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On asymmetric effects in a monetary policy rule. The case of Poland

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Abstract

Asymmetric effects in a monetary policy rule could appear due to asymmetric preferences of the central bank or/and due to nonlinearities in the economic system. It might be suspected that monetary authorities are more aggressive to the inflation rate when it is above its target level than when it is below. It also seems probable that monetary authorities have different preferences and react more strongly when the level of economic activity is low than when it is high. In this paper we investigate whether the reaction function of the National Bank of Poland (NBP) is asymmetric according to the level of inflation gap and the level of output gap. Moreover, we test whether these asymmetries might possibly stem from the nonlinearities in the Phillips curve. Threshold models are applied and two cases of unknown and known threshold value are investigated.

Introduction

The aim of this paper is to search for asymmetric effects in the reaction function of the National Bank of Poland (NBP). We check whether the Polish monetary policy rule is asymmetric concerning levels of the fundamental macroeconomic variables: inflation and output gap. Encompassing the asymmetric elements in the reaction function might give better explanation of the central bank's behavior. This, in turn, could help to form better expectations and forecasts and could be used to build more accurate econometric models of the economy.

If we assume that a central bank has quadratic loss function in the inflation and output gaps and minimizes it subject to linear structure of economy than we will obtain a linear reaction function. However, positive and negative deviations of inflation and output from the reference levels seem to be treated by monetary authorities differently.

On the one hand, central banks may have asymmetric preferences. Some central banks attempt to stabilize output fluctuations accepting inflation being more volatile, it is because they might face some political heat or social pressure. These banks would have greater aversion to recessions than to expansions. Other central banks might be focused on inflation stabilization (e.g. strict inflation targeters) and have greater aversion to high than low inflation because, for instance, they need to build credibility after implementing inflation targeting strategy. Cukierman and Muscatelii (2008) distinguish recession avoidance preferences (RAP) and inflation avoidance preferences (IAP). In the former a central bank takes more precautions against negative output gaps, while in the latter against positive inflation gaps. Such asymmetric preferences lead to nonlinear reaction functions, as the authors show RAP leads to concave Taylor rule while IAP to convex rule in both the inflation and output gaps.

On the other hand, central banks might take into account asymmetries in different channels of the monetary transmission process. Most importantly, the aggregate supply curve might be nonlinear. In empirical studies it is often argued that when the output gap is positive it has positive impact on inflation, while when the output gap is negative it has very small deflationary impact (Laxton et al. 1999, Pyyhtia 1999, Baghli et al. 2006, Buchmann 2009). There are different explanations of this phenomenon, discussed later on, such as for instance nominal wage rigidities, capacity constraints, costly price adjustment, volatility of aggregate demand and supply shocks.

Lastly, the uncertainty regarding the NAIRU or the growth rate of productivity may

lead to nonlinear interest rate policy as well (see Dolado et al. 2004). Therefore central banks might be more aggressive when the output gap reaches a certain threshold and more cautious when the output gap is small.

The structure of this paper is as follows. In the next section a brief review of the literature concerning symmetric Taylor rule and asymmetric effects in both Taylor rule and Phillips curve is made. Section 2 and 3 present our data set and empirical strategy. Section 4 reports the empirical results. The last section concludes.

1 Literature review

1.1 Studies on the Taylor rule

Originally Taylor (1993) specified a simple monetary policy rule:

$$i_t = i^* + \pi_t + \gamma y_t + \beta_\pi(\pi_t - \pi^*) = \alpha + \beta(\pi_t - \pi^*) + \gamma y_t,$$

where i_t is the central bank policy rate, i^* is an equilibrium real interest rate, π_t is the rate of inflation over the previous four quarters, π^* is the inflation target of the central bank, y_t is the percent deviation of the real GDP from its trend. Taylor (1993) analyzes the federal funds rate during 1987-1992 and finds out that it is closely approximated by the rule with parameters $i^* = 2$, $\pi^* = 2$, $\gamma = \beta_\pi = 0,5$. Thus, the central bank rate tends to increase when the inflation is above its target value and when the actual output is above the potential output.

The original Taylor rule has been modified in various ways. The adjustment of the monetary policy rate appears not to be immediate. Central banks dislike jumps and tend to smooth adjustments in their interest rates (Judd and Rudebusch (1998)). Therefore, the Taylor rule is often extended by a lagged interest rate term for instance as in the equation below (it is partial adjustment mechanism Clarida et al. 1998):

$$i_t = (1 - \rho)(\alpha + \beta(\pi_t - \pi^*) + \gamma y_t) + \rho i_{t-1}.$$

The central bank's rate seems to depend on forecasts. The effects of the change of a monetary policy rate appear with delay[1]. If the monetary authorities take into account these delays than they should set their rates according to future movements of inflation and output gap. Clarida et al. (2000) suggest a following forward looking rule:

$$i_t = (1 - \rho)(\alpha + \beta(E(\pi_{t+k}|\Omega_t) - \pi^*) + \gamma E(y_{t+m}|\Omega_t)) + \rho i_{t-1},$$

where Ω_t denotes an information set at time t, y_{t+m} is an output gap between period t and $t + m$, π_{t+k} is a percent change in a price level between periods t and $t + k$.

Moreover, many economists argue that standard monetary policy rules should be augmented by other macroeconomic variables because central banks seem to look on the broader set of factors. It is often proposed to extend the standard rule by: exchange rate, monetary aggregates, asset prices, long term and foreign interest rates. However,

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[1] see Demchuk et al. (2012) for estimates for Poland

in the empirical studies these standard variables often seem to have negligible impact. More recently, for instance, Baxa et al. (2011) and Vašíček (2011), postulate to add some measures of financial stability.

Furthermore Orphanides (2001, 2010) suggests to use real time data, which are available to policymakers at the time of making the decision. The macroeconomic data such as the rate of inflation or the level of GDP are known with the delay. The author argues that reliance on ex-post revised data can be misleading as the monetary authorities could not have actually followed such rule. The researcher can only imperfectly approximate the real information available at time of making a policy decision.

Finally, many recent papers include threshold effects in a monetary policy reaction function. It is argued that the linear specifications can be too simplified. Such approach, also applied in our paper, enables to encompass an asymmetric behavior of central banks.

Bunzel and Enders (2010) find out strong evidence of threshold behaviour of the Federal Reserve in a number of time periods between 1965 and 2007. Among others the authors present model where the central bank is active when the inflation is higher than the interim threshold and when the output gap is negative. It appears that the central bank is more aggressive when the system is above the threshold than when it is below. The model seems to fit data best, what is more, the models with asymmetric effects give better out-of-sample forecasts than the linear models. But, the authors notice also a number of statistical problems that might arise while analysing the asymmetries and result in quite dubious results. For example, the threshold value and Hansen's F statistic decrease when increasing the starting date, moreover, in the high inflation regime excessive amount of interest rate smoothing may be observed.

Cukierman and Muscatelli (2008) using smooth transition regressions study nonlinearities in the monetary policy rule for the UK and the US. They emphasize that the character of nonlinearities changes substantially over different time periods and depends mainly on the regime and the macroeconomic situation. For instance in the 1979 - 1990 in the UK the Taylor rule seems to be concave, what can be interpreted as dominance of recession avoidance preferences, whereas in the 1992-2005 it appears to be convex, what might be interpreted as dominance of inflation avoidance preferences. The similar findings are presented for the US - where the Taylor rule varies across different chairmen of the Fed - inflation avoidance preference dominated under Martin and recession avoidance preference during Burns/Miller and Greenspan.

