JEL Classification: E43, E44
Keywords: money market interest rates, volatility, inflation targeting, zero lower bound, Bayesian VAR, Historical decomposition

Inflation Targeting and Variability of Money Market Interest Rates Under a Zero Lower Bound*

Karel BRUNA - University of Economics, Prague, Department of Monetary Theory and Policy, Prague, Czech Republic (bruna@vse.cz) *corresponding author*

Quang VAN TRAN - University of Economics, Prague, Department of Monetary Theory and Policy, Prague, Czech Republic (tran@vse.cz)

Abstract

The paper presents a formal framework of money market interest rates variability under a zero lower bound in a monetary policy strategy of inflation targeting. The potential factors influencing the variability of money market interest rates are considered within a near zero level of main policy rate variability. At the same time, model optimal main policy rate shows significant volatility due to changes in the structural characteristics of economy facing deep economic and financial shocks, changing perception of inflation risks, central bank's weakened credibility and uncertainty about the efficient transmission of monetary measures. The money market interest rates are modeled in the framework of VAR model with exogenous variables using the example of the Czech economy for a period 2000-2016. The model is estimated by Bayesian method and its structural form is obtained through sign restriction. The repo rate and money market interest rates are decomposed into a series of cumulative structural shocks of each endogenous component in the model. The results show that global financial crisis and the exchange rate alternative monetary policy measures are two main sources of endogenous variables' shocks for interest rates which confirm high importance of net export, banking loans and investment for the dynamics of an open economy.

1. Introduction

In a framework of inflation targeting, the main policy rate and money market interest rates are typically considered as key signaling and transmission variables that initiate further adaptations in client interest rates, exchange rates, expectations and lending/spending activity consistent with inflation target. It is assumed that both the level and variability of main policy rate and money market interest rates are at non-zero level to provide adequate level of real interest rates and optimal stimulus to economic system that could be considered as a series of nominal and real financial and economic shocks. In a short history of inflation targeting in the Czech Republic, central bank developed different stages of the prediction models that reflect the fact of non-zero character of the level and variability of main policy rate and money market interest

*This paper is supported by the Grant Agency of the Czech Republic no. 18-12340S and by the University of Economics, Prague as a part of Institutional Research Support no. IP 100040.

The authors thank anonymous referees for their helpful suggestions and comments.

rates as a natural mechanism for establishing internal price equilibrium in a market economy. It is challenging for all central banks that adopted policy of inflation targeting to correctly reflect and analyze the reality of deep financial and economic crisis that caused a decline in monetary policy interest rates and money market interest rates close to zero level and in some cases even slightly below zero. Consequently, alternative monetary policy measures were being applied in many countries to overcome restrictive character of expected deflation, high credit risk and debt deleveraging resulting in high expected real interest rates, high risk premiums and high debt burden.

The paper presents formal framework of money market interest rates variability under a zero lower bound in a monetary policy strategy of inflation targeting. The goal of the research is to set a general link between alternative monetary policy measures in a model of inflation targeting and the factors influencing the variability of money market interest rates in case of a zero variability of main policy rate when model optimal main policy rate shows high variability due to changing structure of endogenous and exogeneous shocks in economic system. To quantify the variability of money market rate, we use a Vector Auto Regressive (VAR) model with exogenous variables estimated by Bayesian technique for its reduced form. The corresponding structural form is then recovered by sign restriction method. The obtained coefficients are used to decompose residuals into the corresponding structural shocks which allows us to express money market interest rate as a function of individual endogenous structural shocks, hence to measure how each of them contributes to total variability of money market interest rate. For estimation purpose, we use quarterly data from the Czech money market and the Czech economy for a period 2000q1 to 2016q4.

2. Money Market Yield Curve Variability and Inflation Targeting under a Zero Lower Bound

Money Market Interest Rate and Traditional Framework of Inflation Targeting

A concept of preferred habitat theory assumes that agents in the money market compare actual *n*-day interest rate with the expected future development of O/N interest rates average level in *n*-day horizon. The preferences of the agents also make them request increasing term premium reflecting higher maturity included risk premium as a price for credit and liquidity risks. Therefore, the money market equilibrium can be in general expressed as a position of a risk averse speculator who (based on available information (Ω_t)) quotes the actual *n*-day interest rate (IR_t^n) as the sum of the expected average of O/N rates in the period of t to $t+k$ and term/risk premium (ϕ_t^n):

$$IR_t^n = \frac{1}{n}\sum_{k=0}^{n-1} IR_{t+k}^{O/N,\,e}\left|\Omega_t\right. + \phi_t^n \tag{1}$$

In a framework of inflation targeting, it is assumed that central bank uses positive *s*-day targeted interest rate ($IR_{CB,t}^{TARGET,s}$) as a price of main policy measures while the maturity of this rate maximally equals the maturity of ultra-short money market rates. Central bank’s policy instruments are typically used to manage the liquidity of the banking system within a minimum reserves maintenance period. It is assumed that the duration of maintenance period r is longer/maximally equals the maturity of main policy rate ($s \leq r$) while it holds good that r is usually the whole multiple of s. The end of the maintenance period would then be identical with the maturity of a tender for liquidity supply/withdrawal at s-day effective main policy rate.

The main policy rate is considered as an instrumental variable that minimises the values of future deviations of the variables that are the objects of central bank´s interest from targeted values in relation to restrictions given by the existing structure of an economy. Thus the loss function (L_t) of central bank is usually the sum of the present values of quadratic deviations of expected inflation (π_{t+i}^{e}) and expected economic growth (y_{t+i}^{e}) from inflation target (π_{t+i}^{TARGET}) and potential output (y_{t+i}^{*}) (Srour, 1999):

$$L_t = \sum_{i=0}^{\infty} \delta^i \left[(1-\alpha)(\pi_{t+i}^{e} - \pi_{t+i}^{TARGET})^2 + \alpha (y_{t+i}^{e} - y_{t+i}^{*})^2\right] \tag{2}$$

where δ stand for the discount factor ($0 \leq \delta \leq 1$), α and ($1-\alpha$) are the relative weights of quadratic deviations of inflation and economic growth from targeted values and i is a time shift indicating forward looking character of monetary policy and the existence of time lags of the effects within transmission mechanism.

