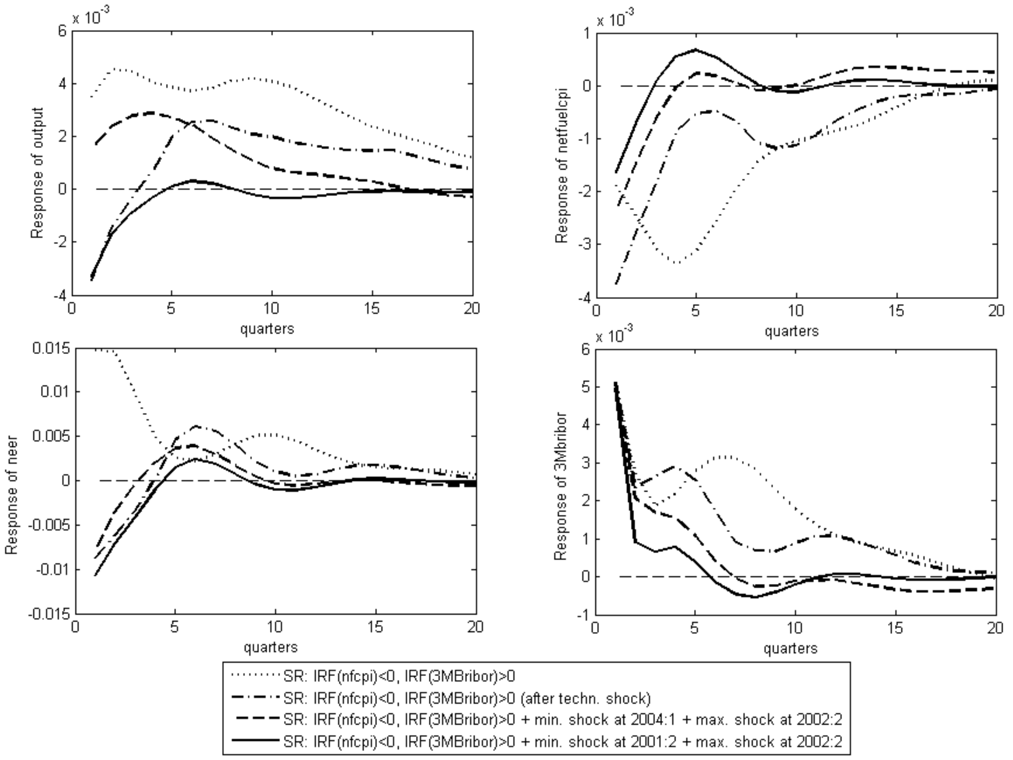
5.2 Quarterly model

Although monthly data capture short-term movements in the economy better, the disadvantage of converting series from quarterly to monthly frequency is the risk of putting noisy information into the data, so changing the relations between the variables. Therefore, as a robustness check, we apply the methods of sign restriction and restrictions on historical shocks on quarterly data as well. In the quarterly models, except for real GDP data we work with quarterly average values of the remaining monthly series. Together with intercept and time trend, we include 2 lags in the VAR again. Sign restrictions are applied for the first two quarters in case of 3-month Bribor, in case of exchange rate or prices for the second quarter only.

The first case of sign restrictions on exchange rate and short-term interest rate does not provide acceptable results. Similarly to the case of monthly data, the problem concerns output impulse responses. Even if the baseline alternative (simple sign restrictions without technology shock pre-identification or historical shocks) suggests that some effects on output are negative, the median response shows more considerable positive pattern, than the negative value of the effect on prices. Prior selection of technology shocks left shocks mostly with positive effects on prices in the period of first year or even longer, leaving questions about the correctness of the monetary policy shock definition again. Even additional restrictions on historical shocks at several time points provide no improvement: all shocks have positive output responses, so the positive impact on output is significant. Moreover, in some cases the median value is four times as higher as the negative value of price effect.

Therefore, as monetary policy shock definition, we prefer the alternative of sign restrictions imposed on prices and interest rates. This definition ensures that price responses are not positive, which is more likely characteristic for monetary policy shock. Moreover, at least a part of output responses are positive in this case. Figure 8 compares the effects of monetary policy shocks according to different approaches of selection.

