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G. Kurovskiy[1]

Disentanglement of natural interest rate shocks and monetary policy shocks nexus

This paper proposes a novel procedure for uniting the identification of monetary policy shocks and natural interest rate shocks. The Russian economy of the 2014–2019 inflation-targeting period is an empirical application of the approach. The model results allow us to make a number of policy conclusions: (i) unlike other papers on the Russian economy there is no output or price puzzles; (ii) over the past six years, monetary policy in Russia has become more predictable; (iii) the monetary transmission period from the key rate to inflation is six to eight months; (iv) monetary policy explains almost 20% of the inflation dynamics, while the natural interest rate explains around 40% of inflation; (v) the estimated natural interest rate declined from 2014 to 2019 following the global trends of declining interest rates; and (vi) the Bank of Russia follows mandate and reacts to inflation under the monetary policy feedback rule without responding to output fluctuations.

Keywords: SVAR; monetary policy; natural interest rate; Russia.
JEL classification: E52; E58; C32.

Introduction

The impact of monetary policy on the real part of the economy has been in the focus of researchers' attention for almost five decades. The question renewed its importance when the world's most influential central banks switched to the inflation-targeting regime. There are two competing strategies on how to achieve the inflation target. The first strategy is to forecast inflation in advance, compare it with a desired target, and manipulate the monetary policy rate to keep inflation on target. The second strategy is to estimate the natural interest rate and keep the policy rate at the natural level. This paper shows how these two strategies may coexist and explains how monetary policy shocks may be estimated simultaneously with the natural interest rate within one model.

The first approach means that central banks, for instance, would increase the policy rate to reduce inflation in two years and return it to the target if (i) they estimate the delay of the policy instrument effect on inflation and economic activity to be two years, and (ii) they predict inflation going above the inflation target in two years. However, not all policy rate raises lead to a decrease in inflation or economic activity but only those shifts that are unexpected to economic agents. In this paper, the author follows Christiano et al. (1999) and defines monetary policy shocks as unanticipated to economic agents changes (or unchanges) in the policy rate.

[1] **Kurovskiy, Gleb** — Bank of Russia, Lomonosov Moscow State University, Moscow; gleb.kurovskiy@gmail.com.

One of the dominating methods of obtaining structural shocks is the identification of structural vector autoregression (SVAR) models. For an extensive review of identification techniques, see the papers by Christiano et al. (1999) and Ramey (2016). The problem with such an approach is double uncertainty around the estimates of monetary policy shocks and predictions of macroeconomic variables.

The second approach means that central banks' experts conduct their monetary policy via monetary stance (the difference between the policy rate and the natural interest rate). The author defines the natural interest rate in the same way as Laubach, Williams (2003, 2016), as a real interest rate when output is equal to its natural level and inflation is equal to its target. Central bankers compare the natural interest rate with the policy rate. If the natural rate is higher than the policy rate, then output is higher than its potential level and/or inflation is higher than its target. Therefore, central banks should increase the policy rate to stabilise inflation and output to their target and potential levels. However, there are at least two problems related to this approach.

Firstly, the gap could never close due to nominal wage and price rigidities (Amato, 2005). Secondly, a natural interest rate is an unobservable variable, and natural rate estimates are highly imprecise. "It is a well-known fact that estimates of the natural rate of interest, commonly referred to as r^*, are highly uncertain no matter which approach is used. For example, the Holston–Laubach–Williams estimate of the US natural rate could currently be anywhere between –3% and +5%" (Cœuré, 2018). To evaluate monetary policy stance, central bank economists need to estimate the natural interest rate and forecast factors, which influence the natural interest rate future dynamics. The dominating part of the natural interest rate factors come from the real part of the economy.

In Ramsey neoclassical growth model (Ramsey, 1928), the natural interest rate depends on the intertemporal substitution, population growth and technological growth. The other factors could be potential output, fiscal policy, and demography (Laubach, Williams, 2003; Holston et al., 2017; Orphanides, Williams, 2002). Therefore, to conduct monetary policy central bankers should predict the factors of a natural interest rate and determine how these factors influence the natural interest rate. Supply shocks, technological shocks, fiscal policy shocks, intertemporal preferences shocks are a number of shocks from the real side of the economy, which could be summarised in natural rate shocks.

From the two approaches, one may observe that there are two different economic reasons for policy rate shifts. Moreover, the magnitude of policy rate changes could be dependent on the approach.

However, there is a two-way feedback between an economic state and monetary policy. Thus, the monetary authorities could predict, for instance, a decline in the natural interest rate. To keep the degree of the stance, the authorities will decrease the policy rate as well. Despite the fact that natural rate shocks are unobservable, central bankers will face rising or decreasing stance rigidity after shifts in the natural rate. Therefore, central bankers will react to natural interest rate shocks with a lag. Though natural interest rate shocks affect the policy rate, they are orthogonal to monetary policy shocks. To sum up, both types of shocks impact the stance of monetary policy. There are several open questions. How to identify monetary policy shocks and natural interest rate shocks separately? Which of the two types of shocks is more important in explaining the inflation variance?

This paper is novel in the following aspects. Firstly, Russia has already had data of at least five years of inflation targeting. The period is enough to estimate the transmission from monetary policy shocks to inflation and output in a pure inflation-targeting regime. Secondly, the paper exploits where the Bank of Russia follows mandate of stabilising inflation but not output or unemployment (like the Federal reserve, the central bank of the United States). The results confirm that the Bank of Russia cares about inflation and does not account for output. Thirdly, the paper aims to unite the ideas of estimating the impact of monetary policy on inflation discussed in monetary shocks identification literature and the procedure of the natural interest rate estimation. The closest work for the monetary policy shocks identification is (Arias et al., 2019). The closest studies of the natural interest rate shocks identification are (Barsky, Sims, 2011) and (Benati, 2016). Finally, the paper results are compared with and distinguished from other papers on the Russian monetary policy (Borzykh, 2016; Pestova et al., 2019; Shestakov, 2017). Starting from 2014, there have been no output or inflation puzzles and the monetary transmission period has been around six to eight months in Russia. The rest of the paper is as follows. Section 1 discusses the identification of monetary and natural interest rate shocks. Section 2 provides the data. Section 3 discusses the results of the Russian economy, while Section 4 is the conclusion.