To set the main policy rate, the present economic structure implies restrictions for achievement of monetary targets. With regard to the central bank’s loss function and model of economic structure, the main interest rate that minimises central bank’s loss function for the actual inflation forecast applied for the model of economic structure in the horizon of efficient transmission (k period) is considered as optimal. Formally the optimal level of the main interest rate ($IR_{CB,t}^{OPTIM}$) is defined by the reaction function of central bank of the Taylor’s type:

$$IR_{CB,t}^{OPTIM} = IR_{CB}^{EQ} + \beta_t (\pi_{t+k}^{e} - \pi_{t+k}^{TARGET}) + \gamma_t (y_{t+k}^{e} - y_{t+k}^{*}) \tag{3}$$

where IR_{CB}^{EQ} is the main policy rate corresponding to long-term economic equilibrium, parameters β_t and/or γ_t express the intensity by which the central bank reacts to the overshooting (undershooting) of inflation target and/or positive (negative) output gap. As stated by Svensson (2000) and Favero and Rovelli (2000), time variable parameters β_t and γ_t are the convolution of parameters describing central bank’s preferences to the inflation and economic cycle and structural characteristics of economy.

Sack (1998) and Rudebusch (2001) point out that there exists a disproportion between the model optimum level of the main policy rate and the targeted main policy rate ($IR_{CB,t}^{TARGET}$) which is less volatile and strongly positively correlated with its lagged values (Clarida, Gali and Gertler 1998) to avoid impairment of central bank’s credibility that could be connected with high variability of the main policy rate (Goodhart 1998). Therefore, the variability of the targeted main policy rate often becomes a part of the central bank’s objective function while optimal main policy rate is based to achieve monetary-policy objectives under the lowest possible variability of the main interest rate.

The dynamics of targeted main interest rate may show deviations from monetary rule (3) due to application of monetary policy strategies following other than inflation targets that are presented as a correlation of random shocks w_t (Rudebusch 2002):

$$IR_{CB,t}^{TARGET} = (1-\rho_1-\rho_2)IR_{CB,t}^{OPTIM} + \rho_1 IR_{CB,t-1}^{TARGET} + \rho_2 w_t \quad (4)$$

$$w_t = \sum_{n=0}^{q} D_1 U_{1,t-n} + \sum_{n=0}^{r} D_2 U_{2,t-n} + \ldots + \sum_{n=0}^{z} D_m U_{m,t-n} \quad (5)$$

where ρ_1 is the weight of the lagged targeted main policy rate, being the measure of central bank's aggressiveness in the stabilisation of inflation and output gap, ρ_2 is the weight of alternative central bank's targets, D_1, D_2, …, D_m are the vectors of parameters, $U_{1,t-n}$, $U_{2,t-n}$, …, $U_{m,t-n}$ are the actual and lagged values of variables considered by the central bank for setting the main interest rate.

Variability of Main Policy Rate Under a Zero Lower Bound

It is normally assumed that optimal main policy rate is positive and potentionally high volatile interest rate that stabilizes inflation and output gap to (near) zero levels considering a model framework of an economy and reflecting exogeneous and endogenous shocks stimulating the dynamics of the whole economic system. In case of expected deep deflation, economic recession and financial instability it seems to be optimal to set the main policy rate to deep negative level and to stay below zero for a long period to enable the real and financial sector to recover. When optimal main policy rate goes to negative, inflation targeting policy faces up its limitation as targeted main policy rate is rarely used to cross its zero lower bound (Bernanke 2000). A set of alternative monetary policies (outright purchases of assets, home currency depreciation, money-financed aggregate demand expansion) are typically suggested to overcome a restrictive character of near zero level targeted main policy rates.

Using these alternative monetary policy measures, targeted main policy rate is meantime fixed to (near) zero level for a long time which reduces its variability and respective covariances to zero in the same period as well. This fact deals with an implicit change in monetary policy mechanism of inflation targeting within which unconventional monetary policy instruments take over a position of main policy rate in the reaction function. Therefore, variability of targeted main policy rate is considered as positive if and only if central bank believes that reaction function could be effectively applied to reach monetary policy targets in the central bank´s loss function. For the case of high restrictive impact of (near) zero targeted main policy rate when $IR_{CB,t}^{OPTIM} < 0$, it holds good:

$$
\begin{aligned}
\operatorname{var} IR_{CB,t}^{TARGET} &= (1-\rho_1-\rho_2)^2 \operatorname{var} IR_{CB,t}^{OPTIM} + \rho_1{}^2 \operatorname{var} IR_{CB,t-1}^{TARGET} + \rho_2{}^2 \operatorname{var} w_t + \\
&+ 2(1-\rho_1-\rho_2)\rho_1 \operatorname{cov}(IR_{CB,t}^{OPTIM}, IR_{CB,t-1}^{TARGET}) + 2(1-\rho_1-\rho_2)\rho_2 \operatorname{cov}(IR_{CB,t}^{OPTIM}, w_t) + \\
&+ 2\rho_1\rho_2 \operatorname{cov}(IR_{CB,t-1}^{TARGET}, w_t) = 0
\end{aligned} \tag{6}
$$

Zero variability of targeted main policy rate reflects the case when correlated shocks that stem from alternative monetary policy measures offset optimal main policy rate (high negative covariance between these variables is maintained) and weight ρ_2 is optimized according it:

$$
\operatorname{var} w_t = \frac{-\left[(1-\rho_1-\rho_2)^2 \operatorname{var} IR_{CB,t}^{OPTIM} + 2(1-\rho_1-\rho_2)\rho_2 \operatorname{cov}(IR_{CB,t}^{OPTIM}, w_t)\right]}{\rho_2{}^2} \tag{7}
$$