Figure 8: Comparison of median impulse responses according to selected identification criteria – results of quarterly models



Source: author‘s own calculations

Simple sign restrictions suggest that price impulse responses peak at -0.34% in the fourth quarter after the shock and the effect becomes negligible approximately after four years[12]. The exchange rate appreciates by 1.5% at the beginning, but the effect decreases in a short period – fulfilling the UIP condition as well in this case. However, compared to the effect on prices the effect on output is high, and relatively permanent, since it dies out after six to seven years. In addition, a next “hump”, that is, a considerable increase of short-term interest rates in the second year is difficult to explain. So as before, we impose additional restrictions to receive more interpretable results.

[12] As we see, this is the only case when the prices react with a classical hump-shape, as one would expect. On the other hand, output and interest rate responses have their drawbacks against those in other cases.

Monetary policy shock identification after prior technology shocks filter results in the following impulse responses. Prices react immediately with -0.37% and the impact starts to fade out afterwards. The effect returns above -0.1% already four quarters after the shock, though followed by a second fall peaking at -0.12% two years after the shock. Short-term interest rates show a similar pattern at this period, making the overall response more persistent: the effect on 3M Bribor dies out after about 5 years. The impact on prices is negligible after three years approximately. Exchange rate shows depreciation in comparison with the baseline by almost 1% in first quarter. During the second and the third year the effect is positive, that is the currency appreciates, possibly due to lower pressure on interest rates. The advantage of this method is that the output effect is negative during the first year (-0.35% in the first quarter). Likely because of lower pressure on interest rates, effect on output turns to positive in the second year (with a maximal value of 0.26%).

Defining historical monetary policy shocks on the top of sign restrictions at 1Q/2004 (already investigated effects of specifying biggest expansionary monetary policy shock at January 2004) and 2Q/2002 (monetary policy contraction in May 2002[13]), the median output effect is positive, however, having smaller values than in the case of the simple sign restrictions. On the other hand, the reaction of short-term interest rates is clearly temporary; the effect is virtually zero after six quarters. The immediate response of prices is -0.24% and it approaches zero in the fourth quarter (also achieving mildly positive values in later periods).

In March 2001, the central bank decreased key interest rate by 25bps. This moment was not anticipated by market participants. If we believe that biggest unexpected expansionary monetary policy shock has occurred after this period, so in 2Q/2001, together with the biggest unexpected contractionary monetary policy shock in 2Q/2002, the impulse responses become even more favourable. Prices answer with an immediate effect of -0.16%, however, they are slightly above the baseline price level during the second year. The price effect is neutral after this period. Similarly as in the previous case, 3M Bribor impact becomes zero after two or three years. Effect on exchange rate has very similar pattern as the two previous alternative responses. The most beneficial advantage of this monetary policy shock definition is output impulse response. The effect in the first quarter is -0.33%, followed by its gradual weakening. After the first year, the impact on output becomes neutral. This is relatively ideal pattern that one would expect as the output impulse response to a contractionary monetary policy shock. On the other hand, increasing price response in the second year is questionable. Possible explanation of a temporary price increase is the reduced supply of goods due to lower output, resulting in raising prices through the supply chain from the producer to the consumer, until the demand is satisfied by a slight increase in output. This effect is visible on output impulse response indeed.

In summary, the alternatives of quarterly models do not confirm in general that changing GDP data frequency to monthly series disrupt underlying relationships between the variables. Our aim is to find the right definition of contractionary monetary policy shock that generates interpretable impulse responses. Though results are ambiguous, we prefer the last two cases, that is, sign restrictions on prices and short-term interest rates together with restrictions on selected historical shocks. Both definitions result in similar impulse responses of interest rate, exchange rate and prices. As for quantitative effects, 50 basis points key interest rate hike

[13] End-of-April key interest rake hike by 50 basis points due to economic imbalances, increased amounts of loans in corporate and population sector and in order to eliminate risks in fiscal development.

lowers prices approximately by 0.2% and has easening effect on inflation during the first year after the shock.

