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Symmetric or asymmetric? Monetary policy and Polish economy reactions over the business cycle

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Abstract

In the paper, we examine whether monetary policy and reactions of the economy to monetary policy are symmetric over the business cycle. Not only do we study the differences between prosperity and slump, but also between all the phases of the business cycle, i.e. recovery, expansion, recession and depression. Moreover, we analyse reactions in all points of the business cycle.

We find asymmetry in the reactions of monetary policy for the output gap close to zero, but the result disappears in a shorter sample. The effects of monetary policy are symmetric for the output gap between -2.0% and 1.5%. The asymmetry appears with the output gap getting closer to its extreme values. This result is robust across various samples.

Keywords: monetary policy, business cycle, semi-structural model, non-linearity

JEL: C11, C32, C61, E12, E32, E52

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1 Introduction

There is a vast literature on monetary transmission in the economy seen from the New Keynesian perspective, where reactions of both the nominal and real economy to the central bank interest rate rises or cuts are symmetric irrespective of the economy's position in the business cycle (e.g. Walsh textbooks from the 1st edition in 1998 to the 4th in 2017, Mishkin's 1995 identification of the transmission channels (1995), Taylor's evaluation of the central banks' reaction to inflation and output gap changes (1995), Boivin, Kiley and Mishkin's on the evolution of the monetary transmission mechanism (2010), Granziera et al. (2018) on post-crisis monetary modelling, or Gali's (2018) on modifications of the New Keynesian approach).

At the turn of the 1990s and 2000s, more and more research noticed that the shape of the aggregate supply, usually presented in the literature under its reversed form as the Phillips curve, may have important implications for policy-makers (e.g. Dupasquier, Ricketts 1998; Nobay, Peel 2000; Semmler, Zhang 2004, Boinet, Martin 2006). Usually, three shapes of the Phillips curve are considered: (1) convex, suggested by, for example, Clark, Laxton and Rose (1996), Schaling (1999), Bean (2004), which may appear if there are capacity constraints; (2) concave (e.g. Stiglitz 1997; Eisner 1997) – if firms are not purely competitive; (3) piecewise convex-concave for the positive-negative output gap respectively (Filardo 1998). Filardo showed that the shape of the Phillips curve has crucial implications for the central banks, since the optimal monetary policy may change with the shape of the Phillips curve.

The non-linearity of the Phillips curve leads to asymmetric responses of the economy to policy actions.[1] Such asymmetries are linked to: (1) the country's position in the business cycle; (2) the direction of the monetary policy change; (3) the size of the policy change; (4) the distance of the current inflation to target inflation. The factors described in points 1 and 2 are mutually correlated, as are those of points 3 and 4.

Lo and Piger (2005) provide an interesting example of the study describing asymmetries in the responses of the economy to changes in the interest rate. It is based on the analysis of fluctuations in the state of the U.S. economy, understood as changes of coefficients in equations describing it in different states. The authors find that the rigidity of prices changes depending on the phase of the cycle as well as the direction and intensity of changes in monetary policy. Moreover, prices are less susceptible to stimuli working towards their decrease than to those acting in a pro-inflationary way. This leads to asymmetry in reactions to monetary policy since each increase in the aggregate demand results, in the first place, in the adjustment of prices, whereas the decline of demand causes, in the first place, a response of the quantities. This means that the responsiveness of the real sector to restrictive monetary policy is higher than its vulnerability to expansive policy.

Lo and Piger's study does not include the effects of the financial crisis and the periods following it of low or negative interest rates and inflation. Other studies done for the U.S. economy that include these periods show partially opposite results, e.g. Barnichon and Matthes (2016) and Tenreyro and Thwaites (2016) suggest that monetary policy shocks have larger effects in expansions than in recessions. These studies show that the persistence of low nominal interest rates after the financial crisis may have disturbed the earlier results.

[1] It is worth noticing that the monetary policy itself may create non-linearity in the real economy (e.g. Saldias 2017). To limit this phenomenon the monetary policy is considered in the individual phases of the business cycle in separation from their dating.

The literature review in Borio and Hoffman (2017) suggests that there is some evidence that monetary transmission is less effective when interest rates are persistently low regardless of the phase of the business cycle.

Most studies on asymmetric reactions of the economy are based on Markov-switching (static or dynamic) models (e.g. Lo, Piger 2005); however, some researchers propose a direct estimation of non-linear equations (e.g. Boinet, Martin 2006), estimations using the piecewise linear function to approximate the non-linear shape of an equation (e.g. Filardo 1998) or a structural VAR with sign and zero restrictions (e.g. Barnichon, Matthes 2016).

The quoted literature shows how different the reaction of the economy to monetary policy may be depending on the phase of the business cycle and, on the other hand, what the optimal monetary policy should be over such a cycle. The latter problem is definitely less often considered.

Positioning the research conducted for Poland among the literature quoted earlier, the answer to the following questions is sought:

1 Is monetary policy symmetric over the business cycle or is it differentiated in individual phases, i.e. does the business cycle enforce monetary policy changes?

2 Does the economy's reaction to monetary policy depend on the phase of the business cycle or is it symmetric over the cycle?

The approach adopted to examine the issue is similar to that of Filardo, i.e. approximation of the non-linear shape of a function by its piecewise linear form. To this end, four sub-models of the base model are estimated corresponding to particular phases of the business cycle, and the next step is to compare the estimated parameters of the sub-models with the parameters of the base model (as in Lo, Piger 2005).

Another value added of the study is a two-stage method for estimating/calculating parameters which makes it possible to observe the continuous changes in the elasticities of the individual variables in the business cycle and compare the significance of the difference between constant and variable elasticities.

The method is described in the second chapter. Chapter 3 presents the base model and the results of the estimation of the base model and of the sub-models being the replication of the base model for each phase of the business cycle. The analysis of the results and their possible implications for economic policies are discussed in Chapter 4. Chapter 5 concludes.

2 Estimation method

Both the structural changes in most European countries in transition and the changes in the statistical definitions of economic categories resulted in a shortening of the homogenous time series – the reliable data starts from 1998 (beginning of negotiations on EU membership and the introduction of inflation targeting, with the reference interest rate equal to 24% and inflation 14.2%). To diminish the bias of the estimation results by data from the beginning of the sample, estimations should rather start from 2002 with the reference interest rate at 10% and inflation at 3.4% (which means a shortening of the sample by about 10%). However, it is also acceptable to choose the beginning of the estimation from the interval between the first quarter of 1998 and the first quarter of 2002.

This means that a maximum 80 quarterly observations are at our disposal. If we estimated directly the sub-models for all phases of the business cycle,[2] i.e. for recession, depression, recovery and expansion, then only about 20 observations could be assigned to each phase. A small number of observations might produce biased results; moreover, it would not be possible to show the behaviour of the economy near the extreme points of the cycle (peak and trough). To reduce the bias and calculate the continuous reaction of the economy over the business cycle, we propose a two-stage study:[3]

Stage 1: Distinction of sub-samples of the set of time series related to the output gap values assigned to the proper phases and periods of the business cycle

In most studies values for two states of the economy are discriminated, i.e. for:

- prosperity – when the output gap exceeds a threshold. The threshold may be understood as a point of transition between two states;
- in the Hidden Markov Model (e.g. Lo, Piger 2005);
- in the self-exciting threshold autoregressive model (SETAR) calculated with the use of, for example, the Caner and Hansen (2004) algorithm;
- as values over/ below the steady state of the output gap for the base model estimated for the entire sample (the method applied in this study);
- slump – when the output gap values are below the threshold.

However, the period of prosperity consists of two opposed phases: expansion and recession; by the same token, the period of slump consists of depression and recovery. To avoid inconsistency of the results we propose another division of the entire sample – into two subsamples comprising recovery and expansion, and recession and depression.

To extract the sub-samples for the growth and decline phases of the business cycle, we choose a method of Wolfram (1971), extended by Houck (1977), for investigating the nonreversibility of linear functions through segmenting the variables involved – the output gap (y) in this study. Let us assume that the variable $\boldsymbol{x}$ depends on the values of $\boldsymbol{y}$, which is being suspected of asymmetry, and on the set of other variables $\boldsymbol{z}$. Then:

$$\Delta x_i = a_0 + \sum_{j=0}^{T_1} a_{1,j} \Delta y_{i,j}^{A_1} + \sum_{j=1}^{T_2} a_{2,j} \Delta y_{i,j}^{A_2} + a_3 z_i \tag{1}$$

where for $i = 1, 2, \ldots, t$:

$$\Delta y_{i,j}^{A_1} = y_{i,j} - y_{i,j-1} \;\text{ if }\; y_{i,j} \geq y_{i,j-1} \;\text{ and} = 0 \text{ otherwise,} \tag{2}$$

$$\Delta y_{i,j}^{A_2} = y_{i,j} - y_{i,j-1} \;\text{ if }\; y_{i,j} < y_{i,j-1} \;\text{ and} = 0 \text{ otherwise,} \tag{3}$$

and j is the number of lags assigned to $\Delta y_{i,j}^{A_1}$ and $\Delta y_{i,j}^{A_2}$.

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[2] By definition, the business cycle is understood as the downward and upward movement of GDP around its long-term growth trend, hence it may be identified with changes of the output gap.

[3] The method was subordinated to the purpose of the study – an analysis of the behaviour of the economy in the business cycle. From this point of view, the issue of cycle dating is less significant than determining the number of quarters subordinated to phases and periods of growth/decline in economic activity. The issues of dating and describing the business cycle in Poland are discussed, e.g. in Gradzewicz et al. (2010) – the author, applying spectral analysis, found roughly 4-year business cycles, or Skrzypczyńska (2013) – where the business cycle in Poland since 1996 to January 2012 estimated on the basis of sectorial indicators of economic activity using Markov switching models obtained cycles lasting 3.5–4.5 and 5.5–6 years. She found that the Polish business cycles were asymmetric both in length and amplitude.

Because the base model comprises model consistent forward- and backward-looking expectations, in this example $T_1 = T_2 = 2$ $(j = 0, 1, 2)$. It means that an observation will be included in a sub-sample if in at least three consecutive periods (quarters) $y_{i,j} \geq y_{i,j-1}$ or $y_{i,j} < y_{i,j-1}$.

Then, on the basis of four sub-samples that are of approximately the same length, we build four models (Figure 1) which have the same structure as the base model:

- Model 1 corresponds to the recession and depression, i.e. a period when the output gap (y) decreases ($y_t \leq y_{t-1}$) in at least three consecutive periods (quarters).
- Model 2 corresponds to the recovery and expansion, when the output gap grows in at least three consecutive periods (quarters) ($y_t \geq y_{t-1}$).
- Model 3 describes the slump, when the output gap takes values below the defined threshold (τ). Estimating the base model for the entire period, with the inflation target equal to 2.5%, the determined values of the output gap (steady state) were derived at the level of 0.2% of the potential product.[4] Assuming this value as a threshold, the area of function defining the slump period was determined for $y < 0.2$. This period comprises the phases of depression and recovery.
- Model 4 corresponds to the period of prosperity when the output gap takes values higher or equal to 0.2. This period comprises expansion and recession.

Since reactions of the economy to the monetary policy shocks may differ in the recession, when y values are above the (τ) threshold, and in the depression, when values of y are below the threshold (similarly, diverse reactions may occur in the recovery and expansion), the advantage of the proposed twofold way of determination of the function's domain is the possibility of observing the reactions of economic factors during recession and depression, as well as recovery and expansion separately.