The asymmetric effects in European Central Bank (ECB) reaction function were

studied by many researchers. Aguiar and Martins (2008) point out that when a central bank needs to build credibility than it would be more precautionary as far as a price stability is concerned. Therefore, it would prefer to have inflation below the target level than above. Such asymmetry is shown for the Euro Area throughout 1995 - 2005, as during this time period the monetary policy had to establish its credibility. Whereas Surico (2003) estimates the asymmetric Taylor rule for ECB concerning the sample 1997:7 - 2002:10 and finds equal reaction to inflation and deflation, but larger policy easing during output recessions than policy tightening during output expansions. In one of the recent papers Gerlach and Lewis (2011) estimate the ECB's monetary policy rule in 1999-2010 and detect a structural break after November 2008 (i.e. the switching point). Interestingly, they use smooth transition model to avoid a discrete break. The authors focus on the recent financial crisis and show that the zero lower bound did not constrain monetary policy during the crisis.

As far as the Polish monetary rule is concerned a few studies were conducted. Urbańska (2002) presents one of the first attempt to estimate the Polish Taylor rule. She concerns the period 03:1998 - 12:2001 and uses the error correction model (ECM). Kotłowski (2006) analyses the individual reaction functions of MPC members in 2004-2005. Przystupa and Wróbel (2006) estimate small structural model with different degrees of forward-lookingness and calculate loss functions to determine the optimal monetary policy rule. Whereas Baranowski (2008) uses real time data to estimate by the ECM backward looking Taylor rule in Q1:1999 - Q3:2007. Moreover, Brzoza - Brzezina et al. (2011) try to determine the extent to which the three chosen central banks (i.e. Bank of England, National Bank of Poland and Swiss National Bank) are forward-looking.

The Taylor rule might be asymmetric because of some asymmetric effects in the monetary transmission mechanism. Here's a brief presentation of the studies for the Polish economy. Postek (2011) presents the 3-equation nonlinear model. The results indicate the following asymmetric effects: a negative relation between the GDP dynamics in the current year and in the previous year if the change of the dynamics reaches a certain level, higher persistence of the increasing or stable inflation than the decreasing one, and stronger reaction of the NBP's reference rate in response to the rapid decrease of inflation than to its rapid increase. Łyziak et. al (2010) apply a small structural model with nonlinear Phillips curve where the impact of the output gap on inflation is stronger when the output gap is positive. Concerning the particular channels of the monetary transmission, Przystupa and Wróbel (2009) study an exchange rate pass-through and

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find an asymmetry of CPI reaction to the output gap and exchange rate movements (i.e. the size and direction of the exchange rate change, and volatility of the exchange rate). Whereas Sznajderska (2012) examines an interest rate pass-through and, for certain retail bank interest rates, finds evidence of asymmetric cointegration and short term asymmetric effects concerning the levels of economic activity and liquidity.

Vašiček (2011) concerns the asymmetric effects in the Polish monetary policy rule. The author investigates the Taylor rules for the Czech Republic, Hungary and Poland and searches for asymmetries assigned to the level of inflation, output gap and financial stress. Our approach is in some cases similar to this paper, however, our results are very different. Vašiček does not find nonlinearities in the Polish Philips curve and what is more he finds little evidence of any linear or nonlinear relationship between inflation and stance of business cycle. The author finds out that the Polish central bank responds rather to the output gap than inflation. There are no asymmetries in the Taylor rule as far as the level of inflation is concerned. Moreover, the analysis shows that NBP seems to be asymmetric along the business cycle as the output gap coefficient is insignificant in the regime below the threshold value and significant above it. The author's interpretation is that the output gap affects NBP's inflation forecasts which are the driver of interest rate setting. In addition, the calculations show that when financial stress is high there is no response to inflation and when it is low the response is positive. The author suggests that the real economy raises concerns only when the inflation stress is low.

1.2   Studies on the Phillips curve

As it was mentioned before a nonlinear monetary policy reaction function might stem from nonlinear Philips curve. The Phillips curve has generally been estimated in a linear framework[2], even though the original work of Phillips (1958) and many other theoretical works pointed to nonlinear relationship.

Many economists argue that the relation between inflation and output gap is nonlinear, therefore the cost of disinflation is changing. Often the Phillips curve seems to be convex. If the economy is overheated an decrease of economic activity causes faster disinflation (cost of fighting inflation is low), while in the contrary when the economy is in recession further decreases of economic activity do not cause much disinflation (cost of fighting inflation is high).

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[2]However, the studies mainly concerned the neutrality of money in short and long term and the existence of the relation between economic activity and inflation at all.

There are many reasons for the nonlinear Phillips curve. For instance, workers are resistant to nominal wage cuts, what causes downward rigidity of nominal wages. It is particularly problematic when the level of inflation is low, because when the inflation rate is high it might be enough to keep the nominal wages constant for some time to decrease the wages. Thus, the central bank to restore the balance on the labor market might tolerate higher inflation. Even long run Philips curve might be down-sloping (in the inflation-unemployment space) because of money illusion (Akerlof et al., 1996), people use to think in nominal terms, therefore in a period of high inflation firms can set lower real wages and hire more workers.

Moreover, firms may face capacity constraints in the short run. When the economy is strong the capacity constraints restrict firms to increase output and encourage them to increase prices, in contrast when the economy is weak it is easier for firms to increase output, what causes a convex Philips curve.

Costly price adjustment (Ball et al. 1988, Dotsey et al. 1999) are another explanation. Any change in firms' activity is costly, therefore firms might be reluctant to make it. When the level of inflation is high demand shock is expected to have more impact on increasing prices and less on increasing production.

Also volatility of aggregate demand and supply shocks (Lucas 1973) might cause some asymmetric effects. Economic entities do not know if any price change is caused by a change in the economy wide aggregate demand or by a change in relative product demand and thus, they are unable to distinguish between changes in general prices and changes in relative prices. The higher the volatility of inflation the more of price changes are assigned to general prices. Therefore, not only the level of inflation but also its stability is an important aspect for monetary authorities.

There are not only studies which show that the Philips curve is convex, some studies point that it might be concave. It might be concave because firms facing monopolistic competition are more willing to reduce prices under weak demand (when the output gap is negative) than to increase them under high demand to avoid being overtaken by rival firms (Stiglitz, 1997).

Filardo (1998) point out that the Philips curve might be convex when the output gap is positive and concave when the output gap is negative. The author shows that the cost of fighting inflation is higher when the economy is weak (5% of output gap) than when it is overheated (2, 1%). Moreover, in both the weak and the overheated economy this cost is higher than it results from the linear model.

2 Data description

We use monthly publicly available data from January 2000 to May 2012. On the one hand usage of monthly data enables us to apply threshold models and have sufficient number of observations while on the other hand interest rates and inflation rates are highly persistent at monthly frequencies what might result in the coefficient of lagged dependent variable close to unity and very limited response of independent variables.