Although targeted main policy rate remains at a zero level which is typically maintained by overall excess of banking system liquidity provided by central bank through alternative monetary policy instruments, the dynamics of economic fundamentals behind money market interest rates could be a source of their significant nominal and real variability. Although the variability of targeted main policy rate is at a zero level, the variability of economic fundamentals is still reflected in the variability of optimal main policy rate, which using Goodman's breakdown of the product of random variables (Goodman 1960) could be written in the following form:

$$
\begin{aligned}
\operatorname{var} IR_{CB,t}^{OPTIM} &= \overline{\beta}^2 \operatorname{var}(\pi_{t+k}^e - \pi_{t+k}^{TARGET}) + \overline{(\pi_{t+k}^e - \pi_{t+k}^{TARGET})}^2 \operatorname{var}\beta + 2\overline{\beta}\overline{(\pi_{t+k}^e - \pi_{t+k}^{TARGET})} \operatorname{cov}_{11}^{\beta\pi} + \\
&+ 2\overline{\beta} \operatorname{cov}_{12}^{\beta\pi} + 2\overline{(\pi_{t+k}^e - \pi_{t+k}^{TARGET})} \operatorname{cov}_{21}^{\beta\pi} + \operatorname{var}\left[\Delta\beta\Delta(\pi_{t+k}^e - \pi_{t+k}^{TARGET})\right] + \\
&+ \overline{\gamma}^2 \operatorname{var}(y_{t+k}^e - y_{t+k}^*) + \overline{(y_{t+k}^e - y_{t+k}^*)}^2 \operatorname{var}\gamma + 2\overline{\gamma}\overline{(y_{t+k}^e - y_{t+k}^*)} \operatorname{cov}_{11}^{\gamma y} + 2\overline{\gamma} \operatorname{cov}_{12}^{\gamma y} + \\
&+ 2\overline{(y_{t+k}^e - y_{t+k}^*)} \operatorname{cov}_{21}^{\gamma y} + \operatorname{var}\left[\Delta\gamma\Delta(y_{t+k}^e - y_{t+k}^*)\right] + 2\operatorname{cov}\left\{\left[\beta(\pi_{t+k}^e - \pi_{t+k}^{TARGET})\right]\left[\gamma(y_{t+k}^e - y_{t+k}^*)\right]\right\}
\end{aligned} \tag{8}
$$

where $\overline{\beta}$ and/or $\overline{\gamma}$ is the mean value of parameter β and/or γ, the term $\overline{(\pi_{t+k}^e - \pi_{t+k}^{TARGET})}$ and/or $\overline{(y_{t+k}^e - y_{t+k}^*)}$ is the mean value of the deviation of expected inflation from the inflation target and/or expected output gap, $\operatorname{cov}_{ij}^{\beta\pi}$ is $\operatorname{cov}\left[(\Delta\beta)^i, (\Delta(\pi_{t+k}^e - \pi_{t+k}^{TARGET}))^j\right]$, $\operatorname{cov}_{ij}^{\gamma y}$ is $\operatorname{cov}\left[(\Delta\gamma)^i, (\Delta(y_{t+k}^e - y_{t+k}^*))^j\right]$, the symbol Δ expresses the deviation of the respective variable from its mean value (e.g. $\Delta\beta = \beta - \overline{\beta}$).

There are a few main elements of variability of optimal main policy rate under a zero lower bound. First, it reflects instability of expected inflation and output gap, which represent the application of actual prediction of inflation factors in the form of inflation forecast to the model of an economic structure. Especially long-lasting deflation pressure and/or economic recession together with deep deleveraging of financial sector produces inflation and economic activity forecast below inflation target and potential output and requires a downward trend of the central bank's optimal main policy rate.

Second, realized economic and financial shock typically makes structural characteristics of economy and consequently the central bank's preferences to the inflation and/or economic cycle unstable which is reflected in the variability of parameters β and γ. In case of stability of structural characteristics, large and relatively closed economies supposed to have low interest rate elasticity of inflation and economic growth due to the limited intensity of transmission between external equilibrium and internal equilibrium that produce high variability of the main policy rate for the achievement of monetary objectives. In small open economies, one can expect higher stability of the main policy rate as a result of negative correlation of the real monetary restriction and exchange rate and its direct and quick impact on efficient transmission of monetary measures. This is also one of the main reasons why large and relatively closed economies follow (under a zero lower bound) alternative monetary measures based on quantitative easing while small open economies prefer a policy of home currency depreciation. Consequently, under a zero lower bound, declining sensitivity of the targeted economic fundamentals to conventional interest rate policy (and predictability of its transmission) together with a switch of central banks' preferences to economic growth and financial stability targets (central bank's policy dynamic inconsistency) could be expected, which generates a series of correlated shocks w_t arising from application of alternative monetary measures and makes parameters β and γ more volatile. Covariance $\text{cov}_{ij}^{\beta\pi}$ and $\text{cov}_{ij}^{\gamma y}$ also shows that the variability of parameters β and γ and therefore the instability of the central bank's optimum main policy rate is influenced by the pro-cyclic character of monetary restriction intensity ($\text{cov}_{ij}^{\beta\pi}$ and $\text{cov}_{ij}^{\gamma y} > 0$).

Third, variability of the optimal main policy rate under a zero lower bound reflects potential asynchronization of the inflation cycle, economic cycle and rate of monetary restriction which stems from nominal and/or real demand and supply side shocks to real economy under financial crisis and post-crisis period (see sign and extent of $\text{cov}\left\{\left[\beta(\pi_{t+k}^{e} - \pi_{t+k}^{\text{TARGET}})\right],\left[\gamma(y_{t+k}^{e} - y_{t+k}^{*})\right]\right\}$). Contrary to pure demand factors of inflation cycle producing the positive covariance of economic cycle and rate of monetary policy restriction, the unstable mix of demand and supply sources of inflation with much lower covariance of inflation and economic cycle and rate of monetary restriction are expected to become dominant. On the other hand, in transition economies sudden depreciation of home currency following outflow of foreign capital under a financial crisis can potentially increase the inflationary pressure in case of deep economic downturn that would require higher main policy rate reaction comparing with other supply side shocks.