The total number of observations is equal to 86. In models 1–4, the respective numbers are: 36, 39 and 38, 48. In models 1 and 2, the sum of observations in the sub-samples is lower than in the entire sample by eleven – they do not meet the selection criteria set up for these models.

All parameters of the base model and four sub-models were estimated with the use of Sims' routine to maximize the likelihood of the model and afterwards with the Metropolis-Hastings MCMC algorithm with 20,000 replications in two blocks to compute the posterior distribution of the model parameter. The acceptation rates were within the band 20–30%, i.e. within the band allowed by the literature (e.g. Mancini 2011).

Stage 2. Calculating parameters of models 1–4 in the entire course of the stylized business cycle

By setting up the same priors for parameters of models 1–4 as for the base model and estimating them, we have got four sets of parameters $\Psi_{k,p}$ for $k = 1,\ldots, 4$ (number of a model) and $p = 1,\ldots, n$ (n = number of parameters) where:

$$\Psi_{k,p} = \left\{ \Psi_{k,p} : \Psi_{k,p} \in \mathrm{R} \wedge \Psi_{k,p} \in \Psi_{k,p_\alpha}, \Psi_{k,p_\beta}, \Psi_{k,p_\delta}, \Psi_{k,p_\kappa}, \Psi_{k,p_\lambda} \right\}$$

Assuming that the *sine* function approximates the stylized business cycle and following Gradzewicz et al. (2010) and Skrzypczyńska (2013) with respect to the length and amplitude of the business cycle in Poland, we construct a *sine* function (Figure 1) with the following form:

[4] A reduction of the inflation target (parameter of the model) from 2.5% to 1.6% causes the output gap steady state to converge to zero. This may indicate an actual concentration on the accomplishment of the target of 1.6%.

$$y_t = \varphi \sin(\omega y_t) \tag{4}$$

where:

φ – the average amplitude of the business cycle in Poland,
ω – the average length of the cycle,
y – the output gap,
$t = 0,\dots, 20$ – the number of quarters in the business cycle.

The position of the parameters $\Psi_{k,p}$ pointed on the sinusoid corresponds to the steady states of the output gap for the respective models[5] which are close to values of the average output gap for these models.

To check the reactions of the economy in all the business cycle, including the extreme points (close to Ψ_{max} and Ψ_{min}) we calculate the values of parameters over the entire sinusoid as follows:

$ps_{t,3,p} = \psi_{3,p} * \Delta(\varphi \sin(\omega y_t))$ – calculated values of the parameters between points $\psi_{3,p}$ (5)

$ps_{t,2,p} = \psi_{2,p} * \Delta(\varphi \sin'(\omega y_t))$ – derivative of the sin function between points $\psi_{3,p}$ and $\psi_{4,p}$ (6)

$ps_{t,4,p} = \psi_{4,p} * \Delta(\varphi \sin(\omega y_t))$ – calculated values of the parameters between points $\psi_{4,p}$ (7)

$ps_{t,1,p} = \psi_{1,p} * \Delta(\varphi \sin'(\omega y_t))$ – derivative of the sin function between points $\psi_{4,p}$ and $\psi_{3,p}$ (8)

$\psi_{1,p}, \psi_{2,p}, \psi_{3,p}, \psi_{4,p}$ are the estimated values of parameters, $ps_{t,p,}, ps_{t,2,p}, ps_{t,3,p}, ps_{t,4,p}$ are calculated values of parameters over the entire sinusoid (Figure 1).

Due to the fact that the sub-samples for models 1 and 2 were constructed on the basis of changes of the output gap (not levels), the values of parameters $\psi_{1,p}, \psi_{2,p}$ were calculated for the derivative of the *sine* function.

The estimated parameters were obtained from a New Keynesian-type model, with built-in trends reflecting the supply side of the economy and AR processes which close the model, making it possible to get equilibria inside the model and identify the non-observable variables. The idea of the model is based on the semi-structural Global Projection Models (GPM), Carabenciov et al. (2013),[6] and is estimated with Bayesian techniques overcoming the short-sample problem and giving the possibility to implement the experts' knowledge. It is a country-specific model, with special attention paid to the real sector and to the exchange rate block allowing, in particular, to employ fundamentals (e.g. output gap, government expenditure) as a proxy for the risk premium in the exchange rate equation, as in Wadhwani (1999).

5 The steady states of output gap for models 1–4 are respectively as follows: -0.03; 0.02; -1.8; 1.2.

6 Carabenciov et al. (2013) proposed the GPM that can be easily expanded to include new countries with their specific features. Currently the GPM consists of the set of satellite models for 6 regions (34 countries) and is mainly used by central banks.

3 The Base Model and results of the estimations

The model has four blocks: IS and Phillips curves, an exchange rate equation and a monetary policy rule. Real variables are specified as gaps, i.e. the differences between their actual values and potentials. The former can be affected by demand factors, the latter represent the supply side of the economy.

The Hybrid IS curve

$$y_t = \alpha_1 E_t y_{t+1} \alpha_2 y_{t-1} + \alpha_3 \left(r_t - r_t^*\right) + \alpha_4 \left(e_t^r - e_t^{r^*}\right) + \alpha_5 gx\_net_t + \alpha_6 g_t + \varepsilon_t^y + \varepsilon_t^{Y^*} + \varepsilon_t^{r^*} \qquad (9)$$

where:

y_t is the output gap,
$r_t = i_t - E_t \pi_{t+1}$ represents the real interest rate,
i_t is the short-term nominal money market rate (WIBOR 3M),
$E_t \pi_{t+1}$ stands for model-consistent expected core inflation,
r_t^* is the natural interest rate i,
$e_t^r = e_t + p_t^{EA} - p_t$ – the real EUR/PLN exchange rate,
e_t is the nominal EUR/PLN exchange rate,
p_t^{EA} is the price level (core HICP) in the euro area,
p_t is the price level (core HICP) in Poland,
e_t^{r*} presents the equilibrium exchange rate
gx_net_t is a gap of the net exports understood as:

$$x\_net_t^* = \alpha_{50} x\_net_{t-1}^* + \alpha_{51} e_t^{r^*} + \alpha_{52} \Delta Y_t^{EA^*} - \alpha_{53} \Delta Y_t^* + \varepsilon_t^{x\_net^*} \qquad (10)$$

where:

$x\_net_t^*$ stands for the potential net exports,
ΔY^{EA^*} – the growth rate of foreign demand (potential GDP in the euro area),
y_t^{EA} – the output gap in the euro area,
ΔY^* – the growth rate of domestic demand (potential Polish GDP),
$\varepsilon^{x\_net^*}$ – shock on the potential net exports,
$(x - m)$ – net exports (volume of exports – volume of imports).

Finally, g_t in equation (10) is the gap of public expenditure, a change in the gap of the public expenditure is equal to the difference in the growth rates between public expenditure ΔG_t and its potential ΔG_t^*

$$\Delta G_t = \alpha_{60} y_t + \alpha_{61} \Delta Y_t + \varepsilon_t^G + \varepsilon_t^y \; \Delta Y_t^* = \frac{A_t}{4} + \acute{n}_A \varepsilon_t^{Y^*} \qquad (11)$$

$$A_t = \left(1 - \acute{n}_A\right) A_0 + \acute{n}_A A_{t-1} + \varepsilon_t^A \qquad (12)$$

where A_0 is the GDP growth rate in the steady state; ε_t^y, $\varepsilon_t^{Y^*}$, $\varepsilon_t^{r^*}$ whileare shocks to demand, supply and marginal productivity of capital respectively. The latter is a part of supply shock.

New Keynesian Phillips curve

$$\pi_t = \beta_1 E_t \pi_{t+1} + (1-\beta_1)\pi_{t-1} + \beta_2 y_t + \beta_3 \left(e_t + p_t^{EA}\right) + \varepsilon_t^s \tag{13}$$

where ε_t^s stands for supply shock.

Monetary policy rule

$$i_t = \lambda_1 i_{t-1} + (1-\lambda_1)\left(\left(r_t^* + \pi_t^*\right) + \lambda_2\left(\pi_t - \pi_t^*\right) + \lambda_3 y_t\right) + \lambda_4\left(e_t^r - e_t^{r^*}\right) + \varepsilon_t^i \tag{14}$$

$$r_t^* = \lambda_{11} r_t + \lambda_{11}\left(\Delta Y_t^* - \Delta Y_{t-1}^*\right) + \lambda_{13}\left(\pi_t - \pi_t^*\right) + \varepsilon_t^{r^*} \tag{15}$$

where π_t^* is the inflation target, ε_t^i represents a shock to the nominal interest rate, whereas $\varepsilon_t^{r^*}$ is a shock to the natural interest rate.

Real exchange rate (Real Interest Rate Parity – RIP)

$$e_t^r = \delta_1 E_t e_{t+1}^r + (1-\delta_1) e_{t-1}^r + \delta_2\left(r_t - r_t^{EA}\right) + \delta_3 y_t + (1-\delta_4)\varepsilon_t^{e^r} \tag{16}$$

$$e_t^{r^*} = \delta_5 e_{t-1}^{r^*} + \delta_6 \Delta gx\_net_t + \varepsilon_t^{e^{r^*}} \tag{17}$$

where:

$\varepsilon_t^{e^r}$, $\varepsilon_t^{e^{r^*}}$ – shocks to real exchange rate and equilibrium exchange rate,

δ_4– indicator that allows for exchange rate interventions, both direct and indirect (moral suasion). In this aim, we smooth the exchange rate shock by estimating its standard error.

The estimation of the exchange rate in open economy models most often leads to the instability of the entire model. Thus, the standard uncovered interest rate parity (UIP) is usually adopted. Due to the significance of the exchange rate for the Polish economy, it is proposed to estimate a custom exchange rate model based on a non-standard UIP. The idea of this approach is developed below.

In the New Keynesian models, the standard exchange rate equation uses a concept of UIP with a time varying or random risk premium, the implicit existence of a direct relation between monetary policy and a spot rate with the coefficient at the interest rate disparity equal to 1. However, such a specification is not supported by the data. To solve the problem, Wadhwani (1999) allowed for a feedback between the exchange rate, the real sector and the interest rate, making the risk premium dependent on deviations of fundamental variables from their steady states. This improved the significance of the disparity, however, at a cost of the exchange rate puzzle, which appeared for numerous pairs of currencies. The introduction of a term structure of the interest rates as in Ang, Bekaert and Wei (2008) improved the results, but only during frequent interest rate changes. That all changed the coefficient at disparity for UIP estimated for Poland from a puzzling – 0.1 to 0.4.

A change in the nominal interest rate affects not only the exchange rate and domestic prices through the exchange rate pass-through effect, the cost of servicing of foreign debt and net exports, but also has a direct impact on domestic prices and aggregate demand. Engel and West (2004, 2006) combined these monetary policy effects with the use of the real interest rate disparity (RIP) instead of the nominal one. When plugged into the exchange rate equation in our model, it moved the estimated value of the coefficient at disparity to the level close to one.

The conversion of the UIP concept to RIP makes the real interest rate significant in explaining the change in the exchange rate – the disparity coefficient is not statistically different from unity, and its fluctuations are structural in the pre-accession period only, while in the subsequent periods they are related to the business cycle.

