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SELECTED MEASURES OF THE IMPACT OF MONETARY DECISIONS ON INFLATION

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Abstract. The principal and fundamental monetary policy target is low and stable inflation, because such inflation impacts on the stability of the financial system and promotes balanced economic growth in the long term. The monetary decisions, having an impact on inflation, may be contemplated as the foundations for stronger and more balanced economic growth. A suitable monetary policy that maintains production near to potential production and that balances demand and supply shock in the economy is the necessary condition for the achievement of low and stable inflation. For analysis of the impact of monetary decisions on inflation we use the traditional vector autoregression model of reduced order of monetary policy. In this paper we present the selected measures of the impact of monetary decisions on inflation using the generalized impulse response. We present the standardized difference between the inflation rate for the scenario with the shock and the inflation rate without the occurrence of shock – the measure taking into account the cumulative impact of monetary policy impulse on inflation and the long-term impact of monetary policy impulse on inflation.

Keywords: vector autoregression model of reduced order, impulse response function, generalized impulse response, measures of the impact of monetary policy on inflation.

JEL Classification: C02 , C22, E31, E52.

1. Introduction

Low and stable inflation is the overriding and primary goal of monetary policy because it affects the stability of financial systems and promotes sustainable economic growth in the long term. A necessary condition for the achievement of low and stable inflation is a suitable monetary policy for persistent production close to potential output, and balancing supply and demand shocks in the economy.

To evaluate the effectiveness of decision-making and the proper implementation of the basic objective of the direct inflation targeting (DIT)

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strategy, we should know what the impact of the monetary decision on inflation is. Therefore, the effectiveness of the impact of monetary policy on inflation is the study of what changes the rate of inflation may induce in the level of interest rates.

An analysis of the influence of the monetary decision on inflation was made using the traditional vector autoregression model of reduced order of monetary policy for inflation forecasting.

At the beginning, we will discuss the theoretical foundations of the vector autoregression model of reduced order.

2. Vector autoregression model of a reduced order – theoretical foundations

Since between inflation and monetary policy instruments and other macroeconomic variables there is feedback, that is, they are of a jointly correlated nature, for the modeling of inflation we can use vector autoregression models, including vector autoregressive models of a reduced order.

For this analysis we chose the vector autoregression model because it has no *a priori* distribution of endogenous and exogenous variables, the explanatory variables are the lags of all the endogenous variables in the model.

Overall, the structural VAR model of order p without constant term can be written in the following matrix form:

$$S \cdot y_t = C_1 \cdot y_{t-1} + C_2 \cdot y_{t-2} + ... + C_p \cdot y_{t-p} + \varepsilon_t ,\ t = p+1, p+2,..., N , \quad (1)$$

where:

y_t – vector of all variables in the model at time t;

y_{t-1} – vector of all variables in the model at time $t-i$, for $i = 1, 2,\ldots, p$. For the model we take into account the stationary variables. If some variable is not stationary, then we take stationary differences of this variable to the model.

$S, C_1, C_2,\ldots, C_p$ – matrices of coefficients;

ε_t – vector whose coordinates are the shocks that are uncorrelated with each other and they are the white noise. The variance and covariance matrix Ω of vector ε_t is a diagonal matrix.

However, the generally reduced form of VAR model of order p without constant term can be written in the following matrix form:

$$y_t = A_1 \cdot y_{t-1} + A_2 \cdot y_{t-2} + ... + A_p \cdot y_{t-p} + e_t , \quad (2)$$

where: y_t – vector of all variables in the model at time t; y_{t-i} – vector of all variables in the model at time $t-i$, for $i = 1, 2,\ldots, p$;

$$A_i = S^{-1} \cdot C_i ,\ i = 1,2,..., p ;$$

$$e_t = S^{-1} \cdot \varepsilon_t \ .$$

A fundamental issue of the reduced form (2) VAR model of order p without constant term is that the residuals from the reduced representation of VAR are linear combinations of the structural innovations ε_t, and then they are correlated, the variance and covariance matrix is not diagonal matrix. Between the matrix of variance and covariance models (1) and (2) the following relationship holds $\Omega = S \cdot D \cdot S^T$.