Variability of Main Policy Rate Under a Zero Lower Bound

Under a zero lower bound, the variability of *n*-month money market interest rate is limited by negative covariance between expected optimal main policy rate and the series of shocks produced by alternative monetary policy measures. Therefore, the variability of money market interest rates reflects especially the variability of risk and term premium while monetary impulses are temporally weak until the exit strategy is being applied:

$$\operatorname{var} IR_t^n = \frac{1}{n^2}\left[\begin{array}{l}(1-\rho_1-\rho_2)^2 \operatorname{var}\sum_{j=0}^{n=1} IR_{CB,t+j}^{OPTIM,e} + \rho_2 \operatorname{var}\sum_{j=0}^{n=1} w_{t+j}^e + \\ + 2(1-\rho_1-\rho_2)\rho_2 \operatorname{cov}(\sum_{j=0}^{n=1} IR_{CB,t+j}^{OPTIM,e}, \sum_{j=0}^{n=1} w_{t+j}^e)\end{array}\right]$$

$$\begin{aligned}&+ \rho_2^2 \operatorname{var}\varphi_t^n + \\ &+ \frac{2}{n}\operatorname{cov}\left\{\left[(1-\rho_1-\rho_2)\sum_{j=0}^{n=1} IR_{CB,t+j}^{OPTIM,e}\right.\right. \\ &\left.\left.+ \rho_1 \sum_{j=0}^{n=1} IR_{CB,t+j-1}^{TARGET,e} + + \rho_2 \sum_{j=0}^{n=1} w_{t+j}^e\right], \varphi_t^n\right\}\end{aligned} \tag{9}$$

$$\begin{aligned}\operatorname{var}\sum_{j=0}^{n-1} IR_{CB,t+j}^{OPTIM,e} =& \\ &= \operatorname{var}\sum_{j=0}^{n-1} \beta_{t+j}\left(\pi_{t+k+j}^{e,t+j} - \pi_{t+k+j}^{TARGET}\right) \\ &+ \operatorname{var}\sum_{j=0}^{n-1} \gamma_{t+j}\left(y_{t+k+j}^{e,t+j} - y_{t+k+j}^{*}\right) \\ &+ 2\operatorname{cov}(\sum_{j=0}^{n-1} \beta_{t+j}(\pi_{t+k+j}^{e,t+j} \\ &- \pi_{t+k+j}^{TARGET}), \sum_{j=0}^{n-1} \gamma_{t+j}(y_{t+k+j}^{e,t+j} - y_{t+k+j}^{*}))\end{aligned} \tag{10}$$

As for a long-end of money market yield curve the expected dynamics of inflation and economic growth reaches the horizon of efficient transmission of monetary policy, variability of money market interest rates may reflect the anticipated macroeconomic effects of monetary policy, which makes it possible to achieve – when a zero lower bound will end soon and exit strategy is planned or at least expected by market - high variability of longer interest rates in the situation of temporarily low variability of short-term interest rates. Therefore, stable expectations of agents are crucial for low variability of long-term money market interest rates in a period within which future variability of optimal main policy rate will be offset by alternative policy measures which stem from expected recovery of economic fundaments, changes in the central bank's preferences back to inflation target and instability of the economic structure. Variability of money market interest rates is then a result of a conflict between the central bank's official inflation forecast and analogical forecast of the financial market that could be significantly influenced by central bank's credibility in a post crisis period and consistency of preceding monetary measures. Because the variability of interest rates in equations (9) and (10) is influenced by variability of the average expected values of the particular factors over the observed period, the shocks affecting variability of interest rates are assumed to be of a long-term character.

3. The Analysis of Endogenous and Exogenous Shocks and Variability of Money Market Interest Rate

Model of Historical Decomposition with Exogenous Variables

As stated before, the variability of money market interest rate is caused by shocks in endogenous and exogenous variables included in the model. To measure their impact, we use the historical decomposition technique for a VAR model with exogenous variables in the following structural form:

$$DY_t = c + \sum_{i=1}^{p} A_i Y_{t-i} + BX_t + U_t , \qquad (11)$$

where Y_t is a vector of endogenous variables, X is a vector of exogenous variable, U_t is a vector of structural shocks, C is vector of constants, D, A_i and B are matrices of coefficients, and p is the length of lags of a VAR model. By multiplying with matrix D^{-1}, equation (11) can be transformed into the following reduced form:

$$Y_t = k + \sum_{i=1}^{p} P_i Y_{t-i} + QX_t + E_t , \qquad (12)$$

where $k = D^{-1}c$, $P_i = D^{-1}A_i$, $Q = D^{-1}B$, and $E_t = D^{-1}U_t$ is the reduced form errors.

Having all coefficients matrices and matrix D, we can decompose each endogenous series into series of individual structural shocks using historical decomposition technique. The principle of this technique comes from the fact that the reduced form of a VAR model in (12) can be expressed by its corresponding moving average representation with recursive substitutions as follows (for $p = 2$ in our case):

$$Y_t = \mu + \sum_{i=1}^{t} \Phi_i E_i + \sum_{i=1}^{t} \Psi_i X_i , \qquad (13)$$

where $Y_1 = K_1 + P_1 Y_0 + P_2 Y_{-1} + QX_1 + E_1$*. As $E_t = D^{-1}U_t$, equation (13) can be rewritten as:

* For other terms Φ_i is a function of P_1 and P_2, Ψ_i is a function of P_1, P_2 and Q.

$$Y_t = \mu + \sum_{i=1}^{t} \Phi_i D^{-1} U_i + \sum_{i=1}^{t} \Psi_i Z_i = \mu + \sum_{i=1}^{t} \Gamma_i U_i + \sum_{i=1}^{t} \Psi_i Z_i, \tag{14}$$

where $\Gamma_i = \Phi_i D^{-1}$. Clearly in equation (14) each endogenous variable in the model is expressed as a sum of structural shocks up to time t. Collecting the contribution of each shock separately, we obtain the decomposition of a series in each period from the beginning to the end.