Equations for the euro area

$$r_t^{EA} = \kappa_1 r_{t-1}^{EA} + \kappa_2 y_t^{EA} + \kappa_3 \left(\pi_t^{EA} - \pi_{EA}^{*}\right) + \varepsilon_t^{r^{EA}} \tag{18}$$

$$\pi_t^{EA} = \kappa_4 \pi_{t-1}^{EA} + \kappa_5 y_t^{EA} + \kappa_6 y_{t-1}^{EA} + \varepsilon_t^{\pi^{EA}} \tag{19}$$

$$\left(y_t^{EA} - y_{t-1}^{EA}\right) = \left(\Delta Y_t^{EA} - \Delta Y_t^{EA^*}\right) \tag{20}$$

$$\Delta Y_t^{EA^*} = \frac{A_t^{EA}}{4} + \acute{n}_A^{EA} \varepsilon_t^{\Delta Y^{EA^*}} \tag{21}$$

$$A_t^{EA} = (1 - \acute{n}_A^{EA})\, A_0^{EA} + \acute{n}_A^{EA} A_{t-1}^{EA} + \varepsilon_t^{A^{EA}} \tag{22}$$

$$y_t^{EA} = \kappa_7 y_{t-1}^{EA} + \acute{n}_A^{EA} \varepsilon_t^{y^{EA}} \tag{23}$$

Four sub-models used to analyse the asymmetric reactions of the economy are of the same structure. The results of the estimations of the base model and of four sub-models are in Table 1 and the full set of numbers showing the magnitude of asymmetric reactions of the main model variables over a business cycle and their significance are put in Table 2. All tables and figures are in the Appendix.

3 Results

3.1 Asymmetric reaction of the monetary policy over the business cycle

The main results are shown in Tables 2 and 3 and in Figure 2. A combination of charts from Figure 2 showing the maximum/minimum value of parameters with pointed significance of asymmetries and Table 3 containing the decomposition of variance of individual explanatory variables provides additional information on the composition and weight of the set of shocks in a given phase of the business cycle. This is paramount for a proper assessment of asymmetries, since in some cases there are shocks which display the strongest asymmetric effect on the interest rate, however, they are insignificant from the statistical point of view or they are significant but less influential than other shocks or have a smaller impact than in other phases of the business cycle. A good example of the first case is the output gap. In depression, it seems to display the strongest asymmetric effect on the interest rate, however, it is insignificant from the statistical point of view. The second case is well illustrated by inflation. It has a significant asymmetric impact on the interest rate during depression, but its importance is the weakest over the business cycle.

A comparison of the results obtained on the full sample and on the sub-samples shows that there is a clear-cut asymmetric reaction of the monetary policy over the business cycle. The smoothing coefficient in the monetary policy rule varies from 0.75 at the turn of recovery and expansion to 0.96

in the mid of depression (Figure 2 and Table 2). The average parameter is 0.83. The monetary policy reacts more aggressively[7] when the output gap is within the range (0, 0.7) with significance at probability value equal to 0.01. For p-value = 0.1 the span of the output gap widens to (-0.2, 1.8). This may mean that the monetary policy authorities reacted pre-emptively, expecting inflationary pressures which may occur in the middle of expansion when the output gap is within the range (0.4, 1.5), Figure 2. Asymmetric reaction with respect to the output gap is insignificant. The finding is close to that of Orphanides and Williams (2004), who show that, assuming learning and imperfect knowledge about the natural rate, monetary policy should react more aggressively with respect to inflation and less aggressively with respect to the output gap. It might seem that the monetary authorities in Poland apply the Orphanides' prescription to make the proper monetary policy, where the more inertial monetary policy, as in the middle of depression, the smaller the effect of a central bank misperception of the natural interest rate and the smaller probability of making a mistake by the central bank with respect to GDP growth. The central bank seems to be most cautious in its reactions within the output range (-2, -0.4).

The impact of the exchange rate on the interest rate change (via both inflation and net exports) is generally weak and asymmetrically insignificant, albeit not constant. It is the weakest in depression and strongest in expansion.

To check the robustness of results, the sample was shortened by the first 12 quarters, i.e. till 2003 Q1. During those 12 quarters the central bank reference rate dropped by more than 10 percentage points. Since 2003, the shifts in the reference rate have been more attenuated. On the one hand, shortening the sample by more than 15% on average may worsen the quality of estimations, but on the other it can bring information on changes in monetary policy. That exercise shows that the average smoothing parameter has moved up to 0.86 with a maximum of 0.96 and minimum of 0.81. This may indicate that monetary policy has been becoming more and more inertial independently of the economy's position in the business cycle.

Moreover, there is a question whether our estimates are not affected by either very low or negative interest rate in the euro area. Namely, in the second quarter of 2012 the 3-month Euribor fell close to zero and from the second quarter of 2015 it was negative due to the ECB quantitative-easing (QE) programme. Importantly, the shadow interest rate implied by models such as Wu J. C., Zhang J. (2017), Wu and Xia (2016) or Krippner (2014) was even lower (Figure 3). In Poland, there was no need to resort to QE, thus the observed and shadow interest rates were supposed to be of a similar level. Obviously, the interest rate disparity between the observed Polish rate and the shadow interest rate in the euro area has significantly changed. Nonetheless, estimations substituting the 3-month Euribor by the shadow rate do not show any significant change of the coefficient at the disparity in the exchange rate equation. The larger disparity has only slightly affected the appreciation of the real exchange rate of the zloty since 2015. In our model, the cumulated appreciation of the zloty in a 3-year horizon would amount to 1.0% compared to the exchange rate path from the equation with the observed interest rates disparity. That difference does not change the fundamental results of the model estimated with the observed interest rates only.

[7] Asymmetry of the reaction is measured as the distance between the average value of a parameter and the value of this parameter for which the t-statistic is significant at two levels: p-value = 0.01 and p-value = 0.1.

3.2 Asymmetric effects of the monetary policy over the business cycle

Asymmetric reactions of the monetary policy authorities affect both the nominal and real economy. The simulation of the short-term interest rate impulse takes into account the variation of the estimated parameters over the business cycle. The obtained responses significantly differ across phases of the business cycle (Figure 4).

A fall in the interest rate by one percentage point in depression tends to display the most stimulating and long-lasting effect on the real economy.[8] It would diminish losses of GDP growth (Figure 4B). The largest effect of this policy might come relatively soon – after just 2 quarters. However, the monetary authorities seem to react with the greatest inertia when the output gap remains between -2.4% and 0.2% of the potential growth. The lack of or at most a weak reaction results in the incomplete use of the monetary policy's ability to influence the real sector. Interest rate cuts in depression and recovery, when the reaction of GDP is the strongest, would have the most stimulating impact on GDP growth.

In depression prices react to the interest rate cut two quarters later than GDP. Their increase is relatively weak (Figure 4C) and does not significantly differ from the average reaction. At the same time, they are directly affected by the depreciation of the exchange rate via the exchange rate pass--through effect (ERPT). However, in depression the ERPT effect is the smallest, at less than 0.02%.

During periods of prosperity, especially in the expansion phase, when the susceptibility of the real economy to monetary tightening is greater, interest rates return to their steady state relatively fast (after 4–5 quarters). Then, increases of the interest rate cause a drop of inflation significantly greater than the average over the business cycle, while its effect on GDP decline is weaker and does not display asymmetry. That reaction of the economy coincides with a period of a more aggressive monetary policy (Table 2). It is worth noticing that whether pursuing the policy is aimed at reducing inflation or promoting growth, the activity of the real economy changes first, while prices do so later on. This may result from a lower degree of forward-lookingness of the Phillips curve than for the U.S. (over 0.6; Gali, Gertler, López-Salido 2005) and for the euro zone (over 0.7, Lagoa 2011).[9]

The impact of the real exchange rate (RER) on the aggregate demand depends on the way in which the RER affects the volume of exports and imports and should therefore be considered together with net exports (NX). Both the RER and NX show significant asymmetry in recovery and depression, that is, when their role is the smallest (Figure 8A and Table 4).

A positive shock to the nominal exchange rate results in an immediate appreciation of the zloty, and only in the subsequent periods does it cause a change in relative prices (costs), leading to a change in competitiveness, affecting the volume of foreign trade. In the first two quarters after the appreciation, the prices of imported final consumption goods decrease on the domestic market, raising the volume of imports. Exports react more slowly, as in the short run the prices of exported goods set up in foreign currencies are fixed in binding contracts. As a result, the trade balance (net exports) deteriorates. Next, after a gradual depreciation of the exchange rate following its initial appreciation and adjustment of the relative prices, the above effects get reversed. The sequence of events is as follows: the appreciation of the nominal exchange rate by 1.0% (RER growth is by only 0.04 percentage points higher) is sufficient to immediately deteriorate net exports by 0.17 percentage points compared

8 The cumulating effect of the impulse response function calculated for the depression phase is almost twice as high as for the average over the business cycle and more than 3 times higher than for the expansion phase.

9 It should be kept in mind that full comparability of results occurs only when the models are estimated by comparable techniques.

to the baseline. Then, its improvement, observed since the third quarter, balances the loss, and finally, the effect of exchange rate changes on the aggregate demand is small and transitory.

If the RER appreciation occurs in the periods of recovery or expansion, then only in the first three quarters will the trade balance slightly deteriorate. Then, along with fading of the exchange rate shock, net exports improve and finally remain almost 0.5 points above their initial level. An improvement of net exports despite the initial appreciation is possible because of the lowest weight of the exchange rate in the determination of the trade flows during an upturn in the economy (Table 5), despite its impact being asymmetric and statistically significant, especially during the recovery (Figure 8A).

However, if the appreciation of the RER occurs in the depression, then the growth of NX will slow down within four quarters by 0.25 percentage points and will not return to its base level – the deficit in trade in goods and services increases or the surplus turns to deficit. Thus, the deterioration of the trade volume results both from a greater impact of the foreign exchange rate on foreign trade and from a greater role of foreign demand, as its fluctuations dominate the growth of the export volume.

It is worth noting that the sensitivity of output gap to a change in government expenditure behaves in the same way as net exports – there are significant asymmetries during an upturn of the economy when sensitivity is the lowest and during depression (for an output gap of the range (-1.4, -0.4)) when the change in government demand stimulated by softer fiscal policy may strongly impact GDP growth. Hence, a monetary policy coherent with fiscal policy may to some extent strengthen the total effect of government spending. The effect is almost twice as large during the economy's decline as during growth. Positive values of coefficients at government spending over the whole business cycle suggest their procyclical character.

Similarly to the aggregate demand, inflation shows a clear-cut asymmetric reaction to inflation expectations (over the whole business cycle), the output gap (the greatest asymmetry is during expansion when the output gap exceeds 2.4%) and the real exchange rate (via the exchange rate pass--through effect – the greatest effect is observed at the turn of expansion and recession, for an output gap of over 2.3%), Table 2. It is worth noting that the greatest asymmetry is associated with the greatest weight of the domestic factors determining inflation (Table 6).

Firms set prices in anticipation of future demand and factor costs; however, only a fraction of firms adjusts prices to their optimal level, while the others update the last period's optimal prices with lagged inflation as a "rule of thumb" – as developed in Gali and Gertler (1999). The fraction of firms adjusting prices to their optimal level varies over the business cycle: the coefficient at expected inflation grows (slightly) from 0.44 in recovery to 0.54 in expansion (it rapidly accelerates when the output gap is greater than one). The opposite reaction occurs during recession and depression.

A similar pattern is observed for the coefficient at the output gap with its minimum (0.1) in the trough and maximum (0.21) in the peak, suggesting convexity of the Phillips curve. Thus, the impact of the output gap is stronger during phases of growth than in phases of decline.