1. Model

The idea to identify two or more shocks that drive the same variable goes back to Cholesky decomposition. Such decomposition allows to simultaneously identify several macroeconomic shocks. The problem with Cholesky identification (or other approaches that identify the structural impact matrix fully) is that they restrict the analysis to a short-run, medium-run or long-run identification with zero restrictions but not its pairwise combinations with sign restrictions. In the case of monetary policy and natural interest rate shocks, the ability to combine short-run and medium-run identification with both zero and sign restrictions is crucial. In particular, Arias et al. (2019) identify monetary policy shocks using short-term restrictions, while Barsky, Sims (2011) could be used to identify the natural interest rate *via* medium-term restrictions. The paper aims to get both monetary policy shocks and natural interest rate shocks in one model because these are the dominating factors of inflation.

The (Barsky, Sims, 2011) two-step procedure identifies shocks that drive total factor productivity. The first step is the identification of a short-run total factor productivity individual shock. The second step involves a medium-run identification. The paper by Uhlig (2004) introduced a medium-run analysis to identify labour productivity shocks. The idea behind the second step is that news shocks are the sources of total factor productivity fluctuations. A natural interest rate should also be subject to medium-run or long-run shocks. A natural interest rate is a long-term equilibrium rate. Therefore, the dynamics of current variables should explain the natural interest rate only at long horizons. Such an idea is very close to the concept of news shocks. Moreover, total factor productivity is one of the drivers of the natural interest rate. Thus, news shocks should also explain some variance of the natural interest rate. Long-run identification bases on the assumption that the data are infinite. Such restriction is bounding in the case of the Russian economy. The homogenous data are only available for five years under the inflation-targeting regime. Therefore, the analysis is restricted to a medium-run identification for up to five years. Barsky, Sims (2011) identify the first step shock as a reduced-form innovation technology shock, which is not appropriate in my case. The current paper performs a slight modification of the (Barsky, Sims, 2011) procedure in application to the policy rate (Table 1).

Table 1. Procedure for estimating monetary policy shocks and natural interest rate shocks

	Algorithm
Step 1	Identify monetary policy shocks analogously to (Arias et al., 2019) using original data with short-run restrictions
Step 2	Perform counterfactual simulations to obtain all the series which are cleaned from the monetary policy shocks
Step 3	Perform the (Uhlig, 2004) approach to get natural interest rate shocks in simulated data using medium-run identification

The monetary policy shock is fully identified in the first step as in (Arias et al., 2019). In the second step, the paper performs counterfactual simulations to obtain all the series, which are cleaned from monetary policy shocks. Further, the paper exploits (Uhlig, 2004) approach to get natural interest rate shocks. The latter should explain a maximum forecast error variance of the policy rate at a five-year horizon. The two-step procedure allows getting monetary policy shocks and natural interest rate shocks. Moreover, the paper follows Benati (2016) and calculates the natural interest rate by simulating counterfactual series, which are driven only by natural interest rate shocks. The natural interest rate is also unaffected by non-persistent shocks as well as by monetary policy shocks because they are cleaned at the second step.

The model is summarised in the following equations (1), (2). The *first step* is:

$$Y_t = B_0 + B_1 Y_{t-1} + \ldots + B_k Y_{t-k} + \ldots + B_p Y_{t-p} + A_0 \varepsilon_t, \tag{1}$$

where Y_t is the vector of $n \times 1$ endogenous variables at period t; B_k is the $n \times n$ matrix of parameters given $k \in [0, 1, ..., p]$; p is a maximum lag order of VAR in canonical form, the lag order is the maximum order by Hannan–Quinn and BIC criteria; A_0 is the $n \times n$ matrix of structural shocks; is the vector of $n \times 1$ shocks at period t.

Three monetary policy rules are considered by imposing both sign restrictions on A_0, which essentially means restrictions on how monetary policy shocks affect macroeconomic variables *via* impulse response functions, and sign and zero restrictions on A_0^{-1}, which in its turn means how the monetary authorities endogenously respond to movements in macroeconomic variables. The second set of restrictions resembles the Taylor rule in a New Keynesian model. The rules will allow determining whether the central bank follows mandate.

Monetary policy rule I. A set of restrictions on endogenous monetary policy is as follows. The central bank raises the policy rate in response to inflation increase. Such a rule essentially means that the central bank reacts to inflation disturbances in the current period. The central bank does not respond to changes in the exchange rate, output or unemployment. The one-period impulse response functions restrictions are the next: a contractionary monetary policy shock results in the hike of interest rates and lowering of inflation. Additional sign restrictions are also considered. The contractionary monetary policy shock decreases output and strengthens the rouble. However, the latter restrictions are excessive for the next monetary policy rules II and III. All the restrictions are symmetric, which means that the policy rate cuts have precisely the opposite effect.

Monetary policy rule II. The Bank of Russia's mandate is to keep stable and low inflation. Thus, the Bank of Russia considers a range of indicators, which could potentially impact inflation in the forecast horizon. One of such indicators is the exchange rate. In Russia, the exchange rate is a variable which reflects the dynamics of oil prices and policy uncertainty. Before 2017, oil prices had an almost one-to-one correlation with the USD/RUB exchange rate. Figure 1 illustrates the moving average correlation between oil prices and the USD/RUB exchange rate. The monthly moving average correlation is calculated in the following way. For each month the 12 months before and the 12 months after are considered. For these 25 observations the correlation coefficient between Brent oil price and the USD/RUB exchange rate is calculated.

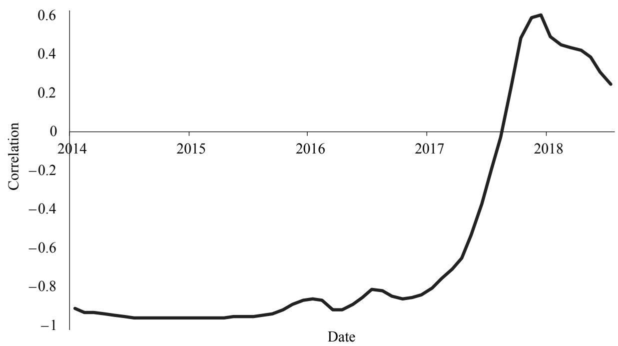

Fig. 1. Two-year moving average correlation between oil prices and USD/RUB exchange rate

Negative oil price shocks resulted in the rouble weakening. The latter leads to inflation increase due to the exchange rate pass-through effect. Thus, monitoring oil prices could allow the central bank to timely react to future changes in inflation. Starting from 2014, some foreign countries imposed a range of sanctions on Russia. One of the effects of these sanctions is the rouble weakening. Russia is a small open economy; exchange rate fluctuations have a significant effect on internal inflation. The Bank of Russia could possibly react with a policy rate increase in response to the exchange rate weakening. By doing so, the Bank of Russia could smooth out the future exchange rate pass-through effect on inflation. A set of restrictions on endogenous monetary policy is the following. The central bank raises the policy rate in response to inflation increase and the exchange rate weakening. The central bank does not respond to changes in output or unemployment. The one-period impulse response functions restrictions are similar to monetary policy rule I.