Writing a model (2) in the following matrix form:

$$y_t = A \cdot X_t + e_t , \tag{3}$$

where:

y_t – vector of all variables in the model at time t;

$$X_t = \begin{bmatrix} y_{t-1} \\ y_{t-2} \\ \vdots \\ y_{t-p} \end{bmatrix};$$

$$A = \begin{bmatrix} A_1 & A_2 & \dots & A_p \end{bmatrix}$$

And denoting by $A(L)$ the lag operator applied to the matrix A and the identity matrix by I, model (3) can be written in the following equivalent form:

$$(I - A(L))y_t = e_t \tag{3'}$$

in which $A(L) = A_1 \cdot L + A_2 \cdot L^2 + ... + A_p \cdot L^p$,

therefore $I - A(L) = I - A_1 \cdot L - A_2 \cdot L^2 - ... - A_p \cdot L^p$.

Lag operator can be written in the general form as:

$$A(L) = B(L) \cdot C(L) , \tag{4}$$

where: $B(L) = B_0 + B_1 L + B_2 L^2 + \ldots + B_q L^q$

$$C(L) = C_1 L + C_2 L^2 + \ldots + C_p L^p .$$

If q = 0, the model is called a vector autoregressive model of reduced order – RR-VAR model. Then the lag operator has the form: $A(L) = B_0 C_1 L + B_0 C_2 L^2 + \ldots + B_0 C_p L^p$.

Assuming that $B = B_0$, $C = \begin{bmatrix} C_1 & C_2 & \dots & C_p \end{bmatrix}$, the matrix A of the vector autoregressive model of reduced order can be written as $A = BC'^T$,
where:

matrix B has dimension $k \times r$, and $C^T = \begin{bmatrix} C_1 \\ C_2 \\ \vdots \\ C_p \end{bmatrix}$ has dimension $r \times k \cdot p$,

k – number of variables in the model,
p – vector autoregression rank,
r – cointegration rank.

Lag length p and the cointegration rank r can select according to the information criteria such as: Akaike's information criterion (AIC) (Juselius, 2006), Schwartz' criterion (SC) (Juselius, 2006), Hannan-Quinn's information criterion (H-Q) (Juselius, 2006) or according to the likelihood ratio test (LR).

The least squares estimators of parameters of RR-VAR model is calculated from the following formula:

$$\tilde{A} = \tilde{B} \cdot \tilde{C}'^T,$$

in which

$$\tilde{B} = \Sigma_u^{\frac{1}{2}} \cdot \tilde{V}, \tag{5}$$

$$\tilde{C}^T = \tilde{V}^T \Sigma_u^{-\frac{1}{2}} Y X^T (X X^T)^{-1}, \tag{6}$$

assuming that Y, X, Σ_u are the matrices of dimension $k \times (N-p)$, $k \cdot p \times (N-p)$, $k \times k$ respectively and Σ_u is positive definite matrix, $rank(X) = k \cdot p$, $rank(Y) = k$; Y – observation matrix of y_t; X – observation matrix of $y_{t-1}, y_{t-2}, ..., y_{t-p}$, for $t = p+1, p+2, ..., N$; N – number of observations (length of the sample).

In the formulas (5) and (6) $\tilde{V} = [\tilde{v}_1 \quad \tilde{v}_2 \quad \dots \quad \tilde{v}_r]$ is the $k \times r$ matrix of the orthonormal eigenvectors corresponding to the r the largest eigenvalues of the following matrix:

$$\frac{1}{N-p} \Sigma_u^{-\frac{1}{2}} Y X^T (X X^T)^{-1} X Y^T \Sigma_u^{-\frac{1}{2}}. \tag{7}$$

Furthermore, since Σ_u is any positive definite $k \times k$ matrix, it can be assumed that

$$\tilde{\Sigma}_u = \frac{1}{N-p} Y\,(I_{N-p} - X^T (X\,X^T)^{-1} X) Y^T, \tag{8}$$

where: I_{N-p} is the $(N-p)\times(N-p)$ identity matrix.

Since the analysis of the impact of the monetary decision on inflation was based on the traditional vector autoregression model of the reduced order of monetary policy, then we present the general form of this model below.

In traditional VAR models of monetary policy we select three variables: the inflation rate, the interest rate (e.g. the reference rate) and the production – the output dynamics – for monthly data and the GDP for quarterly data.