In the case of a monetary policy rule estimation an important aspect of the data selection process is determining the dependent variable. The Polish monetary policy rate is usually adjusted by multiples of 25 basis points and the decisions concerning its level are taken once a month. Taking into account this discreteness we decided to concentrate on the money market rate, which is more variable and determines the real rate of making transactions. The Polish central bank reference rate and the money market rates move almost in line during the examined time period (see Figure 1). In the study we will use the 1 week money market rate - WIBOR 1W as dependent variable.

All data are obtain from the webpage of the Polish Central Statistical Office or the National Bank of Poland database. Let as denote the other time series used in the estimations:

- $cpi1$ - year on year consumer price index;

- $cpi2$ - quarter on quarter consumer price index, seasonally adjusted;

- $cpia$ - the deviation of cpi from the actual inflation target;

- $cpib$ - the deviation of cpi from its smoothed by Hodrick Prescott filter trend of inflation (i.e. $cpi1$);

- gap - the difference between logarithm of the seasonally adjusted measure of GDP and the trend obtained by Hodrick Prescott filter, GDP is disaggregated to monthly frequencies; We use Fernandez method to disaggregate quarterly data into monthly frequencies (cf. Fernandez, 1981). We use an output gap computed for monthly industrial production index to augment the related series. Moreover, we lengthen the time series by AR(2) process to diminish the role of last observations.

- $reer$ - difference between logarithm of real effective exchange rate deflated by CPI (which is calculated by the National Bank of Poland) and the trend obtained by Hodrick Prescott filter;

- $infe1$ - inflation expectations of Polish bank analysts for forecasting horizon of 12 months from the survey conducted by Reuters;

- $infe2$ - inflation expectations of Polish consumers for forecasting horizon of 12 months, calculated from the survey conducted by Ipsos (cf. Łyziak and Stanisławska 2006);

- $\Delta ieuro$ - the change of 1 month EURIBOR.

The graphs of the applied variables are presented in Figure 1 in the Appendix.

Belke and Klose (2011) argue that different regression coefficients can be obtained when using ex-post data, real-time data and non-modified real-time forecasts. They estimate the ECB response function in period 1999Q1 - 2010Q2 and find out that higher inflation and output gap coefficients are obtained when one uses real time data instead of ex-post data, moreover the output gap coefficient is reduced when one uses real time forecasts. However, we do not use the data from projections of inflation and GDP because they are publicly available since 08:2004 and 05:2005 respectively. Moreover, these are quarterly not monthly data.

3 Methods of estimation and testing

3.1 The Phillips curve estimation

Before proceeding with the analysis of the Taylor rule we examine nonlinearities in the Polish Philips curve. We do only a preliminary analysis and further studies are needed when using different measures of inflation and output gap as well as different specifications of the Philips curve. As the main aim of this paper is to analyse possible asymmetries in the Taylor rule, the estimations of the Phillips curve aim to show if the asymmetries in the Taylor rule might stem from the nonlinear relation between the inflation rate and the level of economic activity. Therefore, to obtain comparable results we use similar data in both the Phillips curve and the Taylor rule estimations. It means that when estimating the Philips curve we consider monthly data. We consider two measures of inflation: year on year CPI as the central bank target is maintaining this rate at the relevant level and quarter on quarter CPI as such rate is most often used and enables better economic explanation from independent variables to CPI.

We use GMM estimation method with lagged values of the measure of inflation, output gap, exchange rate gap and inflation expectations of the Polish customers and bank analysts as instruments.

We estimate the New Keynesian hybrid Phillips curve with forward and backward looking components of expected price movements, output gap and exchange rate pass-through:

$$\pi_t = \lambda_1 E(\pi_{t+k}|\Omega_t) + \lambda_2 \pi_{t-k} + \alpha y_{t-n} + \phi e_{t-m} + \epsilon, \tag{1}$$

where: π_t is an inflation rate measured by $cpi1$ or $cpi2$, y_t is an output gap measured by gap, e_t is an exchange rate gap measured by $reer$. Ω_t in this and other equations denotes an information set at time t. Various combinations of the lead and lag values (i.e. k, n, m) will be tested, where $k, n, m \in \{3, 4, \ldots, 12\}$ and the model which fits the data best will be chosen.

Next, the asymmetries concerning the level of output gap are tested in the two following ways:

$$\begin{aligned} \pi_t = \quad & (\lambda_{11} E(\pi_{t+k}|\Omega_t) + \lambda_{21}\pi_{t-k} + \alpha_1 y_{t-n} + \phi_1 e_{t-m})I_t + \\ & + (\lambda_{12} E(\pi_{t+k}|\Omega_t) + \lambda_{22}\pi_{t-k} + \alpha_2 y_{t-n} + \phi_2 e_{t-m})(1 - I_t) + \epsilon, \end{aligned} \tag{2}$$

$$\pi_t = \lambda_1 E(\pi_{t+k}|\Omega_t) + \lambda_2 \pi_{t-k} + \alpha_1 y_{t-n} I_t + \alpha_2 y_{t-n}(1 - I_t) + \phi e_{t-m} + \epsilon, \tag{3}$$

where:

$$I_t = \begin{cases} 1 & \text{if } y_{t-n} \geq \tau, \\ 0 & \text{otherwise.} \end{cases}$$

In the Equation (2) we concern the case when the whole Phillips curve rule changes according to the value of the threshold variable. Whereas in the Equation (3) we concern the case when only the coefficients of the output gap change depending on the value of a known threshold value. The way in which the threshold values (τ) are obtained is presented in Section 4.3.

Dolado et al. (2004)[3] show that when the Philips curve is nonlinear (convex or concave) than the Taylor rule resembles a linear one but it is extended by the interaction term of expected inflation and the output gap. For example when a Phillips curve is convex, an expected inflation caused by a higher output gap will be larger than in a linear specification, so anticipating this policy makers will react more forcefully (what is captured by the interaction term). Thus, additionally, we perform a similar test to Dolado et al. (2004) and we try to include a nonlinear component $y_{t-n}y_{t-n}$. We test whether the additional component is statistically significant in the following equation:

$$\pi_t = \lambda_1 E(\pi_{t+k}|\Omega_t) + \lambda_2 \pi_{t-k} + \alpha y_{t-n} + \alpha_1 y_{t-n}y_{t-n} + \phi e_{t-m} + \epsilon. \tag{4}$$

3.2 The Taylor rule estimation

We then turn to an analysis of the Polish Taylor rule. We consider two models with two different measures of inflation target (*cpia* and *cpib*) to check the robustness of the results.

As previously, to allow for correlation between the error term and the forward looking variables, we use GMM method with instruments such as lagged values of the inflation gap, the output gap, the domestic short term interest rate as well as the short term interest rate in the euro area, and the real effective exchange rate.

Firstly, we estimate the symmetric Taylor rule as in the following equation:

$$i_t = \rho i_{t-1} + \beta E(\pi_{t+h} - \pi^*_{t+h}|\Omega_t) + \gamma E(y_{t+l}|\Omega_t) + \alpha, \tag{5}$$

where: i_t is the one week Polish money market rate (Wibor 1W), π^* is an inflation target, measured as the actual inflation target (*cpia*) or the smoothed by Hodrick Prescott

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[3]Dolado et al. (2004), concerning the central banks of Germany, France, Spain, the US and Euro area, find out that the Philips curve is convex in all cases except the US.

filter trend of actual inflation ($cpib$), y_t is the output gap. We choose the lead values $h \in \{3, 4, \ldots, 12\}$ and $l \in \{0, 1, \ldots, 3\}$ which fit the model best.