The convexity of the Phillips curve can be explained (as in Filardo 1998) by capacity constraints. If so, inflation is increasingly sensitive to changes in output as the economy expands. Thus, capacity constraints restrict firms' ability to further expand output and the increase in demand is more likely to show up as higher inflation than larger output. The slope of the Phillips curve steepens, reducing the cost of fighting inflation. In contrast, when the monetary policy authorities increase interest rates, the real sector declines, firms face fewer capacity constraints, and inflation becomes less sensitive to output changes.

In the case of Poland, as shown in Figure 5, such explanation is true when the output gap is over 1.5% of its potential level (it is close to the peak) and at the beginning of the recovery when the output gap is below -2.0% and excess capacity reduces the effects of the monetary policy. This discrepancy is greater in the growth phases of the cycle than in the phases of decline. For the output gap from the interval (-2.0, 1.5) there is no difference between the linear and non-linear reaction. This may suggest that the monetary policy should react more aggressively when the economy is overheated, since the same result may be achieved at a lower cost. In the remaining phases of the cycle, small, gradual interest rate changes should generate a lower cost of disinflation than large ones.

The sacrifice ratio below 1.0 during expansion confirms that aggressive monetary policy when the economy is overheated generates the lowest costs of fighting inflation, while any attempt to restrict inflation during depression might be very costly.

Finally, the nominal exchange rate adjusted by foreign prices shows the price elasticity with respect to the exchange rate and indicates that there is a significant asymmetry in the inflation reaction to the exchange rate changes over the business cycle: the elasticity varies from 0.02 at the lowest point of depression to 0.135 at the peak of economic activity. However, in the range of the output gap (-1; 1), the elasticity is almost constant and amounts to 0.06 in the phases of economic growth and to 0.09 during economic decline. The slightly larger price elasticity with respect to the exchange rate during a downturn is related to market imperfection and segmentation, manifested in the efforts of exporting companies in a given country to build a stable market share in the importing country: enterprises exporting to a country with a depreciating currency are then more inclined to lower prices than to raise them during the appreciation of the currency (Przystupa, Wróbel 2011). This effect disappears in the extreme points of the business cycle.

The cumulated price increase related to the cumulated exchange rate change in a given period, or the exchange rate pass-through effect – ERPT, is on average equal to 0.08. It is also worth noticing that it declined significantly from 0.21 in 2004–2008 to 0.18 in 2010 and 0.08 in 2017. This is a structural decline, associated with changes in the production process caused by its internationalisation, and with the stabilising role of the central bank's inflation targeting policy (e.g. Forbes, Hjortsoe, Nenova 2017). The ERPT effect fluctuates across the business cycle, its amplitude between peak and trough amounts to 0.13 and in spite of a large drop in the average pass-through, it tends to remain stable.[10] The asymmetry of the ERPT in the extreme points of the business cycle, besides the pricing to market phenomenon, is reinforced by the convexity of the Phillips curve (Figure 5).

To calculate the ERPT the nominal exchange rate shock (NER) was standardized to 1% of the exchange rate change. The NER shock consists of several shocks grouped as in Table 7.

The weight of the real disparity in explaining the change in the real exchange rate is 19.1% (Table 8) and is more than double the weight of the nominal disparity in the NER model. Furthermore, it is on average over 30% less than the weight of demand. However, it varies significantly in the business cycle: in the growth phases the difference is insignificant, but it clearly grows in the phases of decline, especially in depression. In the NER model, the weight of demand shocks is 3 to 5 times greater than that of disparity. However, if we consider the simultaneous impact of the monetary policy shock on the exchange rate and on prices (RER model), the combined weight of disparity and prices (37.2%) exceeds the weight of demand by 30%. A correct estimation of the weight of monetary policy shock is important for determining its impact on the exchange rate, prices, and aggregate demand. The prevailing monetary policy shocks in the period of recovery and expansion mean that this policy can be most effective at times when the output gap is greatest and especially when it is greater than 1.5%.

[10] In Przystupa and Wróbel (2011) it was estimated to be 0.17.

In this period, the monetary policy effectively reduces inflation at the lowest cost for GDP growth, while not allowing further appreciation of the domestic currency. Unlike loosening the policy during a negative demand gap, it leads to GDP growth inhibiting depreciation.

Central bank interventions, which are also part of the monetary policy, have little and only a short-term effect on changes in the zloty exchange rate.

In contrast, the "external environment" plays a non-negligible role. It consists primarily of external shocks whose significance grows in the decreasing phases of the cycle, when the potential for reducing their negative effects is minimal.

4 Conclusions

The main findings of the paper may be summarized as follows: there is both an asymmetric reaction of the monetary policy in the different phases of the business cycle and asymmetric effects of the monetary policy over the business cycle. However, while the asymmetry in reactions of the monetary policy is the strongest and significant for the output gap close to zero, the asymmetric effects of the monetary policy are weak or not significant for the output gap between -1.5% and 1.5%. They become greater and significant when the output gap is closer to its extreme values over the business cycle.

1 Considering asymmetric reactions of the monetary policy in the business cycle, we observe that between 2000–2017 the monetary policy authorities reacted more aggressively when the output gap was within the range (-0.2, 1.8), i.e. during the turn of recovery and expansion. This may mean that the monetary policy reacted pre-emptively to an anticipated increase in inflation which may be expected since the middle of expansion. At the same time, asymmetric reaction with respect to the output gap is insignificant. On the other hand, the central bank was the most cautious in its reactions within the output gap range (-2, -0.4). Shortening the sample by the first two years (since 2003 the reference rate has been moving moderately) shows that the average smoothing parameter has moved up, which indicates that monetary policy has been becoming more and more inertial independently of the economy's position in the business cycle.

2 Considering the asymmetric effects of the monetary policy over the business cycle:

– depression: reduction of the interest rate has the most stimulating and long-lasting effect on the real economy; this would reduce losses in GDP growth and the maximum effect might come relatively soon; alas, this is when the monetary authorities react with the greatest caution;

– expansion: each increase of the interest rate causes a drop of inflation significantly greater than the average over the business cycle, while its effect on GDP decline is weaker and does not display any asymmetry.

3 The sensitivity of the output gap to government expenditure change shows significant asymmetries during an upturn of the economy when sensitivity is the lowest and during depression when the change in government demand stimulated by the fiscal policy may strongly impact GDP growth. The effect is almost twice as high during the economy's decline as during growth. Positive values of coefficients at government spending over all the business cycle suggest their procyclical character.

4 The exchange rate pass-through effect: the average ERPT is equal to 0.08 and has varied across the business cycle – from 0.02 in the lowest point of depression to 0.14 in the peak. The asymmetry of the ERPT in extreme points of the business cycle, besides the pricing to market phenomenon, is reinforced by the convex shape of the NKPC in Poland, stronger during phases of growth than in phases of decline.

References

Ang A., Bekaert G., Wei M. (2008), The term structure of real rates and expected inflation, *The Journal of Finance*, 63(2), 797–849.

Barnichon R., Matthes C. (2016), *Gaussian mixture approximations of impulse responses and the nonlinear effects of monetary shocks*, Federal Reserve Bank of Richmond Working Paper Series WP, 16–08.

Bean Ch.R. (2004), Asset prices, financial instability, and monetary policy, *American Economic Review*, 94(2), 14–18.

Boinet V., Martin Ch. (2006), *Optimal non-linear monetary policy rules*, Brunel Business School, Brunel University.

Boivin J., Kiley M., Mishkin F. (2010), *How has the monetary transmission mechanism evolved over time?*, NBER Working Paper, 15879.

Borio C., Hofmann B. (2017), *Is Monetary Policy Less Effective When Interest Rates Are Persistently Low?*, Reserve Bank of Australia.

Caner M., Hansen B. (2004), Instrumental variable estimation of a threshold model, *Econometric Theory*, 20(05), 813–843.

Carabenciov I., Freedman Ch., Garcia-Saltos R., Laxton D., Kamenik O., Manchev C. (2013), *GPM6 – the global projection model with 6 regions*, IMF Working Paper, WP/13/87.

Clark C., Laxton D., Rose D. (1996), *Asymmetry in the U.S. output-inflation nexus*, Staff Papers, 43(1), International Monetary Fund.

Dupasquier C., Ricketts N. (1998), *Non-linearities in the output-inflation relationship: some empirical results for Canada*, Bank of Canada Working Paper, 98–14.

Eisner R. (1997), *A new view of the NAIRU*, in: P. Davidson, J. Kregel (eds.): *Improving the Global Economy: Keynesianism and the Growth in Output and Employment*, Edward Elgar.

Engel Ch., West K. (2004), *Exchange Rates and Fundamentals*, NBER Working Paper, w10723.

Engel Ch., West K. (2006), Taylor rules and the Deutschmark – Dollar real exchange rate, *Journal of Money, Credit, and Banking*, 38(5), 1175–1194.

Filardo A. (1998), New evidence on the output cost of fighting inflation, *Economic Review*, 3rd quarter, 33–61.

Forbes K., Hjortsoe I., Nenova T. (2017), *Shocks versus structure: explaining differences in exchange rate pass-through across countries and time*, Discussion Paper, 50, June, Bank of England, External MPC Unit.

Gali J., Gertler M. (1999), Inflation dynamics: a structural econometric analysis, *Journal of Monetary Economics*, 44(2), 195–222.

Gali J., Gertler M., López-Salido D. (2005), Robustness of the estimates of the hybrid New Keynesian Phillips curve, *Journal of Monetary Economics*, 52(6), 1107–1118.

Gali J. (2018), The State of New Keynesian Economics: A Partial Assessment, *Journal of Economic Perspectives*, 32(3), 87–112.

Gradzewicz M., Growiec J., Hagemejer J., Popowski, P. (2010), Cykl koniunkturalny w Polsce – wnioski z analizy spektralnej, *Bank i Kredyt*, 41(5), 41–76.

Granziera E., Haavio M., Juselius M., Kortelainen M., Vilmi L. (2018), Post-crisis monetary policy modelling, *Bank of Finland Bulletin*, 1/2018.

Houck J.P. (1977), An Approach to Specifying and Estimating Nonreversible Functions, *American Journal of Agricultural Economics*, 59(3), 570–572.

Lagoa S. (2011), *Determinants of inflation differentials in the euro area: Is the New Keynesian Phillips Curve enough?*, DINAMIA'CET Working Paper, 2011/08, November, https://repositorio.iscte-iul.pt/bitstream/10071/3687/1/DINAMIA_WP_2011-08.pdf.

Lo Ming Chien, Piger J. (2005), Is the response of output to monetary policy asymmetric? Evidence from a regime-switching coefficients model, *Journal of Money, Credit and Banking, Blackwell Publishing*, 37(5), 865–886.

Mancini-Griffoli T. (2011), *Dynare User Guide. An introduction to the solution & estimation od DSGE models*, http://www.dynare.org/documentation-and-support/user-guide/Dynare-UserGuide-ebBeta.pdf.

Nobay B., Peel D. (2000), Optimal monetary policy with a nonlinear Phillips curve, *Economics Letters*, 67(2), 159–164.

Orphanides A., Williams J.C. (2004): *Robust Monetary Policy with Imperfect Knowledge*, Conference on Monetary Policy and Imperfect Knowledge, Würzburg, 14–15 October.

Przystupa J., Wróbel E. (2011), Asymmetry of the exchange rate pass-through: an exercise on the Polish data, *Eastern European Economics*, 49(1), 30–51.