Thus, assuming that the lag length is p, then the traditional VAR model can be written in the following standard form:

$$\begin{cases} \pi_t = \alpha_{11}^1 \pi_{t-1} + \alpha_{12}^1 Y_{t-1} + \alpha_{13}^1 i_{t-1} + \alpha_{11}^2 \pi_{t-2} + \alpha_{12}^2 Y_{t-2} + \alpha_{13}^2 i_{t-2} + \ldots + \\ \qquad + \alpha_{11}^p \pi_{t-p} + \alpha_{12}^p Y_{t-p} + \alpha_{13}^p i_{t-p} + e_{1t} \\ Y_t = \alpha_{21}^1 \pi_{t-1} + \alpha_{22}^1 Y_{t-1} + \alpha_{23}^1 i_{t-1} + \alpha_{21}^2 \pi_{t-2} + \alpha_{22}^2 Y_{t-2} + \alpha_{23}^2 i_{t-2} + \ldots + \\ \qquad + \alpha_{21}^p \pi_{t-p} + \alpha_{22}^p Y_{t-p} + \alpha_{23}^p i_{t-p} + e_{2t} \\ i_t = \alpha_{31}^1 \pi_{t-1} + \alpha_{32}^1 Y_{t-1} + \alpha_{33}^1 i_{t-1} + \alpha_{31}^2 \pi_{t-2} + \alpha_{32}^2 Y_{t-2} + \alpha_{33}^2 i_{t-2} + \ldots + \\ \qquad + \alpha_{31}^p \pi_{t-p} + \alpha_{32}^p Y_{t-p} + \alpha_{33}^p i_{t-p} + \varepsilon_{3t} \end{cases} \tag{9}$$

$$t = p+1,\ p+2, \ldots, N$$

or equivalently:

$$y_t = A_1 y_{t-1} + A_2 y_{t-2} + \ldots + A_p y_{t-p} + e_t \quad t = p+1,\ p+2, \ldots, N\,. \tag{10}$$

Model (10) can be also written as:

$$y_t = A \cdot X_t + e_t\,. \tag{11}$$

In the above formulas:

y_t – vector of all variables in the model at time *t*; $y_t = \begin{bmatrix} \pi_t \\ Y_t \\ i_t \end{bmatrix}$;

π_t – inflation rate at time *t*,

i_t – reference rate at time t,
Y_t – output at time t;

Vector y_t is the vector of endogenous stationary variables.

$$X_t = \begin{bmatrix} y_{t-1} \\ y_{t-2} \\ \vdots \\ y_{t-p} \end{bmatrix};$$

$y_{t-i} = \begin{bmatrix} \pi_{t-i} \\ i_{t-i} \\ Y_{t-i} \end{bmatrix}$ – vector of all variables in the model at time $t-i$, for $i = 1, 2,\ldots, p$;

$$A = \begin{bmatrix} A_1 & A_2 & \ldots & A_p \end{bmatrix}$$

A_i for $i = 1, 2, ..., p$ – 3×3 matrices of coefficients;

$e_t = \begin{bmatrix} e_{1t} \\ e_{2t} \\ e_{3t} \end{bmatrix}$ – vector of white noise shocks; it is assumed that e_t is the three-dimensional random variable having a normal distribution $N(\theta, D)$, where D – variance and covariance matrix.

3. The impulse response function

The most intuitive tool to analyze the interaction among variables in the system is the impulse response function for each of the series.

To see this, by using recursive substitution, we can write the VAR model in its Vector Moving Average (VMA) representation. However, to trace the impact of an impulse to one of the variables on itself and on the rest of the variables in the system, what is required is the VMA representation based on the orthogonal structural shocks, instead of the reduced form residuals, which are correlated with each other.

From model (3') we have $y_t = \dfrac{e_t}{I - A(L)}$, thus the model in the vector moving average representation can be written in the following form:

$$y_t = \sum_{i=0}^{\infty} (A(L))^i \cdot e_t\ . \tag{12}$$

Using the definition e_t model (12) has the following form:

$$y_t = \sum_{i=0}^{\infty} (A(L))^i \cdot S^{-1} \cdot \varepsilon_t \tag{13}$$

or equivalently:

$$y_t = \sum_{i=0}^{\infty} \Phi_i \cdot \varepsilon_t \,, \tag{13'}$$

where $\Phi_i = (A(L))^i \cdot S^{-1}$.

From equation (13') it is clear what the response of variables to a unit impulse at time *t* is. Coefficients Φ_i provide the impulse response of each variable included in the model to various structural shocks. The impulse response function of each variable in the model create all the coefficients Φ_i corresponding to this variable.

4. Methods for identifying the impulse response

In practice, the determination of coefficients Φ_i is not easy because we do not know the elements of the matrix *S*. Therefore, in the further part we discuss the methods of identifying the impulse response applied in practice.