Next, we estimate the asymmetric Taylor rules. Namely, we estimate the threshold model for the Polish monetary reaction function as:

$$
\begin{aligned}
i_t = \quad & \left(\rho_1 i_{t-1} + \beta_1 E(\pi_{t+h} - \pi^*_{t+h} | \Omega_t) + \gamma_1 E(y_{t+l} | \Omega_t) + \alpha_1 \right) I_t + \\
+ \; & \left(\rho_2 i_{t-1} + \beta_2 E(\pi_{t+h} - \pi^*_{t+h} | \Omega_t) + \gamma_2 E(y_{t+l} | \Omega_t) + \alpha_2 \right) (1 - I_t) + \epsilon_t,
\end{aligned}
\tag{6}
$$

$$
\begin{aligned}
i_t = \rho i_{t-1} \quad + \quad & \beta_1 E(\pi_{t+h} - \pi^*_{t+h} | \Omega_t) I_{t+h} + \gamma_1 E(y_{t+l} | \Omega_t) J_{t+l} + \\
+ \quad & \beta_2 E(\pi_{t+h} - \pi^*_{t+h} | \Omega_t)(1 - I_{t+h}) + \gamma_2 E(y_{t+l} | \Omega_t)(1 - J_{t+l}) + \alpha + \epsilon_t,
\end{aligned}
\tag{7}
$$

where

$$
I_t = \begin{cases} 1 & \text{if } m_t \geq \tau_1, \\ 0 & \text{otherwise}, \end{cases} \qquad J_t = \begin{cases} 1 & \text{if } n_t \geq \tau_2, \\ 0 & \text{otherwise}, \end{cases}
$$

and m_t and n_t are the threshold variables in period t, in our case it is the inflation gap or the output gap. As far as the Equation (7) is concerned we consider the case where $m_t \neq n_t$ and m_t denotes the inflation gap and n_t denotes the output gap. It means that the central bank responds asymmetrically to the level of inflation gap depending on the value of inflation gap but not depending on the value of the output gap and opposite, in the same time the central bank responds asymmetrically to the level of the output gap depending on the value of the output gap but not depending on the value of the inflation gap. We consider also the case when $J_t = 1$ for each t and m_t is an inflation gap, that is an asymmetry according only to the inflation gap, and the case when $I_t = 1$ for each t and n_t is an output gap, that is the asymmetry according only to the level of output gap.

3.3   The choice of the threshold value

In both the estimations of the Taylor rule and the Phillips curve we consider two cases of known and unknown threshold values. In case of unknown parameter we estimate the threshold value using the procedure presented in Caner and Hansen (2004). The threshold value is the one that minimizes the sum of the square errors (S_n) of the 2SLS estimation, i.e.:

$$
\bar{\tau} = argmin_{\tau \in \Gamma} S_n(\tau).
$$

We draw the LR-like statistics:

$$LR_n(\tau) = n\frac{S_n(\tau) - S_n(\bar{\tau})}{S_n(\bar{\tau})}. \tag{8}$$

The shape of this statistic indicates the strength of the threshold effect. When the LR statistic line has a clearly defined minimum (a V-shaped line) it means that the threshold effect is strong. Whereas, when it has irregular shape it is an indication of weaker threshold effects. The critical value cuts off the interval of all possible threshold values.

We compute the Sup test proposed by Caner and Hansen (2004). This test is often used to test the presence of threshold effects (see Bunzel and Enders (2010) or Mandler (2011)). To do so we estimate by GMM the Equation (2) or (6), respectively, for a fixed value $\tau \in \Gamma$. Then we calculate the Wald statistic for $H_0 : \rho_1 = \rho_2, \alpha_1 = \alpha_2, \beta_1 = \beta_2, \gamma_1 = \gamma_2$, we denote it by $W_n(\tau)$. We repeat this calculation for all $\tau \in \Gamma$ and the Sup statistic is then the largest value of these statistics, $SupW = sup_{\tau \in \Gamma} W_n(\tau)$. The asymptotic distribution of this statistic is not chi-square as the parameter τ is not identified under the null hypothesis. Therefore, we need to calculate it by simulation (so-called bootstrapping). We define pseudodependent variable $\bar{\epsilon}_t(\tau)\eta_t$ where $\bar{\epsilon}_t(\tau)$ is the error term for the Equation (2) or (6) and η_t is i.i.d. $N(0,1)$. We repeat the calculations for the pseudodependent variable in place of i_t for the unrestricted model. The resulting statistic $SupW^*$ has the needed asymptotic distribution.

In the case of known threshold parameter we use the chosen quantiles of the output gap or inflation gap. For the Phillips curve it is $\tau = 0$ or $\tau = 0,7$ quantile of the measure of the output gap, which correspond to the regimes of positive and negative output gap and the regime of very high output gap. For the Taylor rule these are medians of the the measures of output gap and inflation gap, which divide the sample into two equal subsamples.

4 Empirical results

The unit root tests show that the analyzed variables can be treated as stationary in the period from 01:2000 to 05:2012. We present the results of ADF, PP, and KPSS tests in Table 9 in the Appendix. For each of the variables at least one test indicates stationarity.

4.1 A preliminary analysis of the nonlinear Philips curves

As a benchmark we estimate a linear Philips curve. Table 1 presents the results of estimation of the Equation (1) for two possible specifications of the Phillips curve for monthly observations. In the first model we use quarter on quarter consumer price index, which is most often used in the estimations of the Phillips curve, with lead and lag values selected as $n = 3, k = 10, m = 4$. While, in the second model we use year on year consumer price index, which is latter on used in the estimations of the Taylor rule, with lead and lag values selected as $n = 12, k = 10, m = 4$. These lead and lag values seem to fit the data reasonably well and the results are not too sensitive to their changes. Both specifications seem to us to be correct, and thus we estimate both of them to check the robustness of the results.

Table 1: The symmetric Phillips curves - Equation (1)

	λ_1	λ_2	α	ϕ	R^2	p-value(J-stat)	sup-Wald	p-value(F-stat) $\lambda_1 + \lambda_2 = 1$
model 1	0,636***	0,343***	0,021*	-0,022***	0,60	0,09	78,89***	0,59
	(0,090)	(0,073)	(0,013)	(0,006)				
model 2	0,725***	0,325***	0,444***	-0,123***	0,69	0,67	141,30***	0,28
	(0,069)	(0,036)	(0,057)	(0,031)				

Standard errors in parenthesis (Newey-West), $*\backslash **\backslash ***$ denote statistical significance at the 1%\5%\10% level, respectively; in the first model (model 1) we use seasonally adjusted quarter on quarter CPI as dependent variable, lead and lag values in Equation (1) are selected as $n = 3$, $k = 10$, $m = 4$; in the second model (model 2) we use year on year CPI as dependent variable; lead and lag values in Equation (1) are selected as $n = 12$, $k = 10$, $m = 4$; in both cases we use monthly data; p-value(J-stat) represents p-value of Hansen's J-statistic for testing over-identifying restrictions; the sample is from 01:2000 to 05:2012.