Monetary policy rule III. To check whether the central bank reacts to output fluctuations, another monetary policy rule is implemented. A set of restrictions on endogenous monetary policy is the following. The central bank raises the policy rate in response to inflation increase, output increase, and the exchange rate weakening. The central bank does not respond to changes in unemployment. The one-period impulse response functions restrictions are similar to monetary policy rule I. If impulse response functions of inflation to monetary policy shocks in rules II and III are identical, then adding output response in the feedback rule is excessive. The one-period impulse response functions restrictions are similar to monetary policy rule I.

In the *second step*, the series are re-run in a way to clean the data from monetary policy shocks. Define $\hat{Y}_t$ as counterfactual series, which are subject to all the shocks except for monetary policy shocks. *Finally,* the model is identified *via* Uhlig (2004) approach to explain a maximum forecast error variance of the policy rate, cleaned from monetary policy shocks, at a five-year horizon.

$$\hat{Y}_t = C_0 + C_1\hat{Y}_{t-1} + \ldots + C_k\hat{Y}_{t-k} + \ldots + C_p\hat{Y}_{t-p} + u_t, \quad (2)$$

where C_k is the $n \times n$ matrix of parameters given $k \in [0, 1, \ldots, p]$; p is a maximum lag order of VAR in canonical form identical to the first step; u_t is the vector of $n \times 1$ shocks at period t.

2. Data

The dataset contains monthly Russian data on the interbank interest rate (MIACR) from two to seven days, consumer price index (CPI), unemployment (U), USD/RUB exchange rate (ExR), two economic activity series: index of industrial production (IPI) and index of core industries output (IBI) from January 2014 to July 2019. The Federal State Statistics Service is the source of CPI, U, IPI, and IBI. The Bank of Russia is the source of the exchange rate and MIACR. Monthly growth are calculated rates for exchange rate, CPI, IPI, IBI and keep unemployment and MIACR at levels. The number of variables is identical to (Arias et al., 2019), except for total reserves and non-borrowed reserves. The latter variables are excluded because the Bank of Russia never targeted them during the period of analysis. Except for the exchange rate and MIACR, all the series are seasonally adjusted with X13-ARIMA-SEAT.

3. Results

This section provides the results of the monetary policy rule estimates, covers the benefits and drawbacks of the chosen rule. Finally, the section discusses the natural interest rate shocks and the dynamics of the natural interest rate itself.

3.1. Implicit monetary policy rule

To choose the implicit monetary policy rule, the paper relies on the analysis of impulse response functions and the policy feedback rule. Standalone, it is not sufficient to compare either impulse response functions or policy feedback across different monetary policy rules. The policy feedback rule is defined by coefficients in the VAR model. Impulse response functions are additionally determined by the matrix of structural shocks. Both coefficients and structural matrix differ from monetary policy rule I to III. Going from monetary policy rule I to III, the paper imposes additional information on the central bank's behaviour, being the third rule with the largest number of restrictions. If augmentation of information keeps the reaction of inflation to monetary shocks and the feedback rule the same, then such constrains are excessive. To assess the uncertainty around the estimates the bootstrap procedure is performed.

The matrix of structural of shocks is not fully identified in the (Arias et al., 2019) procedure. Therefore, the paper chooses a number of rotation matrices[2] to characterise the uncertainty around the identification. Further, the bootstrap procedure[3] is performed to describe

[2] Number of rotation matrices is equal to 100.

[3] Number of bootstrap samples is equal to 1000. The total number of simulating paths is less than or equal to 100000. In practice, the number of draws cannot be exactly equal to 100000. All the draws that do not satisfy monetary policy rules' restrictions are rejected.

the uncertainty around the path of matrices of structural shocks estimates. All further confidence intervals for impulse response functions, policy feedback rules, forecast error variances decompositions, structural shocks, and counterfactual simulations are calculated *via* bootstrap.

To estimate monetary policy rules, the papers includes unemployment (U), the interbank interest rate (MIACR) from two to seven days, consumer price index (CPI), USD/RUB exchange rate (ExR), and index of core industries output (IBI). Oil prices are excluded from the analysis subject to several reasons. Firstly, oil prices mainly characterise the state of foreign markets. The exchange rate includes this information. Prior to 2017, the dynamics of oil prices and exchange rates were almost one-to-one. Secondly, the period of analysis is limited; it is preferred to reduce the number of included variables to five to decrease the uncertainty around coefficients estimates. In Figure 2, the response of macroeconomic variables are drawn to the unit monetary policy shock under the first monetary policy rule. The black line is a median point estimate of the draws that satisfy monetary policy rule I. The grey lines in this figure as well as in Figures 3–8 below are one-standard deviation confidence intervals: 16% and 84% percentiles. The period is equal to 1 month.