Data and Their Pre-Processing

This research is performed using the publicly available data for the Czech Republic. The main sources of data are the databases of the Czech Statistical Office and the Czech National Bank. The real GDP series of Germany is provided by Destatis database, the historical series on oil price (Europe Brent Spot Price FOB) by US Energy Information Administration database and the series on EURIBOR 12 months by European Money Markets Institute, and finally series on CPI in Euro Area 19 and unit labor costs series for Czech Republic are from the OECD database. All series are quarterly data from 2000Q1 to 2016Q4. Each of them consists of 68 observations. All series are listed in Table 1.

Table 1 List of Primary Data Used for Econometric Analysis

	Notation	***Full name***	***Unit***
1	REPO	Monetary policy Repo rate	%
2	YD	Disposable income	Mil. CZK *
3	CPI	Consumer Price Index	Index
4	CONS	Households consumption	Mil CZK *
5	INV	Investments	Mil. CZK *
6	UNE	Unemployment rate	%
7	NX	Net export	Mil. CZK *
8	CRE	Client loans	Mil. CZK
9	PRIBOR	Interbank pribor one year rate	%
10	EURER	Average EURCZK exchange rate	CZK
11	ULC	Unit labor costs,year-to-year change	%
12	PROGINF	Inflation Prognoses	%
13	GDPGE	German GDP	index
14	EURIBOR	Interbank euribor one year rate	%
15	OILP	Average oil price Crude Brent Europe	USD
16	USDER	Average USDCZK exchange rate	CZK
17	CPIEA19	Consumer Price Index in Euro Area 19	index

Notes: (*) denotes real variables.

For model estimation series repo rate REPO, unemployment rate UNE, unit labor costs ULC, and interbank interest rates PRIBOR and EURIBOR are kept unchanged. On the other hand, the oil price series in USD is converted into series in CZK using exchange rate USD/CZK, nominal client loans and exchange rate EUR/CZK are transformed into real quantities using price index CPI and price indices CPI and CPIEA19 respectively. After that these series and the rest are converted into corresponding year-to-year percentage changes series. All series thus have the same measure and the number of observation is reduced to 64. In Table 2 we show some descriptive statistics of the original data set we use for our analysis.

After that series on Disposable income, CPI, Consumption, Investment, Net Export, EURCZK exchange rate, Oil price, German GDP, are converted to year on year change series (in per cents). With respect to series on client loans volume, first we convert it into a series of real values and then we transform it into a series of year on year change rates. The number of observations of our dataset is then reduced to 62. The length of untransformed series is adjusted accordingly. The descriptive statistics of transformed series are shown in Table 3. In our analysis the endogenous variables are those variables from the Czech economy (they are ten) and the exogenous variables are the GDP of Germany, Oil price, Inflation prognosis, Unit labor costs and Euribor rate.

Table 2 Descriptive Statistics of Original Data Used for Analysis

	Mean	***Median***	***Maximum***	***Minimum***	***Std. Dev.***	***Skewness***	***Kurtosis***
	Mean	*Median*	*Maximum*	*Minimum*	*Std. Dev.*	*Skewness*	*Kurtosis*
CONS	447,866	459,540	520,902	344,552	46,511	-0.58	2.15
CPI	108.47	111.70	124.30	88.60	11.72	-0.09	1.53
CRE	707,599	765,019	966,663	425,333	166,709	-0.47	1.82
EURER	28.48	27.55	36.02	24.29	3.27	0.69	2.43
EURIBOR	2.39	2.21	5.37	-0.02	1.59	0.21	1.87
GDPGE	98.80	99.06	110.35	89.55	5.79	0.16	1.73
INV	249,114	249,076	323,714	178,900	35,280	0.01	2.23
UNE	6.87	7.10	9.30	4.10	1.30	-0.61	2.50
NX	24,329	22,828	91,071	-34308	32,452	0.29	2.14
OILP	63.23	59.99	123.78	20.50	28.01	0.21	1.84
ULC	2.11	2.20	7.30	-1.76	2.20	0.38	2.60
PROGINF	-0.11	-0.10	1.45	-1.60	0.63	0.04	3.03
PRIBOR1Y	2.51	2.30	5.90	0.45	1.56	0.56	2.48
REPO	1.96	2.00	5.25	0.05	1.66	0.58	2.30

Table 3 Descriptive Statistics of Transformed Data Used for Analysis

	Mean	***Median***	***Maximum***	***Minimum***	***Std. Dev.***	***Skewness***	***Kurtosis***
CONS	2.19	2.76	5.87	-2.38	1.84	-0.57	2.71
CRE	0.27	1.14	19.07	-35.02	11.79	-1.15	4.41
EURER	-1.88	-1.91	9.33	-17.91	5.78	-0.24	3.05
GDPGE	1.16	1.36	6.01	-7.85	2.49	-1.33	6.16
INV	2.63	3.13	18.98	-14.27	6.21	-0.41	3.71
NX	0.60	0.08	22.63	-6.87	3.30	4.79	33.64
OIL	3.35	2.915	54.605	-44.35	26.29	-0.19	1.99
PI	2.13	1.74	7.43	-0.42	1.78	1.00	3.70
YD	4.16	4.61	14.17	-6.76	3.76	-0.37	3.70

Empirical Econometric Analysis

We choose the Bayesian method to estimate the model parameters (see Luetkepohl (2005) and Canova (2007) for more information on this method). This method allows us to ignore the possible issue with stationarity in series included in our model.