4.1. The method proposed by Sims

Sims (1980) proposed to use a recursive decomposition of the estimated residuals in order to obtain orthogonalized innovations allowing the researcher to "identify" the impulse response functions. This kind of identification is implemented by using a lower triangular matrix coming from Cholesky decomposition (Horn, Johnson, 1985) of the variance-covariance matrix of the residuals.

Remember that the Cholesky decomposition can introduce a variance and covariance matrix that is generally a positive symmetric matrix D of the form:

$$D = M \cdot M^T \tag{14}$$

where *M* is a lower triangular matrix.

However, this method of identification of the impulse response affects the existence of a strong asymmetry in the system analyzed variables, because the first variable does not affect the other variables, while the other variables in the model affect the variable that precedes it. By changing the order of the variables in the system, it produces different impulse response functions for each variable.

Then, if the impulse response results are not too different for the different orderings of variables, it can analyze the impulse response and thus the dynamics of the model on the estimated impulse responses.
However, in general the problem is the existence of a large number of variables orderings given by $k!$, where k – number of variables in the model.

In order to solve this problem, as an alternative to the method proposed by Sims, there are other methods of impulse response, including the concept of generalized impulse response.

4.2. The other methods of impulse response

Assuming that the monetary transmission mechanism is linear, in the analysis of the impact of shocks it is necessary to use the expected value of effects of random disturbances, which in the VAR models may be an unconditional response to the impulse. However, in the nonlinear model of the monetary transmission mechanism, the effects of random disturbances are unknown and not determined *a priori*, and their identification requires a different approach than in linear models. Then the analysis of the effects of random disturbances using the unconditional expected value of impulse response may be unworkable, and then one should use the concept of generalized impulse response. This concept of impulse response can be used for linear and nonlinear models. In this paper we use the concept of generalized impulse response to linear models.

4.2.1. The generalized impulse response GIR

The method of generalized impulse response has been proposed by Koop, Pesaran, Potter (1996). This method involves comparing two forecasts of the model. One forecast takes into account one-time shock, while the second forecast is determined for a situation without the occurrence of shock. Thus, the generalized impulse response is the difference of two conditional expected values, which we can generally write for the following vector y:

$$GIR_y(n, e_j, w_{t-1}) = E(y_{t+n} / e_j, w_{t-1}) - E(y_{t+n} / w_{t-1}), \tag{15}$$

where:

$GIR_y(n, e_j, w_{t-1})$ – generalized impulse response of variables in the vector y at time n;

y_{t+n} – vector variables of the model at time $t+n$;

n – horizon of analysis;

e_j – shock vector that corresponds to $k \times 1$ vector with not null element at the j-th element and zeros elsewhere;

w_{t-1} – historical or starting values of the variables in the model;

$E(\cdot / \cdot)$ – the conditional expected value.

Analyzing the impact of the monetary decisions on inflation based on the traditional VAR monetary policy model, the generalized response of inflation to monetary policy impulse represents the first coordinate of the vector $GIR_y(n, s_t, w_{t-1})$,which can be written as follows:

$$GIR_\pi(n, e_j, w_{t-1}) = E(\pi_{t+n} / e_j, w_{t-1}) - E(\pi_{t+n} / w_{t-1}), \tag{16}$$

where:

$GIR_\pi(n, e_j, w_{t-1})$ – generalized impulse response of inflation to monetary policy impulse in horizon n;

π_{t+n} – inflation rate that is the variable that the reaction is analyzed at time $t+n$.

We consider the monetary policy shock as shock e_j, for instance the interest rate changes at time t.

Assuming that the residuals from the VAR model are multivariate normally distributed, we have the generalized impulse response from a shock (one standard deviation) to the j-th residual given by:

$$GIR_y(n, e_j, w_{t-1}) = \frac{1}{\sqrt{\sigma_j^2}} A^n \cdot D \cdot e_j . \tag{17}$$

The matrix A is a matrix associated with the operator:

$$A(L) = A_1 \cdot L + A_2 \cdot L^2 + ... + A_p \cdot L^p \text{, then } A = A_1 + A_2 + ... + A_p .$$

Therefore, to evaluate the impact of monetary policy decisions on inflation on the basis of the traditional VAR monetary policy model, the generalized response of inflation to monetary policy impulse is the first coordinate of the vector calculated from the formula (17).

5. Measures of the impact of monetary policy on inflation

One of the applied measures of the impact of monetary policy on inflation, taking into account the inflation rate in only one period, is the standardized difference between the inflation rate for the scenario with the shock and the inflation rate without the occurrence of shock. We can write this by using the generalized impulse response, as follows:

$$\frac{GIR_{\pi}(n, e_j, w_{t-1})}{e_{ji_t}}, \tag{18}$$

where e_{ji_t} is the coordinate of vector e_j informing about the size of monetary policy shock.

