WP/14/186

IMF Working Paper

A Model-Based Analysis of Spillovers: The Case of Poland and the Euro Area

Michal Andrle, Roberto Garcia-Saltos, and Giang Ho

INTERNATIONAL MONETARY FUND

 WP/14/186

IMF Working Paper

Research Department

A Model-Based Analysis of Spillovers:
The Case of Poland and the Euro Area[1]

Prepared by Michal Andrle, Roberto Garcia-Saltos, and Giang Ho

Authorized for distribution by Benjamin Hunt

October 2014

Abstract

This paper studies economic and financial spillovers from the euro area to Poland in a two-country semi-structural model. The model incorporates various channels of macro-financial linkages and cross-border spillovers. We parameterize the model through an extensive calibration process, and provide a wide range of model properties and evaluation exercises. Simulation results suggest a prominent role of foreign demand shocks (euro area and global) in driving Poland's output, inflation and interest rate dynamics, particularly in recent years. Our model also has the capability for medium-term conditional forecasting and policy analysis.

JEL Classification Numbers:

Keywords: Poland, Euro area, semi-structural model, spillovers

Author's E-Mail Address: mandrle@imf.org; rgarciasaltos@imf.org; gho@imf.org

[1] We would like to thank Julie Kozack, Christian Ebeke and Ben Hunt for valuable comments and suggestions. All responsibility for errors remains with the authors.

Contents Page

Appendices

Tables

Figures

I. INTRODUCTION

The recent episodes of financial and sovereign stress in the euro area have rekindled concerns over potential spillover effects to emerging Europe. This paper studies spillovers from the euro area to Poland, specifically seeking to answer one question: to what extent developments in the euro area drive Poland's output, inflation, and interest rate dynamics. Poland makes a nice case for studying this issue, being a small open economy with extensive trade and financial linkages with euro area countries. For example, in 2011 over half of Polish exports went to euro area countries, and about sixty percent of the Polish banking system is owned by core euro area banks. Business cycles in Poland and the euro area have also become increasingly synchronized.[1] It is therefore crucial for policy making and forecasting to understand the impact of international shocks on the economy and analyze their transmission mechanisms in an internally and externally consistent framework.

We build a semi-structural, forward-looking, two-country model with emphasis on cyclical dynamics of the economy. The model uses a small number of behavioral equations, derived from economic theory (although not fully developed from micro foundations), to characterize the evolution of key macroeconomic variables, such as output, inflation, interest rate, and the exchange rate. Linkages between Poland, modeled as a small open economy, and the euro area work through both real and financial channels. We introduce cross-border links in the interbank market premium to capture the early transmission of financial stress, especially in periods of market turmoil, as observed at the start of the 2008-09 crisis. Model parameterization is based on an extensive calibration process, and we provide an evaluation of the model's properties. Our model allows for identification of key structural shocks, notably country-specific and common (or global) demand shocks. The model is suited for medium-term forecasting and for constructing counterfactuals for policy analysis.

Our results suggests that Poland's economy has become more susceptible to external shocks. For example, foreign shocks (of either euro area or global origin) on average account for a little over half of Poland's output volatility, and about a quarter of its inflation cyclical dynamics. Poland's exchange rate flexibility has played a key stabilizing role. The results using the semi-structural model are consistent with evidence from a VAR model analysis of the Polish economy in Andrle, Garcia-Saltos, and Ho (2013).

The paper is organized as follows. In Section II we describe the model structure. In Section III we discusses model parameterization. Selected results from model simulation are pre-

[1] For example, the simple correlation in quarterly year-on-year growth rates for the post-2004 period is 0.81.

sented in Section IV, and in Section V we conclude with the main take-aways from our analysis.

II. A Model of Poland and the Euro Area

A. Modeling philosophy

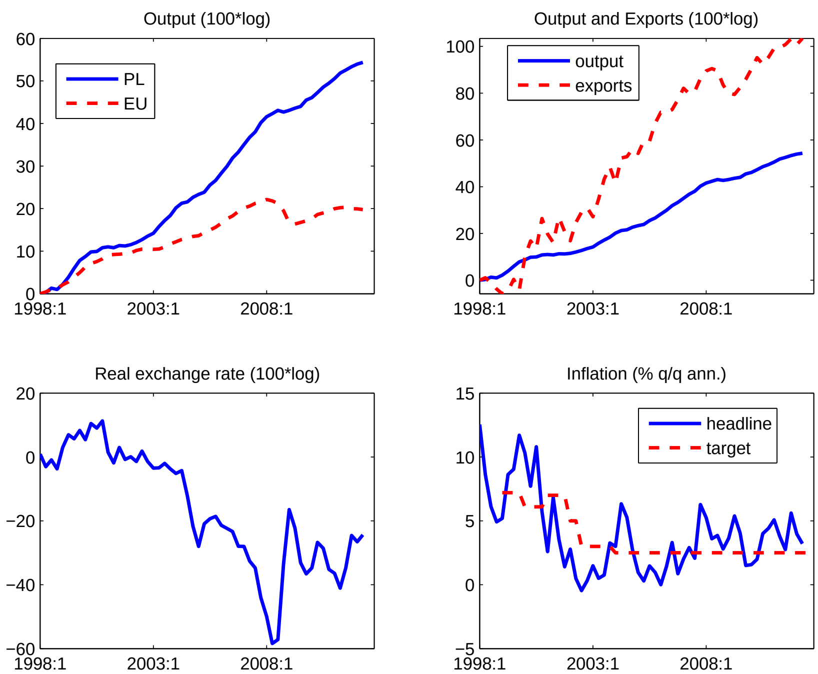
The model is built and designed top-down, with an eye on its aggregate properties, while also being informed by observed data. We impose much of the discipline brought by structural dynamic stochastic general equilibrium models (DSGE) but relax their strict assumptions when deemed useful.

The model is trend-cyclical, i.e. it focuses on business cycle dynamics of the data in a structured way. Trends are characterized by a system of interlinked stochastic processes, which have economic interpretation but are not based upon explicit optimizing behavior. Modelling Poland's trend developments in a fully structural way is beyond the scope of this paper and would require elements such as the process of income convergence, technology adoption and foreign direct investment, trend real exchange rate appreciation due to the Balassa-Samuelson effect, and variation in the inflation target during the process of disinflation, and others. Further, the differential growth rates between the euro area and Poland or the increase in trade openness (as manifested by increasing export shares in GDP) would require modeling off-balanced growth convergence in a complex way, as suggested by the stylized facts in Figure 1.

We proceed, however, with the assumption that productivity growth shocks drive primarily the low frequencies of the data. The cyclical dynamics due to these productivity shocks then may resemble a demand shock, when the wealth effect results in an increase in output and little change or a small increase in inflation. The cyclical dynamics of the Polish economy seem consistent with the dominance of demand shocks, as exemplified by the positive comovement of the cyclical component of output and the deviation of inflation from the inflation target (Figure 2).

Our model fits into a family of the existing models of the Polish economy. On one hand, there is the National Bank of Poland (NBP)'s projection model NECMOD (see, for instance, Budnik and others (2009) or Greszta and others (2012)), a large-scale econometric model with ad-hoc short-run dynamics, with a relatively limited role for active interest rate policy.[2] And on the other hand, NBP developed a complex, estimated DSGE model SOE-PL (see, for instance, Grabek, Klos, and Koloch (2009)), a medium-size model derived from 'micro foundations,' featuring a full stock-flow consistency. Our model fits in between these two type of models. Compared to SOE-PL, it is a less restricted and less rigorous smaller version of a structural DSGE model, though with a more elaborate version of the foreign block. It shares its focus on cyclical dynamics but the dynamics of trends are modeled jointly with the cyclical dynamics. With respect to NECMOD, our model is more aggregated and relies more on forward-looking dynamics of policy rate and the inflation targeting regime.

Figure 1. Stylized facts – trends

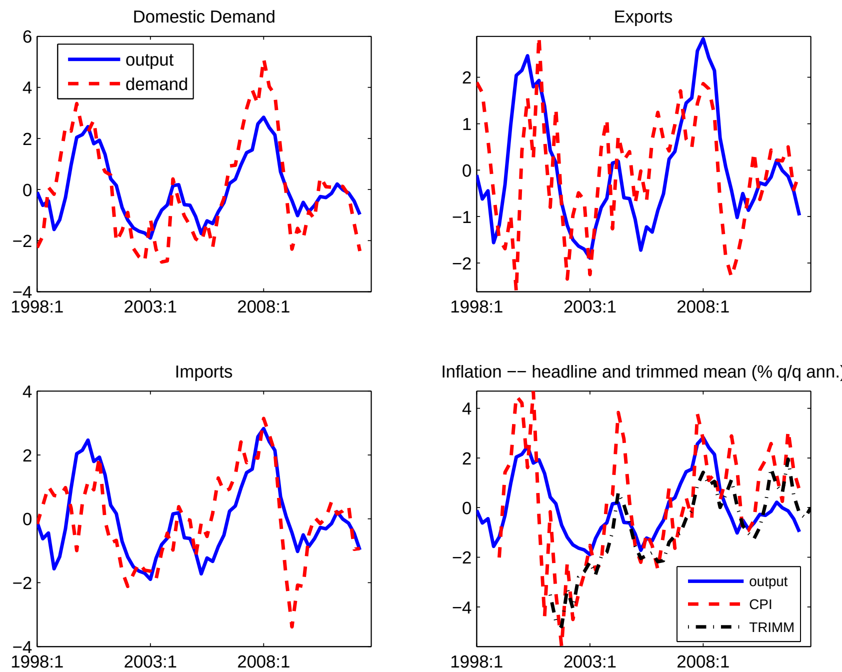


B. Model structure

The model is essentially a one sector, small open economy, New Keynesian model. The real interest rate affects households and firms via intertemporal decisions, forward-looking monetary policy determines the nominal rate of interest, and nominal rigidities are formalized

[2]By *ad hoc* we intend its literal meaning 'for this,' meaning a solution created for a specific problem.

Figure 2. Stylized facts – cycle



Note: Band pass cycles, scaled to output variance in percent. In each subplot, the solid blue line represents output.

using a version of a New Keynesian Phillips curve. The exchange rate ties the domestic and foreign interest rate according to a version of uncovered interest rate parity (UIP). The list of relevant behavioral equations is included in Appendix A.

Notation and units of the model: We use the symbol $*$ to distinguish euro area variables from domestic (Poland) variables, uppercase letters to denote the variables themselves, $\bar{X}$ to denote the trend or equilibrium value of variable X, and lowercase letters to denote deviations from the time-varying trend (so that $x = X - \bar{X}$). Output and real exchange rate deviations are in percent (100×log deviations). Nominal and real interest rates, inflation, unemployment, and the rate of exchange rate depreciation are in percent per annum or annualized, respectively. The frequency of the model is quarterly.

1. Output

Output is determined by the trend and cyclical component. Both the trend, or potential, output and the cyclical component, or output gap, are modeled jointly and aggregate to total output:

$$Y_t = \bar{Y}_t + y_t. \tag{1}$$

The domestic output gap, y_t, is determined by the real interest rate, real exchange rate, and foreign output. The factors behind output dynamics reflect key drivers of consumption, investment, and the trade balance. The expectational dynamics allow for both persistent effects of past shocks and the expected path of real interest rate, real exhange rate, or foreign demand to determine the current output growth:

$$y_t = \beta_1 y_{t-1} + \beta_2 y_{t+1} - \beta_3 [r_t + \hat{\chi}_t] + \beta_4 z_t + \beta_5 y_t^* + \varepsilon_t^{y,iid} + \varepsilon_t^{y,ar} + \varepsilon_t^{cf}. \quad (2)$$

The real interest rate and the real exchange rate affect both output and inflation and capture the monetary policy of the central bank. It is the real interest rate deviation from its trend rate $r_t = R_t - \bar{R}_t$, that is relevant for decisions of households and firms. The real interest rate is defined using the Fisher relationship $R_t = I_t - \pi_{t+1|t}$, where I_t denotes the nominal rate of interest. Analogously, it is the real exchange rate deviation from its trend, z_t, that is relevant for the business cycle dynamics and inflation.

We acknowledge that the real interest rate relevant for households and firms may differ from the risk-free policy rates. We augment the risk-free rate with an exogenous interest rate premium, $\hat{\chi}$. We use the observed difference between the policy rate and the interbank lending rate (WIBOR in Poland) to define the premium resulting from the increased counter-party risk at interbank markets, as observed during the Great Recession. In reality, borrowers also face an external finance premium—see for instance Bernanke and Gertler (1989) for description of financial accelerator mechanism—which evolves in a countercyclical manner as illustrated also during the recent global financial crisis. We reflect the accelerator mechanism directly in our calibration of semi-structural parameters and as a part of the shock to demand ε_t^{ar}.[3]

Finally, there are two different types of demand shocks in the model. The first is a domestic demand shock, ε_t^{ar}, whereas the second is a common (global) demand shock to both Poland and the euro area, ε_t^{cf}. The effects of those two shocks are different, since the latter impacts both economies and thus contributes to a global increase in resource utilization and demand pressures. Whether there is a truly global demand shock is an interesting question. The literature on common world and regional cycles, for example Matheson (2013) or Kose, Otrok, and Prasad (2012), suggests there are strong commonalities across countries, but the analysis is a

[3]Consider the simplest case of the external finance premium deviation from trend, say $xfp_t = \kappa y_t + \varepsilon_t^{xfp}$, where the premium responds to output cycle. By substituting such a premium into (2), the output gap equation remains unchanged, but the semi-structural parameters change, i.e. the coefficient on the real interest rate would increase. That is a spirit of a financial accelerator. The shock to the premium would not be distinguishable from a demand shock. More complex formulations are possible but for parsimony principles we opt out from using the external finance premium formulation.

reduced-form one. The common shock, due to its distinct impulse response function, is identified and picks up the comovement unexplained by other factors and spillovers. The demand shock ε_t^{ar} is autocorrelated with persistence ρ^{ar}, the common demand shock persistence is ρ^{cf}.

Having specified the cyclical component of output, the determination output is completed by specifying the trend, or potential, level of output. Our specification follows Carabenciov and others (2013) and defines the trend output using a version of a local linear trend model. Trend output is subject to level and growth rate shocks, with a well-defined steady-state output growth that it converges towards:

$$\begin{aligned} Y_t &= \bar{Y}_t + y_t && (3) \\ \bar{Y}_t &= \bar{Y}_{t-1} + \mu_t/4 + \varepsilon_t^{\bar{Y}} && (4) \\ \mu_t &= \rho_\mu \mu_{t-1} + (1-\rho_\mu)\mu_{ss} + \varepsilon_t^{\mu}. && (5) \end{aligned}$$

For simplification, we postulate a complete trend-cycle dichotomy between the output's trend and cycle components. In reality, there are likely to be permanent productivity shocks hitting the Polish economy, which induce cyclical dynamics and wealth effects associated with expected long-run gains in productivity (for instance foreign direct investment and technology adoption). Part of those shocks will be picked up in our demand shocks.

2. Unemployment

The specification of unemployment follows a dynamic version of Okun's law. Unemployment's cyclical dynamics make use of a robust empirical regularity in the relationship between unemployment and output, or Okun's law:

$$u_t = \alpha_1 u_{t-1} + (1-\alpha_1)\alpha_2 y_t + \varepsilon_t^u. \qquad (6)$$

The unemployment gap u_t is a function of its lagged value, the contemporaneous output gap, and a disturbance term ε_t^u. Although unemployment does not interact with the rest of the model in important ways, this equation allows us to exploit observed unemployment data. Okun's law is used only to back out the likely path of unemployment, given other variables, and does not contribute to identification of structural shocks in our framework.