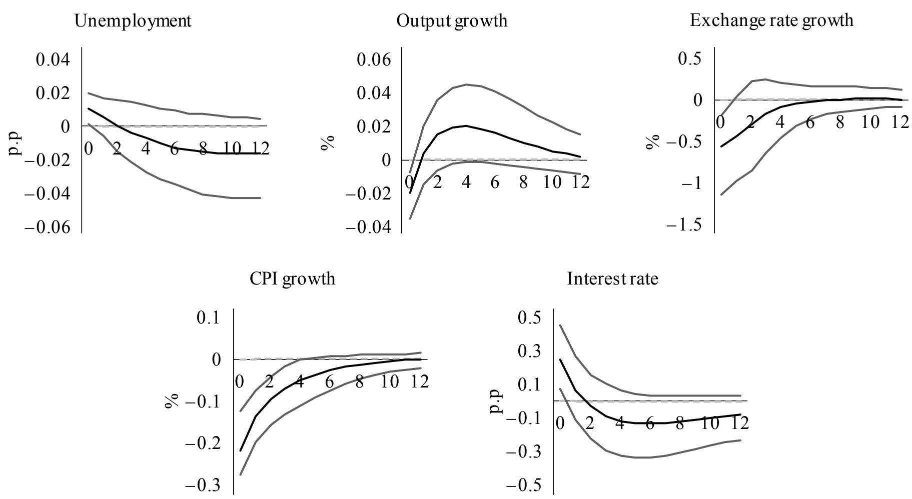

Fig. 2. Impulse response functions to unit monetary policy shock under monetary policy rule I

The results show that interest rate hikes lead to the decline in economic activity. The CPI becomes lower, output declines, and unemployment increases. There is no price or output puzzles. The rouble appreciates because an interest rate increase makes the economy more attractive for foreign investors. They can get higher returns for a rouble of investments, thus foreign investors increase demand for the rouble and its price. The results are significant for the exchange rate, output and unemployment for one month.

In Fig. 3, the paper augments restrictions by imposing the reaction of the central bank to an exchange rate in the policy feedback rule. The black line is a median point estimate of the draws that satisfy monetary policy rule II. The period is equal to 1 month. The response of inflation has changed from parabolic to hump-shaped. The effect of the shock has spread more smoothly along the periods. Moreover, the period of inflation response has increased from four to seven months. The exchange rate response has also increased its significant reaction to four months.

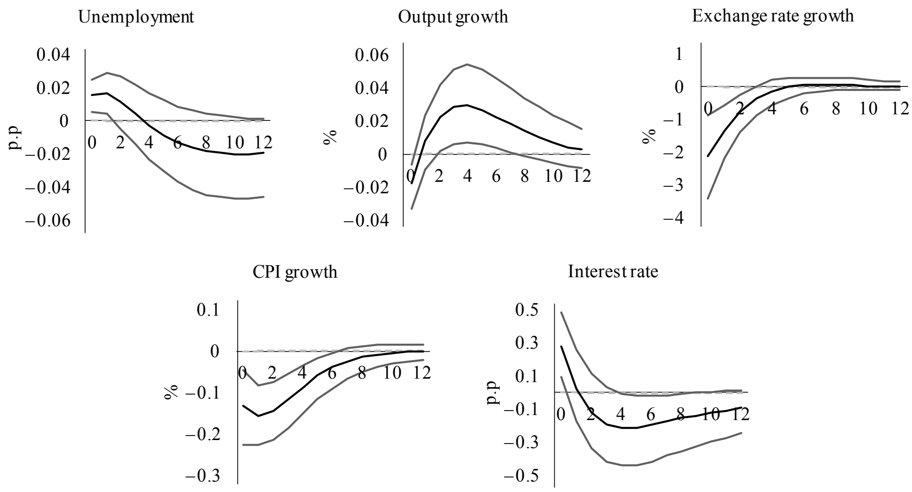

Fig. 3. Impulse response functions to unit monetary policy shock under monetary policy rule II

Further, in Fig. 4 the restrictions are augmented by the endogenous response of the central bank to changes in output. The black line is a median point estimate of the draws that satisfy monetary policy rule III. The period is equal to 1 month.

Responses of macroeconomic variables to identical monetary policy shocks are almost the same (at 90% level) under monetary policy rules II and III. Thus, one can draw a conclusion that monetary policy rule II is correct and enough to obtain canonical impulse responses[4]. Hence, rule II could be used to answer the following questions: what share of inflation does monetary policy explain, has the monetary policy of the Bank of Russia become more predictable, how does the central bank respond to changes in inflation and exchange rate? The paper further investigates policy feedback under different monetary policy rules. Equation (1) implies the following feedback rule where contemporaneous coefficients are the results of identification A_0^{-1}:

$$\begin{aligned} MIACR_t &= \beta_0 + \beta_y IPI_t + \beta_\pi CPI_t + \beta_{er} EXR_t + \beta_u U_t + \\ &+ \sum_{k=1}^{p} \left(\beta_{k,y} IPI_{t-k} + \beta_{k,\pi} CPI_{t-k} + \beta_{k,er} EXR_{t-k} + \beta_{k,u} U_{t-k} \right) + \varepsilon_{1t}, \end{aligned} \tag{3}$$

where β_j are feedback coefficients of our interest $j = 1, ..., N+1$; N is a number of variables; p is the maximum lag order which is equal to one; ε_{1t} is the first shock in (1).

The results are summarised in Table 2.

Table 2 implies that for the second and third monetary policy rules under or without sign restrictions an endogenous reaction of the central bank is identical. However, one can still observe differences for the first feedback rule. In general, 1 percentage point of inflation increase should result in 1.75 percentage point increase of the interest rate. The 10% rouble weakening should

[4] The results for impulse response functions in case of the absence of sign restrictions on exchange rate and output are similar. Monetary policy rule II without these restrictions also produces canonical impulse responses. For the sake of space are not provided. Nevertheless, the author could provide them on request.

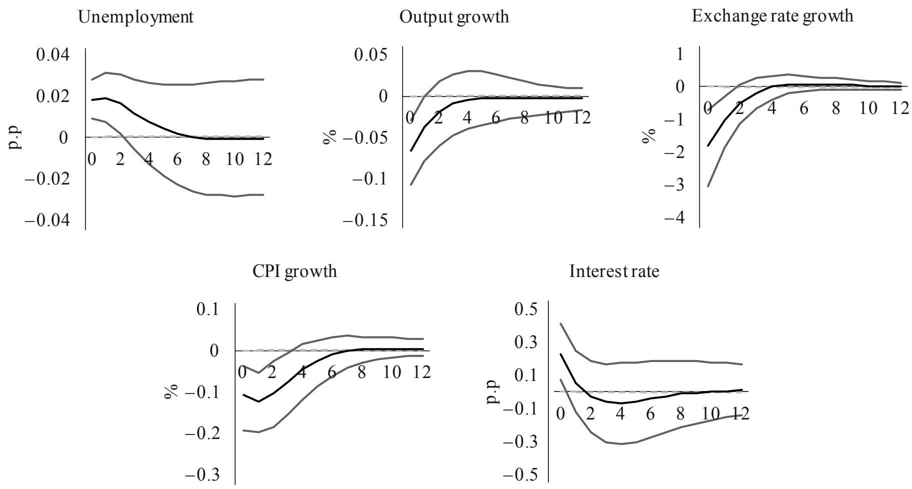

Fig. 4. Impulse response functions to unit monetary policy shock under monetary policy rule III