Przystupa J., Wróbel E. (2016), Modelling monetary transmission in less developed emerging markets: the case of Tunisia, *Bank i Kredyt*, 47(5), 395–434.

Schaling E. (1999), *The non-linear Phillips curve and inflation forecast targeting*, Bank of England Working Papers, 98.

Semmler W., Zhang W. (2004), *Monetary policy with nonlinear Phillips curve and endogenous NAIRU*, Working Paper, 55, February, University of Bielefeld, Center for Empirical Macroeconomics.

Skrzypczyńska M. (2013), Cykl koniunkturalny w Polsce – analiza sektorowa, *Bank i Kredyt*, 44(2), 175–206.

Stiglitz J. (1997), Reflections on the natural rate hypothesis, *Journal of Economic Perspectives*, 11(1), 3–10.

Taylor J.B. (1995), The monetary transmission mechanism: an empirical framework, *Journal of Economic Perspectives*, 9(4), 11–26.

Tenreyro S., Thwaites G. (2016), Pushing on a string: US monetary policy is less powerful in recessions, *American Economic Journal: Macroeconomics*, 8(4), 43–74.

Wadhwani S. (1999), On sterling's puzzling behaviour, *Bank of England Quarterly Bulletin*, November.

Walsh C. (2017), *Monetary Theory and Policy*, MIT Press.

Wolffram R. (1971), Positive measures of aggregate supply elasticities: some new approach – some critical notes, *American Journal of Agricultural Economics*, 53(2), 356–359.

Wu J.C., Xia F.D. (2016), Measuring the macroeconomic impact of monetary policy at the zero lower bound, *Journal of Money, Credit and Banking,* 48(2–3), 253–291.

Wu J.C., Zhang J. (2017), *A shadow rate New Keynesian Model*, Chicago Booth Research Paper, 16–18, http://dx.doi.org/10.2139/ssrn.2843627.

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Appendix

Table 1
Results of the estimations of the base model and sub-models

Parameter (at)	Base model		Model 1 (recession and depression)	Model 3 (slump)	Model 2 (recovery and expansion)	Model 4 (prosperity)
	Prior distribution	Mode (t-statistic)	Mode (t-statistic)			
Block of the aggregate demand						
Hybrid IS curve						
α_1 output gap (y_{t+1})	Beta(0.22, 0.08)	0.198 (28.28)	0.197 (49.25)	0.194 (32.33)	0.206 (2.196)	0.233 (4.144)
α_2 output gap (y_{t-1})	Beta(0.7, 0.05)	0.676 (25.31)	0.686 (17.15)	0.668 (16.26)	0.683 (14.85)	0.622 (13.13)
α_3 gap of interest rate	Normal(-0.1, 0.08)	-0.099 (3.372)	-0.081 (3.164)	-0.141 (3.126)	-0.167 (4.980)	-0.112 (2.288)
α_4 gap of exchange rate	Normal(0.12, 0.09)	0.067 (454.6)	0.052 (382.0)	0.124 (88.61)	0.091 (3.181)	0.085 (2.857)
α_5 gap of net exports	Normal(0.2, 0.1)	0.201 (3.022)	0.288 (4.097)	0.249 (4.643)	0.097 (4.991)	0.209 (5.326)
α_6 gap of gov. expenditure	Gamma(0.1, 0.07)	0.159 (2.888)	0.114 (2.569)	0.218 (3.956)	0.176 (3.900)	0.129 (3.255)

Table 1, cont'd.

Parameter (at)	**Base model**		**Model 1 (recession and depression)**	**Model 3 (slump)**	**Model 2 (recovery and expansion)**	**Model 4 (prosperity)**
	Prior distribution	**Mode (t-statistic)**	**Mode (t-statistic)**			
			Block of the aggregate demand			
			Gap of net exports			
α_{50} potential net exports (t –1)	Normal(0.7, 0.04)	0.757 (19.25)	0.754 (37.70)	0.725 (7.454)	1.045 (69.67)	0.728 (26.03)
α_{51} equilibrium exchange rate	Normal(0.2, 0.04)	0.286 (9.287)	0.193 (3.511)	0.128 (4.267)	0,315 (7.021)	0.241 (3.266)
α_{52} Δ of potential GDP in the EA	Normal(1.1, 0.04)	0.973 (2.949)	0.957 (3.197)	0.945 (23.09)	0.979 (19.32)	1.025 (17.08)
α_{53} Δ of potential GDP in Poland	Normal(1.05, 0.25)	0.775 (3.110)	0.753 (3.322)	0.746 (3.937)	0.781 (3.782)	0.787 (2.971)
α_{54} output gap in the EA	Normal(1.04, 0.1)	1.0317 (13.491)	1.0324 (11.10)	1.0282 (15.26)	1.0329 (11.23)	1.0386 (18.96)
α_{55} real effective exchange rate	Normal(-0.1, 0.03)	-0.126 (6.261)	-0.581 (7.265)	-0.642 (17.68)	-0.198 (3.193)	-0.062 (13.13)
α_{56} volume of imports in (t –1)	Normal(0.2, 0.1)	0.289 (2.921)	0.297 (2.811)	0.301 (3.742)	0.283 (2.830)	0.281 (2.973)
α_{57} output gap in Poland	Normal(1.1, 0.4)	1.243 (14.47)	1.282 (71.22)	1.281 (16.01)	1.253 (73.71)	1.232 (4.172)

Table 1, cont'd.

Parameter (at)	Base model		Model 1 (recession and depression)	Model 3 (slump)	Model 2 (recovery and expansion)	Model 4 (prosperity)
	Prior distribution	**Mode (t-statistic)**	**Mode (t-statistic)**			
			Block of the aggregate demand			
α_{58} real effective exchange rate	Normal(0.1, 0.03)	0.133 (4.439)	0.093 (3.721)	0.172 (17.61)	0.051 (2.715)	0.287 (15.73)
α_{59} volume of exports in (t – 1)	Normal(0.2, 0.05)	0.198 (5.852)	0.111 (3.266)	0.206 (7.354)	0.245 (8.167)	0.209 (13.02)
			Gap of the public expenditure			
α_{60} output gap in Poland	Gamma(0.2, 0.01)	0.233 (13.71)	0.220 (20.06)	0.236 (72.77)	0.223 (17.15)	0.235 (25.17)
α_{61} Δ of GDP in Poland	Gamma(1.01, 0.06)	1.017 (17.24)	0.989 (19.78)	0.914 (26.11)	0.991 (18.81)	1.021 (31.58)
α_{62} Δ of potential GDP in Poland	Gamma(1.01, 0.06)	1.021 (15.91)	1.051 (13.47)	1.022 (22.42)	1.019 (20.85)	1.017 (9.310)
			New Keynesian Phillips curve			
β_1 HICPt+1	Normal(0.4, 0.07)	0.483 (7.419)	0.468 (7.244)	0.477 (8.195)	0.507 (7.054)	0.513 (9.311)
β_2 output gap	Normal(0.29, 0.16)	0.145 (12.94)	0.124 (13.01)	0.151 (9.321)	0.161 (11.88)	0.178 (3.213)

Table 1, cont'd.

Parameter (at)	**Base model**		**Model 1 (recession and depression)**	**Model 3 (slump)**	**Model 2 (recovery and expansion)**	**Model 4 (prosperity)**
	Prior distribution	**Mode (t-statistic)**	**Mode (t-statistic)**			
			New Keynesian Phillips curve			
β_3 nominal exchange rate adj. by foreign prices	Beta(-0.1,0.07)	-0.082 (7.661)	-0.059 (9.187)	-0.023 (3.236)	-0.088 (18.92)	-0.135 (16.61)
			Monetary policy rule			
λ_1 nominal interest rate in t –1	Beta(0.78, 0.08)	0.833 (11.09)	0.901 (11.87)	0.980 (12.84)	0.697 (9.522)	0.733 (9.761)
λ_2 HICP-inflation target	Gamma(1.5, 0.06)	1.499 (25.71)	1.489 (25.19)	1.610 (27.91)	1.516 (24.92)	1.361 (25.05)
λ_3 output gap	Normal(0.5, 0.1)	0.510 (5.842)	0.502 (6.026)	0.543 (6.687)	0.549 (7.197)	0.493 (4.725)
λ_4 real exchange rate	Normal(-0.1, 0.07)	-0.027 (2.573)	-0.011 (2.878)	-0.044 (3.692)	-0.028 (2.439)	-0.025 (2.532)
			Natural interest rate			
λ_{11} real interest rate	Normal(0.7, 0.05)	0.706 (12.84)	0.701 (11.68)	0.699 (61.22)	0.804 (73.09)	0.727 (23.78)
λ_{12} Δ of potential GDP in Poland	Normal(0.56, 0.18)	0.579 (3.057)	0.607 (3.408)	0.594 (5.327)	0.564 (3.133)	0.569 (3.986)
λ_{13} HICP – inflation target	Normal(0.67, 0.03)	0.696 (15.13)	0.596 (21.28)	0.549 (23.07)	0.694 (19.83)	0.688 (19.67)

Table 1, cont'd.

Parameter (at)	Base model		Model 1 (recession and depression)	Model 3 (slump)	Model 2 (recovery and expansion)	Model 4 (prosperity)
	Prior distribution	**Mode (t-statistic)**	**Mode (t-statistic)**			
			Real exchange rate (Real Interest Rate Parity – RIP)			
δ_1 expected real FX (e^r_{t+1})	Beta(0.7, 0.05)	0.676 (13.97)	0.685 (13.67)	0.624 (12.93)	0.704 (13.91)	0.697 (14.12)
δ_2 real interest rate disparity	Beta(0.95, 0.04)	0.964 (24.11)	0.954 (24.17)	0.848 (21.21)	0.977 (28.70)	0.975 (27.53)
δ_3 output gap (y_t)	Normal(0.5, 0.45)	0.479 (9.355)	0.517 (20.48)	0.485 (10.14)	0.431 (13.69)	0.456 (5.686)
δ_4 indicator of direct/indirect interventions	Normal(0.1, 0.2)	0.051 (4.557)	0.032 (3.226)	0.024 (3.881)	0.077 (4.001)	0.062 (3.311)
			Equilibrium exchange rate			
δ_5 equilibrium exchange rate ($t-1$)	Normal(0.5, 0.1)	0.452 (3.767)	0.472 (7.066)	0.462 (5.372)	0.418 (11.467)	0.426 (22.51)
δ_6 gap of net exports	Normal(0.5, 0.1)	0.587 (6.146)	0.592 (7.411)	0.595 (7.324)	0.539 (16.97)	0.541 (11.43)

Table 1, cont'd.

Parameter (at)	**Base model**		**Model 1 (recession and depression)**	**Model 3 (slump)**	**Model 2 (recovery and expansion)**	**Model 4 (prosperity)**
	Prior distribution	**Mode (t-statistic)**	**Mode (t-statistic)**			
			Equations for the euro area			
Real short-term interest rate						
κ_1	Beta(0.78, 0.12)	0.93 (8.361)	0.95 (7.822)	0.96 (8.361)	0.85 (8.534)	0.88 (8.576)
κ_2	Normal(0.5, 0.17)	0.47 (2.977)	0.48 (3.023)	0.51 (3.211)	0.43 (2.729)	0.45 (2.747)
κ_3	Normal(0.2, 0.05)	0.13 (2.783)	0.13 (2.641)	0.14 (2.831)	0.12 (2.413)	0.12 (2.576)
HICP core inflation						
κ_4	Beta(0.95, 0.02)	0.93 (13.85)	0.91 (12.83)	0.93 (15.33)	0.95 (16.68)	0.96 (17.12)
κ_5	Beta(0.2, 0.08)	0.79 (28.04)	0.77 (31.13)	0.78 (30.07)	0.81 (34.12)	0.82 (37.28)
κ_6	Normal(-0.9, 0.1)	-0.92 (10.11)	-0.89 (8.13)	-0.91 (10.33)	-0.95 (12.01)	-0.96 (12.17)
Output gap						
κ_7	Beta(0.95, 0.04)	0.79 (23.45)	0.79 (23.45)	0.79 (23.45)	0.79 (23.45)	0.79 (23.45)
$\acute{n}_A^{EA}$	Beta(0.85, 0.129)	0.89 (7.124)	0.88 (7.124)	0.87 (7.124)	0.91 (7.124)	0.93 (7.124)
π_{EA}^*		0.475				

Source: own calculations.