In both models all coefficients are statistically significant and have the expected signs. The decrease of e_t means depreciation of the Polish zloty. Therefore, the relation between the level of inflation (π_t) and the measure of an exchange rate gap (e_{t-4}) is

correctly negative. The inflation rate heavily depends on its expected value, both of the coefficients (λ_1) are close to 0,7, what indicates high degree of forward-lookingness. The property of dynamic homogeneity, which requires that the sum of backward and forward looking components ($\lambda_1 + \lambda_2$) is equal to one, is fulfilled. The standard statistical test do not reject the hypothesis that $\lambda_1 + \lambda_2 = 1$.

Hansen's sup-Wald statistic shows if there are any threshold effects if the sample is divided into two subsamples depending on the level of a threshold variable. In our cases the reported values of the test indicate strong threshold effect in both models, so it appears that the reaction of the inflation rate is different when the output gap is relatively high and when it is relatively low. As far as the threshold value is concerned, the LR statistics presented in Figure 3 show quite different values for the two models. The evidence of threshold effect seem to be weaker for the first model, as the shape of the LR line is more irregular and it has two possible minimums. Whereas, for the second model the statistic is more V-shaped with one clearly defined minimum.

Next we proceed to test the asymmetric effects by estimation of the Equations (2),(3), and (4) (see Tables 2, 3, and 4), thus, we apply the three methods of testing. The results seem to strongly depend on the applied base periods (i.e. the previous quarter or the previous year). Indeed, the asymmetric effects are quite different for the two estimated models. In case of the first model the level of inflation seems to be influenced by the measure of economic activity more strongly when the level of economic activity is high. However, in case of the second model, the conclusion is opposite, the level of inflation seems to depend on the measure of economic activity more strongly when the level of economic activity is low. But simultaneously in this case the coefficient of expected inflation seems to increase, what might indicate that for longer term inflation the role of expectations is more significant, especially when the output gap is high. Thus, these are rather inflation expectations not the level of economic activity which affect the rate of inflation.

At first we will discuss the results for the first model. In this case (see Table 2) the coefficient of output gap is higher when the output gap is above the threshold value than when it is below ($\alpha_1 > \alpha_2$). It indicates that the Polish Phillips curve might be convex. As it was discussed earlier a stronger reaction of a rate of inflation when a high level of output gap is observed might stem from nominal wage rigidities, capacity constraints, costly price adjustments or volatility of economic shocks. Moreover, it seems that the exchange rate pass-through is slightly higher when the level of economic activity is high

than when the level of economic activity is low ($|\phi_1| > |\phi_2|$). More advanced study of this effect in Poland was carried out by Przystupa and Wróbel (2009). They argue that the asymmetry along the business cycle might be caused by behaviour of firms which set their investment decisions according to expected profits, which are the highest in the early expansion and the lowest in the early recession. Furthermore, when applying the second estimation method (see Table 3), where we assume that the threshold value is known and equal to 0 or 0,7 quantile of the output gap, the results point to the same conclusion. The reaction of inflation is stronger to high level of economic activity than to low level of economic activity, nevertheless, in this case the effect is not statistically significant. Indeed, the Wald test do not reject the hypothesis that $\alpha_1 = \alpha_2$. Similarly, in the third method (see Table 4) we obtain positive nonlinear coefficient (α_1), what could indicate convex Phillips curve, but the coefficient is also statistically insignificant.

Concerning the second model, the asymmetric effects also seem to be significant, as they are confirmed by all three methods. But the results for the second model are opposite to the results for the first model. The coefficient of output gap is higher when the output gap is below the threshold value than when it is above ($\alpha_1 < \alpha_2$) (see Table 2 and Table 3). The Wald tests reject the hypothesis that $\alpha_1 = \alpha_2$. Thus, we can confirm the thesis that the reaction of inflation rate is stronger when the level of economic activity is relatively low than when it is high. In addition by estimating the Equation (4) (see Table 5) we obtain α_1, the nonlinear component, statistically significant and negative. The negative coefficient indicates concave Phillips curve (as the second derivative with respect to the output gap is negative), what is in line with the results of the first and the second method. It is worth noting that the forward looking component λ_1 is higher for the second model that for the first model. Even when the level of economic activity is high firms might anticipate future price decreases and, in turn, they might not increase their prices. Also the concave Phillips curve might be a consequence of monopolistic competition (see Stiglitz, 1997).

Table 2: The asymmetric Phillips curves - Equation (2)

		λ_1	λ_2	α	ϕ	*No.obs.*	R^2	p-value(J-stat)	τ
model 1	$I_t=0$	0,389***	0,540***	-0,016	-0,018*	100	0,660	0,405	0,010
		(0,135)	(0,107)	(0,022)	(0,010)				
	$I_t=1$	0,425**	0,282***	0,108**	-0,021***	46	0,357	0,118	
		(0,199)	(0,092)	(0,054)	(0,008)				
model 2	$I_t=0$	0,654***	0,341***	0,556***	-0,173**	48	0,149	0,307	-0,014
		(0,192)	(0,084)	(0,211)	(0,072)				
	$I_t=1$	0,832***	0,367***	0,224***	-0,090***	89	0,641	0,672	
		(0,098)	(0,040)	(0,083)	(0,027)				

Standard errors in parenthesis (Newey-West), $*\backslash**\backslash***$ denote statistical significance at the 1%\5%\10% level, respectively.

Table 3: The asymmetric Phillips curves - Equation (3)

		τ	λ_1	λ_2	α_1	α_2	ϕ	R^2	p-value(J-stat)	Wald test $\alpha_1 = \alpha_2$
model 1	0,7 quantile		0,613***	0,296***	0,042*	-0,001	-0,024***	0,368	0,226	0,330
			(0,112)	(0,075)	(0,026)	(0,025)	(0,006)			
	0		0,626***	0,293***	0,039	0,002	-0,024***	0,362	0,224	0,424
			(0,116)	(0,075)	(0,027)	(0,026)	(0,006)			
model 2	0,7 quantile		0,913***	0,371***	0,155*	0,778***	-0,103***	0,681	0,701	0,000
			(0,085)	(0,035)	(0,083)	(0,092)	(0,029)			
	0		0,953***	0,376***	0,124*	0,827***	-0,101***	0,671	0,710	0,000
			(0,094)	(0,036)	(0,092)	(0,104)	(0,029)			

Standard errors in parenthesis (Newey-West), $*\backslash**\backslash***$ denote statistical significance at the 1%\5%\10% level, respectively.

Table 4: The nonlinear Phillips curves - Equation (4)

	λ_1	λ_2	α	ϕ	α_1	R^2	p-value(J-stat)
model 1	0,609***	0,357***	0,020	-0,023***	0,119	0,604	0,085
	(0,113)	(0,079)	(0,015)	(0,006)	(0,467)		
model 2	0,896***	0,341***	0,527***	-0,105***	-7,290***	0,693	0,591
	(0,085)	(0,033)	(0,048)	(0,028)	(-1,702)		

Standard errors in parenthesis (Newey-West), $*\backslash**\backslash***$ denote statistical significance at the 1%\5%\10% level, respectively; α_1 is the coefficient of nonlinear component $y_{t-10}y_{t-10}$.