Table 2. Monetary policy feedback rule contemporary coefficients

Model	MP I	MP II	MP III	MP I sign	MP II sign	MP III sign
β_π	2.25	1.74	1.76	2.55	1.76	1.74
	(1.57; 3.22)	(0.70; 3.27)	(0.56; 4.49)	(1.87; 3.54)	(0.76; 3.20)	(0.55; 4.47)
β_{er}	0	0.10	0.10	0	0.09	0.11
		(0.03; 0.21)	(0.03; 0.23)		(0.03; 0.20)	(0.03; 0.30)
β_y	0	0	3.10	0	0	3.08
			(0.71; 9.53)			(0.78; 9.12)

Notes. The confidence intervals (in brackets) are 16% and 84% percentiles. All the other contemporary coefficients are equal to zero. “MP” stands for monetary policy rule, the mark “sign” means that additional sign restrictions on the exchange rate and output are imposed.

result in 1 percentage point rise of the interest rate. Together with impulse response functions, feedback rules suggest that monetary policy rule II is sufficient, while the third rule does not help in estimation of IRFs and policy rules. All further results are presented for monetary policy rule II.

Monetary policy shocks themselves are of interest in this paper. Shocks allow describing the episodes of monetary policy decisions from the expectation perspective. Bloomberg and Reuters regularly survey analytics before and after decisions made by the Bank of Russia Board of Directors. Thus, central bankers can understand whether their changes of policy rates are in line with the projections of the analysts. Such surveys provide evidence on the efficacy of forward guidance policy. Nevertheless, analysts are only a small fraction of population and surveys could only partly reveal the expectations of population in general. The paper estimates monetary policy shocks for the overall economy; hence, shocks reflect better whether the expectations of policy rate changes correspond to the actual rises, cuts or flats. Figure 5 describes various episodes of monetary policy shocks on the example of four statistically significant shocks. The black line in the picture is a median point estimate of the draws that satisfy monetary policy rule II. The dotted grey lines are two-standard deviation confidence intervals: 5% and 95% percentiles.

The Bank of Russia suspended exchange rate market operations on November 10, 2014. The paper corresponds this date to the beginning of the floating exchange rate regime. In two months,

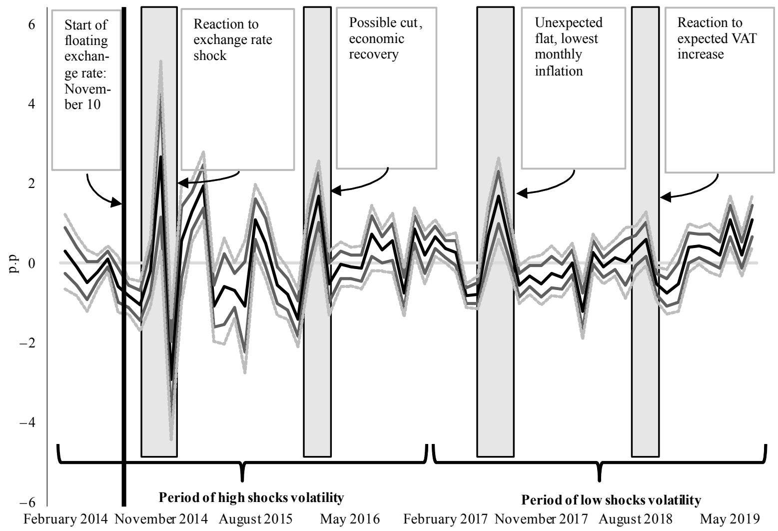

Fig. 5. Monetary policy shocks under monetary policy rule II

the rouble exchange rate plummeted almost two times due to an oil price shock. The Bank of Russia reacted to inflation shock and raised the policy rate up to 17%. Such an increase was an unexpected one to economic agents. At that time, the central bank just started inflation targeting and the communication could not have been effective. The shock at the end of 2014 is the highest shock with the point estimate to be 2.4, and the upper 68% boundary up to 4.0 percentage points. March 2016 and summer 2017 are the episodes which shed light on the concept of monetary policy shocks. Though in these periods the policy rate was flat indeed, the economy experienced shocks.

According to Bloomberg, 21 out of 39 analysts were expecting policy rate cut in June 2017. The Board of Directors decision to keep the policy rate flat was unexpected to analysts, and hence, the decision can be characterised as a shock. The peak shock in summer 2017 is 1.5 percentage points. Analysts found the economic recovery supported by the lowest monthly seasonally adjusted inflation in August 2017; they were waiting for the lessening of monetary policy. According to Bloomberg data, 16 out of 16 analysts were expecting a flat policy rate in autumn 2018. The Bank of Russia raised the policy rate to prevent future consequences of VAT pass-through on inflation. This episode is an example of an interest rate hike. Overall, the standard deviation of monetary shocks has decreased from 1.08 in 2014 and 2017 to 0.38 afterwards. The volatility dynamics shrinkage could be attributed to the rising efficacy of forward guidance and budget rule.

3.2. Benefits and drawbacks of (Arias et al., 2019) method on the Russian example

The previous results suggest that there are no output and price puzzles, the impact of monetary shocks on inflation and other variables is statistically significant. The results are different from those obtained for the Russian economy earlier. The paper (Borzykh, 2016) studies the transmission of monetary shocks to volume of credits. The author exploits a recursive identification and obtains that the contractionary effect of monetary policy can be observed only on some subsamples. Another paper (Pestova et al., 2019) supports the study (Borzykh, 2016) that contractionary monetary policy does not lead to inflation slowdown by applying a factor analysis with sign restrictions. The paper (Shestakov, 2017) finds evidence on the absence of the cost channel in the Russian economy. All these papers apply either a recursive identification or sign restrictions on impulse response functions.