Table 2
Asymmetric reactions of the main model variables over a business cycle

Coefficient at		**Span of the output gap and of the coefficients for which reactions over the business cycle are asymmetric at p-value of**								
		recovery		**expansion**			**recession**		**depression**	
		p.v. = 0.01	**p.v. = 0.1**	**p.v = 0.01**	**p.v. = 0.05**	**p.v.= 0.1**	**p.v = 0.01**	**p.v.=0.1**	**p.v.=0.01**	**p.v. = 0.1**
IS curve										
α_1 output gap (y_{t+1})	a				(0.237, 0.249)	(0.22, 0.249)		(0.231, 0.249)		
	b				**>1.46**	**>0.2**		**>1.83**		
α_3 gap of interest rate	a		(-0.166, -0.144)		(-0.189, -0.177)	(-0.189, -0.144)				
	b		**(-0.35, 0.2]**		**(0.45, 1.47)**	**(0.2, 2.26)**				
α_4 gap of exchange rate	a	(0.117, 0.156)	(0.098, 0.156)							(0.128, 0.156)
	b	**<-1.7**	**<-0.97**							**<-0.8**
α_5 gap of net exports	a		(0.097, 0.135)		(0.087, 0.094)	(0.087, 0.135)				(0.278, 0.313)
	b		**(-1.05, 0.2)**		**(0.55, 1.17)**	**(0.2, 1.75)**				**<-0.7**
α_6 gap of government expenditure	a		(0.094, 0.126)		(0.085, 0.093)	(0.085, 0.126)				(0.188, 0.194)
	b		**(-0.6, 0.2)**		**(0.47, 1.25)**	**(0.2, 2.8)**				**(-1.4, -0.4)**
Hybrid Phillips curve										
β_1 $HICP_{t+1}$	a		(0.442, 0.458)	>0.512		(>0.497)	(0.512, 0.54)	(0.497, 0.538)	(0.512, 0.526)	(0.497, 0.526)
	b		**<0.2**	**>2.3**		**>1.92**	**>0.2**	**>0.2**	**(-1.1, 0.2)**	**(-1.5, 0.2)**
β_2 output gap	a		(0.101, 0.107)			(0.186, 0.211)				
	b		**<-1.8**			**>2.43**				
β_3 nominal exchange rate adj. by foreign prices	a		(-0.054, -0.023)					(-0.135, -0.119)		
	b		**<-1.6**					**>2.3**		
Monetary policy rule										
λ_1 nominal interest rate $t-1$	a	(0.69, 0.72)	(0.69, 0.75)	(0.69, 0.72)		(0.69, 0.75)			(0.94, 0.978)	(0.89, 0.978)
	b	**(0, 0.2)**	**(-0.2, 0.2)**	**(0.2, 0.7)**		**(0.2, 1.8)**			**(-0.2, -0.3)**	**(-2.4, 0.2)**
λ_2 HICP – inflation target	a					(1.42, 1.442)				(1.558, 1.58)
	b					**(0.4, 1.5)**				**(-0.4, -1.7)**

Table 2, cont'd.

Coefficient at		Span of the output gap and of the coefficients for which reactions over the business cycle are asymmetric at p-value of								
		recovery		expansion			recession		depression	
		p.v. = 0.01	**p.v. = 0.1**	**p.v = 0.01**	**p.v. = 0.05**	**p.v.= 0.1**	**p.v = 0.01**	**p.v.=0.1**	**p.v.=0.01**	**p.v. = 0.1**
		Real uncovered exchange rate								
δ_1 expected real FX (e^r_{t+1})	a		(0.543, 0.58)			(0.75, 0.795)				(0.539, 0.58)
	b		**<-1.45**			**(1, 2.6)**				**<-2.75**
δ_2 real interest rate disparity	a	(0.833, 0.845)	(0.833, 0.89)							
	b	**(-2.4, -1.7)**	**(-0.7, -2.9)**							
δ_3 output gap (y_t)	a					(0.385, 0.425)				
	b					**(0.4, 2.65)**				
δ_4 interventions	a		(0.024, 0.031)					(0.07, 0.079)		
	b		**<0.2**					**(0.2, 1.75)**		

Notes:
The table shows coefficients at a variable which significantly differ from those of the base model.
a – range of coefficient, b – range of output gap.

Source: own calculations.

Table 3

Decomposition of variance of the short-term interest rate (in %)

Variance	Inflation-inflation target	Output gap	Real exchange rate	External shocks*
2000 Q1–2017 Q4	53.6	17.8	4.5	24.1
Recovery	57.1	18.7	4.7	19.5
Expansion	56.9	16.3	**8.2**	**17.7**
Recession	53.4	16.5	2.7	27.4
Depression	**44.5**	**19.8**	2.9	**31.8**

* External shocks are composed of the shock on the EURIBOR 3M and on the euro area output gap. Substitution of the EUROIBOR by the shadow rate changes the internal weight of the shock components, significant during expansion (increase in the share of the EUROIBOR) and during depression (increase in importance of the euro area output gap).

Source: own calculation.

Table 4

Decomposition of variance of the output gap (in %)

Variance	Supply		Domestic demand	Net exports	Exchange rate	External factors
		of which interest rate				
2000 Q1–2017 Q4	22.01	0.55	31.45	8.17	1.06	37.31
Recovery	20.98	1.11	30.66	7.99	1.19	39.18
Expansion	27.62	0.25	32.59	9.25	1.36	29.18
Recession	22.50	0.12	32.10	8.25	0.91	36.23
Depression	15.92	0.58	30.19	7.01	0.75	46.14

Source: own calculations.

Table 5

Decomposition of variance of exports and imports (in %)

Variance	Supply	Domestic demand	Net exports	Exchange rate	Foreign demand and prices
			Volume of exports		
2000Q1 – 2017Q4	5.99	5.36	10.99	7.38	70.28
Recovery	7.32	6.43	14.61	6.9	64.74
Expansion	7.91	8.33	15.71	5.88	62.17
Recession	4.23	3.31	7.76	9.58	75.12
Depression	4.52	3.4	5.9	7.1	79.08
			Volume of imports		
2000Q1 – 2017Q4	19.98	25.53	17.61	6.81	30.07
Recovery	24.3	28.44	19.46	5.3	22.5
Expansion	25.4	29.22	20.42	4.81	20.15
Recession	15.12	21.04	16.36	8.3	39.18
Depression	15.13	23.45	14.17	8.83	38.42

Source: own calculations.

Table 6

Decomposition of variance of the HICP inflation (in %)

Variance	Inflation expectations	Inertia of inflation	Output gap	Exchange rate	Foreign demand and prices
2000Q1 – 2017Q4	9.8	11.9	17.55	8.29	52.46
Recovery	13.8	8.5	18.73	7.16	51.81
Expansion	14.2	8.8	28.17	11.47	37.36
Recession	7.6	12.1	17.58	8.38	54.34
Depression	8.1	12.7	12.24	4.94	62.02

Source: own calculations.

Table 7

Decomposition of the nominal exchange rate shock (in %)

Shocks of	Monetary policy	Domestic	External
Average 2000–2017	9.3	34.5	56.2
Recovery	10.2	28.4	61.4
Expansion	9.7	33.6	56.7
Recession	9.1	36.3	54.6
Depression	8.2	41.1	50.7

Source: own calculations.

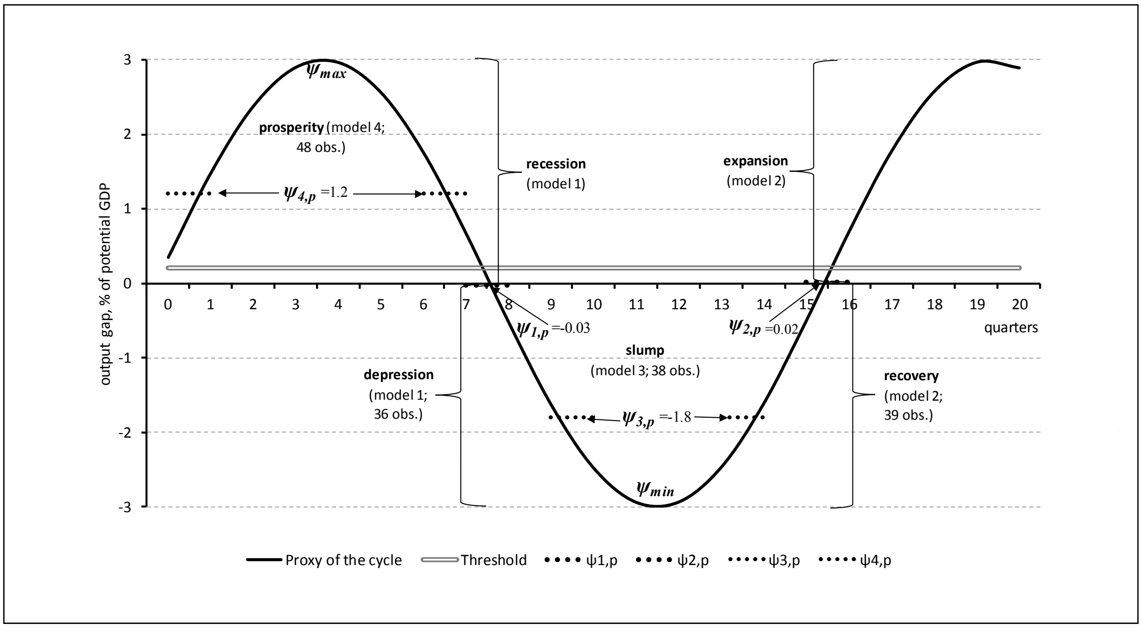
Table 8

Decomposition of the real exchange rate (RER) shock (in %)

Decomposition of RER	Disparity	Prices	Output gap	Interventions	External environment
2000Q1 – 2017Q4	19.1	18.1	28.8	2.0	32.0
Recovery	24.6	23.8	24.6	2.7	24.3
Expansion	21.7	27.6	27.4	2.4	20.9
Recession	16.8	13.3	29.7	1.9	38.3
Depression	13.2	9.0	32.9	1.6	43.3

Source: own calculations.