3. Inflation dynamics

Inflation dynamics are modeled in two steps, with headline and core inflation rates being defined. Core, or underlying, inflation is driven by the New Keynesian Phillips curve that ties current inflation to expected inflation and shocks that hit the economy. Domestic demand pressures are represented by the output gap, y_t, while the real exchange rate gap, z_t, reflects the exchange rate pass-through on inflation. Headline inflation combines core inflation and direct effects of oil prices:

$$\pi_t^{core} = \lambda_1 \pi_{t+1}^{core} + (1-\lambda_1)\pi_{t-1}^{core} + \lambda_2 y_t + \lambda_3 z_t + \lambda_4 lrpoil_t + \varepsilon_t^{\pi_{core}}, \text{ and} \tag{7}$$

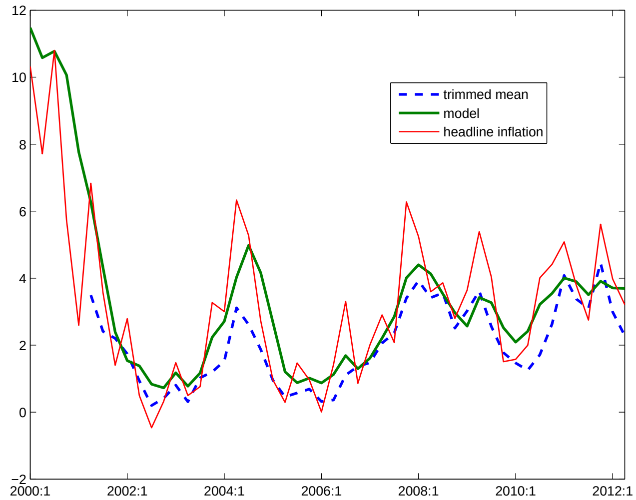
$$\pi_t = (1-\omega)\pi_t^{core} + \omega \pi_t^{oil} + \varepsilon_t^{\pi}. \tag{8}$$

The homogeneity of the inflation process, as indicated by the weights on lead and lagged inflation summing to one, is a crucial property of the model. There is nothing in (7) that pins down the steady-state level of inflation. The long-run level of inflation is uniquely determined by the decision of a monetary policy authority. The coefficients $\lambda_{2,3,4}$ play a complex role determining jointly the weight of each inflation driver in the real marginal costs and their speed of pass-through. In a fully structural model, the coefficient λ_1 would be determined by the discount factor and the degree of indexation to past inflation or inflation target for firms that do not re-optimize their prices in the current period, see Christiano, Eichenbaum, and Charles L. (2005), and the value of λ_1 would be smaller than $1/2$. The semi-structural nature of the model respects the homogeneity, but does not restrict the coefficient in absolute terms. The degree of nominal rigidity is determined largely by the slope of the Phillips curve.

Core inflation is unobservable in our model, that is we do not use observed data on core inflation. Our definition of core inflation differs from the often-used concept of CPI excluding food and energy components. While we exclude the direct impacts of oil on core inflation, the gradual pass-through of oil prices into other price categories is captured via a deviation of the real price of oil from its trend, $lrpoil$, in (7). Core inflation identified by our model is close to a trimmed mean measure of inflation, as seen in Figure 3, without the model using the trimmed-mean inflation data.[4]

[4] National Bank of Poland (NBP) provides multiple measures of “core inflation”, including the 15% trimmed mean measure.
See `http://www.nbp.pl/homen.aspx?f=/en/statystyka/core.html`

Figure 3. Model-based "core" inflation versus trimmed mean inflation



Note: Q/Q annualized growth rates, seasonally adjusted

The model structure captures both the short-run and medium-term propagation of oil prices in both economies. The gradual pass-through of oil prices via the real oil price gap is key to potential second-round effects of oil prices and the reaction of monetary policy to those effects. On the other hand, the immediate impact of oil prices on headline inflation via energy intensive final goods, transportation, and fuels is hard for monetary policy to counter, but has only a short-lived impact. The real price of oil follows an exogenous process and also responds to the global output cycle.

There is a clear distinction between the effects of two cost-push shocks in the model. The cost-push shock ε_t^{core} is a *long-lived* cost-push shock. It is a supply-side shock, which propagates through the economy for several quarters with a negative impact on aggregate demand due to the reaction of the monetary policy authority. However, quarter-on-quarter dynamics of inflation contain a great deal of non-persistent, high-frequency volatility, which often can be explained by spikes in oil prices and exchange rate. Other times this volatility is unexplainable by fundamentals. Joint modeling of a *short-lived* cost-push shock, ε_t^{π}, with the long-lived one allows the short-lived shock to pick-up the high-frequency volatility in cases when fundamentals do not. The shock also works as a time-varying weight in the log-linear identity (8).

4. Exchange rate dynamics

An important part of international comovement is due to interconnected financial markets and international arbitrage among many types of assets. In the model, financial arbitrage is operationalized by a modified version of the uncovered interest parity (UIP):

$$I_t = I_t^* + 4 \times (S_{t+1}^e - S_t) + \overline{FXPREM}_t + \varepsilon_t^S \tag{9}$$

$$\bar{R} = \bar{R}_t^* + g_{Z,t} + \overline{FXPREM}_t. \tag{10}$$

Equation (9) is uncovered interest parity (UIP), and equation (10) is a long-run version of UIP which connects the trend component of real interest rates and trend real exchange rate depreciation. This dual specification guarantees economic consistency among trends in the model, and makes only the cyclical dynamics of interest rates and exchange rate subject to the arbitrage condition. While the UIP hypothesis is sometimes considered empirically implausible, Baxter (1994) investigates the hypothesis and finds evidence of the relationship between real exchange rates and real interest rate differential at both trend and business cycle frequencies.

The exchange rate expectations, $S_{t+1|t}^e$, can deviate from pure model-consistent expectations, $S_{t+1|t}$. Our specification follows Benes and others (2003) and postulates that the expectation is a weighted average of model-consistent expectations and the past level of the exchange rate (taking into account the trend real appreciation), specifically:

$$S_{t+1|t}^e = \delta S_{t+1|t} + (1-\delta)\left[S_{t-1} + 2 \times (g_{Z,t} - \pi_{ss}^* + \pi_{tar,t})/4\right]. \tag{11}$$

5. Monetary policy

The monetary policy authority sets the nominal rate of interest and determines the inflation target. The policy interest rate (I_t) is determined by an inflation-forecast-targeting interest rate rule:

$$I_t = (1-\gamma_1)[(\bar{R}_t + \pi_{t+1}^{tar}) + \gamma_2(\pi_{t+4}^{yoy} - \pi_{t+4}^{tar}) + \gamma_3 y_t] + \gamma_1 I_{t-1} + \varepsilon_t^I \tag{12}$$

The central bank aims to achieve a policy rate on average that is the sum of the equilibrium real interest rate and the announced inflation target $(\bar{R}_t + \pi_{t+1}^{tar})$, while adjusting the rate in response to deviations of the expected year-on-year inflation rate from the target $(\pi_{t+4}^{yoy} - \pi_{t+4}^{tar})$ and to the current output gap. In so doing, the central bank also attempts to smooth out movements in the policy rate (lagged term).

The inflation target is public knowledge and assumed to be fully credible. On purpose, the model does not explicitly account for issues related to imperfect credibility of the inflation target or actions of the monetary policy authority. The inflation target is operationalized using an exogenous process:

$$\pi_t^{tar} = \pi_{t-1}^{tar} + \varepsilon_t^{\pi_{tar}}, \tag{13}$$

hence the changes in the target are perceived as permanent. In the case when an anticipated time-varying path is announced in advance, the information set of agents can be augmented to cover the whole path in all of our modeling exercises and use.

6. Euro area block

The euro area block follows a New Keynesian model of a closed economy. The euro area economy is assumed to not be affected by economic developments in Poland given the relative size of the two economies. The cyclical dynamics of the EA model are determined by:

$$y_t^* = \beta_1^* y_{t-1}^* + \beta_2^* y_{t+1}^* - \beta_3^*[r_t^* + \hat{\chi}_t^*] + \varepsilon_t^{y^*,iid} + \varepsilon_t^{y^*,ar} + \varepsilon_t^{com} \tag{14}$$

$$\pi_t^* = (1-\omega^*)\pi_t^{core^*} + \omega^* \pi_t^{oil^*} + \varepsilon_t^{\pi^*} \tag{15}$$

$$\pi_t^{core^*} = \lambda_1^* \pi_{t+1}^{core^*} + (1-\lambda_1^*)\pi_{t-1}^{core^*} + \lambda_2^* y_t^* + \lambda_4^* lrpoil_t + \varepsilon_t^{\pi_{core^*}} \tag{16}$$

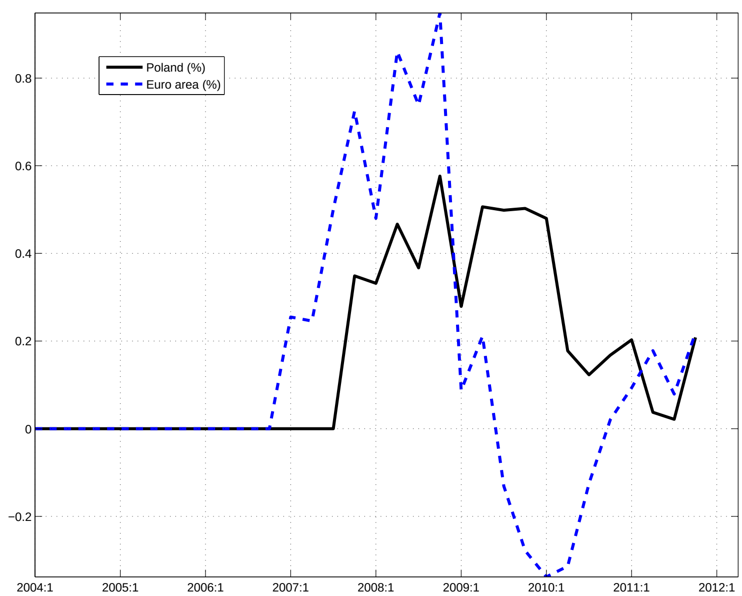
$$I_t^* = (1-\gamma_1^*)[\bar{R}_t^* + \pi_{t+1}^{tar^*} + \gamma_2^*(\pi_{t+4}^{yoy^*} - \pi_{t+4}^{tar^*}) + \gamma_3^* y_t^*] + \gamma_1^* I_{t-1}^* + \varepsilon_t^{I^*} \tag{17}$$

C. Linkages and spillovers

Our model incorporates the traditional macro-financial linkages, that is the interest rate, exchange rate, and trade channels. These traditional channels explain well the majority of historical recessions that were precipitated by central banks tightening the policy rates in response to demand pressures. Traditional channels should not be underestimated, as they form a powerful source of international shock transmission. However, the more recent crises, in particular the 2008-09 global financial crisis, were caused by shocks that were primarily financial in nature. Financial developments (including asset price movements) played a precipitating role and served as a mechanism of propagating the crisis across markets and across countries. Although the arbitrage principle embodied in uncovered interest parity ensures close links between the euro area and Polish interest rates, macro-financial linkages can be strengthened.

The changing nature of business cycles and cross-border linkages makes it necessary to find ways to introduce into macro models other types of macro-financial linkages, over and beyond the standard interest rate and exchange rate effects.[5] We attempt to do it via the interbank market premium and a global demand shock. Our measure of the interbank market premium is the spread between an interbank lending rate (3-month WIBOR for Poland, 3-month EURIBOR for euro area) and the policy interest rate. This spread is close to zero in normal times, but a rising spread can be an indicator of funding pressures in the interbank market during a crisis. Figure 4 shows that at the peak of the 2008-09 crisis, when Lehman collapsed in 2008Q3, the EURIBOR premium reached over 90bps, and the WIBOR premium almost 60bps.[6]

Figure 4. Interbank market premium



We model the interbank market premiums as exogenous processes, with cross-country spillovers:

$$\chi_t = \rho^{\chi}\chi_{t-1} + (1-\rho^{\chi})[\chi_{SS} + \psi(\chi_t^* - \chi_{SS}^*)] + \varepsilon_t^{\chi}, \text{ and} \quad (18)$$

$$\chi_t^* = \rho^{\chi^*}\chi_{t-1}^* + (1-\rho^{\chi^*})\chi_{SS}^* + \varepsilon_t^{\chi^*}. \quad (19)$$

We treat the premiums as exogenous, since they tend to be fast-moving financial indicators triggered by liquidity problems in the interbank market. Therefore, they are largely independent of the real economy. The parameter ψ governs the strength with which strains in the euro

[5] See, for instance, Carabenciov and others (2013) for a discussion.

[6] We set the pre-crisis premium, which were sufficiently close to zero, to exactly zero.

area's interbank market are transmitted to the Polish interbank market, and captures the high correlation of premium observed in the data.[7] The magnitude of spillovers also depends critically on the degree of persistence in the premium process (ρ^{χ^*}), that is how long agents expect financial markets in the euro area to remain unsettled. High premiums negatively affect real output, as specified in equations (2) and (14), potentially through a squeeze of credit supply as a result of liquidity dry-up in the interbank market. An advantage of this variable is that it is available in a timely manner, possibly well in advance of output developments, and therefore could be fed into the forecast, particularly in unusual episodes. The disadvantage is that, by narrowly focusing on the first signs of trouble in financial markets that are not picked up by normal interest rate movements, its potential impact on real economic activity can be limited.

Our model also incorporates a common demand shock. The stylized shock is motivated by empirical findings that common or global shocks, as opposed to country-specific shocks, are the prominent source explaining international business cycle synchronization (see for instance work by Bordo and Helbling (2010); Matheson (2013)). The persistence of the common demand shock is set identical to the persistence of the euro area demand shock, so the effect of both is the same in the euro area. The identification of a common demand shock is thus determined by the reaction of the Polish economy. It turns out that the important aspect of the data that identifies the common shock is the reaction of the real exchange rate.

D. Data

We use six observable variables for Poland, four for the euro area, and oil prices. The variables used for Poland's economy are: real GDP, CPI inflation, the short-term nominal interest rate, the interbank premium, the nominal exchange rate, and the inflation target. For the euro area's economy the variables are output, headline CPI inflation, policy rate, and the interbank market premium.[8] The oil price is BRENT. Data are quarterly, and the sample spans 1999Q1-2012Q2.

[7] Kollmann, Enders, and Muller (2011) provide a micro-founded theory for the international transmission of financial shocks by incorporating a "global bank" into a two-country business cycle model.

[8] We use the output gap estimate from the Global Projection Model with six regions, see e.g. Carabenciov and others (2013).

III. MODEL PARAMETERIZATION

We choose to calibrate the parameters of the model. Bayesian estimation was considered, but did not give robust results given the short sample (1999Q1 – 2012Q2) and questionable data quality. In our modeling strategy we do not aim to build a model as a true data-generating process. Instead, we see it as an eclectic approach to deal with policy analysis a forecasting. Calibration allows us to blend data evidence, empirical results from other studies, and our prior judgements on the model's behavior in a flexible way. [9]

Our parameterization aims to balance the story-telling power of the model with good multiple-step ahead projection properties, coherence of model's first and second moments with the data, and economic plausibility of impulse response functions. In principle, we make use of so-called 'system priors' (see Andrle and Benes (2013)) in our calibration process. System priors seek to guide the estimates of model's parameters that are consistent with a priori aggregate properties of the model. For example, a demand shock is restricted to deliver a positive response of inflation and interest rates, with inflation returning to the target in no more than three years. Another example is the prior about the sacrifice ratio – the cumulative output loss after a permanent disinflation, which requires knowledge about the recent state of the economy, the degree of monetary policy transparency, and nominal rigidities, etc. In general, system priors impose discipline on a combination of dynamic parameters to ensure the model generates sensible key properties, where sensibility is judged by both economic theory and empirical evidence. This is especially important when the model is used in forecasting mode, i.e., when it becomes part of the data generating process.