4.2 The symmetric Taylor rules

We begin the analysis of the Polish Taylor rule with estimating the symmetric monetary policy rules. We consider two models to check if the results change when applying different measures of inflation target. Model 1 uses the actual inflation target and model 2 uses the HP filter of inflation (CPI). We estimated also the models with inflation expectations ($infe1$ and $infe2$) instead of the inflation gap (measured by $cpia$ or $cpib$)[4], however, we obtained less statistically significant inflation coefficients, what might indicate that the Polish central bank looks on the shorter term inflation forecasts. Indeed, the selected lead length of inflation gap is 3 months. The results for all specifications of the symmetric monetary policy rule are presented in Table 5.

Table 5: The symmetric Taylor rules - Equation (5)

	ρ	β	γ	α	R^2	p-value(J-stat)	sup Wald	
							π_t	y_t
model 1	0,967***	0,051***	0,027***	0,001***	0,99	0,72	29,22	26,91
	(0,000)	(0,018)	(0,008)	(0,000)				
model 2	0,960***	0,108***	0,021*	0,002***	0,99	0,70	45,81*	26,96
	(0,000)	(0,038)	(0,011)	(0,000)				

Standard errors in parenthesis (Newey-West), $*\backslash**\backslash***$ denote statistical significance at the $1\%\backslash5\%\backslash10\%$ level, respectively; lead values in Equation (5) were selected as $h = 3$, $l = 1$; as the measure of the inflation target: in the first model (model 1) we use actual inflation target, whereas in the second model (model 2) we use the trend of inflation rate; p-value(J-stat) represents p-value of Hansen's J-statistic for testing over-identifying restrictions; the sample is from 01:2001 to 05:2012.

The lagged interest rate term ρ is statistically significant in all equations. The coefficient is very close to unity, it oscillates from 0,96 to 0,97. The ρ coefficient measures the extend of monetary policy inertia and its significant value is interpreted as the desire of the central bank to smooth interest rate adjustment process and indicates persistent policy of the central bank. The smoothing coefficient absorbs serial correlation, which in case of the interest rates in monthly frequency is substantial. Moreover, high value of the smoothing coefficient might stem from the omission of other persistent variables and exogenous shocks (Rudebusch, 2002, 2006). Therefore, the interpretation of the smoothing parameter is not straightforward. All coefficients have expected signs. The coefficients on inflation and output gap are positive and significant at conventional levels.

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[4]We do not report these results as the models with the inflation gaps seem to fit the data better.

The Polish central bank probably takes into account more information than the inflation and output gaps when setting its interest rate. But we decided to present the results for the Taylor rule without the additional variables due to relatively small number of observations as well as the suggestions of Przystupa and Wróbel (2006). However, the real effective exchange rate and the short term euro area interest rate are taken as instruments in our GMM estimations.

The sup-Wald statistics presented in Table 5 reject the null hypothesis of no threshold effects only according to the level of inflation gap in the second model. Moreover, the LR-statistics shown in Figure 2 indicate that the asymmetric effects are not very clear. However, we proceed in the next section with testing the possible asymmetric effects in the Taylor rule. We suspect that not all coefficients change significantly when changing the inflation gap or output gap regime, especially it might not be the case of lagged interest rate coefficient.

4.3 The asymmetric Taylor rules

The results of testing the degree of dissimilarity between all (four) coefficients in each regime are presented in: Table 6 - for an inflation gap as the threshold variable and in Table 7 - for an output gap as the threshold variable.

Let us consider an asymmetric effect according to the level of the inflation gap. In case of the first model $\beta_1 > \beta_2$ for both the threshold variables, what suggests that the central bank reacts more aggressively to the level of inflation gap when it is high. Also in case of the second model β_1 is statistically significant and β_2 is not (see Table 6), what leads to the same conclusion.

The result is in accordance with the fact that the Polish central bank implemented inflation targeting strategy in 1998. Thus, the central bank tried to make its policy more credible and transparent to better influence inflation expectations and could have more inflation avoidance preferences. In January 2004 permanent inflation target $2,5\%+/-1\%$ was set, actually it was announced in February 2003 and since then the realization of the strategy really starts. The permanent target enables the verification of the effects of monetary policy action every month and not at the end of year as before. Moreover, inflation forecasts are published since August 2004, GDP forecasts since 2005, and MPC minutes since 2007.

Concerning the output gap coefficient it appears to be higher when the output gap is relatively high (see Table 7) but not necessary higher when the inflation gap is high (see

model 1 in Table 6). The periods of high level of economic activity are often associated with the periods of high level of inflation rate, thus, the results seem to indicate more active monetary policy in such economic conditions.

It is worth noting that, in some cases when dividing the sample into two subsamples we obtain statistically insignificant output gap or inflation gap coefficients. Such results might appear due to the shortness of the sample, crisis distortions[5], as well as disturbances before 2004 when large decreases of the money market rate were observed[6].[7]

When applying the second estimation method (Equation (7)) quite similar results are obtained. Concerning the direction of the asymmetry the results (presented in Table 8) show both that the central bank reacts more strongly to the high inflation rate ($\beta_1 > \beta_2$) and reacts more strongly to the high output gap ($\gamma_1 > \gamma_2$). But if we allow for two different threshold variables - an inflation gap and an output gap - in one equation we obtain a stronger reaction of the central bank to high level of inflation gap and a weaker reaction of the central bank to high level of economic activity. But the stronger reaction to low level of economic activity seem to be rather some compensation for very high reaction to high level of inflation and not necessary the result of monetary authorities' decisions.

What is important, the Wald test rejects the null hypothesis of equal coefficients only for the second model when an inflation gap is a threshold variable. The result is in line with the values of the sup-Wald statistics computed for the first estimation method. Thus, this asymmetric effect seems to be the strongest one.

The asymmetry assigned to the level of the inflation gap might, as it was mentioned before, stem from asymmetric preferences of the central bank as it is an inflation targeter. Whereas the asymmetry assigned to the level of output gap might stem from nonlinear

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[5]From November 2008 to June 2009 the decreases of the reference rate began (from 6 to 3,5%). In October 2008 the National Bank of Poland implemented a special polices (so called Confidence Package) to provide liquidity in the banking sector. The special policies included repo and swap operations, earlier redemption of 10 year bonds, and reduction of the reserve requirement rate by 0,5%.

[6]The process of disinflation appeared in Poland due to economic transformation from a centrally planned economy into a market economy (which began in 1989).

[7]Also it is important to keep in mind that we use ex post data, which are only some approximation of the real data available to the monetary authorities when taking the decisions. Moreover, when taking consumer price index as the measure of inflation we have to be aware of the fact that there are some movements of this index which are independent of the central bank, such as changes in commodity prices. Not to mention long delays with which monetary transmission mechanism operates which might not be fully captured by the estimated equations.

Phillips curve. If the Phillips curve is concave central bank has to take significantly more action to reduce inflation when the level of economic activity is high. If the Phillips curve is convex it might react more aggressively to high level of economic activity because the periods of excess demand might cause severe recession to lower the inflation generated when the level of economic activity is high. But our results do not resolve which is the shape of the Phillips curve. Thus, the asymmetries in the Taylor rule seem not to result from nonlinearities in the Phillips curve.