The problem with such identifications is that they allow the central bank to react in a policy irrelevant way. For instance, if there is an output slowdown, then central bankers can increase interest rates. The (Arias et al., 2019) procedure impose a restriction on the central bank to shift interest rates only in response to output accumulation. To provide evidence that such restrictions are meaningful, the paper estimates the feedback rule under sign restrictions on the impulse response function and without feedback rule restrictions (Table 3). The absence of feedback rule restrictions results in a non-zero probability rise of the policy rate in response to exchange rate strengthening or output declining.

Table 3. Unrestrictive monetary policy feedback rule

Model	MP no	MP III
β_π	2.27	1.76
	(0.76; 6.60)	(0.56; 4.49)
β_{er}	0	0.10
	(–0.11; 0.31)	(0.03; 0.23)
β_y	–0.09	3.10
	(–3.31; 9.43)	(0.71; 9.53)

Notes. The confidence intervals (in brackets) are 16% and 84% percentiles. All other contemporary coefficients are equal to zero. “MP” stands for monetary policy rule, the mark “no” means that sign restrictions on the impulse response function are imposed while feedback rule restrictions are not imposed.

To further investigate the appropriateness of the identification applied in this paper, the papers estimates forecast error variance decompositions (Fig. 6). The black line at the figure

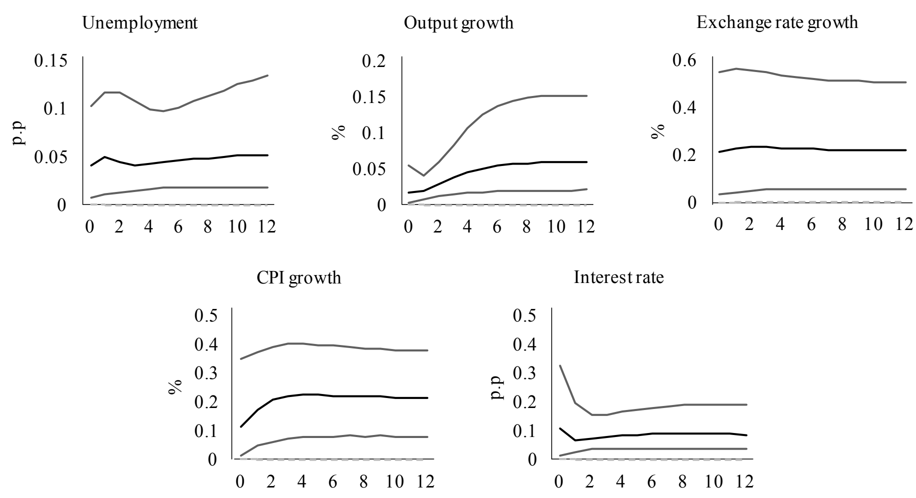

Fig. 6. Forecast error variance decompositions of monetary policy shock under monetary policy rule II

is a median point estimate of the draws that satisfy monetary policy rule II. The period is equal to 1 month.

Monetary policy shocks explain 10% of interest rate dynamics and 20% of CPI growth. Though the shares of forecast error variance attributed to monetary policy shocks are significant, they are small. The paper cannot compare forecast error variance decompositions with (Arias et al., 2019) because they do not provide these results[5]. The question is what does the rest of inflation and policy rate explain? The paper suggests that the majority of inflation is explained by natural interest rate dynamics.

3.3. Natural interest rate results

The natural interest rate could shed light on small forecast error variance decompositions under monetary policy shocks. The paper identifies natural interest rate shocks to the series cleaned from monetary policy shocks *via* (Uhlig, 2004) approach. From the shocks of equation (2), the paper choses the linear combination of those that best explain the cleaned policy rate at a five-year horizon[6]. A five-year period is sufficient to decimate the effect of temporary nominal shocks. Output itself is driven by demographic trends, total factor productivity shocks, and budget policy shocks. Hence, these long-term factors could explain natural interest rate shocks. Figure 7 depicts the impact of the unit natural interest rate shock on macroeconomic variables. The black line at the picture is a median point estimate of the draws that satisfy monetary policy rule II, which essentially means that all the series were cleaned from the monetary policy shocks under monetary policy rule II. The period is equal to 1 month.

The results of identification suggest that a natural interest rate increase lead to a CPI increase. Suppose that the natural interest rate is lower than the policy rate. Hence, there is a contractionary effect of monetary policy on the economy. The economy is hit by a positive natural interest rate shock. The difference between the natural interest rate and the policy rate shrinks, namely the natural interest rate goes up more than the policy rate. Thus, the contractionary effect of monetary policy declines. There is a stimulating effect of a positive natural interest rate

[5] Nevertheless, one can reproduce the results of Arias et al. (2019) and get that monetary policy shocks explain less than 20% of the Federal reserve rate and less than 20% of the consumer price index.

[6] The application of (Uhlig, 2004) approach to the identification of the natural interest rate in equation (2) $\hat{Y}_t = C_0 + C_1\hat{Y}_{t-1} + \ldots + C_k\hat{Y}_{t-k} + \ldots + C_p\hat{Y}_{t-p} + u_t$ is a five-steps procedure. Firstly, without a loss of generality, the author assumes that the fifth variable in (2) is cleaned from monetary policy shocks. Secondly, (2) is transformed to the moving-average representation: $\hat{Y}_t = [C(1)]^{-1}C_0 + [C(L)]^{-1}u_t \equiv Q(L)u_t$, where $C(L) = I - C_1L - \ldots - C_pL^p$ and $Q(L) = I + Q_1L + Q_2L^2 + \ldots$. Thirdly, given the Cholesky decomposition of $\mathrm{E}(u_tu_t') = \tilde{A}_0(\tilde{A}_0)'$, the author calculates the variance $\mathrm{VAR}(\hat{Y}_t) = W = \sum_{h=0}^{k}(\tilde{A}_0)'C_h'(e_je_j')C_h\tilde{A}_0$, where $k = 60$ is the forecast horizon of five years for the monthly data, $e_j = (0,0,0,0,1)$. Fourthly, the author calculates the eigenvectors associated with W, where the first eigenvector explains the maximum variance of the cleaned from monetary policy shocks interest rate. Finally, the author gets the transformation of the initial matrix $\tilde{A}_0R$, where R is the ordered eigenvector matrix. $\tilde{A}_0R$ is a structural impact matrix, where the first structural shock of $\tilde{A}_0Ru_t$ explains the maximum variance of the interest rate at a five-year horizon, meaning that it includes persistent shocks corresponding to the interest rate.