There are three groups of parameters. We distinguish coefficients affecting the steady-state, the dynamics, and the stochastic processes. The steady-state values are set to reflect longer-term tendencies of the variables and economic theory. Dynamic parameters are determined by in-depth analysis of impulse-response behavior of the model, and–after stochastic parameters are set–their estimates are finalized. The calibrated values for selected parameters are listed in Tables 1 and 2 in Appendix B.

The values of steady-state coefficients reflect the trend development of both economies. Note that the flexible local linear trend specification of trend output, the real exchange rate, etc. allows for persistent deviation of the trend rate of change from the constant, steady-state growth

[9] It is well known in the literature that maximum likelihood is the best choice in the case of the true model. Slight misspecification, however, can have disastrous consequences. In our case, the maximum likelihood equivalence to one-step-ahead forecast error minimization is also inconsistent with our emphasis on multi-step prediction capabilities of the model, see e.g. Tiao and Xu (1993).

and real exchange rate appreciation. It is our prior that trends should be relatively smoother than the actual path of variables, representing mostly low-frequency dynamics of model's variables.[10] We set the steady-state growth of the Polish economy to 3.5%, annualized, and 2% for the euro area. Steady-state inflation in Poland is 2.5%, in line with NBP's official inflation target, and 1.9% in the euro area. We set the inflation target process as a random-walk and respect the path and announcement of all changes in the inflation target since 1998, using the mean of the tolerance band. The trend real interest rate is 2.5% in the steady-state in Poland and 2% in the euro area. Finally, the steady-state real exchange rate appreciation is 3.5% per year, consistent with the data. The steady-state levels of interbank premiums are zero.

As mentioned above, an important concept is the sacrifice ratio. The baseline calibration, in the case of perfectly credible monetary policy, implies the sacrifice ratio in Poland to be roughly 0.4%, smaller than one would expect in the euro area. This is one of the most sensitive statistics to parameterization, a concept that is only weakly identified by the data on a particular country. The calibration reflects the recent state of the economy, a transparent monetary policy, and the relatively smaller degree of nominal price and wage rigidities than in the euro area, see Brzoza-Brzezina and Socha (2007). Other important parameters include the forward-looking coefficient of the Phillips curve, $\lambda_1 = 0.45$. The central bank's interest rate rule features a significant degree of inertia, $\gamma_1 = 0.75$, with a strict adherence to inflation targeting with the weight on projected deviation from the target, $\lambda_2 = 1.75$, and on the output gap, $\gamma_3 = 0.25$.

The role of oil prices is limited in our baseline calibration. That is not to say that oil prices are not important for developments in the euro area and in Poland. The weight on oil –both via direct and indirect effects– is calibrated to be larger in the euro area than in Poland. In Poland, the direct effect was set close to zero, for parsimony, and the indirect, gradual effect is $\lambda_4 = 0.001$. One reason is the role of administrated prices and energy regulation.[11] Further, our model focuses on underlying inflation pressures, with our concept of unobserved core inflation close to a trimmed mean measure of inflation, rather than headline excluding food and energy. In essence, our measure works as a lower envelope of all core inflation measures in Poland since 2003, see e.g. (NBP, 2012, pp. 26, Fig. 2.4).

[10] Unless a priori restrictions are imposed on the estimation, or with misspecified models, the trend component estimates may turn out rather volatile due to a 'pile-up' problem, see Stock and Watson (2005). Theory implies that the natural rate of output or natural rate of interest rate can be very volatile, as implied by the New Keynesian models.

[11] We find that in Poland oil prices (in national currency) hardly explain the wedge between headline inflation and inflation excluding food and energies, while in the euro area the alignment is much stronger (Figure 21).

Stochastic parameters were set to further advance the consistency of the model with the covariance structure of the data, and our priors about the structural interpretation of past data by the model. Unlike the impulse-response functions, the population correlations and spectral density of model variables are functions of all parameters, and offer testable implications. Additional restrictions were based on the plausibility of the structural shock interpretation of past developments, reflecting the narrative evidence and other studies, such as Brzoza-Brzezina, Makarski, and Wesolowski (2012). In particular, our calibration of the relative standard deviation of domestic, euro area and common demand shocks also reflect findings from VAR analyses of the roles of domestic and external shocks in Poland's economy (see a companion paper Andrle, Garcia-Saltos, and Ho (2013)).

IV. Model Properties & Evaluation

This section provides a discussion of model properties along many dimensions and examines the spillovers between the euro area and Poland. Specifically, we present selected impulse-response functions of the model, forecast-error variance decompositions, and population cross-correlations of the model. Using the actual data, we interpret the economic developments in Poland using historical shock-decomposition analysis, and provide a conditional recursive forecasting exercise to assess the forecasting properties of the model.

A. Impulse response functions

We present a selected set of impulse response functions (IRFs) from model simulations (Figures 5 to 12). All shocks are of one standard deviation in their magnitude.

A demand shock in Poland (Figure 5) puts pressure on core and headline inflation, triggering a hike in the policy interest rate and real exchange rate appreciation. Foreign variables remain unchanged due to the small-open-economy assumption. The peak response of inflation is roughly one third of the peak response of output. The inflation response is limited, as some increase in demand can be satisfied from abroad. The monetary policy authority manoeuvres the interest rate in such a way as to guide the inflation back to the target, which takes about two and a half years.

Figures 6 and 7 show the responses to a negative demand shock from the euro area versus the common world shock, respectively. A 1.5 percentage point drop in euro area's output gap reduces home output gap by about 0.5 percentage point, dampening inflationary pressures, decreasing the policy interest rate and causing the real exchange rate to depreciate (which mitigates the negative effect on output). While similar, the responses are amplified in the case of a common shock, since Poland would be affected not only directly but also indirectly through weakening demand in the euro area. As a result, there is a larger drop in headline and core inflation, a larger reduction in the policy interest rate, and a stronger depreciation of the exchange rate. In fact, it is the differential effect on Poland's observed exchange rate that helps identify a common shock from a euro area demand shock.

A shock to home core inflation, or a cost-push shock (Figure 8), triggers reaction by the central bank to increase the policy rate. Output falls in response to the real exchange rate appreciation and expected increase in the real rates to curb the inflationary shock. Thus, unlike a demand shock, a cost-push shock moves output and inflation in opposite directions. This is a key identifying restriction the model uses when interpreting the available data evidence. Note that the cost-push shock in our model has a negative effect on output solely due to a monetary policy tightening. A monetary policy shock (Figure 9) reduces inflation as well as output.

The effects of permanent disinflation can be studied with a permanent shock to the inflation target (Figure 10). As expected, nominal variables (inflation, policy interest rate, and nominal exchange rate) settle at a new, lower level after about two years. Recall, that the model assumes perfect credibility of monetary policy. There is some short-run monetary policy inertia resulting in a persistent increase in the real interest rate. Disinflation thus has persistent recessionary effects, and it takes about three years for the output gap to return its original level. In this regard, the sacrifice ratio – the cumulative output loss required to reduce the inflation rate by one percentage point – is a simple measure to evaluate the cost of disinflation. This ratio amounts to about 0.5 percentage point. We consider the disinflation shock as a key shock that illustrates a purposeful monetary policy.

A temporary nominal exchange rate depreciation of 10 percent, due to a transitory change in the exchange rate premium, leads core inflation to increase by about 0.3 percentage point on impact (Figure 11). The depreciation accumulates to about 1.5 percentage points by the tenth quarter. The output gap is higher, as the weaker exchange rate boosts exports but also due to the lower real interest rate resulting from higher inflation.

Finally, a shock to the euro area's interbank market premium is depicted in Figure 12. A 100 basis points rise in the EURIBOR spread is estimated to raise Poland's WIBOR spread by about 20 basis points a few quarters later, which can then take a long time to return to normal levels. Poland's output gap is lower by over 0.2 percentage points, which results not only directly from the impact on domestic demand but also indirectly from weaker foreign demand.

B. Correlation analysis

The cross-correlation structure of model variables is affected by all parameters. Empirically meaningful cross-correlations require both the dynamic responses of the model to be realistic and the relative variances to match the structure of the economy. The cross-correlation of key economic variables were also used to assess the empirical plausibility of the model. In Figure 13, the cross-correlations of the model are contrasted to estimates using the available data. The cross-correlation of core inflation and cyclical component of output is in line with the data evidence both in Poland and in the euro area. The data counterpart of core inflation is in both cases a trimmed-mean measure of core inflation. Figure 13 also depicts the cross-correlation of domestic and foreign output at cyclical frequencies and the cross correlation of nominal interest rates. While underestimating the cross-correlation of output gaps, the model tends to overestimate the comovement of nominal interest rates.

C. Variance decomposition

The forecast error variance decomposition (FEVD) with forecast horizon up to twenty quarters is depicted in Figure 14. FEVD reveals the importance of various shocks as they propagate through the model and, most importantly, sheds light on the role of common shocks and spillovers. Results suggest that foreign demand shocks (euro area and common) are particularly important in driving output, inflation, and interest rate dynamics in Poland. For example, about 50 percent of the output variance is due to foreign shocks, of which one third is the demand shock from the euro area. Foreign shocks also account for about 25 percent of inflation variance and about 60 percent of interest rate variance. The remaining variance of inflation is due to 'long' and 'short' cost-push shocks and exchange rate shocks. Domestic demand shocks affect inflation in a modest way due to the small-open-economy nature of the Polish economy. Shocks to the euro area's interbank market premium, however, do not play a material role in driving Poland dynamics, since the shock is calibrated to be of a small magnitude. Finally, common demand shocks explain a significant fraction of euro area's output and interest rate variance (about 30 percent), though not so much of inflation. Inflation in Poland is influenced great deal by cost-push, exchange-rate, and commodity price shocks.[12]

The results are in line with empirical VAR estimates from a companion paper, Andrle, Garcia-Saltos, and Ho (2013), and seem intuitive for a small open economy with extensive links to the euro area. One contribution of our analysis is that the semi-structural model allows us to separately identify common and euro area shocks. However, our results on the relative importance of common shocks are still substantially lower than estimates in Matheson (2013), which finds that global and regional shocks explain over 70 percent of the GDP growth dynamics in advanced Europe and Poland. Our results, however, differ from an estimated DSGE model of the Polish economy by Grabek, Klos, and Koloch (2009), where the role of foreign variables is smaller in general. In a model built using a comparable sample after 1999, world shocks account for only 15% of output variance in the first quarter and only 5.6–3.3% from the fourth quarter up to the twentieth quarter.

The key role is played by dominant demand shocks and also the existence of a correlated demand shock in the model. Justiniano and Preston (2008), for instance, document the failure of open economy DSGE models to mimic the cross-correlation patterns between the US and Canadian economy, even after adding correlated shocks. The lack of spillovers in modern DSGE models seem to be due to the dominance of technology shocks as a source of business cycle dynamics. Technology shocks, however, shift the production possibility frontiers and induce strong consumption sharing and cross-border investment, resulting in small output co-movement.

D. Policy analysis

A distinct advantage of structural and semi-structural models over other methods is the ability to construct counterfactuals for policy analysis. There are a number of counterfactuals that could be explored with our model, depending on questions asked. We present two experiments for demonstration purposes – a delayed policy response to a demand shock and an increased persistence of the euro area interbank market premium shock.

As for the first experiment, we examine a situation in which there is a negative demand shock in the euro area but the monetary policy reaction is delayed (Figure 15). In particular, the first

[12]All of our computations assume constant inflation target. Otherwise unconditional inflation variance would become unbounded and unrealistic.

scenario assumes that the ECB is constrained by the binding zero lower bound and thus cannot lower the nominal interest rate for four quarters. In the second scenario, the ECB's monetary policy rate can adjust, but Poland's central bank delays its reaction by one quarter, for example due to concerns over the impact of rising global risk aversion on the exchange rate (and therefore inflation, given pass-through).[13] In each case, markets are assumed to fully anticipate the central bank's inaction and act accordingly.[14] These two scenarios are compared with the baseline, in which monetary policy in both regions responds instantaneously to the negative demand shock. Importantly, we do not assume the output shock in the euro area to be too long-lasting, nor do we assume a sequence of adverse demand shocks, as has been the case during the Great Recession or recent sovereign crisis.

Simulation results suggest that if the ECB delays its action or the rate just simply cannot adjust, Poland's output falls by an additional 0.1 percentage point compared to the baseline, but the decline in inflation is smaller by 0.25 percentage points. The extra impact on output does not seem severe, since there are two opposing effects: a negative external demand effect and a positive exchange rate effect. On one hand, euro area's output is lower due to the lack of monetary policy support, which then affects Poland through direct trade channel. On the other hand, the immediate reduction in the domestic interest rate–with the euro-area rates unchanged–brings about a larger real depreciation, mitigating the negative output response by supporting net exports. Exchange rate pass-through causes inflation to decline by less than in the baseline. If markets believe that the NBP would delay reducing the policy rate by one quarter, the economy suffers from a deeper downturn compared to the baseline, and inflation also drops by more in the absence of a pass-through effect from the exchange rate.

In the second experiment, we study an increase in the euro area's interbank market premium, but the shock is perceived to be more persistent (Figure 16). If markets expect the interbank lending and borrowing will remain impaired for a longer period of time, the cutback in production would be more substantial. Shock persistence is primarily governed by the autocorrelation parameter of the process for the euro area's premium (ρ^{χ^*}). Thus, in this counterfactual, we set a slightly higher persistence ($\rho^{\chi^*} = 0.85$) than the baseline ($\rho^{\chi^*} = 0.79$). As expected, a more persistent increase in the premium is associated with a larger reduction in output (via both trade and financial channels) and inflation relative to the baseline. In response, Poland's central bank reduces the policy rate more aggressively by an extra 20 basis points.

[13]Delayed monetary policy reaction does not mean in this case a zero lower bound, an issue Poland has not yet faced.

[14]The relevant information is for how many periods the agents perceive the central bank to be passive, even if the bank would react sooner.

The experiment illustrates the need to explore the robustness of model properties to shock specification.

E. Estimates of trends and structural shocks

We use the model and available data to identify all unobservable variables – trend values and structural shocks. The identification of shocks and trends is the key input to forecasting and policy analysis. The structural interpretation of the data is model-dependent and constitutes an important litmus test for the sensibility of the model.

We present the simulated equilibrium variables, as well as the implied output gap and core inflation in Figure 17. Recall that neither core inflation in Poland nor in the euro area is observed. Yet, our measure of core inflation (i.e. headline inflation stripped of oil price inflation and high-frequency price dynamics) implied by the model captures well a slow-moving component of headline (Figure 3). This core component is correlated with the output gap, as is the observed trimmed-mean inflation correlated with a cyclical component of output. Poland's output gap (unobserved) is also highly correlated with euro area's output gap (observed), although with a much smaller dip in 2009, when Poland was the only EU country to escape a recession.

The estimates of potential output, trend real exchange rate and the neutral real rate of interest are subject to revisions. It is the final estimate of potential output, the equilibrium real exchange rate, and the equilibrium real interest rate for Poland and the euro area that are shown (dashed lines) together with their actual values (solid lines) in Figure 17. The real-time properties of our estimates are not explored in this paper, since during the actual forecasting process these estimates would be subject to a great deal of expert judgment.[15] The equilibrium real exchange rate was appreciating up until 2008, consistent with the convergence hypothesis, but has remained broadly constant post-crisis. [16]

[15]However, the revision variance of potential output growth and output gap are relatively small due to the specification of the stochastic process for the trend. Namely, the GDP trend growth is a mean-reverting process and the output gap is a persistent variable, given by a set of structural equations. For instance, the excessive revision variance of the Hodrick-Prescott filter is driven by the naive assumption that GDP trend growth is a random-walk and the output gap is an uncorrelated white noise. See Andrle (2013) for details of the analysis of the model as an explicit signal-extraction filter.

[16]The increasingly fast rate of real exchange rate appreciation in the run-up to the crisis has been an issue in Poland and other Central European countries, as timely indication how much of the appreciation is due to productivity gains in traded sector and convergence, and what part constitutes disinflationary appreciation undermining the competitiveness of exporters is very hard. Although our model can be a helpful tool in the analysis, other sources of information need to be used.