Table 6: The asymmetric Taylor rules - an inflation gap as a threshold variable - Equation (6)

		ρ	β	γ	α	No. obs.	R^2	p-value(J-stat)	τ
model 1	$I_t=0$	0,906***	-0,420	0,157***	-0,001	40	0,98	0,77	-0,012
		(0,032)	(0,270)	(0,061)	(0,002)				
	$I_t=1$	0,981***	0,061***	0,023***	0,001	94	1,00	0,52	
		(0,006)	(0,020)	(0,008)	(0,000)				
model 2	$I_t=0$	0,993***	0,221	0,004	0,001	43	0,99	0,84	-0,006
		(0,018)	(0,198)	(0,057)	(0,002)				
	$I_t=1$	0,959***	0,155***	0,010	0,002***	91	0,99	0,73	
		(0,008)	(0,038)	(0,009)	(0,000)				

Standard errors in parenthesis (Newey-West), $*\backslash**\backslash***$ denote statistical significance at the 1%\5%\10% level, respectively.

Table 7: The asymmetric Taylor rules - an output gap as a threshold variable - Equation (6)

		ρ	β	γ	α	No. obs.	R^2	p-value(J-stat)	τ
model 1	$I_t=0$	0,884***	-0,034	-0,034	0,004***	47	0,98	0,66	-0,015
		(0,022)	(0,043)	(0,076)	(0,001)				
	$I_t=1$	0,975***	0,013	0,023***	0,001***	87	1,00	0,88	
		(0,005)	(0,015)	(0,008)	(0,000)				
model 2	$I_t=0$	0,888***	0,062	-0,070	0,004***	47	0,98	0,46	-0,015
		(0,021)	(0,046)	(0,072)	(0,001)				
	$I_t=1$	0,974***	0,036	0,016	0,001***	87	1,00	0,83	
		(0,005)	(0,029)	(0,010)	(0,000)				

Standard errors in parenthesis (Newey-West), $*\backslash**\backslash***$ denote statistical significance at the 1%\5%\10% level, respectively.

Table 8: The asymmetric Taylor rules - Equation (7)

Both an inflation gap and an output gap as threshold variables - the medians are the threshold values

	ρ	β_1	β_2	γ_1	γ_2	α	R^2	p-value(J-stat)	Wald $\beta_1 = \beta_2$	Wald $\gamma_1 = \gamma_2$
model 1	0,948***	0,084*	-0,023	0,023*	0,044*	0,002***	0,99	0,76	0,28	0,51
	(0,012)	(0,045)	(0,060)	(0,012)	(0,024)	(0,000)				
model 2	0,950***	0,228***	-0,077	0,002	0,057*	0,002***	0,99	0,75	0,05	0,14
	(0,009)	(0,062)	(0,093)	(0,014)	(0,026)	(0,001)				

An inflation gap as a threshold variable - the median is the threshold value

	ρ	β_1	β_2	γ	α	R^2	p-value(J-stat)	Wald $\beta_1 = \beta_2$	-
model 1	0,950***	0,102*	-0,016	0,026***	0,001**	0,99	0,76	0,23	-
	(0,012)	(0,060)	(0,057)	(0,009)	(0,001)				
model 2	0,945***	0,208***	-0,065	0,023***	0,001**	0,99	0,80	0,02	-
	(0,009)	(0,052)	(0,073)	(0,007)	(0,001)				

An output gap as a threshold variable - the median is the threshold value

	ρ	β	γ_1	γ_2	α	R^2	p-value(J-stat)	-	Wald $\gamma_1 = \gamma_2$
model 1	0,957***	0,027	0,046**	0,026*	0,002***	0,99	0,81	-	0,53
	(0,008)	(0,020)	(0,011)	(0,025)	(0,000)				
model 2	0,954***	0,076***	0,039	0,012**	0,002***	0,99	0,68	-	0,31
	(0,008)	(0,028)	(0,012)	(0,019)	(0,000)				

Standard errors in parenthesis (Newey-West), $*\backslash**\backslash***$ denote statistical significance at the 1%\5%\10% level, respectively.

5   Concluding remarks

In the paper we check the existence of the threshold effects in the reaction function of the National Bank of Poland and in the Polish Phillips curve. We estimate a number of models with unknown and known threshold values. When the threshold value is assumed to be unknown we estimate it by minimizing the sum of squared errors from the relevant equation. We consider two different measures of an inflation rate in the Phillips curve as well as two different measures of an inflation target in the Taylor rule.

Our preliminary analysis of the Phillips curve for Poland suggests that the curve is asymmetric according to the level of output gap. But the direction of the asymmetric effect seems to strongly depend on the used specification. While using quarter on quarter CPI, the rate of inflation seems to be more strongly influenced by the output gap when the output gap is relatively high, to the contrary, while using year on year CPI, the rate of inflation seems to be more strongly influenced by the output gap when the output gap is relatively low. However, in case of the latter model the forward looking component is higher indicating higher firms' forward lookingness.

The estimations of an asymmetric Taylor rule seem to indicate that the central bank reacts slightly more strongly to the level of inflation and the level of economic activity when they are relatively high, what might be the result of implementing the inflation targeting strategy and the need to build credibility. Thus, it appears that the NBP has rather inflation avoidance preferences and not the recession avoidance ones. The asymmetric effects in the Taylor rule do not stem from nonlinearities in the Phillips curve.

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A   Unit root tests

Table 9: Unit root tests 2000:01 2012:05

	ADF	PP	KPSS
cpi1	0,005***	0,080*	0,218
cpi2	0,010***	0,006***	0,155
cpia	0,134	0,128	0,209
cpib	0,008***	0,056*	0,225
gap	0,066*	0,175	0,117
WIBOR 1W	0,000***	0,002***	0,373*
reer	0,002***	0,002***	0,088
infe1	0,037**	0,032**	0,307
infe2	0,006***	0,178	0,231
Δ ieuro	0,000***	0,000***	0,091

The description of the variables is presented in the Section 2; the Table presents the results of Augmented Dickey-Fuller (ADF), Phillips-Perron (PP), and Kwiatkowski-Philips-Schmidt-Shin (KPSS) tests; in the ADF test, the Akaike Criterion is used to indicate the lag length, whereas for the PP and KPSS tests we use the Bartlett kernel estimation with the Andrews bandwidth selection method; $*\backslash **\backslash ***$ denotes that the null hypothesis is rejected at the 1%\5%\10% level, respectively.