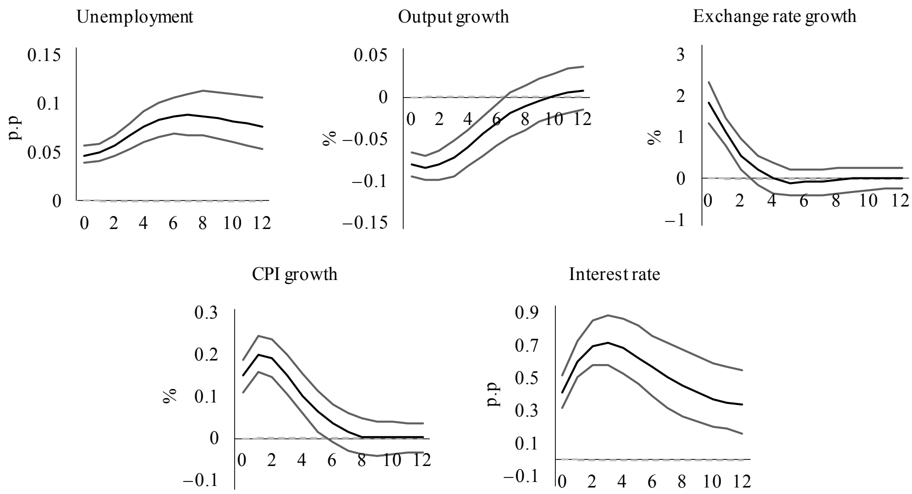

Fig. 7. Impulse response functions to unit natural interest rate shock

shock on inflation and output. Natural interest rate shocks explain about 40% of consumer price variation and around 40% of output (see Fig. A1 in Appendix). The variance of policy rate, inflation and output, which is not explained by monetary policy shocks, is mostly explained by natural interest rate shocks. Monetary policy shocks and natural interest rate shocks altogether explain up to 60% of variation in inflation. These two types of shocks are sufficient to describe the stance of monetary policy.

The paper supposes that the only drivers of changes in the natural interest rate are natural interest rate shocks. The paper performs counterfactual simulations (Fig. 8) where only natural interest rate shocks are kept[7]. The black line at Fig. 8 is a median estimate of the series driven by only natural interest rate shocks. The grey lines are actual series. Figure 8 illustrates that the natural interest rate (the lower-right graph) is declining from 13% in 2015 to 6% in summer 2019. The natural interest rate dynamics are volatile but if the output proxy variable is changed to the index of production function then the natural interest rate becomes less volatile (see Fig. A2 in Appendix). Overall, for both proxy variables the summer of 2019 is under the contractionary effect of monetary policy.

4. Conclusion

This paper proposes a procedure for the identification of monetary policy shocks and natural interest rate shocks, which are the dominating drivers of the monetary policy stance. To disentangle natural interest rate shocks from monetary policy shocks, a three-stage procedure is performed. Firstly, the paper estimates monetary policy shocks, secondly, cleans out the series from the impact of monetary policy shocks and, finally, explains the rest of the policy rate variance by natural interest rate shocks.

[7] The nominal natural interest rate is equal to a real natural interest rate plus inflation expectations at a long horizon, which are assumed to be constant and equal to the inflation target of 4%.

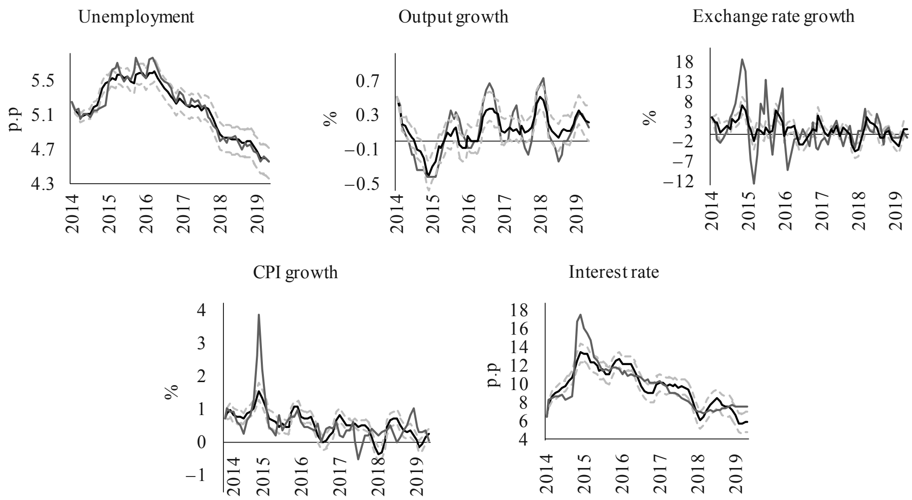

Fig. 8. Counterfactual simulations of the series driven by only natural interest rate shocks

The simultaneous estimation of monetary policy shocks and natural interest rate shocks allows us to reconcile the response period of inflation on both types of shocks. The transmission period of inflation is estimated to be up to eight months, while the effect from natural interest rate shocks lasts up to six months. The transmission period does not go beyond an one-year period, which is less than in the USA, where the effects were estimated to be up to two years as in (Christiano et al., 1999) or up to five years as in (Arias et al., 2019). One application of this result is that the monetary authorities should focus primarily on two-three quarters ahead of forecasts. The paper also provides forecast error variance decompositions, which show that monetary policy explains almost 20% of the inflation dynamics, while the natural interest rate explains around 40% of inflation. Thus, it is valuable to estimate the natural interest rate to better predict the dynamics of inflation.

The paper provides the dynamics of monetary policy shocks in the Russian economy. Overall, shocks resemble the expectations of professional analysts. The small shocks partly show that during these periods the communication policy was successful, while some deviations might indicate that the communication policy could be improved during those times. However, it should also be recognised that the start of inflation targeting was the crisis period, which is supported by larger monetary policy shocks. Altogether, the predictability of the monetary authorities' actions has been improved. Another result suggests the declining dynamics of the natural interest rate in Russia. The natural interest rate dynamics are in line with the results for other countries (Holston et al., 2017). Despite the 2014–2015 crisis, the natural interest rate decreased from almost 9% in 2014 to 7% in 2019.