5.3 Alternative measure of economic activity

In effort to estimate the effects of monetary policy, an additional option is to include real output gap in the VAR as the variable of economic activity, instead of real output. The rationale behind is that monetary policy makers tend to react to the output gap rather than GDP. Giordani (2004) shows that the omission of output gap spuriously produces a price puzzle.

For the construction of output gap, we apply potential output estimated by HP filter from previously used real GDP data.[14] Unfortunately, using output gap instead of output at the primary sign restrictions on exchange and interest rates does not prevent from the price puzzle results. Moreover, in order to explain positive output responses, the argument of non-separated monetary and technology shocks cannot be employed, since a positive technology shock should not increase the output gap. Therefore, monetary policy shocks are identified by sign restrictions on net fuel CPI and short-term interest rate, as well as by historical shock restrictions.

For models at both monthly and quarterly frequency, the biggest expansionary monetary policy shock has been defined in December 2002. This refers to the most extensive key interest rate cut in November 2002. The 150 basis points decrease was a response to a substantial short-term foreign capital inflow, exerting pressures on currency appreciation and thus slowing down the restructuring process of the economy. For the monthly model, an additional, already discussed contractionary monetary policy shock in May 2002 has been detected.

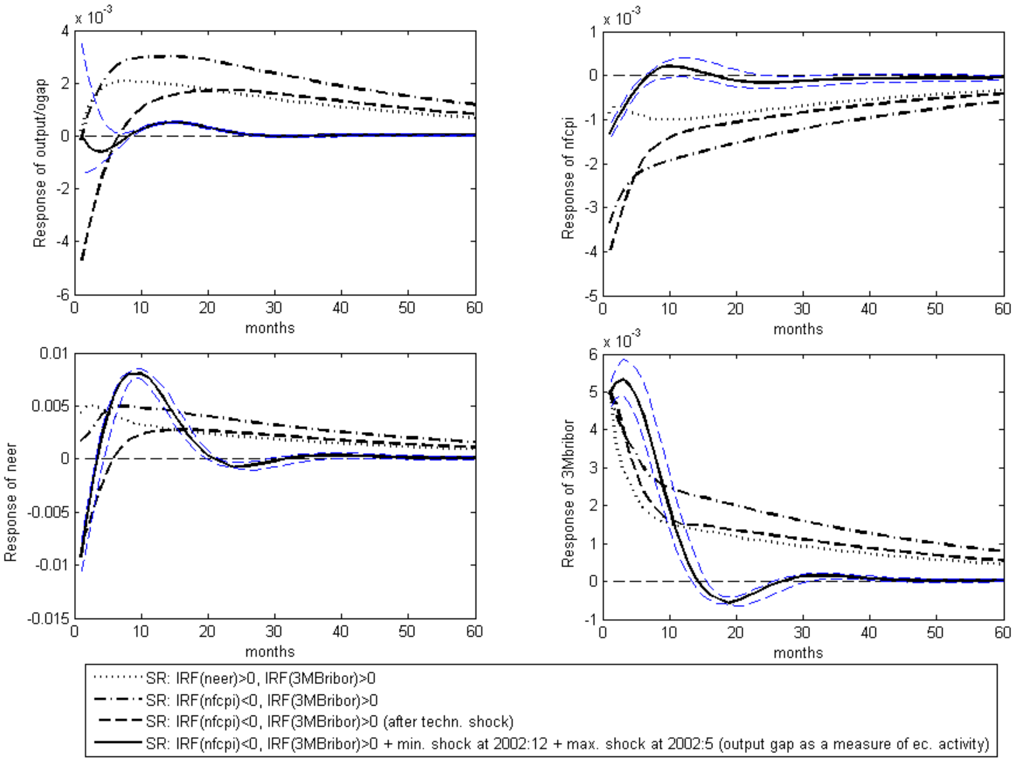
According to the monthly model (Fig. 9), prices respond immediately with a decrease of 0.13% and after 6 months, the effect is virtually insignificant. Exchange rate responds with an initial depreciation of nearly 1%, followed by an appreciation after 3 months up to 0.8% before the end of the first year after the shock. The effect fades out around 20 months. Short-term interest rate responses have steeper slope than those in case of output models. The impact of the shock becomes definitively insignificant after 25 months.