With respect to the number of observations in our dataset as well as the result of information criteria, the length of lags of our VAR model $p = 2$. When estimating parameters of our model by Bayesian method, we use the so called Menessota prior (see Luetkepohl (2005) for priors). In order to recover the structural form in (11) from the reduced from (12), we need to identify matrix D from covariance matrix $\Sigma_E = E_t' E_t$. For this purpose, we use the sign restriction approach which has been used in several studies in the past (Faust (1998), Canova and De Nicolo (2002), Uhlig (2005)). Our focus is placed on the response of the other endogenous variables to a shock in repo rate and rate PRIBOR and the expected signs of the responses to a positive change of an endogenous variable are summarized in Table 4. All necessary calculations have been done in Matlab with our own programming.

Table 4 The Supposed Sign of Responses with Respect to a Positive Change of a Variable

	REPO	***YD***	***PI***	***CONS***	***UNE***	***INV***	***NX***	***CRE***	***PRIB1Y***	***EU-RER***
REPO	+	-	-	-	+	-		-	+	
PRIB1Y		-	-	-	+	-	-	-	+	-

In Figures 1 and 2 we compare the estimated repo rate and one year pribor rate with their actual counterparts. In both cases, there is a high closeness between them indicating that our model is correctly specified. Figure 1 confirms that since the end of 2012 repo rate and consequently also 1Y pribor rate dropped to near zero level which is maintained by the end of 2016 with a zero volatility of both rates. Due to long-lasting undershooting of inflation target, CNB decided to apply a strategy of home currency depreciation and set a floor at a weaker level of EUR/CZK exchange rate to boost the whole economy and overcome deflationary expectations.

Figure 1 The Modeled Repo Rate Compared to the Actual Repo Rate (in %)

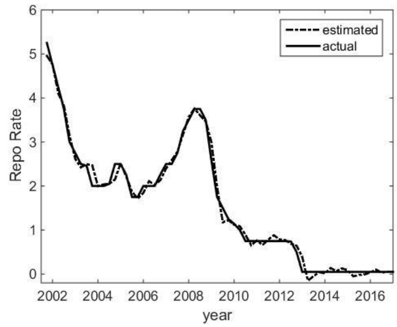
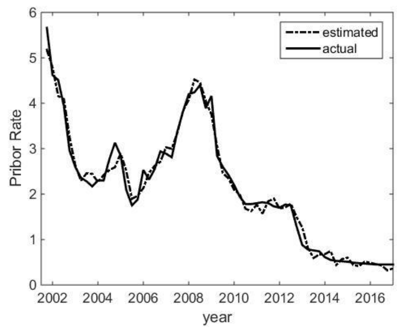


Figure 2 The Modeled 1y Pribor Rate Compared to the Actual 1y Pribor Rate (in %)



We disassemble two series: repo rate and 12 months pribor rate (Figures 3 and 4) as a cumulative sum of individual structural shocks. The size of each shock in each quarter is expressed by a bar of a certain color whose magnitude is scaled according to the left-hand-side *y*-axis. One can observe that the magnitude as well as the sign of each shock may change from a quarter to a quarter and in each quarter the shocks differ in their signs, hence the aggregate impact of all shocks tends to be much lower. We display the aggregate results for a quarter in the same figures as a black line with the magnitude corresponding to the scale on the right-hand-side *y*-axis. As at the beginning the impact of Y_0 and Y_{-1} is still very strong and it dies out after a dozen of periods, we show them for periods from 2004Q1 to the end. We proceed similarly when we calculate the impact of each individual shocks on repo rate and 1y pribor rate in the actual periods (Figures 5 and 6). Finally, we evaluate the impact of exogenous variables on repo rate and 1y pribor rate (Figure 7 and 8).