F. Historical shock decomposition

Historical shock decompositions confirm the prominent role of foreign demand shocks in driving Poland's output and inflation dynamics, particularly in recent years. Figure 18 decomposes the estimated output gap over the 2001Q1-2012Q2 period into relative contributions of various structural shocks, and Figure 19 does the same for the deviation of quarter-on-quarter rate of inflation from the target. The decompositions are essentially the model's interpretation of historical economic developments. Despite their usefulness, they need to be interpreted with care.[17]

1. Output

The output decomposition reveals a remarkable difference between the 2009 downturn and those occurring earlier in the decade. While the earlier downturns were driven primarily by domestic demand shocks, foreign demand shocks (common and euro area) were the ones behind the economic slowdown in 2009 and slowed the recovery in 2010, with the euro area demand contributing on average a little over half of the negative contribution. Foreign shocks have substantially increased in importance since 2006-07 and amplified Poland's business cycle fluctuations, fueling the boom and deepening the bust. By contrast, exchange rate movements have played an instrumental stabilizing role. In fact, real exchange rate depreciation seems to be a major factor supporting Poland's growth during 2009. These findings about the roles of foreign shocks and exchange rate shocks are consistent with estimates in Brzoza-Brzezina, Makarski, and Wesolowski (2012).[18] More generally for emerging Europe, Matheson (2013) found that global shocks explained almost entirely the 2009 growth slowdown.

The contribution of the euro area's shock to interbank market premium to Poland's output volatility is modest and mainly restricted to the onset of the crisis. This is consistent with our intuition that our financial variable captures the very early signs of trouble in financial markets. The continued induced uncertainty gets identified in our framework as a negative demand shock. The model seems to attribute a large part of the current slowdown in the first two quarters of 2012 (the end of our sample) to weakening domestic demand.

[17] Despite assumed independence among shocks, the actual estimates of shocks feature perfect linear combinations since there are more shocks than observed data. The sample covariance matrix of shocks is thus singular.

[18] Using a small open economy DSGE model, the authors simulate Poland's GDP growth in case of euro adoption in 2007 and find that giving up exchange rate flexibility would have taken about 6 to 10 percentage points from 2009 year-on-year growth rate. They also carried out a historical shock decomposition of output using the model, giving broadly similar results to ours with the exception of a larger contribution from "financial" shocks.

2. Inflation

Headline inflation in Poland has been persistently above target for most of the time since 2007. Our inflation decomposition suggests that while demand pressures (both domestic and foreign) played some role in 2008 and early 2009, recent deviations from the target have been driven by exchange rate depreciation (2011) and cost-push shocks most recently.[19] Unlike in the case of the model's underlying inflation, headline inflation variation is is affected more by commodity prices effects and 'short-lived' cost-push shocks. The parameterization of direct and indirect effect of oil in Poland implies smaller effects, mostly through gradual pass-through, due to lower level of observed comovement of inflation dynamics with oil prices in Zloty, than the analogous measure for the euro area (Figure 21). The time-varying nature of the pass-through, not only due to regulation of prices of energy, is then captured by the cost-push shocks. The major effect of cost-push shocks to both core and non-core inflation is in 2004, associated with the Poland's entry into the European Union.

Finally, we note that the contribution of monetary policy shock is small in both output and inflation decompositions. This means that monetary policy in Poland behaves broadly as predicted by the monetary policy rule, i.e. responding to output developments and inflation deviations from target in a Taylor-rule manner. Therefore little of the non-systematic movement in the policy rate is needed for the model to explain output and inflation dynamics.

G. Recursive forecast and conditional forecasting

In addition to understanding past economic developments, the model can be used to forecast future developments. Our model exhibits satisfactory forecasting performance, as indicated by a recursive 8-quarter-ahead forecasting exercise for output, headline and core inflation, and the policy interest rate (Figure 20). As mentioned above, the flexible treatment of equilibrium variables, e.g. allowing permanent shifts in the level of potential output, is important for the model to avoid making systematic forecast errors over a long time period. Our recursive forecast is conditioned on a given inflation target for Poland only. As can be seen from Figure 20, the model captures the cyclical dynamics of variables considered relatively well in terms of tracing the business cycle dynamics of the data, and the directional coherence of forecasts.

[19]We have not investigated a hypothesis of lower credibility of the inflation target but it would be feasible using just a slight modification of our modeling framework.

In the proper real-time forecasting exercise, the forecast for Poland is conditioned on a projected path of foreign variables. Unless perfect foresight is assumed, the way in which conditioning is done matters, especially when there are more shocks than variables in the semi-structural model of the euro area. Note that the structure of the euro area block matters, even though the forecast would be conditioned on a path of foreign variables determined by experts, consensus forecast, or another model.

The recursive forecast exercise in this paper is for model evaluation purposes only. A serious forecast would, apart from conditioning on foreign variables, rely on expert judgement in setting up the initial cyclical position of the economy, the forecast itself, and would make extensive use of high-frequency indicators available for near-term forecasts.

V. Concluding Remarks

In this paper, we build a semi-structural, two-country model with the primary purpose of studying economic and financial spillovers from the euro area (and the world) to Poland. The model focuses on business-cycle dynamics of aggregate output, inflation, interest rate, and the exchange rate, while taking into account key features of the Polish economy in specifying the stochastic trend processes. We calibrate the dynamic parameters of the model by carefully studying its properties, for instance impulse-response behavior and cross-correlation of variables, and by considering empirical estimates in the literature where available. A wide range of model evaluation exercises are provided to acknowledge both strengths and weaknesses of the model.

Our results suggest that foreign shocks play a prominent role in driving Poland's output, inflation, and interest rate dynamics, particularly in recent years. Euro area and global demand shocks account for about half of Poland's output variance and were the main driver of the downturn in 2009, according to the historical shock decomposition exercise. While these shocks tend to amplify Poland's business-cycle fluctuations, the flexible exchange rate represents a key counter-cyclical force. The model also sheds light on Poland's inflation dynamics by evaluating the relative importance of demand pressures, exchange rate shocks, oil price developments, and cost-push shocks.

Finally, we demonstrate the potential usefulness of the model for policy analysis and conditional forecasting. The simple and flexible modeling framework enriches the toolbox of monetary policy analysis and country surveillance and complements purely data-driven tools and expert judgment in medium-term forecasting.

References

Andrle, Michal, 2013, "What is in Your Output Gap? Unified Framework & Decomposition into Observables," Working Paper WP 13/105, International Monetary Fund, Washington DC.

Andrle, Michal, and Jaromir Benes, 2013, "System Priors: Formulating Priors about DSGE Models System Properties," Working Paper WP/13/257, International Monetary Fund, Washington DC.

Andrle, Michal, Roberto Garcia-Saltos, and Giang T. Ho, 2013, "The Role of Domestic and External Shocks in Poland: Results from an Agnostic Estimation Procedure," Working Paper 13/220, International Monetary Fund, Washington DC.

Baxter, Marianne, 1994, "Real exchange rates and real interest differentials: Have we missed the business-cycle relationship?" *Journal of Monetary Economics*, Vol. 33, pp. 5–37.

Benes, Jaromir, Tibor Hledik, David Vavra, and Jan Vlcek, 2003, "The Quarterly Projection Model and Its Properties," in D.M. Laxton, W. Coates, and D. Rose (eds.), *The Czech National Bank's Forecasting and Policy Analysis System*, pp. 63–97 (Prague: Czech National Bank).

Bernanke, Ben, and Mark Gertler, 1989, "Agency Costs, Net Worth, and Business Fluctuations," *American Economic Review*, Vol. 79, No. 1, pp. 14–31.

Bordo, Michael D., and Thomas F. Helbling, 2010, "International Business Cycle Synchronization in Historical Perspective," NBER Working Papers 16103, National Bureau of Economic Research, Inc.

Brzoza-Brzezina, Michal, Krzysztof Makarski, and Grzegorz Wesolowski, 2012, "Would It Have Paid to be in the Eurozone?" Working Paper 128, National Bank of Poland, Economic Institute.

Brzoza-Brzezina, Michal, and Jacek Socha, 2007, "Downward Nominal Wage Rigidity in Poland," Working Paper 41, National Bank of Poland, Economic Institute.

Budnik, K., M. Greszta, M. Hulej, O. Krzesicki, R. Lewinska, K. Murawski, and M. Rot, 2009, "An Update of the Macroeconometric Model of the Polish Economy NECMOD," Working Paper 64, National Bank of Poland, Economic Institute.

Carabenciov, Ioan, Charles Freedman, Roberto Garcia-Saltos, Douglas Laxton, and Ondrej Kamenik, 2013, "GPM6 - The Global Projection Model with Six Regions," Working Paper 13/87, International Monetary Fund, Washington DC.

Christiano, Lawrence J., Martin Eichenbaum, and Evans Charles L., 2005, "Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy," *Journal of Political Economy*, Vol. 113, No. 1, pp. 1–45.

Grabek, Grzegorz, Bohdan Klos, and Grzegorz Koloch, 2009, "SOE-PL 2009 – An Estimated Dynamic Stochastic General Equilibrium Model for Policy Analysis and Forecasting," Working Paper 83, National Bank of Poland, Economic Institute.

Greszta, M., M. Hulej, R. Lewinska, A. Michalek, P. Ponsko, B. Rybaczyk, and B Schulz, 2012, "Re-estimation of the quarterly model of the Polish economy NECMOD 2012," Working Paper July, National Bank of Poland, Economic Institute.

Ho, Giang, and Y. Lu, 2013, "Financial Condition Index for Poland," Working Paper 13/252, International Monetary Fund, Washington DC.

Justiniano, Alejandro, and Bruce Preston, 2008, "Can Structural Small Open Economy Models Account for the Influence of Foreign Disturbances?" NBER Working Papers 14547, National Bureau of Economic Research, Inc.

Kollmann, Robert, Zeno Enders, and Gernot J. Muller, 2011, "Global Banking and International Business Cycles," *European Economic Review*, Vol. 55, No. 3, pp. 407–426.

Kose, A., C. Otrok, and E. Prasad, 2012, "Global Business Cycles: Convergence or Decoupling?" *International Economic Review*, Vol. 53.

Matheson, Troy, 2013, "The Global Financial Crisis: An Anatomy of Global Growth," Working Paper forthcoming, International Monetary Fund, Washington DC.

NBP, 2012, "Inflation Report," Techn. Rep. November, National Bank of Poland, Economic Institute.

Stock, James H., and Mark W. Watson, 2005, "Understanding Changes in International Business Cycle Dynamics," *Journal of European Economic Association*, Vol. 5, No. 3, pp. 968–1006.

Tiao, George C., and Daming Xu, 1993, "Robustness of maximum likelihood estimates for multi-step predictions: The exponential smoothing case," *Biometrika*, Vol. 80, No. 3, pp. 623–641.

APPENDIX A. MODEL EQUATIONS

$$
\begin{aligned}
y_t &= \beta_1 y_{t-1} + \beta_2 y_{t+1} - \beta_3[r_t + \hat{\chi}_t] + \beta_4 z_t + \beta_5 y_t^* + \varepsilon_t^{y,iid} + \varepsilon_t^{y,ar} + \varepsilon_t^{com} && (20)\\
\pi_t &= (1-\omega)\pi_t^{core} + \omega\pi_t^{oil} + \varepsilon_t^{\pi} && (21)\\
\pi_t^{core} &= \lambda_1 \pi_{t+1}^{core} + (1-\lambda_1)\pi_{t-1}^{core} + \lambda_2 y_t + \lambda_3 z_t + \lambda_4 lrpoil_t + \varepsilon_t^{\pi_{core}} && (22)\\
I_t &= (1-\gamma_1)[\bar{R}_t + \pi_{t+1}^{tar} + \gamma_2(\pi_{t+4}^{yoy} - \pi_{t+4}^{tar}) + \gamma_3 y_t] + \gamma_1 I_{t-1} + \varepsilon_t^{I} && (23)\\
I_t &= I_t^* + 4 \times (S_{t+1}^e - S_t) + \overline{FXPREM}_t + \varepsilon_t^{S} && (24)\\
S_{t+1|t}^e &= \delta S_{t+1|t} + (1-\delta)\left[S_{t-1} + 2 \times (g_{Z,t} - \pi_{ss}^* + \pi_{tar,t})/4\right] && (25)\\
\bar{R} &= \bar{R}_t^* + g_{Z,t} + \overline{FXPREM}_t. && (26)
\end{aligned}
$$

$$
\begin{aligned}
y_t^* &= \beta_1^* y_{t-1}^* + \beta_2^* y_{t+1}^* - \beta_3^*[r_t^* + \hat{\chi}_t^*] + \varepsilon_t^{y^*,iid} + \varepsilon_t^{y^*,ar} + \varepsilon_t^{com} && (27)\\
\pi_t^* &= (1-\omega^*)\pi_t^{core^*} + \omega^*\pi_t^{oil^*} + \varepsilon_t^{\pi^*} && (28)\\
\pi_t^{core^*} &= \lambda_1^* \pi_{t+1}^{core^*} + (1-\lambda_1^*)\pi_{t-1}^{core^*} + \lambda_2^* y_t^* + \lambda_4^* lrpoil_t + \varepsilon_t^{\pi_{core^*}} && (29)\\
I_t^* &= (1-\gamma_1^*)[\bar{R}_t{}^* + \pi_{t+1}^{tar^*} + \gamma_2^*(\pi_{t+4}^{yoy^*} - \pi_{t+4}^{tar^*}) + \gamma_3^* y_t^*] + \gamma_1^* I_{t-1}^* + \varepsilon_t^{I^*} && (30)\\
lrpoil_t &= \rho^{oil} lrpoil_{t-1} + (1-\rho^{oil})\theta^{oil,y} y_t^* + \varepsilon_t^{lrpoil} && (31)
\end{aligned}
$$

$$
\begin{aligned}
Y_t &= \bar{Y}_t + y_t && (32)\\
\bar{Y}_t &= \bar{Y}_{t-1} + \mu_t/4 + \varepsilon_t^{\bar{Y}} && (33)\\
\mu_t &= \rho_\mu \mu_{t-1} + (1-\rho_\mu)\mu_{ss} + \varepsilon_t^{\mu} && (34)\\
u_t &= \alpha_1 u_{t-1} + (1-\alpha_1)\alpha_2 y_t + \varepsilon_t^{u} && (35)\\
Z_t &= \bar{Z}_t + z_t && (36)\\
\bar{Z}_t &= \bar{Z}_{t-1} + g_{Z,t}/4 + \varepsilon_t^{\bar{Z}} && (37)\\
g_{Z,t} &= \rho_{gz} g_{Z,t-1} + (1-\rho_{gz}) g_{Z,ss} + \varepsilon_t^{gz} && (38)\\
\pi_t^{tar} &= \rho^{\pi_{tar}} \pi_{t-1}^{tar} + (1-\rho^{\pi_{tar}})\pi_{SS}^{tar} + \varepsilon_t^{\pi_{tar}} && (39)\\
\chi_t &= \rho^{\chi}\chi_{t-1} + (1-\rho^{\chi})[\chi_{SS} + \psi(\chi_t^* - \chi_{SS}^*)] + \varepsilon_t^{\chi} && (40)\\
\chi_t^* &= \rho^{\chi^*}\chi_{t-1}^* + (1-\rho^{\chi^*})\chi_{SS}^* + \varepsilon_t^{\chi^*} && (41)
\end{aligned}
$$