Output gap responds negatively in the first 7 months, however, the results are insignificant. On the other hand, the positive responses (overheating) during the second year are of much smaller extent than the output responses. Of course, the two types of results are not completely comparable, but still output gap responses are interpretable.

Regarding the quarterly model (Fig. 10), output gap responds significantly negatively in the first year, with a peak of -0.13pp. After this period, the impact is virtually zero. Price responses have a significant negative hump-shape, peaking at 1 year after the monetary policy shock (cca. -0.1%). The effect becomes insignificant in 3 years horizon. The impact on the exchange rate is rather favourable, the currency appreciates during the first 1.5 year, then slightly depreciates, as one would expect at the process fulfilling the UIP condition. However,

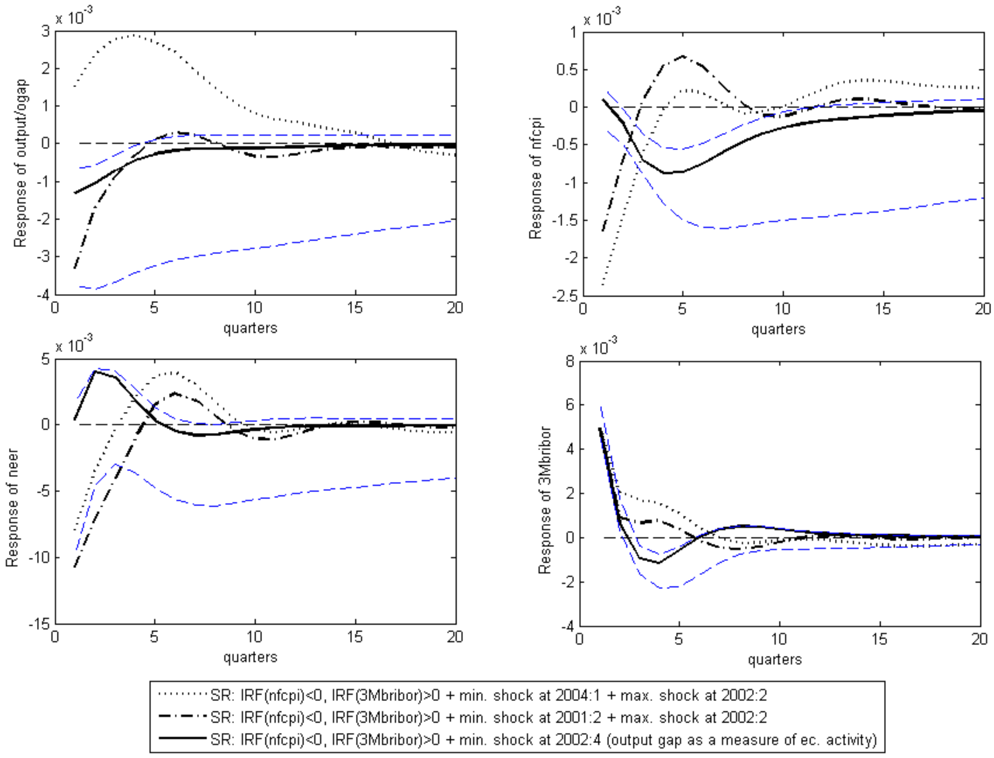
[14] There is 1 lag of endogenous variables and time trend included in both monthly and quarterly model. Except for that, to obtain normally distributed residuals, dummy variables enter the monthly model. The model is estimated on period 2000:M2-2006:M12 at a monthly frequency and on 1999:Q1-2007:Q4 at a quarterly one.

Figure 9: Comparison of output gap model results with output model results at monthly frequency
16% and 84% quantiles of output gap results are represented by blue dashed lines.



Source: author's own calculations

Figure 10: Comparison of output gap model results with output model results at quarterly frequency
16% and 84% quantiles of output gap results are represented by blue dashed lines.