Figure 3 The Cumulative Effect of Shocks on Repo Rate

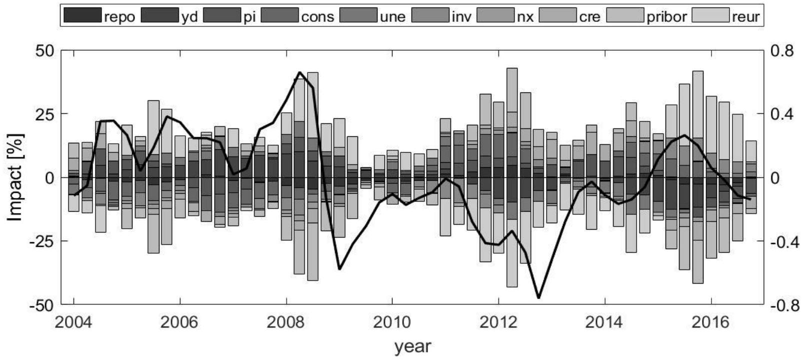


Figure 4 The Cumulative Effect of Shocks on 1y Pribor Rate

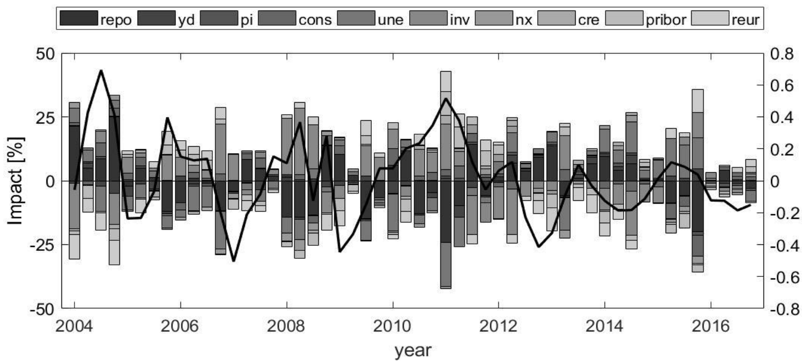


Figure 5 The Effect of Shocks on Current Period Repo Rate

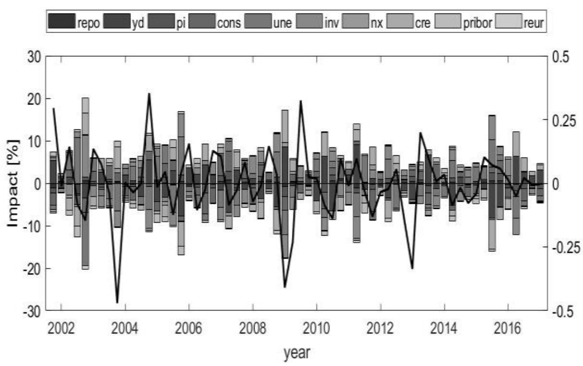
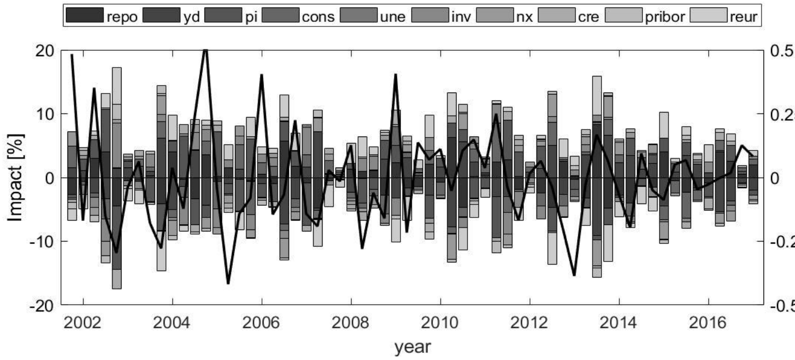


Figure 6 The Effect of Shocks on Current Period 1y Pribor Rate



As far as the impact of endogenous variables included in the model is concerned, in Figures 3 and 4 we can see two groups of factors which affect the money market interest rate in both directions. The structure of each group is not constant over time and so does the impact of each endogenous variable in the model. On the other hand, long-lasting character of contribution of specific variable to repo rate and money market interest rate dynamics confirms series correlation of these shocks that is in line with our explanation of dynamics of interest rates as a trend driven macroeconomic variables. The structure and the extent of the shocks also slightly differs for both the repo rate and 1y pribor rate which is more volatile but in general both rates could be explained via the same story. The positive impact of endogenous variables on repo rate and money market rates are shown in case of the dynamics of bank loans, consumption and unemployment before first negative effects of crises came in 2008 and 2009. Negative shocks in pre-crisis period are represented by the investments, net export and disposable income. The global financial crisis produced high external shock, deep decline in inflation with limited deflation expectations and pessimistic investments expectations that stay behind negative impact of investments, bank loans, and inflation on money market interest rates. Since 2011 investments and banking loans start to recover but unemployment and consumption remain weak. The application of exchange rate commitment in 2013 initiated positive impact of real exchange rate, unemployment and consumption (maintaining positive effects of net export).

Figure 7 The Impact of Exogenous Variables on Repo Rate

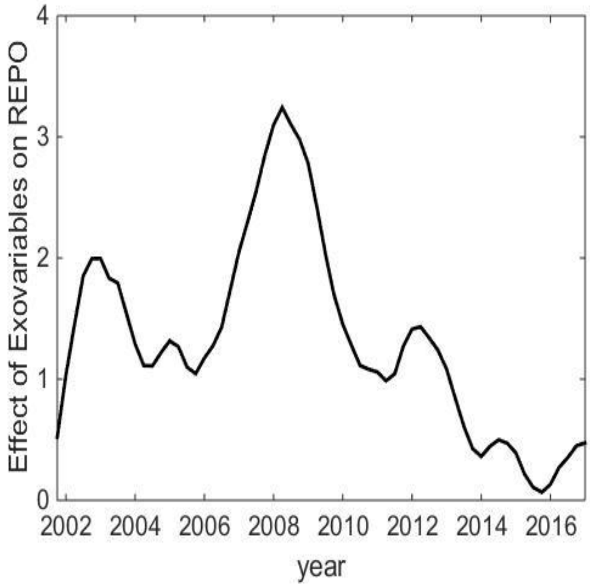


Figure 8 The Impact of Exogenous Variables on 1y Pribor Rate

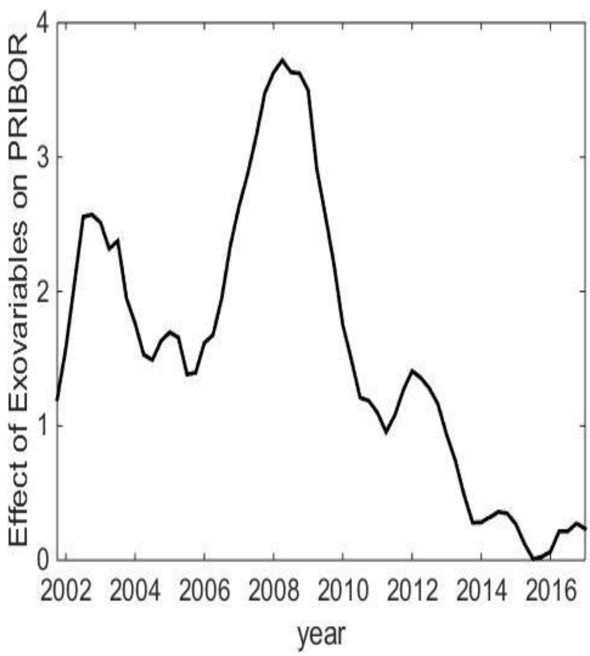


Figure 5 and 6 shows individual shocks and their contribution to one period dynamics of the repo rate and 1y pribor rate. The results confirm lower magnitude of the shocks in case 1y pribor rate comparing with the repo rate and much volatile quarter by quarter adaptations of both rates. Central banks' long-term horizon forecasting typically smooths these short-term fluctuations to overcome the uncertainty about trend reversals which stabilizes the repo rate and consequently the 1y pribor rate but also reduces the ability of CNB to adapt its policy if sudden change is needed. Too long cumulation of the shocks is then followed by lagged but quantitatively fast reaction of main policy rate which makes 1y pribor rate changes less predictable.