Further investigation could include the analysis of factors that resulted in the natural interest rate shocks. The current analysis allows us to conclude that the natural interest rate is determined by persistent factors that are mainly presented in output.

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References

Amato J. D. (2005). The role of the natural rate of interest in monetary policy. *CESifo Economic Studies*, 51 (4), 729–755.

Arias J. E., Caldara D., Rubio-Ramirez J. F. (2019). The systematic component of monetary policy in SVARs: An agnostic identification procedure. *Journal of Monetary Economics*, 101, 1–13.

Barsky R. B., Sims E. R. (2011). News shocks and business cycles. *Journal of Monetary Economics*, 58 (3), 273–289.

Benati L. (2016). A new approach to estimating the natural rate of interest. *Discussion Paper* DP1610. Universität Bern.

Borzykh O. (2016). Bank lending channel in Russia: A TVP-FAVAR approach. *Applied Econometrics*, 43, 96–117 (in Russian).

Christiano L. J., Eichenbaum M., Evans C. L. (1999). Monetary policy shocks: What have we learned and to what end? *Handbook of Macroeconomics*, 1 (A), 65–148.

Cœuré B. (2018). Forward guidance and policy normalization. *Speech at the Deutsches Institut für Wirtschaftsforschung*. https://www.ecb.europa.eu/press/key/date/2018/html/ecb.sp180917_1.en.html.

Holston K., Laubach T., Williams J. C. (2017). Measuring the natural rate of interest: International trends and determinants. *Journal of International Economics*, 108, 59–75.

Laubach T., Williams J. C. (2003). Measuring the natural rate of interest. *Review of Economics and Statistics*, 85 (4), 1063–1070.

Laubach T., Williams J. C. (2016). Measuring the natural rate of interest redux. *Business Economics*, 51 (2), 57–67.

Orphanides A., Williams J. C. (2002). Robust monetary policy rules with unknown natural rates. *Brookings Papers on Economic Activity*, 2, 63–145.

Pestova A. A., Mamonov M. E., Rostova N. A. (2019). Monetary policy shocks in the Russian economy and their macroeconomic effects. *Economic Policy*, 4, 48–75 (in Russian).

Ramey V. A. (2016). Macroeconomic shocks and their propagation. *Handbook of Macroeconomics*, 2, 71–162.

Ramsey F. P. (1928). A mathematical theory of saving. *The Economic Journal*, 38 (152), 543–559.

Shestakov D. E. (2017). The cost channel of monetary policy transmission in the Russian economy. *Russian Journal of Money and Finance*, 9, 38–47 (in Russian).

Uhlig H. (2004). Do technology shocks lead to a fall in total hours worked? *Journal of the European Economic Association*, 2 (2–3), 361–371.

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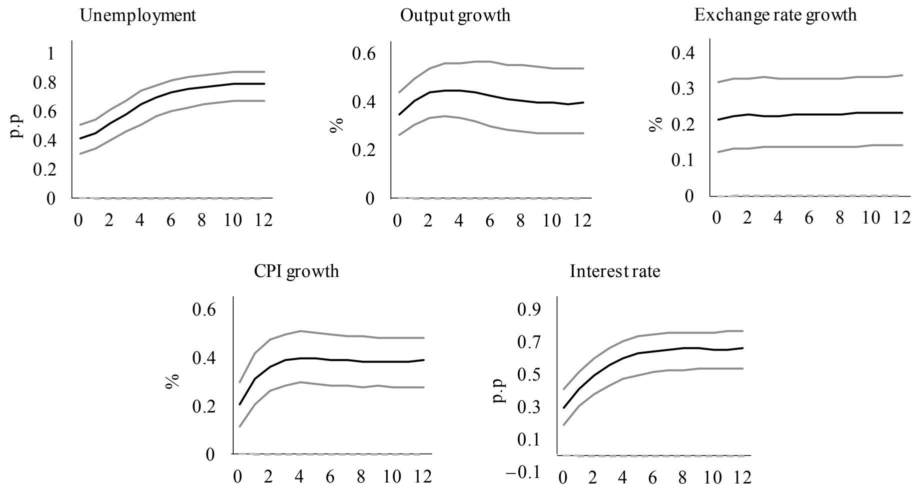
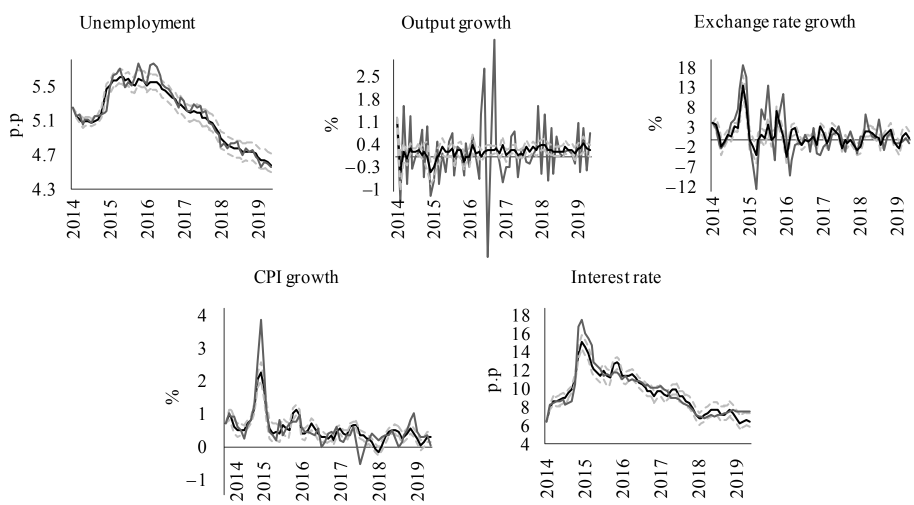
Appendix



Notes. The black line is a median point estimate of the draws that satisfy monetary policy rule II. The grey lines are one-standard deviation confidence intervals: 16% and 84% percentiles. The period is equal to 1 month.

Fig. A1. Forecast error variance decompositions of natural interest rate shock



Notes. The black line is a median estimate of the series driven by only natural interest rate shocks. The light grey lines are one-standard deviation confidence intervals: 16% and 84% percentiles. The grey lines are actual series.

Fig. A2. Counterfactual simulations of the series driven by only natural interest rate shocks (IPI is a proxy for output dynamics)