Source: author's own calculations

the NEER responses are not significantly different from zero over the entire time horizon. Finally, in comparison with output model results, the short-term interest rate responses fall back to zero more sharply, and turn to negative numbers for three quarters. There is an insignificant impact after 1.5 years.

Overall we can confirm that using output gap instead of output can lead to more interpretable results, at least in the case of quarterly model. The specification of the monetary policy shock is however not straightforward and except for the right sign restrictions, suitable historical shocks have to be defined.

6 Comparison of V4 countries results

This section is to compare the results of this paper for Slovakia with structural VAR impulse response results of other countries in the Central European region, the Czech Republic, Hungary and Poland. For this purpose, I refer to the recent paper of Vonnák (2009), who investigates the role of monetary policy in the abovementioned small open economies. He identifies the effects of monetary policy and risk premium shocks by imposing contemporaneous and sign restrictions. For both shocks, contemporaneous zero restrictions are imposed on industrial production and consumer prices. To disentangle monetary policy shocks from risk premium shocks, it is assumed that after an unexpected monetary tightening the domestic interest rate increases and the exchange rate appreciates (immediately, without any lags).

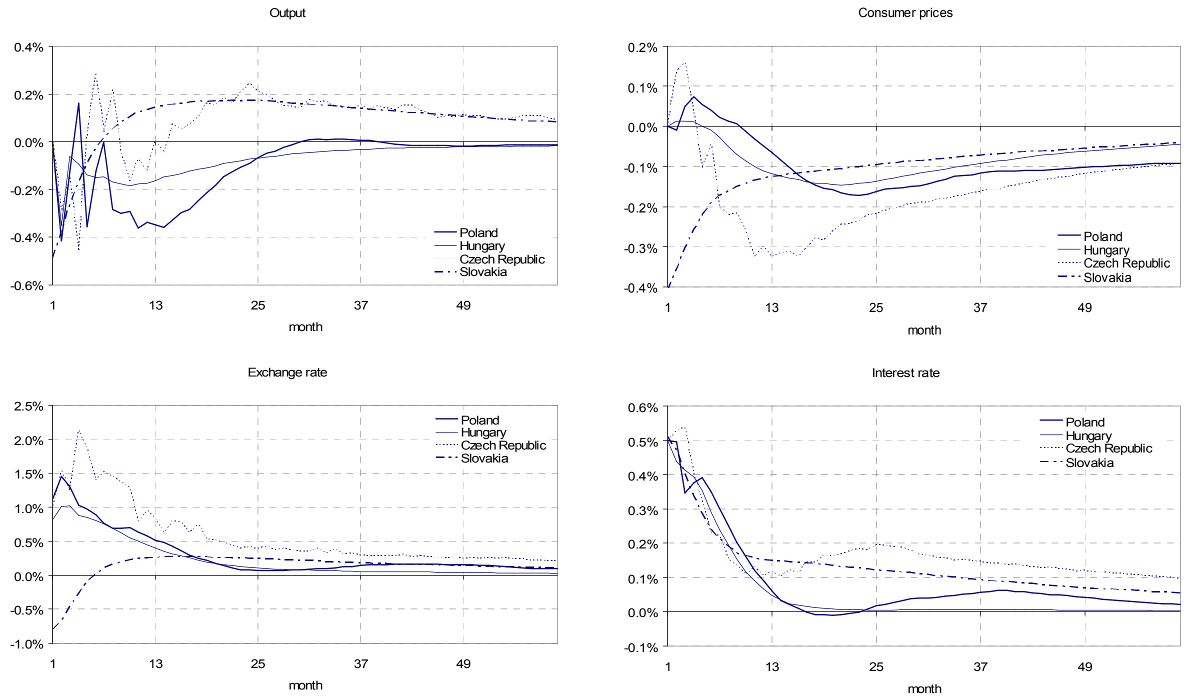
Clearly, the results are not comparable due to different variables (estimated monthly GDP series vs. industrial production) and identification strategy (I impose sign restrictions on net fuel CPI and interest rate, after a technology shock filter). Nevertheless, the results are compared to check the size of the responses, whether or not there are huge differences in contrast to results of other countries with a slightly different approach. As Figure 11 shows, the size of the responses is comparable with Vonnák (2009) outcomes[15]. More visible distinctions are reflected in shapes of price and exchange rate impulse responses. Unfortunately, prices in Slovakia do not respond with a hump-shape, the peak effect becomes evident immediately. In contrast with other currencies, the Slovak koruna depreciates in first months after the shock. This difference stems from the distinct definition of the monetary policy shock.