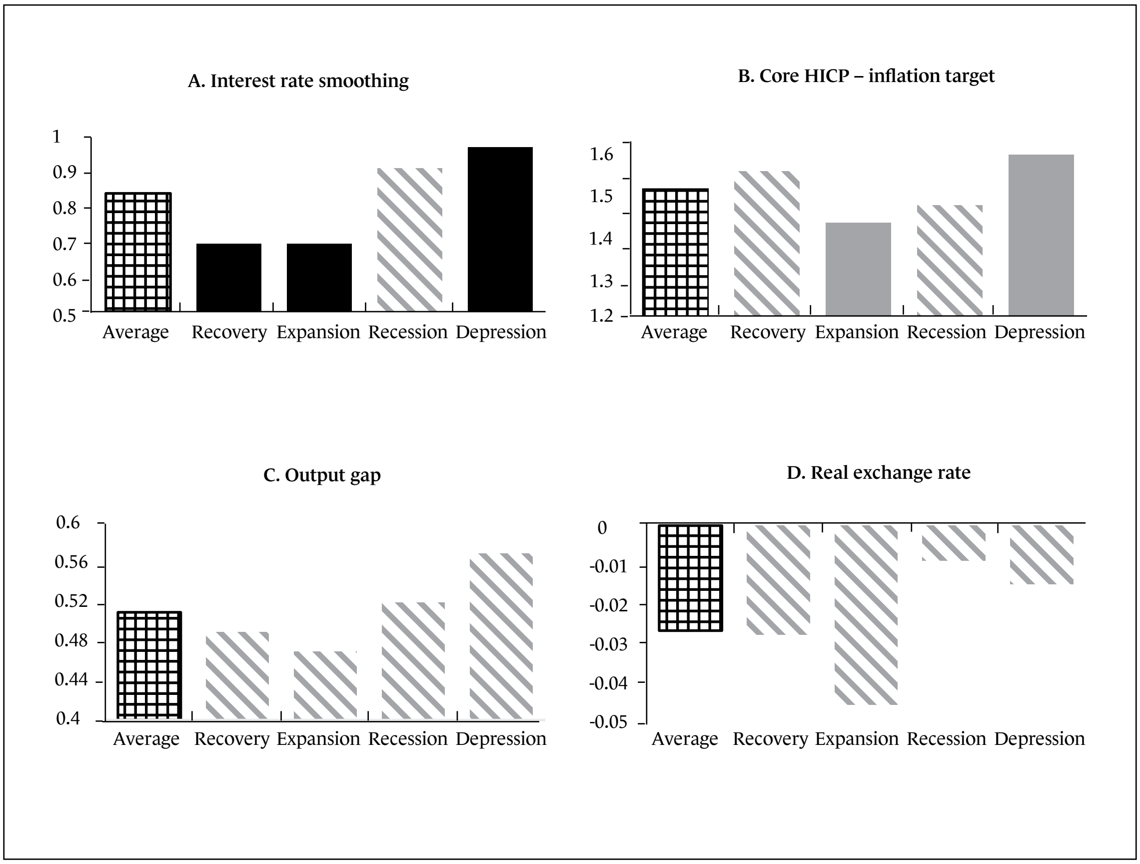
Figure 1
Stylized business cycle (average length of the cycle and max.- min. values of the Polish output gap)



Source: own calculations.

Figure 2

Monetary policy rule – significance of asymmetries



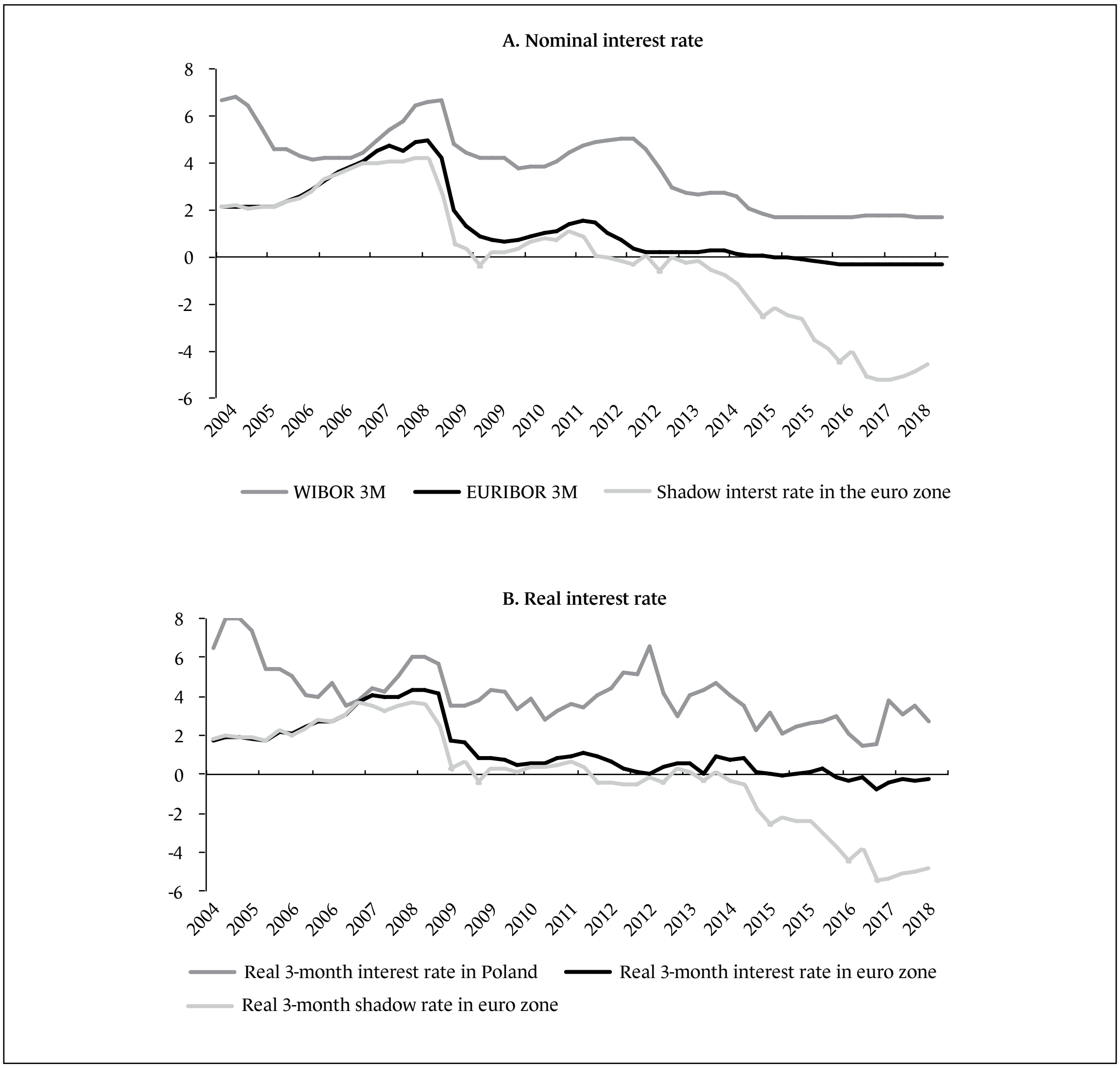
Notes:

The black bar shows significance at the p-value = 0.01; the dark grey bar means significance at the p-value = 0.1 level, i.e. the black and dark grey bars confirm an asymmetric reaction; the bar in diagonal lines means no asymmetry.

The left axis shows value of parameters of the base model (average) and the maximum value of parameters in the phases of the business cycle.

Source: own calculations.

Figure 3
Observed and shadow nominal and real three-month interest rates in the euro zone

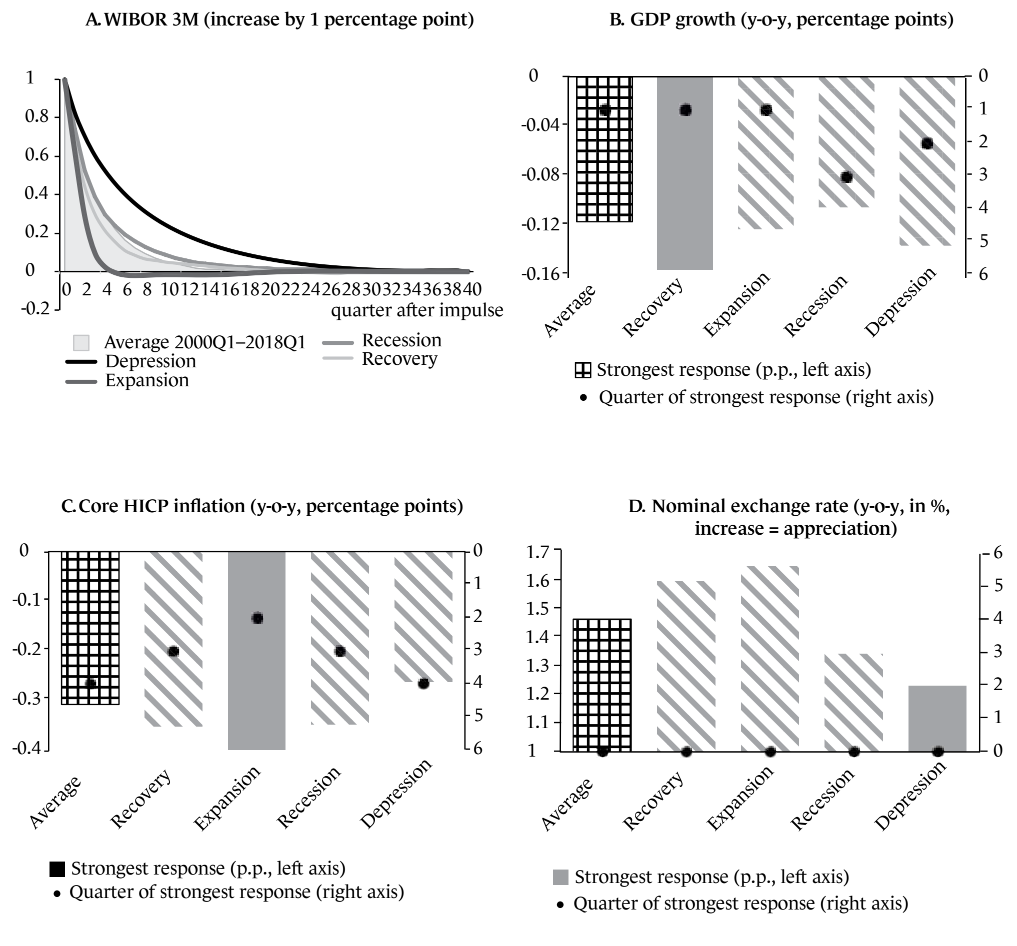


Notes:
Shadow interest rate calculated as in Wu and Xia (2016).
Real interest rate: nominal interest rate adjusted by expected core inflation.

Source: Shadow rate: https://www.quandl.com/data/SHADOWS/EUROPE-European-Central-Bank-Shadow-Rate; Nominal interest rates and HICP less energy and food: EUROSTAT.