APPENDIX B. TABLES AND FIGURES

Table 1. Calibrated Dynamic Parameters

		Poland	Euro area
	Output gap		
β_1	Lag	0.700	0.600
β_2	Lead	0.100	0.400
β_3	Interest rate gaps	0.090	0.050
β_4	REER gap	0.050	0.000
β_5	Foreign output gap	0.200	0.000
	Headline inflation		
ω	Weight of oil inflation	0.001	0.015
	Core inflation		
λ_1	Lead	0.450	0.550
λ_2	Output gap	0.080	0.050
λ_3	REER gap	0.030	0.000
λ_4	Real oil price gap	0.003	0.002
	Monetary policy rule		
γ_1	Lag	0.750	0.750
γ_2	Inflation gap	1.750	1.700
γ_3	Output gap	0.250	0.150
	UIP		
δ	Expected change in ER	0.700	-
	Unemployment		
α_1	Lag	0.150	-
α_2	Output gap	1.000	-

Table 2. Calibrated Stochastic Parameters

		Poland	Euro area
$\varepsilon^{y,iid}$	Demand shock	0.200	0.100
$\varepsilon^{y,ar}$	Correlated demand shock	0.250	0.200
ε^{com}	Common shock	0.150	0.150
ε^{π}	High-frequency shock to headline inflation	0.600	0.600
$\varepsilon^{\pi_{core}}$	Cost-push shock	0.300	0.200
ε^{I}	Monetary policy shock	0.150	0.250
ε^{S}	Exchange rate shock	15.000	-
ε^{lrpoil}	Real oil price shock	10.000	10.000
$\varepsilon^{\bar{Y}}$	Shock to potential output	0.050	-
ε^{μ}	Shock to potential output growth	0.050	-
$\varepsilon^{\bar{Z}}$	Shock to trend ER	1.000	-
ε^{gz}	Shock to trend ER growth	0.650	-
$\varepsilon^{\pi_{tar}}$	Shock to inflation target	0.420	-
ε^{χ}	Premium shock	0.160	0.150

Figure 5. Shock to domestic demand ($\varepsilon_t^{y,ar}$)

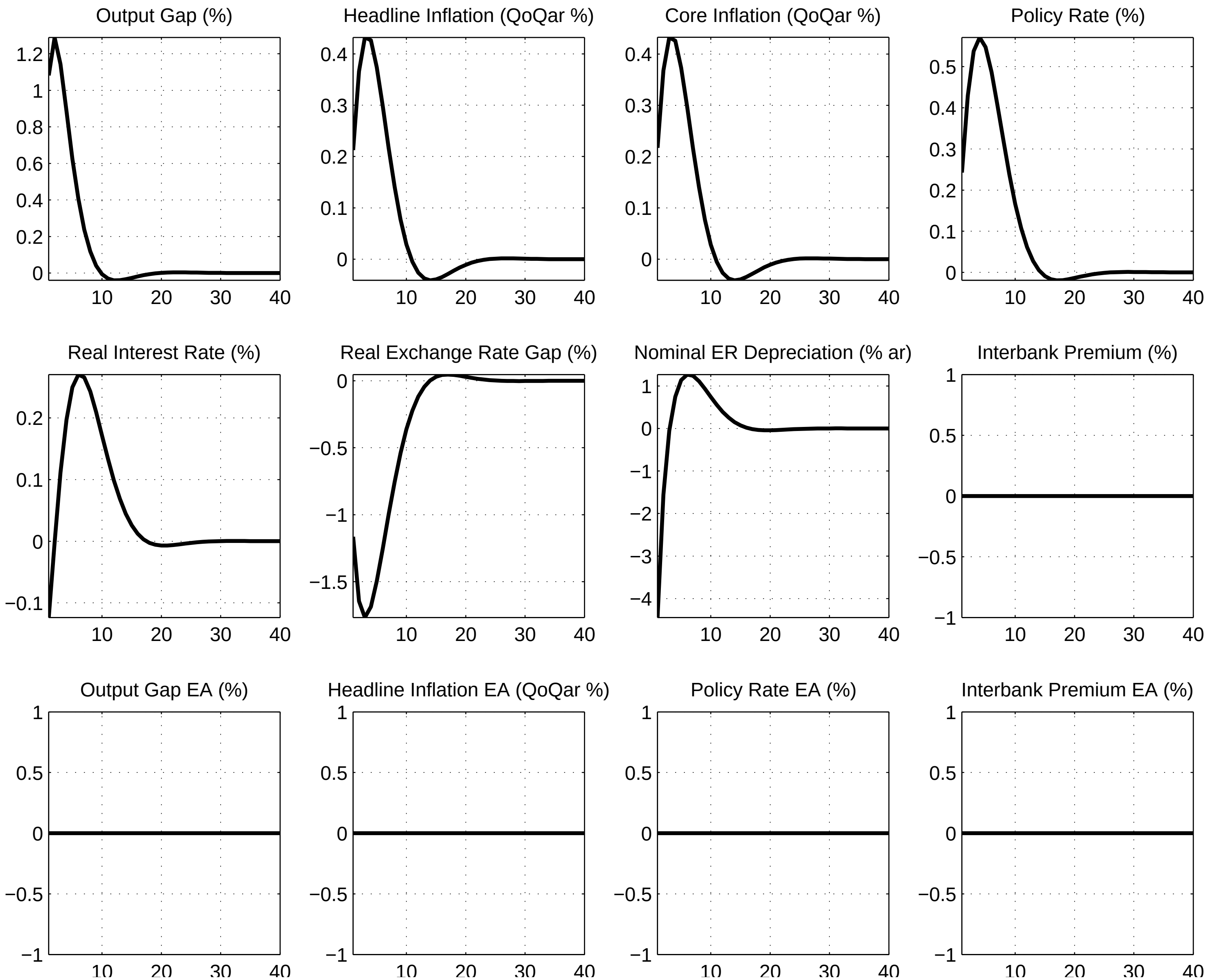


Figure 6. Negative shock to foreign demand ($\varepsilon_t^{y^*,iid}$)

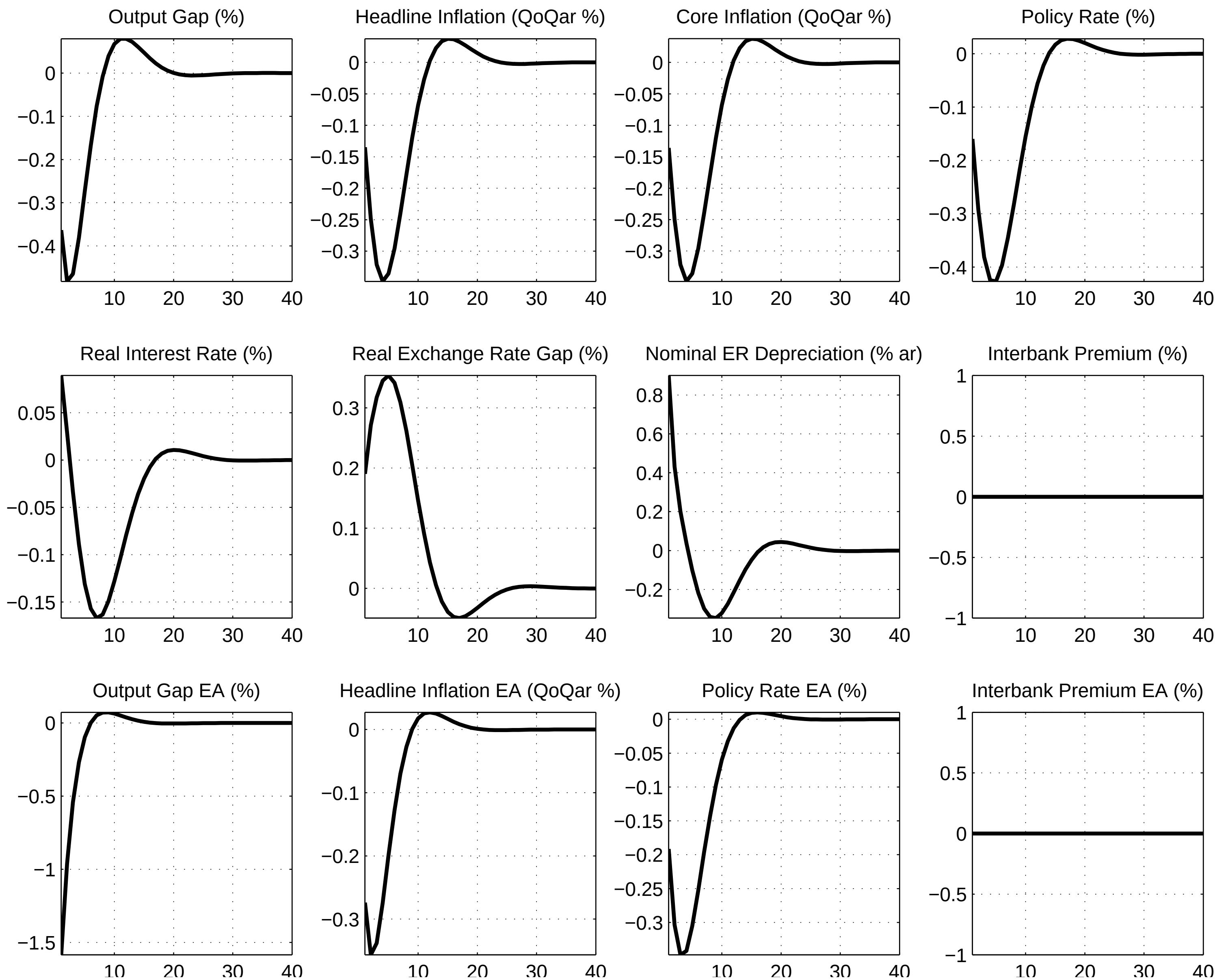


Figure 7. Negative global demand shock (ε_t^{com})

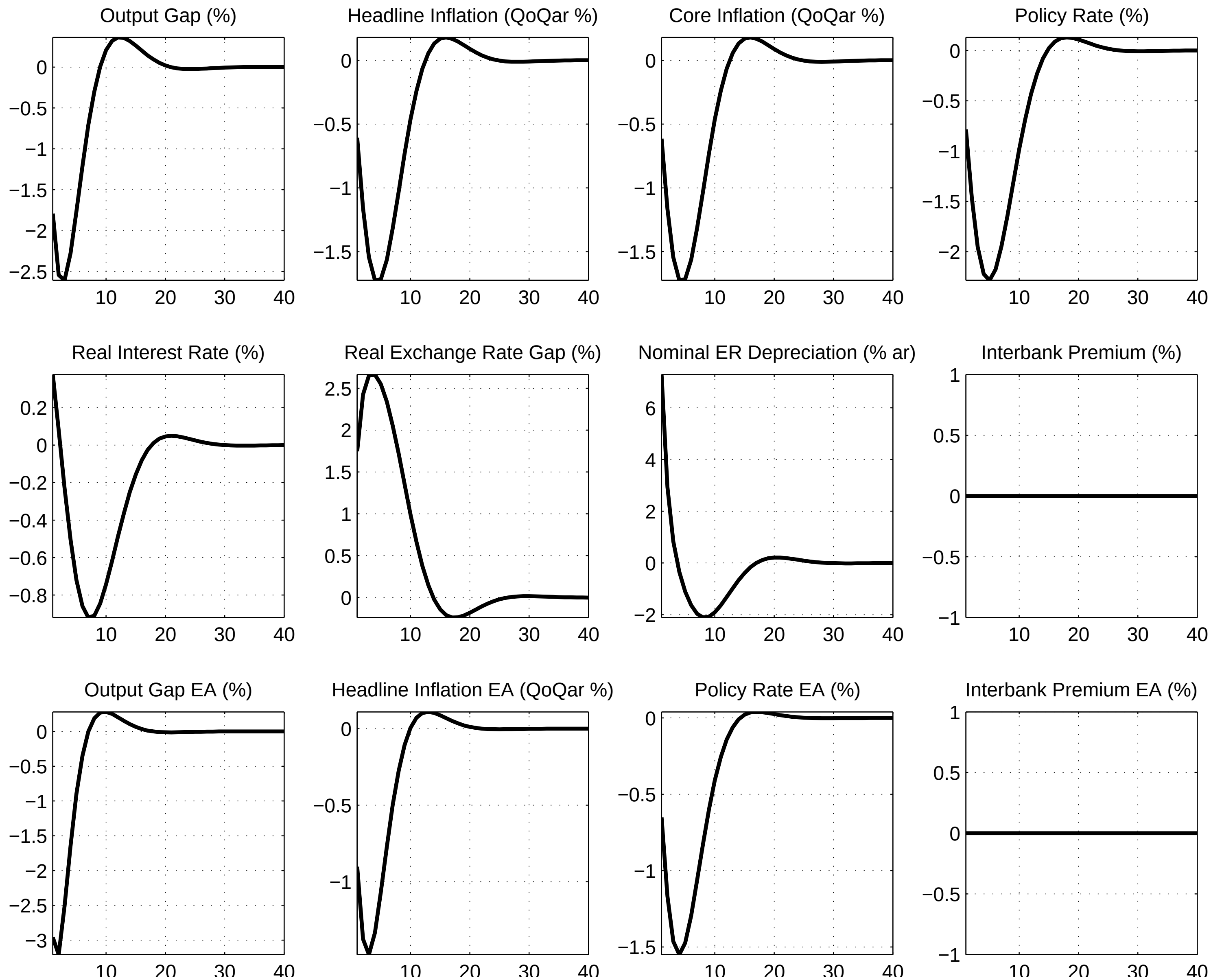


Figure 8. Shock to home core inflation ($\varepsilon_t^{\pi_{core}}$)

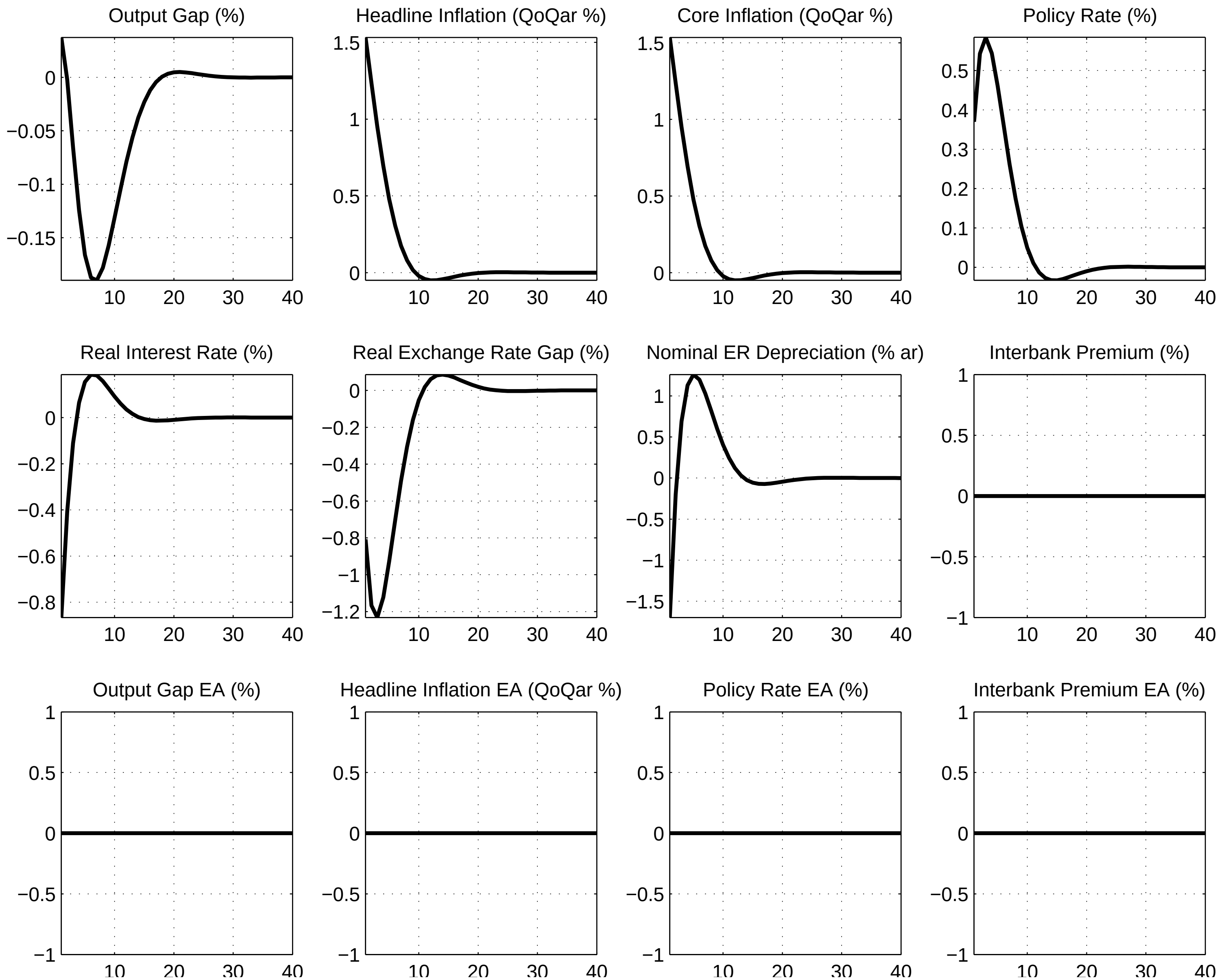


Figure 9. Shock to domestic monetary policy (ε_t^I)