In Figure 7 and 8 we can observe a positive, but declining impact of exogenous variables on the repo rate and the money market interest rate except the period 2006 – 2010. It reflects a pre-crisis boom in foreign demand for the gross export together with high growth of oil price followed by their declining trend after 2008. In the last several years their influence is almost negligible due to overall stabilization of these factors. As the repo rate and the money market interest rates reached their (near) zero levels with (near) zero volatility and therefore strategy of home currency depreciation was adopted, the effects of exogenous variables must be absorbed in endogenous ones which could be a source of new shocks when economic recovery will come and exit strategy will follow then.

4. Conclusion

Before the exit from unconventional monetary policy strategies, main policy rate as well as money market interest rates variability could be found in the proximity of the zero lower bound. It raises a point on the potential factors which keep them that low as well as what may influence their apparent involatility. While money market interest rates are close to a near zero level, the optimal main policy rates may exhibit significant volatility as the economy faces deep economic and/or financial shocks and uncertainties of various kinds. Therefore, we presented the model where main aspects of near zero variability together with inherent high variability of main policy rate could be explained applying a series of shocks that come from alternative monetary policy measures. The attention is paid on variability of model optimal main policy rate due to shocks in the structural characteristics of economy, central bank's perception of inflation risks, its weakened credibility and uncertainty about the efficient transmission of alternative monetary measures. Variability of money market interest rates is driven by monetary forces especially when the exit from zero lower bound strategy is expected by market.

The money market interest rates in the Czech economy are modeled in the framework of VAR model with exogenous variables. The model is estimated by Bayesian method and its structural form is obtained through sign restriction. The model's parameters are then used to decompose money market interest rate series into a series of cumulative structural shocks of each endogenous component in the model. The results show that global financial crisis and the exchange rate commitment are two main sources of endogenous variables' shocks on money market interest rates. These endogenous variables shocks confirm high importance of banking loans, unemployment, consumption and investment as extremely sensitive economic variables for the dynamics of an open economy as well as reaching the inflation target. Exogeneous sources of interest rate dynamics steeply declined after the impact of a pre-crisis boom in foreign demand for the gross export together with high growth of oil price diminished and exchange rate interventions were being applied by central bank to boost the whole economy and overcome deflationary expectations.

Policy implications that stem from the research are these ones. The first, to understand correctly the problem of variability of main policy rate and money market interest rates the variables chosen for the estimation of the model should be directly linked to the character of the economy that enable to correctly reflect endogenous and exogenous shocks that the economy faces up. In case of small open economy, it assumes to employ both the dynamics of foreign demand and relative price competitiveness of the economy that is essential for the dynamics of all other variables within the model and consequently main policy rate and money market interest rates. The second, high volatility of quarter by quarter shocks of individual variable confirmed an importance of a reflection of economy's "story" which support smoothing in setting the main policy rate and stabilize variability of money market interest rates when the central bank's policy is credible. The third, when zero lower bound is met, in order to consistently follow the concept of inflation targeting it requires to adopt some unconventional monetary policy strategy to offset a cumulation of negative shocks for the main policy rate and to stimulate economic activity. Last but not least expected exit from unconventional policy regime seems to be the main source of potentially higher money market interest rates variability when keeping the main policy rate unchanged before exit's real application.

REFERENCES

Bartolini L, Bertola G, Prati A (2002): Day-To-Day Monetary Policy and the Volatility of the Federal Funds Interest Rate. *Journal of Money, Credit, and Banking,* 34(1):37-159.

Blake A, Mumtaz H (2012): *Applied Bayesian Econometrics for Central Bankers*. CCBS Technical Handbook ed. 4, Bank of England.

Canova F. (2007): *Methods for Applied Macroeconomic Research*. Princeton University Press, Princeton.

Canova F, De Nicolo G (2002): Monetary Disturbances Matter for Business Fluctuations in the G-7.

Journal of Monetary Economics, 49:1131-1159.

Favero CA, Rovelli R (2000): Modeling and Identifying Central Bank Preferences. Bocconi: IGIER Universita Bocconi*, Working Paper,* No. 148.

Faust J (1998): The Robustness of Identified VAR Conclusions about Money. *Carnegie Rochester Conference Series on Public Policy,* 49:207-244.

Goodman LA (1960): On the Exact Variance of Products. *Journal of the American Statistical Association*. 55(292):708-713.

Kadiyala RK, Karlson S (1997): Numerical Methods for Estimation and Inference in Bayesian VAR Models. *Journal of Applied Econometrics*,12(2):99 – 132.

Luetkepohl H (2005): *New Introduction to Multiple Time Series Analysis*, Springer - Verlag, Berlin.

Rudebusch GD (2001): Is the Fed Too Timid? Monetary Policy in an Uncertain World. *Review of Economics and Statistics*. 83(2):203-217.

Rudebusch GD (2002): Term Structure Evidence on Interest Rate Smoothing and Monetary Policy Inertia. *Journal of Monetary Economics,* 49(6):1161-1187.

Sack B (2000): Does the Fed Act Gradually? A VAR Analysis. *Journal of Monetary Economics*, 46(1):229-256.

Srour G (1999): Inflation Targeting under Uncertainty. *Technical Report*, No. 85Ottawa: Bank of Canada.

Uhlig H (2005): What are the Effects of Monetary Policy on Output? Results from an Agnostic Identification Procedure. *Journal of Monetary Economics*, 52:381-419.

Wieland V (1999): Monetary Policy, Parameter Uncertainty and Optimal Learning. *Finance and Economic Discussion* Series, No. 1999-48, Washington: Board of Governors of the Federal Reserve System.