If we want to study the impact of the monetary decisions on inflation to take into account the adjustment path, not only the end point, we can use the following measure which takes into account the cumulative impact of monetary policy impulse on inflation in the time interval [0, n], defined by the following formula (Postek, 2011):

$$\frac{\sum_{i=1}^{n} GIR_{\pi}(i, e_j, w_{t-1})}{e_{ji_t}}. \tag{19}$$

While the long-term impact of monetary policy impulse on inflation is calculated by the formula:

$$\frac{\lim_{n\to\infty} \sum_{i=1}^{n} GIR_{\pi}(i, e_j, w_{t-1})}{e_{ji_t}}. \tag{20}$$

As the shock there can be assumed a unit vector with the coordinates corresponding to the monetary policy instrument, equal to one and other coordinates equal to zero, then $e_{ji_t} = 1$.

Then, when we conduct an analysis based on the traditional VAR monetary policy model, we have $e_2 = \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}$.

The shock may also be the vector with coordinates corresponding to the monetary policy instrument equal to the rest of the reference rate calculated from the model, then $e_{ji_t} = i_t - i_t^*$, where: i_t – the actual value of the reference rate at time t, i_t^* – theoretical value of the reference rate at time t.

6. The empirical analysis

For the calculation of the standardized difference between the inflation rate for the scenario with the shock and the inflation rate without the occurrence of shock, and for an analysis of measure taking into account the cumulative impact of monetary policy impulse on inflation we used: the monthly inflation rate data (data published by the Central Statistical Office) (source: www.stat.gov.pl), the monthly reference rate data (data published by the NBP) – data at the end of the month, as well as monthly industrial production growth rate data (data published by the Central Statistical Office) (source: www.stat.gov.pl) from the period between January 2004 and March 2010.

The stationarity of the series was tested by means of the Dickey-Fuller test, which states that the series of inflation and reference rate are integrated of degree 1; therefore, for further analysis we take the stationary series of first increments, however the series of output growth is stationary.

Then, selected on the basis of the information, criteria vector autoregression rank p and cointegration rank r p =1, r = 3. These results were obtained from all the various criteria: the AIC criterion, the SC criterion and H-Q criterion. Then we estimated the matrix of parameters:

$$A_1 = \begin{bmatrix} 0.411 & 0.008 & -0.136 \\ 0.950 & 0.801 & 4.281 \\ 0.156 & 0.002 & 0.419 \end{bmatrix},$$

as well as the variance and covariance matrix of model residuals:

$$D = \begin{bmatrix} 0.123 & 2.682 & 0.004 \\ 2.682 & 29.448 & 0.867 \\ 0.004 & 0.867 & 0.028 \end{bmatrix}.$$

Assuming that the interest rate shock is 1, we obtained the following values of measure of the impact of monetary policy decisions on inflation, which is presented in Table 1.

The obtained values of measures of reaction of impact of the monetary decisions on inflation for the interest rate shock equaling 1 are also presented in Fig. 1. In Table 2 we summarize the values of measures of the impact of monetary policy decisions on inflation for the interest rate shock equaling 0.25.

Table 1. The measures of reaction of the impact of monetary policy decisions on inflation for monetary policy shock equaling 1

Time horizon *n*	Measure of the impact of monetary policy decision on inflation	Measure of the cumulative impact of monetary policy decision on inflation	Month	Forecasts of increases of inflation rate	Actual inflation rate	The actual value of the reference rate
			03.2011		4.3	3.75
1	0.03	0.03	04.2011	0.34	4.50	4.00
2	0.04	0.06	05.2011	0.17	5.00	4.25
3	0.04	0.10	06.2011	0.10	4.20	4.5
4	0.04	0.14	07.2011	0.07	4.10	4.5
5	0.04	0.18	08.2011	0.06	4.30	4.5
6	0.03	0.21	09.2011	0.05	3.90	4.5
7	0.03	0.24	10.2011	0.04	4.30	4.5
8	0.02	0.26	11.2011	0.04	4.80	4.5
9	0.02	0.28	12.2011	0.03	4.60	4.5
10	0.02	0.30	01.2012	0.03	4.10	4.5
11	0.01	0.32	02.2012	0.02	4.30	4.5
12	0.01	0.33	03.2012	0.02		
13	0.01	0.34	04.2012	0.02		
14	0.01	0.35	05.2012	0.02		
15	0.01	0.35	06.2012	0.01		
16	0.01	0.36	07.2012	0.01		
17	0.01	0.37	08.2012	0.01		
18	0.00	0.37	09.2012	0.01		

Source: own calculations.