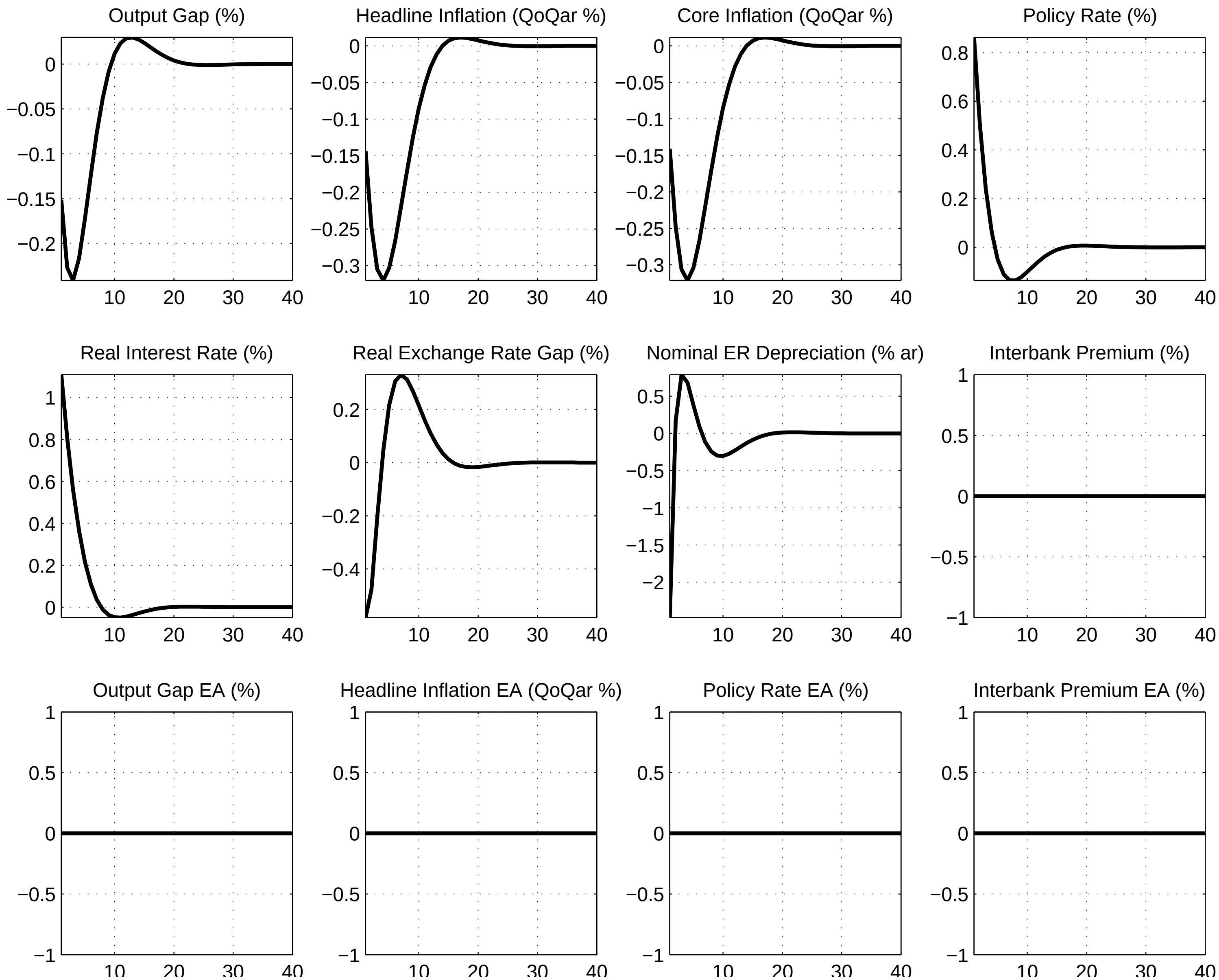


Figure 10. Permanent disinflation shock ($\varepsilon_t^{\pi_{tar}}$)

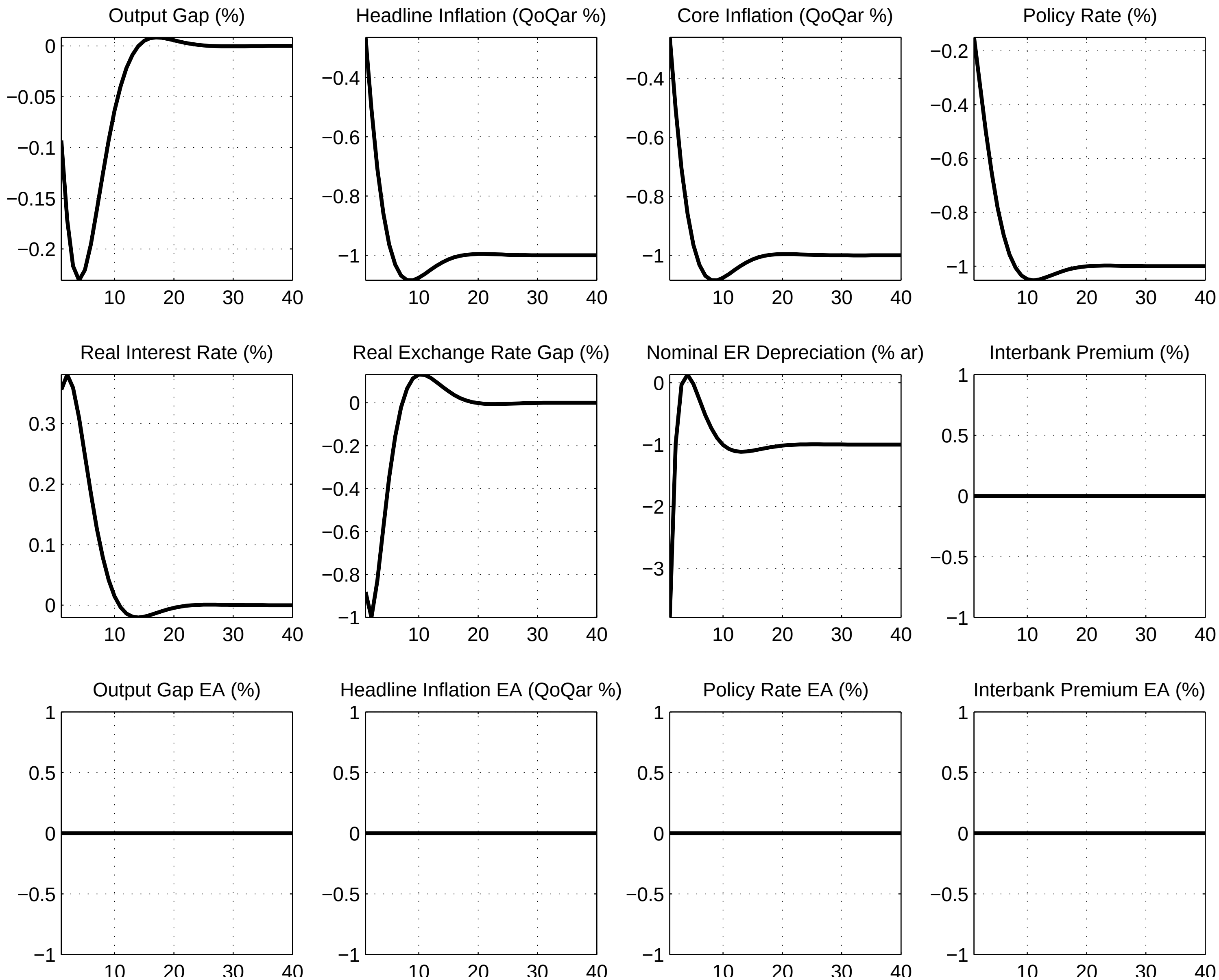


Figure 11. Shock to exchange rate (ε_t^S)

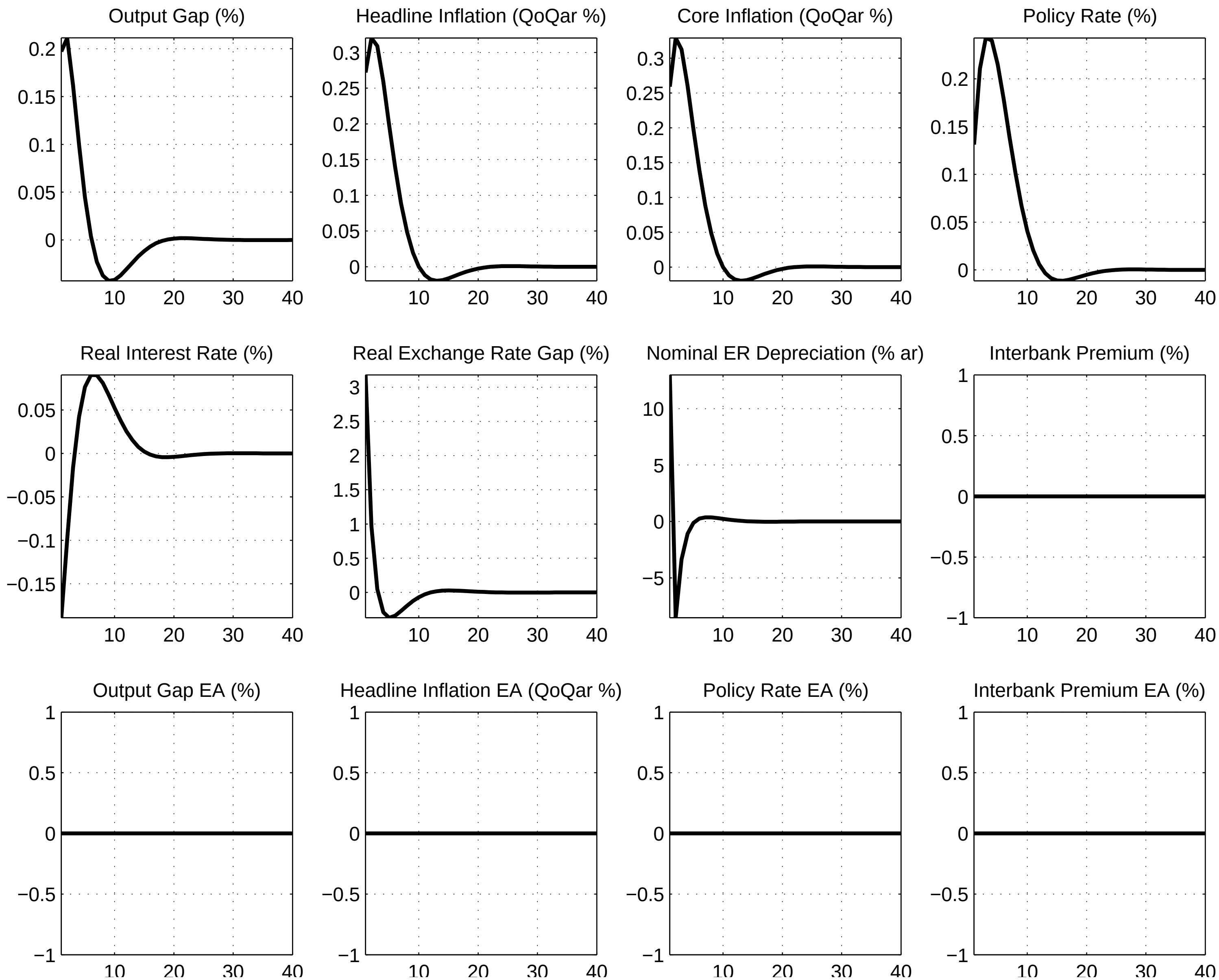


Figure 12. Shock to foreign interbank market premium ($\varepsilon_t^{\chi^*}$)

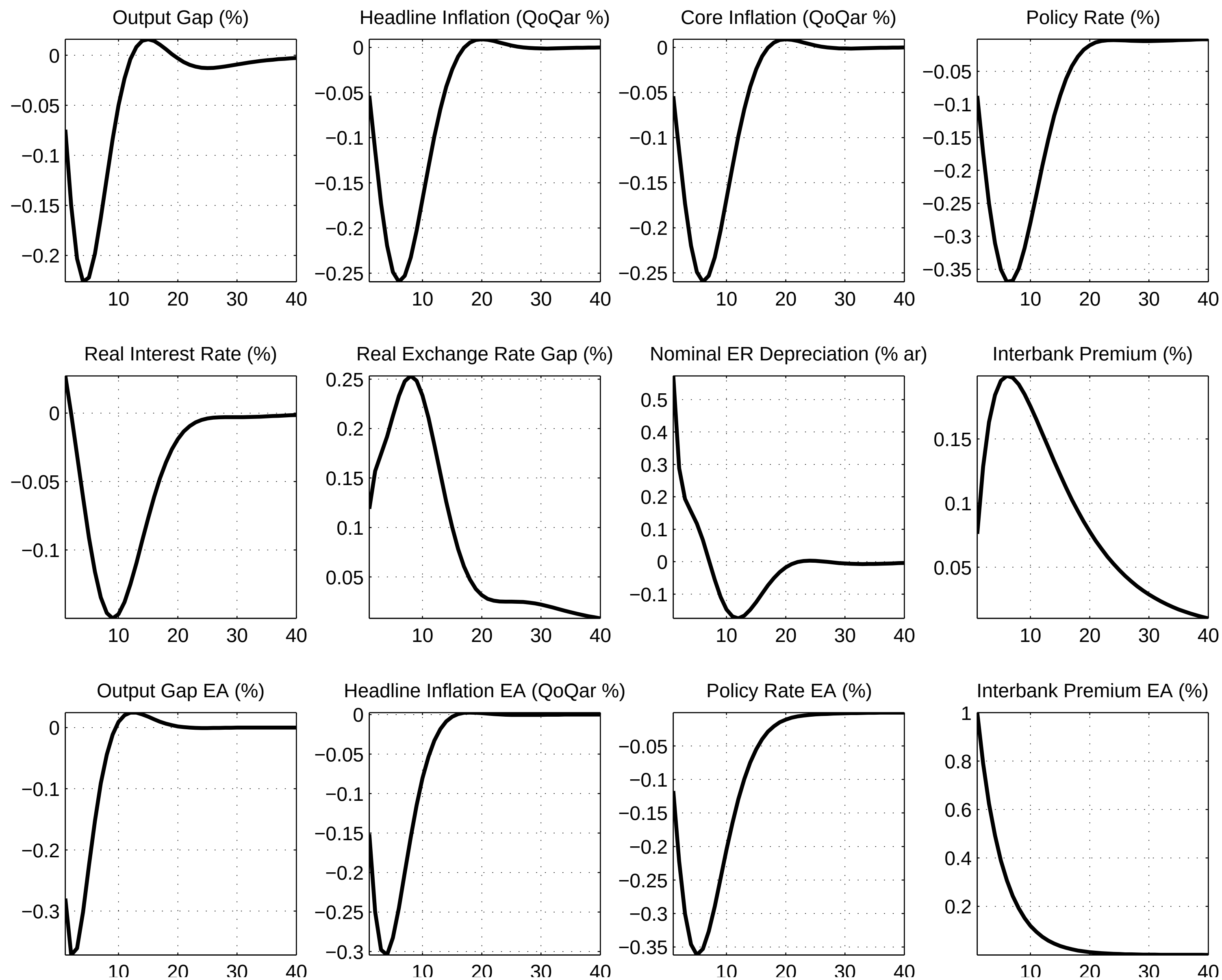


Figure 13. Output gap, core inflation and interest rates – Correlations (2000Q1 - 2012Q4)