B Figures

Figure 1: Variables used in the estimations

Money market rates

Consumer price index

Inflation gap

Inflation expectations

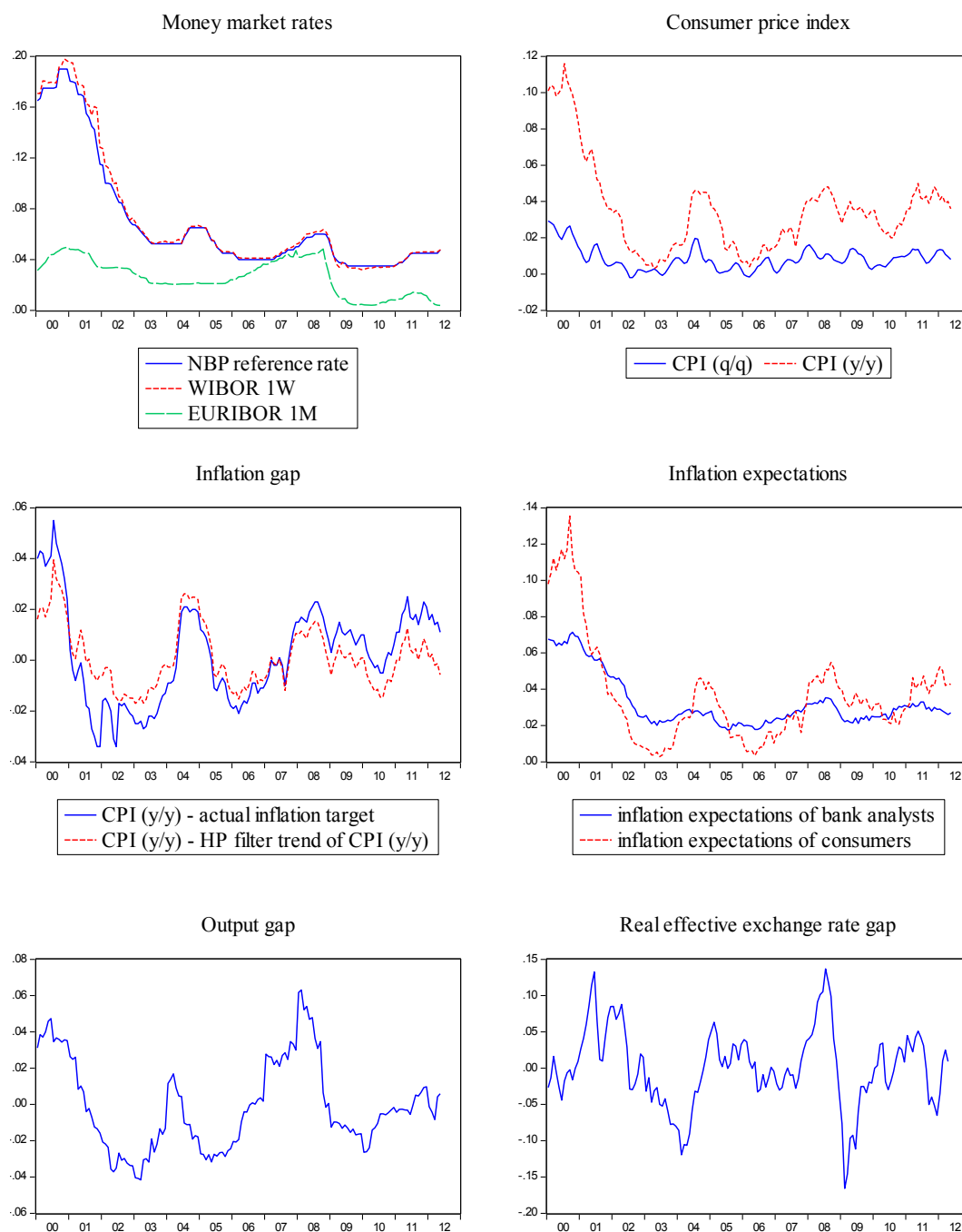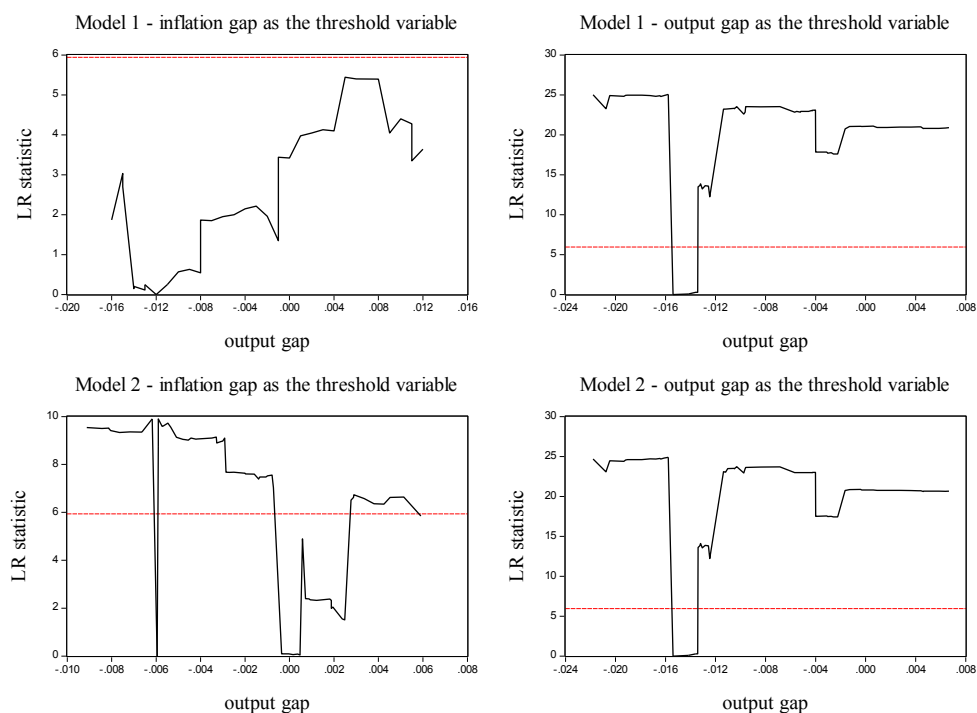**Output gap**

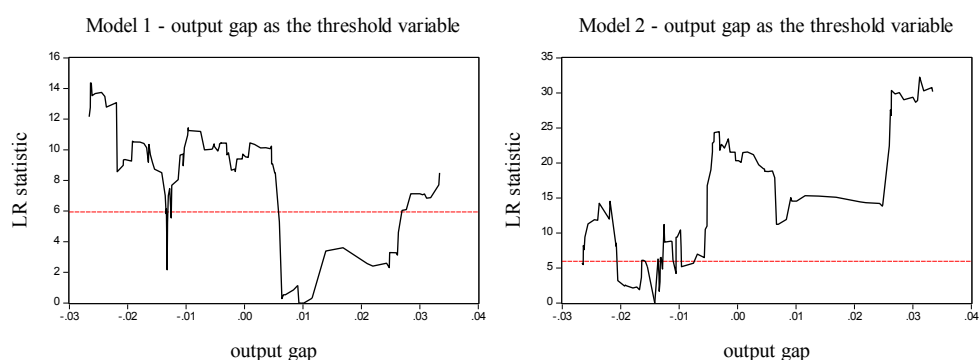**Real effective exchange rate gap**

Figure 2: The likelihood ratio statistics for the Taylor rule

The graphs present LR-statistics for possible values of the threshold variable. It tests whether particular value belongs to the threshold interval (Hansen 2000). The red line corresponds to 90% critical value.

Figure 3: The likelihood ratio statistics for the Phillips curve

The graphs present LR-statistics for possible values of the threshold variable. It tests whether particular value belongs to the threshold interval (Hansen 2000). The red line corresponds to 90% critical value.