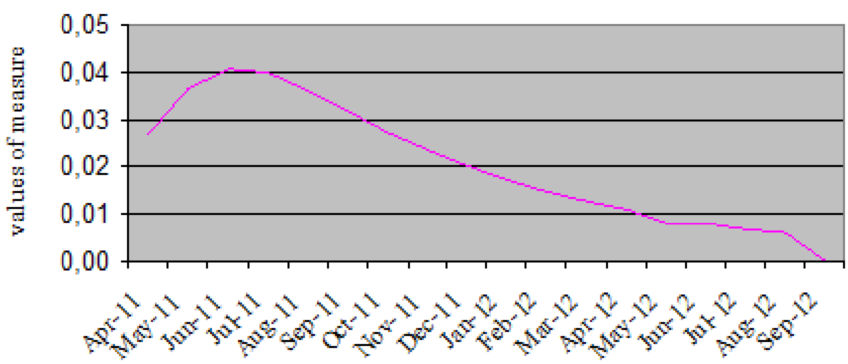

Fig. 1. Measures of the impact of monetary policy decision on inflation for the interest rate shock equals 1

Source: own calculations.

Table 2. The measures of reaction of the impact of monetary policy decisions on inflation for monetary policy shock equaling 0.25

Time horizon *n*	Measure of the impact of monetary policy decision on inflation	Measure of the cumulative impact of monetary policy decision on inflation	Month	Forecasts of increases of inflation rate	Actual inflation rate	The actual value of the reference rate
			03.2011		4.3	3.75
1	0.03	0.03	04.2011	0.34	4.50	4.00
2	0.04	0.06	05.2011	0.17	5.00	4.25
3	0.04	0.10	06.2011	0.10	4.20	4.5
4	0.04	0.14	07.2011	0.07	4.10	4.5
5	0.04	0.18	08.2011	0.06	4.30	4.5
6	0.03	0.21	09.2011	0.05	3.90	4.5
7	0.03	0.24	10.2011	0.04	4.30	4.5
8	0.02	0.26	11.2011	0.04	4.80	4.5
9	0.02	0.28	12.2011	0.03	4.60	4.5
10	0.02	0.30	01.2012	0.03	4.10	4.5
11	0.01	0.32	02.2012	0.02	4.30	4.5
12	0.01	0.33	03.2012	0.02		
13	0.01	0.34	04.2012	0.02		
14	0.01	0.35	05.2012	0.02		
15	0.01	0.35	06.2012	0.01		
16	0.01	0.36	07.2012	0.01		
17	0.01	0.37	08.2012	0.01		
18	0.00	0.37	09.2012	0.01		

Source: own calculations.

The obtained values of measure of reaction of the impact of the monetary decisions on inflation for the interest rate shock which equals 0.25 are also presented in Fig. 2.

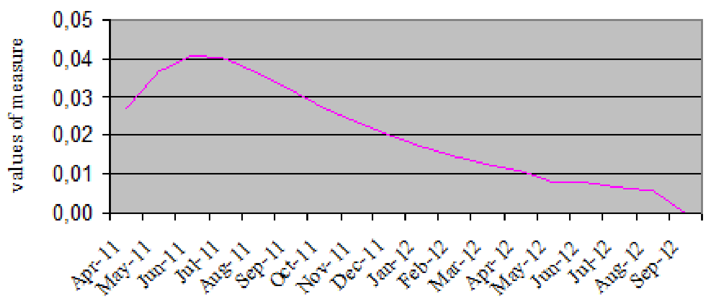

Fig. 2. Measure of the impact of monetary policy decision on inflation for the interest rate shock equals 0.25

Source: own calculations.

6. Concluding remarks

On the grounds of the analysis, we found that a horizon of 18 months is the impact of interest rate shock on inflation. Moreover, the strength of this effect is decreasing. The obtained measures have a small value. This probably applies to the fact that monetary policy has a more effective impact on inflation when economic growth accelerates; however, 2011 was the year in which the crisis affected the financial markets.

The estimated measures quantify, in a general way, the impact of monetary policy on inflation. They are useful to evaluate how large the cumulative changes in interest rates should be so as to bring the expected value of inflation to the desired level within a determined time horizon.

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