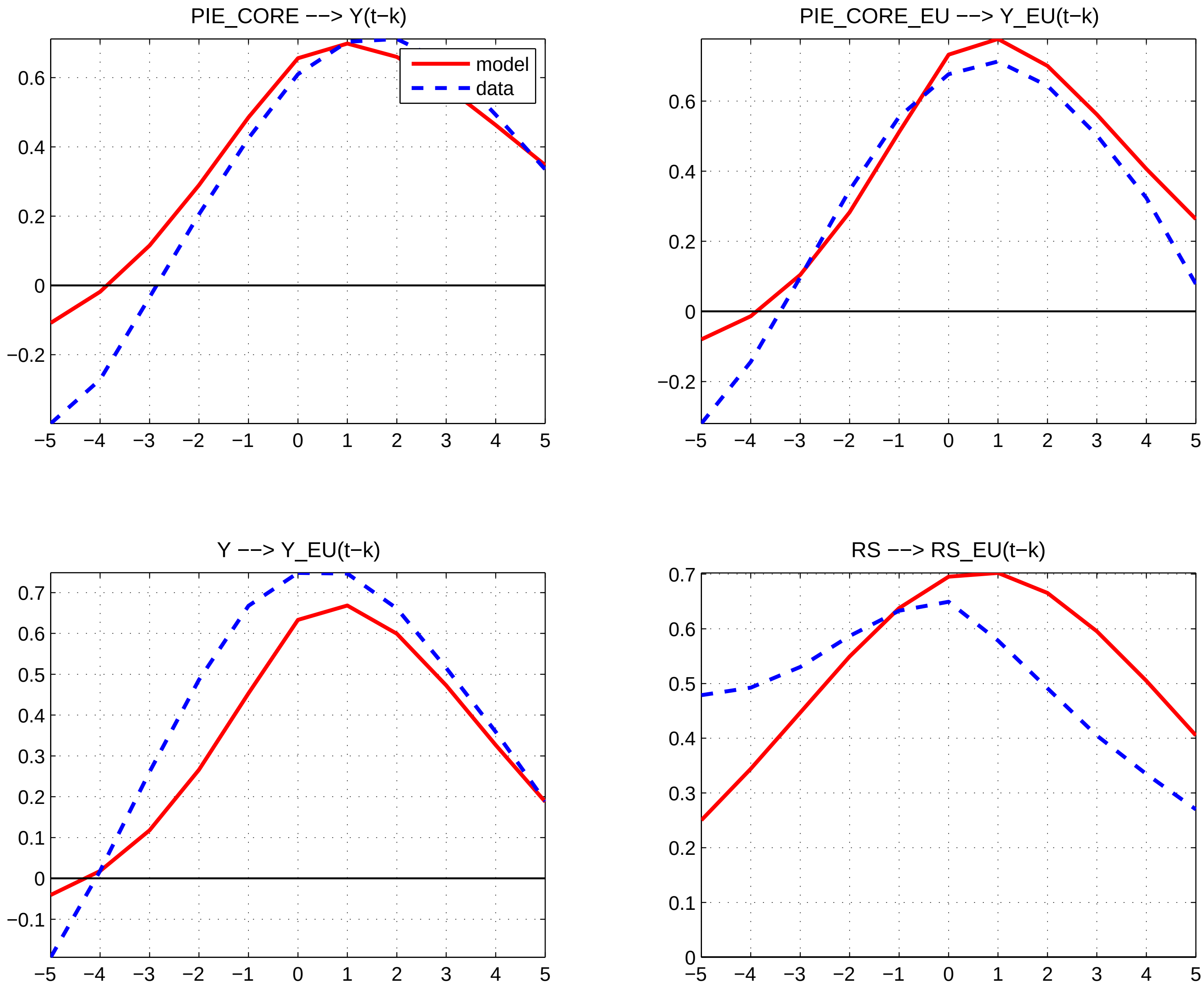


Figure 14. Forecast error variance decomposition for Poland and Euro area

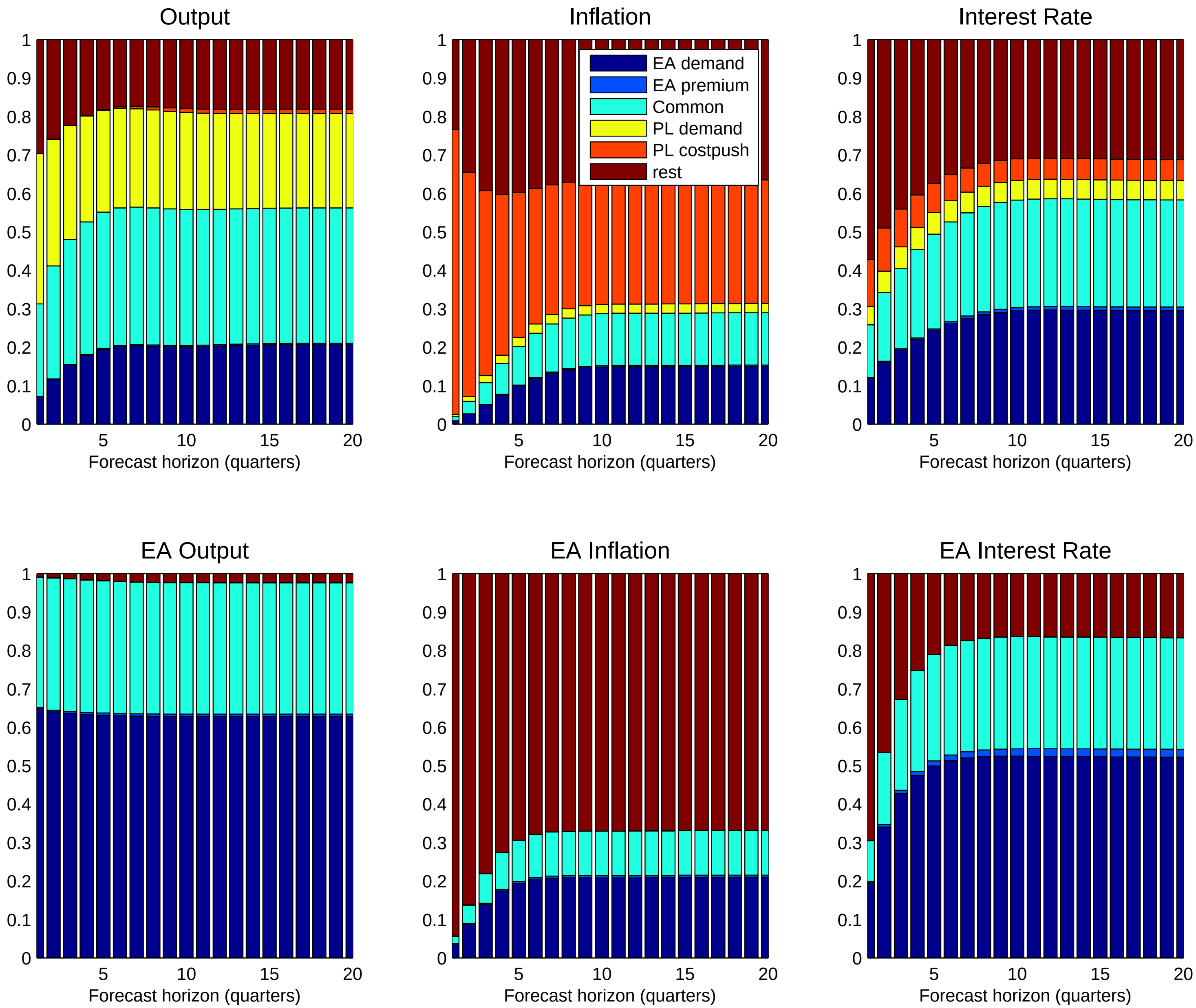


Figure 15. Counterfactual 1: Responses to euro area demand shock with monetary policy delay

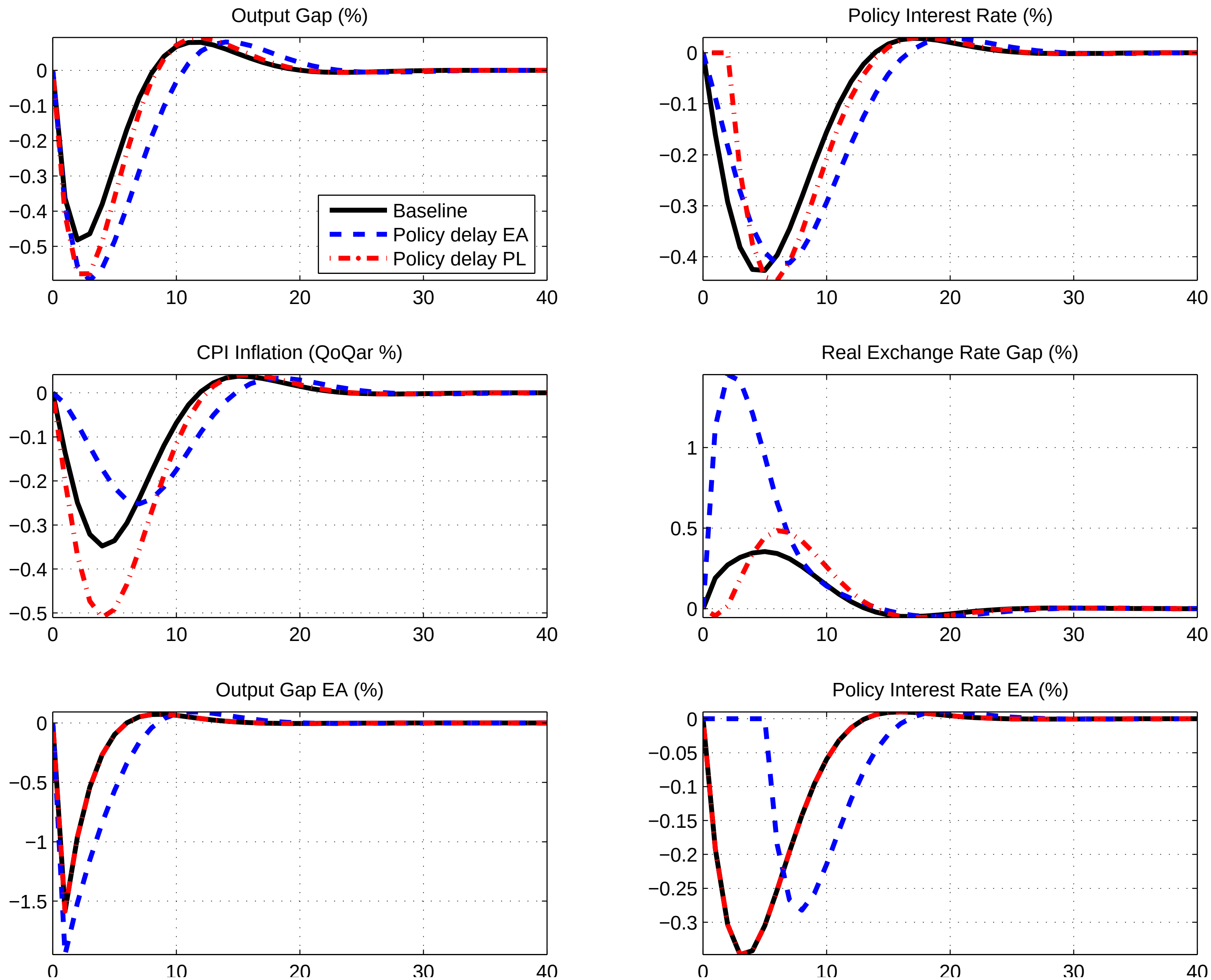


Figure 16. Counterfactual 2: Responses to euro area financial shock with higher shock persistence