Figure 4

Reaction of GDP growth, inflation and exchange rate to the monetary policy shock



Notes:

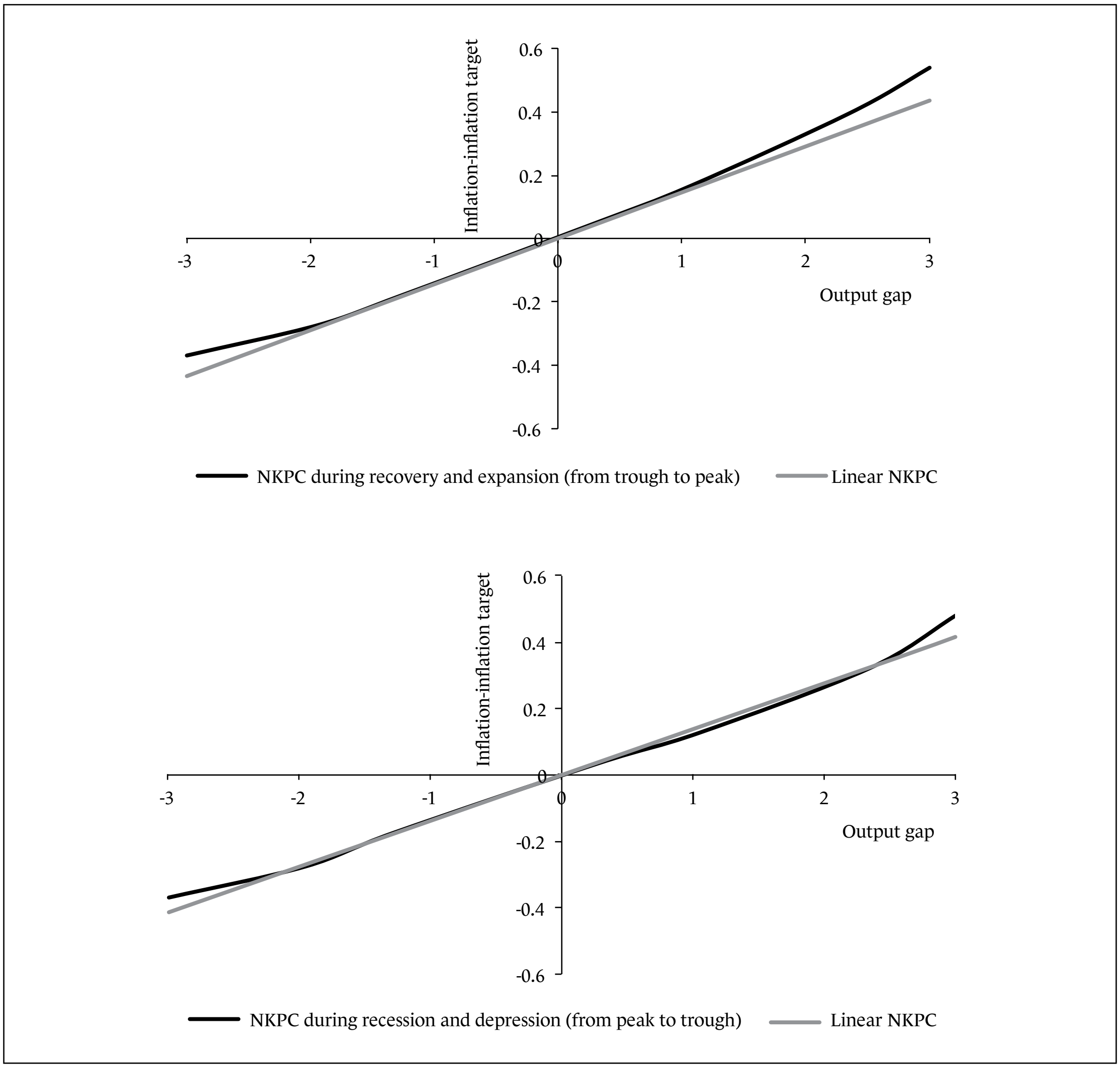
The dark grey bar means significance at the p-value = 0.1 level, i.e. confirms an asymmetric reaction.

The bar in diagonal lines means no asymmetry.

In the presentation of the impulse response functions (IRF) we have adopted the convention that irrespective of the considered period of the cycle, we show responses to the increase of the interest rate. Nevertheless, in the interpretation we refer to the effects of monetary policy tightening in the positive phases of the business cycle and to monetary policy easing in the negative phases.

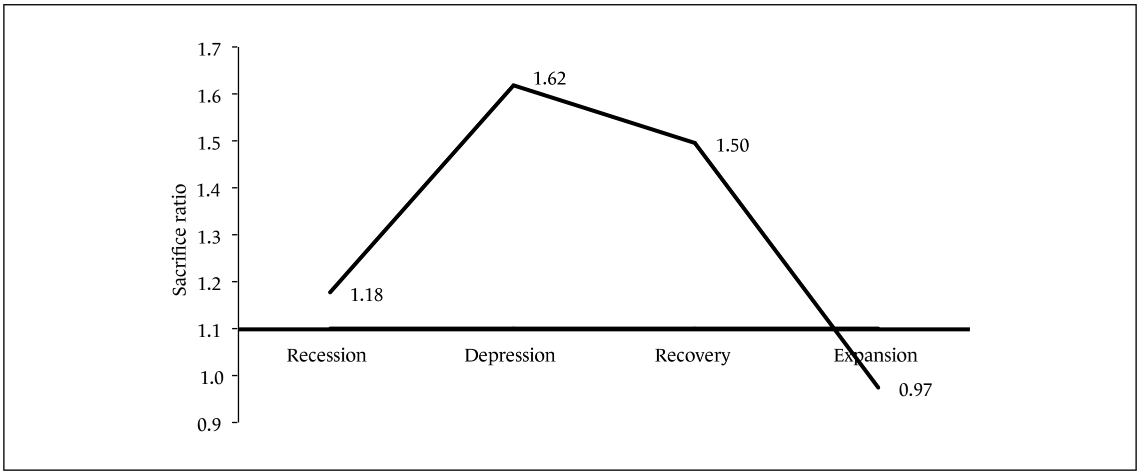
Source: own calculations.

Figure 5
Asymmetry of the hybrid NKPC



Source: own calculations.

Figure 6
Sacrifice ratio defined as a cumulated impulse of output gap/cumulated impulse of inflation

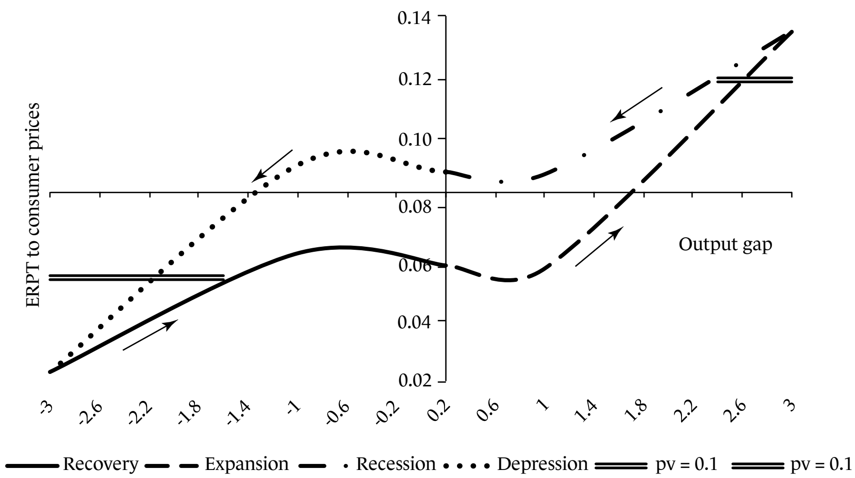


Note: intersection of axes at the point calculated for the linear (average) reaction (1.098).

Source: own calculations.

Figure 7

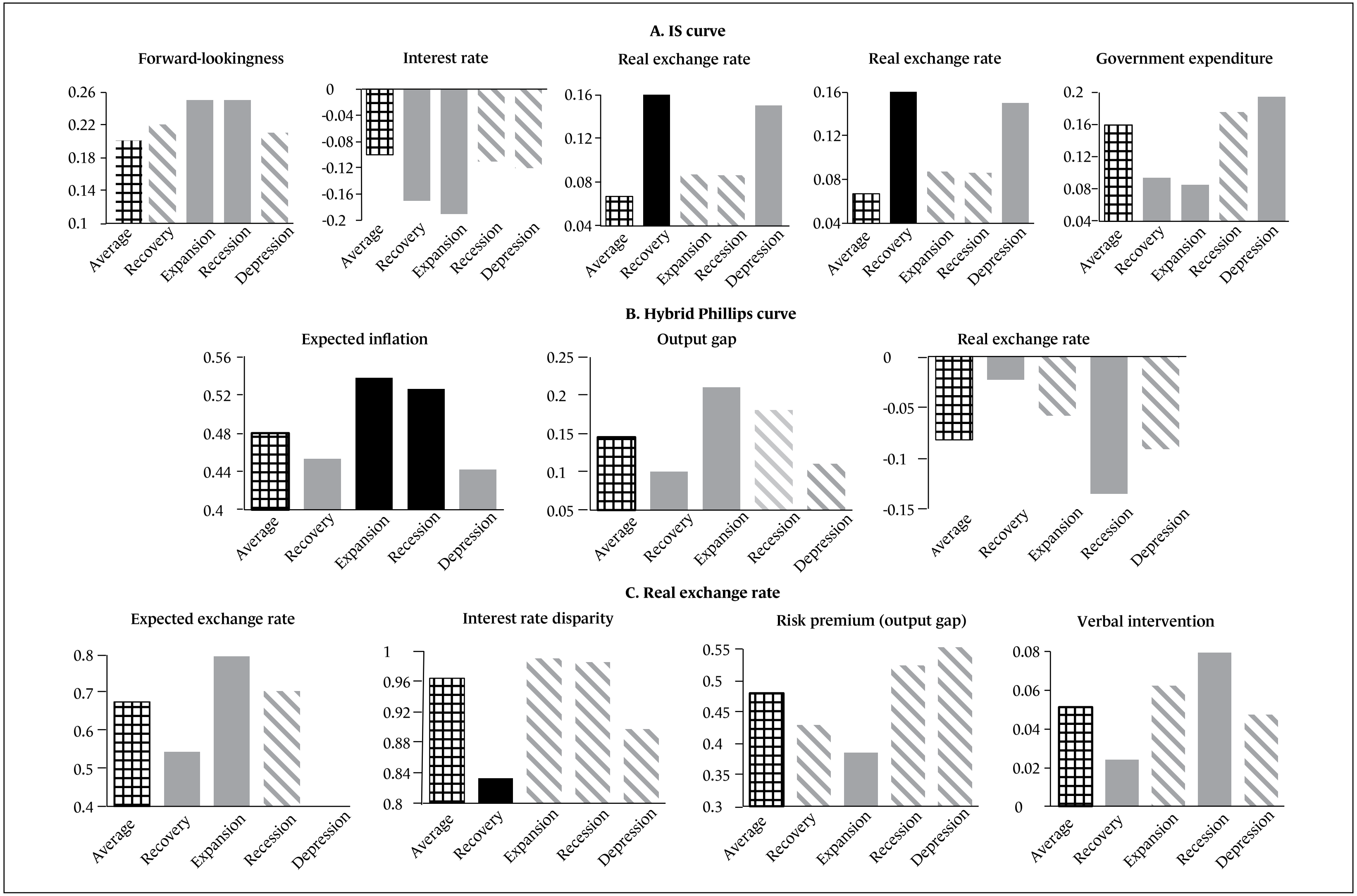
Exchange rate pass-through effect over the business cycle



Notes:
Axis intersection: horizontal – at the average ERPT (0.082); vertical – at the threshold between prosperity and slump (for output gap equal to 0.2% of the potential GDP).
Pv = 0.1 – values of ERPT below 0.054 and over 0.119 significantly differ from the average ERPT with 90% probability. That corresponds to the output gap below -1.6% and over 2.3%.

Source: own calculations.

Figure 8
Asymmetries in the economy's response to the monetary policy shocks



Notes:
The black bar shows significance at the p-value = 0.01; the dark grey bar means significance at the p-value = 0.1 level, i.e. black and dark grey bars confirm an asymmetric reaction; the bar in diagonal lines means no asymmetry.
Source: own calculations.