7 Conclusion

The aim of this paper was to estimate the effects of monetary policy shocks on the Slovak economy, especially on output and on consumer prices (net of food, fuel, regulated prices and the effect of indirect taxes). For this purpose, we applied the approach of structural VARs and investigated impulse responses of variables on structural disturbances selected by sign restrictions. In most cases, to improve the definition of monetary policy shock, additional identification of historical shocks was needed. To utilize all available information, impulse responses originating from a monthly model were analyzed. However, due to conceivable problems caused by the transformation of quarterly GDP data to monthly series, quarterly model was examined as well.

[15] To match up the results, just as in case of Slovakia, impulse responses are normalized to as initial interest rate response to be 50 points increase. Further, exchange rates are defined as a unit of foreign currency in terms of the domestic currency, that is, increase means appreciation.

Figure 11: Comparison of the results with the other Central Europe countries' impulse responses



Source: Vonnák(2009) and author's own calculations

The advantage of structural VAR approach lies in the possibility of using the joint dynamics of output, prices, exchange rates and interest rates to identify monetary policy shocks. The method of sign restrictions in the framework of structural VARs seems to be in comparison with long- or short-term restriction alternatives more reliable. Although, we encountered many difficulties, we came to the following findings.

Unanticipated 50 basis points increase of key interest rate results in an immediate 0.2% to 0.4% decrease of consumer prices (measured by net fuel CPI). The effect of the shock on prices becomes negligible, in average, after 5 years. To make the size of the shock imaginable, an immediate short-term interest rates increase is supposed to reflect the basic interest rate hike in its full extent. In most cases, the initial effect fades out relatively quickly and the short-term interest rate impulse response falls to 0.10% - 0.13% within a one-year horizon. Although, the effect on nominal effective exchange rate is ambiguous, if we abandon the UIP condition, the response is around 1% depreciation, followed by 0.3% to 0.5% appreciation one year after the shock.

Most questions arise at inspecting the output effects. One would expect that in response to interest rates increase, due to slowdown of consumption and investment incentives, output performs should be negative, or at least neutral. To the contrary, output responds mostly positively. Negative output effects are obtained only after a prior technology shock filter, or additional selection of impulse responses based on specifying the dates of historical monetary policy shocks. In those cases, the immediate impact on output is around -0.4% and the effect becomes positive not later than during the second year after the shock.

Including output gap instead of real GDP partly helps to find out more interpretable results. Quarterly VAR model with sign restrictions on prices and interest rate as well as restrictions on historical shocks suggest significantly negative response of output gap, negative price response with a peak at one year horizon, initial appreciation of the currency and short-term interest rate increase. However, standard restrictions on exchange and interest rate do not imply an improvement against output models.

Considering the abovementioned findings, there remain many questions whether the method is applicable in terms of Slovak data. From one point of view, we suspect that the problem lies in data issues. Data are of small range, slightly longer than a decade. Except for that, GDP series contain many data revisions including methodology changes. Although, GDP levels data are consistent through real growth rates, it may be the case that the relations between variables are not entirely captured. On the other hand, Slovakia is specific in a sense that the country belongs to emerging economies with significant structural reforms launched in the early 2000s and a rapid growth as an answer. In these circumstances, GDP growth has been driven by productivity factors, not reflecting effects of monetary policy in its full extent. In other words, no matter whether the monetary policy acted contractionary or expansionary, output development benefiting from investments, new know-how and technologies, as well as increased productivity, has been affected almost in no way. Nevertheless, this fact supports the results found in some empirical literature, e.g. Uhlig (1995), that variations in monetary policy account for little variation in output.

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