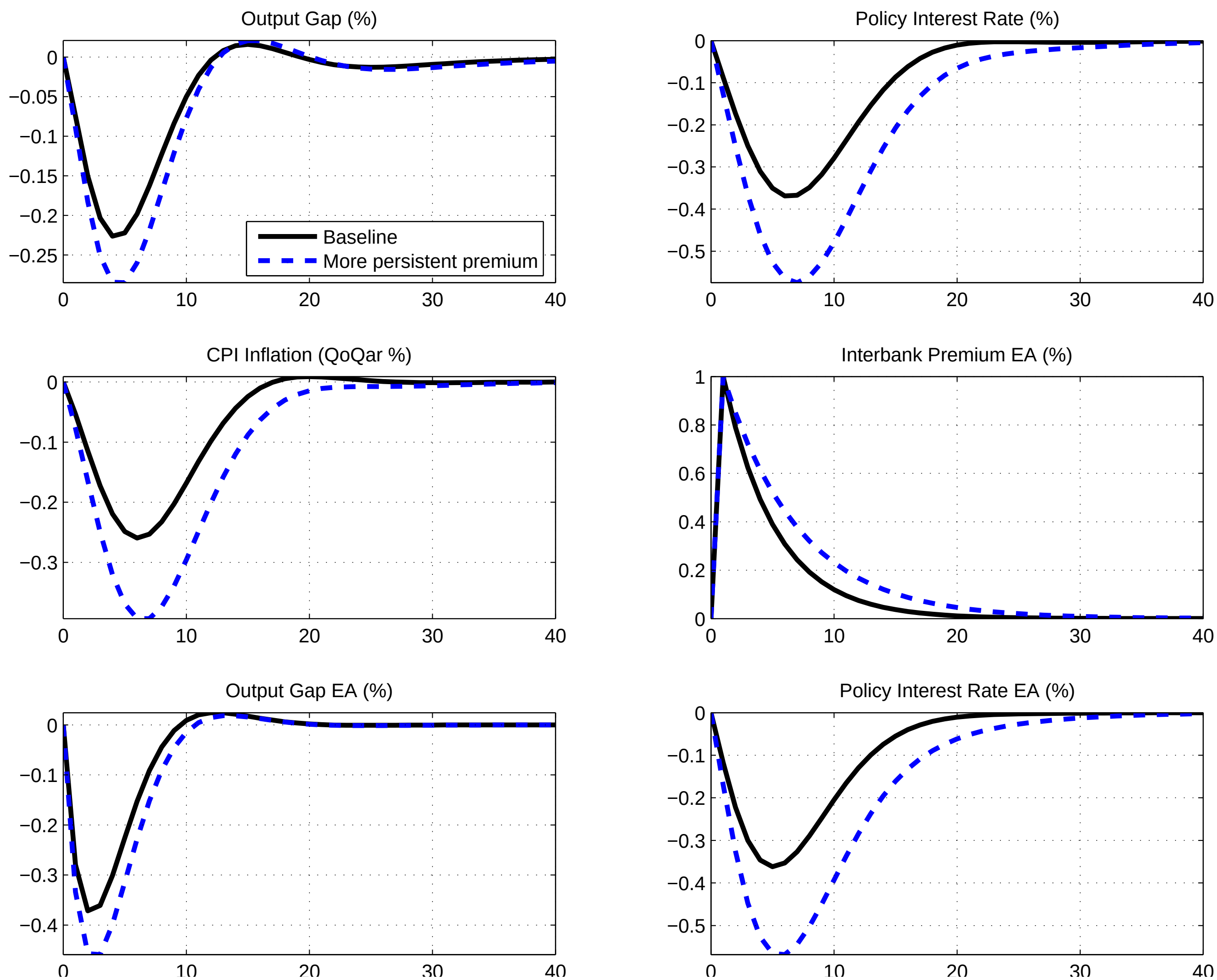


Figure 17. Estimated output gap, core inflation, and equilibrium variables

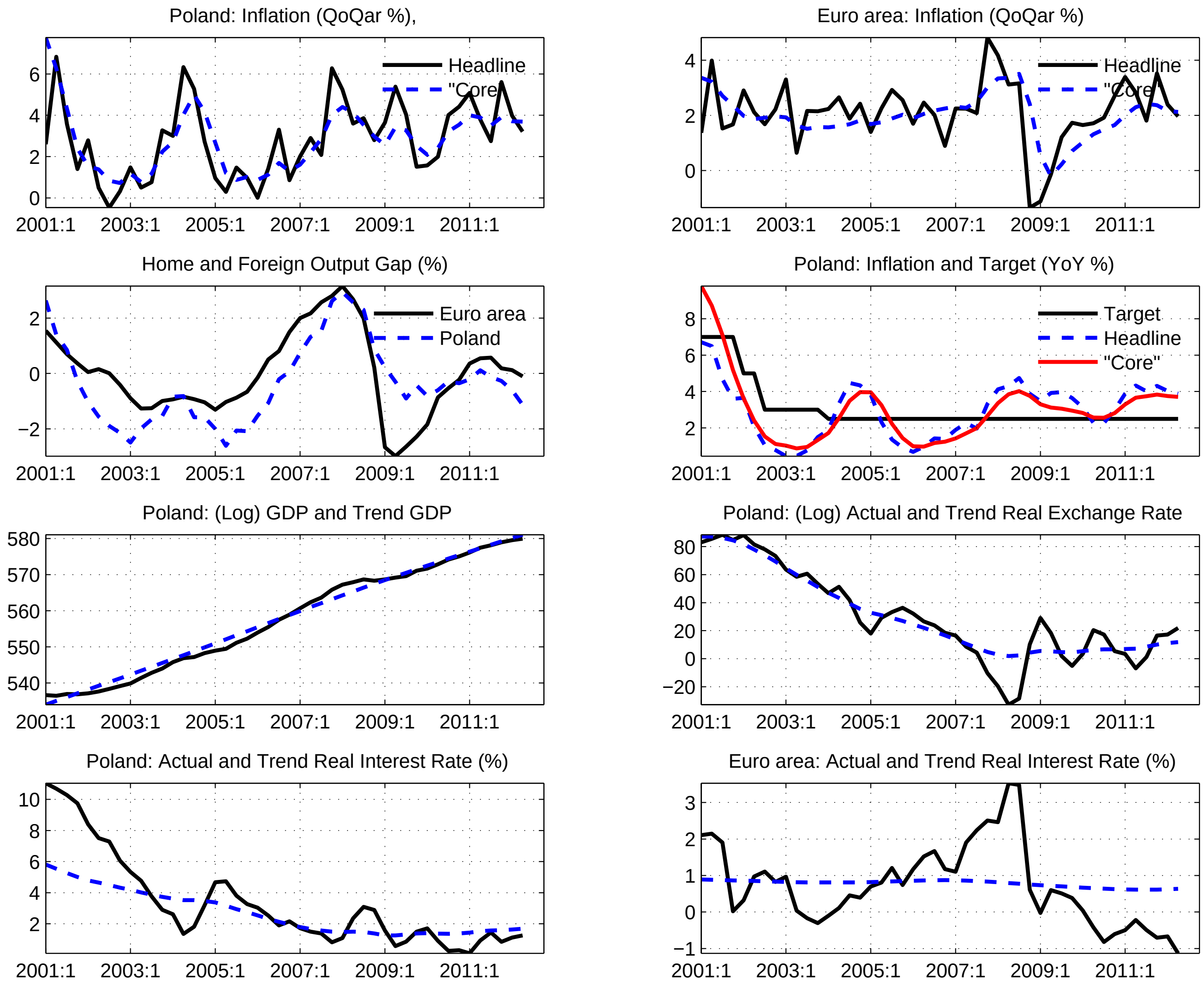


Figure 18. Historical shock decomposition - Output

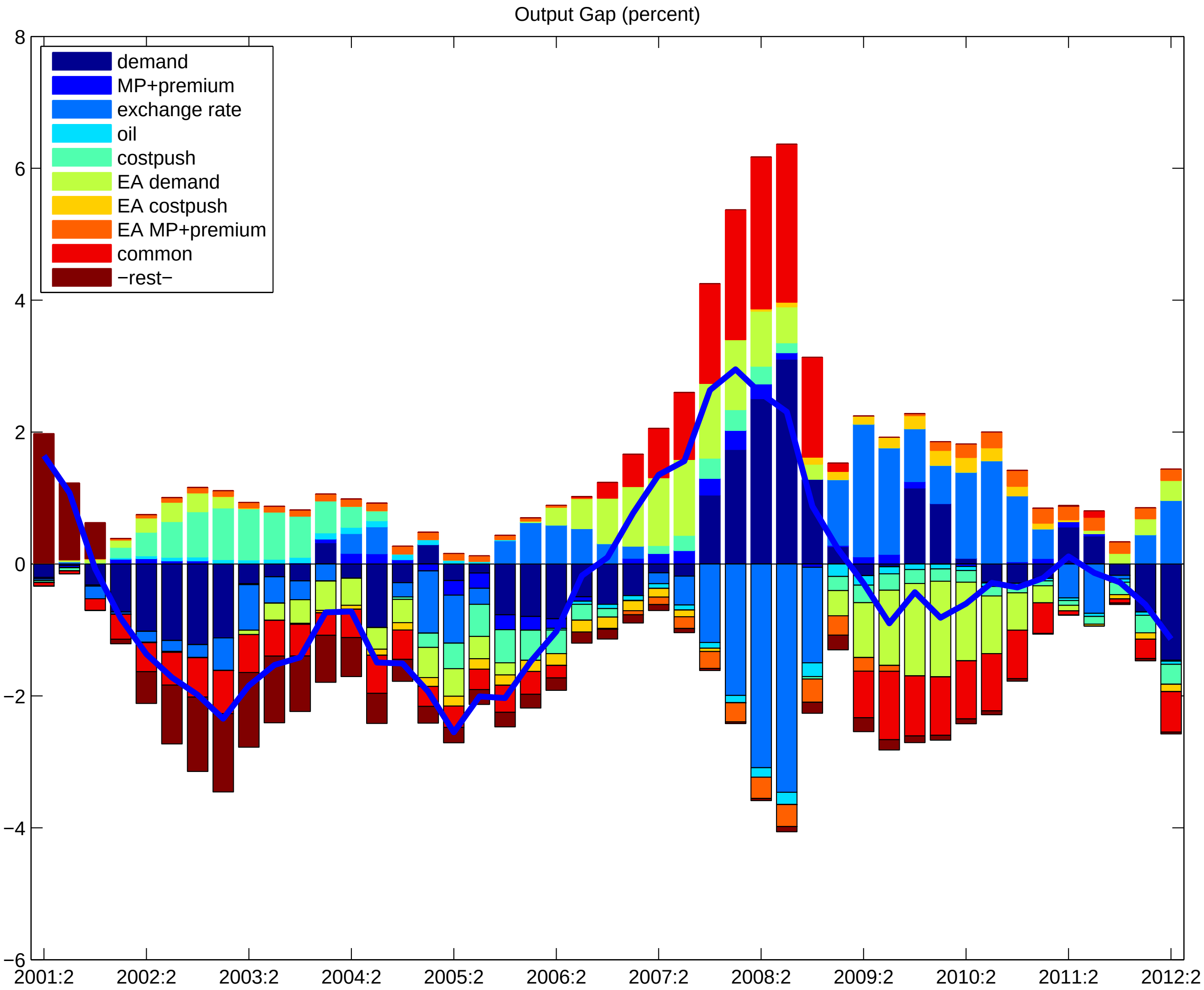


Figure 19. Historical shock decomposition - Inflation

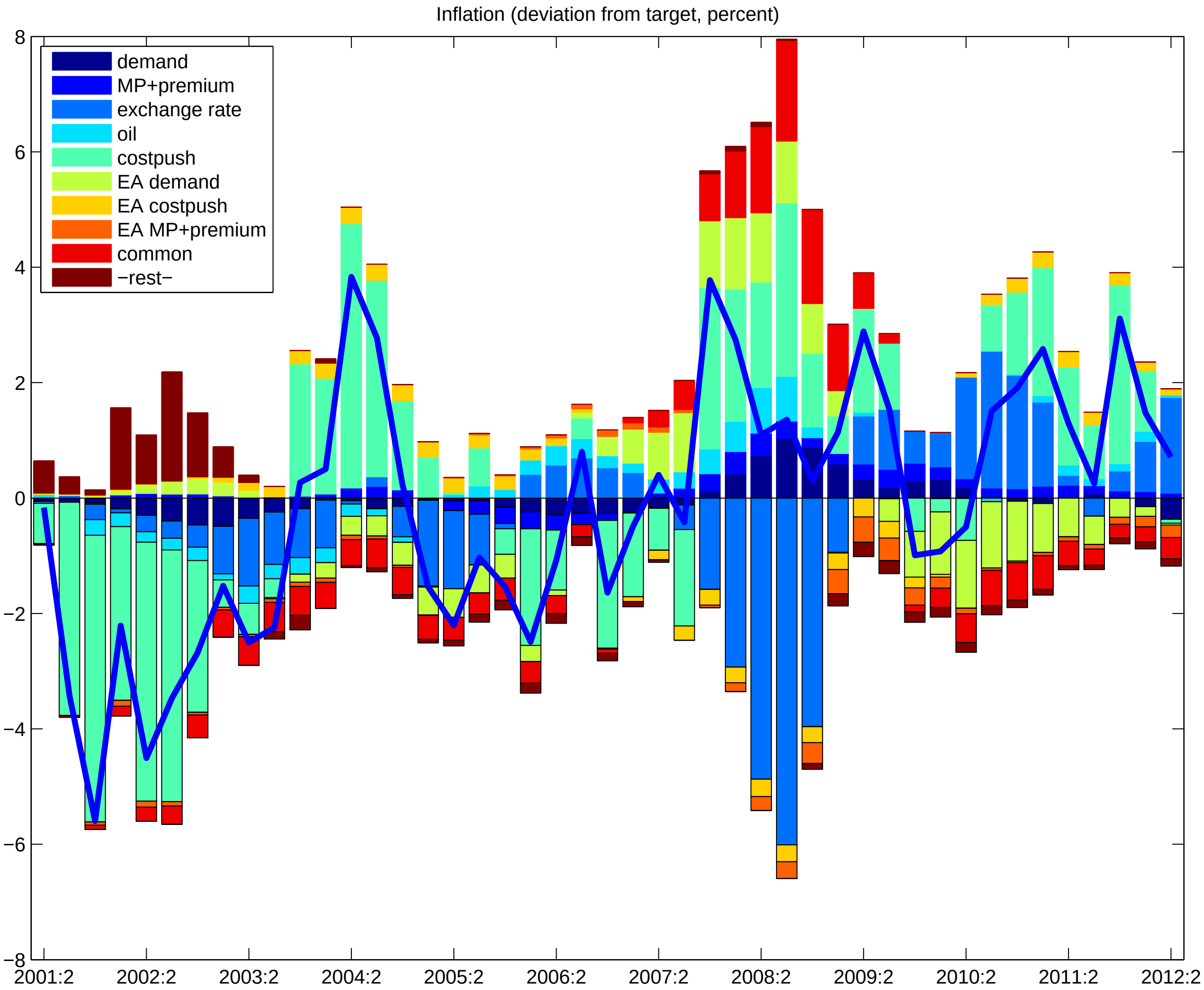


Figure 20. Conditional in-sample forecast (8 quarters ahead)

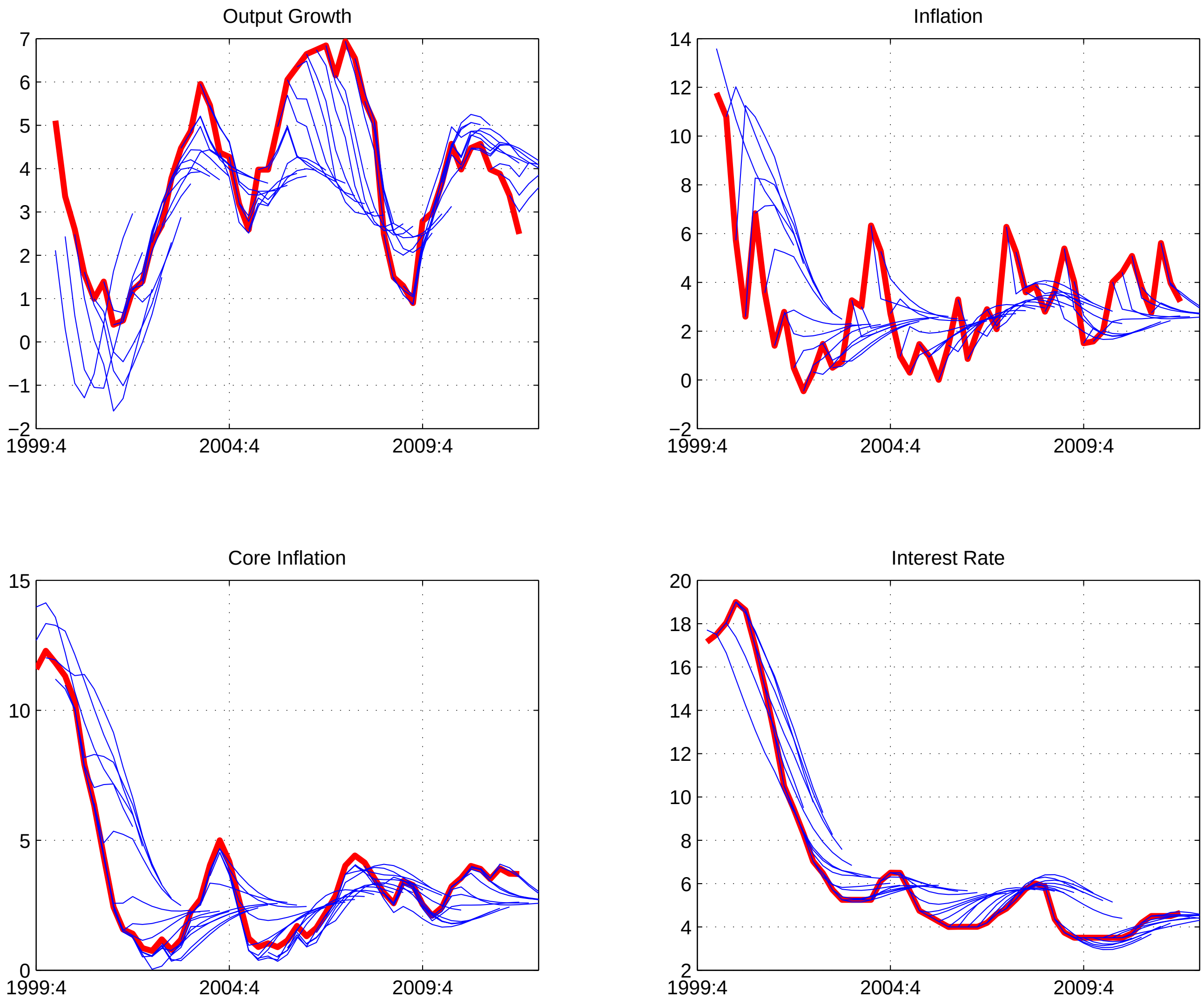


Figure 21. Non-core “wedge” and oil prices