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Gap Model of the Visegrad Group

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Abstract

We estimate a medium-scale gap model of the Visegrad Group including core macroeconomic variables as aggregate demand, aggregate supply, interest rates, exchange rates and unemployment, further enriched by a fiscal block for Slovakia. This model takes a form of global projection model, since incorporating mutual linkages between the economies and also their most important trading partner, aggregated eurozone. Although proposed in mostly linear form and not properly derived from micro-foundations as standard dynamic stochastic general equilibrium models, combination of relatively simple structure together with plausible impulse responses makes the model suitable for policy analysis. In addition, since the trading partners of Slovakia are modelled endogenously, we can capture spillovers between the countries and their final impact on the Slovak economy. Enrichment for the fiscal block makes the model applicable also for fiscal policy purposes.

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1 Introduction

There is a number of different modelling approaches applied by central banks and analysts across the world to simulate and forecast macroeconomic behaviour. The toolkit varies from simple vector autoregressive (VAR) models and structural econometric models applied mostly for forecast purposes to complex dynamic stochastic general equilibrium (DSGE) models widely used for policy simulations. In this paper, we aim to find a trade-off between macroeconomic fundamentals, proper impulse responses and plausible data fit, mostly proposed by gap models. In general, gap model is a macroeconomic model of unobserved gaps, in other words differences between actual values of macroeconomic variables and their long-run trend values, based on a small number of behavioural equations and underlying stochastic processes. As the model is in the general equilibrium form, it simultaneously determines values for all modelled gaps. These models are often referred to as quarterly projection models, since are mostly based on quarterly data, or global projection models, if incorporating a number of countries and their mutual linkages.

Gap models are based on a small number of linear behavioural equations capturing macroeconomic fundamentals and underlying stochastic processes pinning down the long-run trend values. This is in contrast to the standard DSGE models based on the agents' utility maximization and eventuating into highly nonlinear systems that need to be approximated, mostly linearized, to be solved.[1] Though the micro-foundations of the gap models are incomparable with those of the DSGE models, simple structure of these models and their identification restrictions produce impulse responses that are in line with standard theoretical predictions thus over-performing, for instance, the global VAR models. Furthermore, it is fairly convenient to extend these models with other sectors and countries.

Core structure of the presented model is based on Carabenciov et al. (2008), including the economies of the Visegrad Group, i.e. Slovakia, Czech Republic, Poland and Hungary, together with the economy of the eurozone. Yet, we propose important extensions of the original work. First, we enrich the model by a fiscal block for Slovakia thus capturing both the pass-through of fiscal impulse on aggregate demand as well as the impact of government debt on risk premia and exchange rate with secondary effect on potential output. Second, we distinguish between different types of risk premia and treat them endogenously allowing for (i) imperfect control over the domestic money market as well as the foreign exchange market, (ii) additional spillovers between the economies based on the interaction of market premia and (iii) risk premia effect on the potential output as well as the output gap. Finally, we incorporate also government bond yields with ten years maturity, thus approximating the term-structure of interest rates, and additional long-term risk premium influenced by the fiscal policy.

Furthermore, we extend the model for the emerging economies of the Visegrad Group, allowing for trend currency appreciation and historical changes in inflation targeting, mostly in line with Carabenciov et al. (2013). However, the model distinguishes from a fully structural model, since not incorporating phenomenon like increasing trade openness, captured by rising export to GDP ratio, or different inflationary pressures on prices of goods and services, since implementation of these effects would require modelling off-balanced growth in a complex way and is behind the goals of this paper. We also depart from the identification of structural shocks to the potential productivity driven by investors with great market share, like Volkswagen or Samsung, and many one-off effects typical for emerging small open economies, since they are mostly based on judgmental inputs. Of course, if the model is applied for forecasting purposes, we need to exogenize and precisely identify these effects before the forecast.

[1] See for example Smets and Wouters (2003) for the baseline DSGE model or Gali and Monacelli (2005) for the small open economy version of the DSGE model.

Since the Visegrad Group countries are not only the most important trading partners of Slovakia, except the eurozone, but also share the same historical development and similar economic structure, it is reasonable to decompose the region into particular economies, while we can capture their different development and spillovers from one country to another. On the other hand, importance of the fiscal policy in the post-crisis years motivated the authors to extend the model for the fiscal block. We can thus distinguish between the short-run cyclical development driven mostly by the monetary policy, although the fiscal policy also matters, and the long-run potential development influenced by the policy of fiscal authorities. Although the model is not constructed for forecast purposes, it can be also applied as the control method to standard forecasting models.

The paper is structured as follows. First, we propose the literature review with focus on the advantages of our solution. Second, we make the model and data overview and describe the technical aspects of the model. Third, we describe the structure of the model equations, and fourth, we discuss the model parametrization consisting of the calibration as well as the Bayesian estimation techniques. Finally, we evaluate the model with impulse response functions and historical variables decomposition, while proposing also simple simulation exercise.

2 Related literature

Our model is inspired mainly by the work of Carabenciov et al. (2008) which presents a global projection model (GPM) for three big economies: United States, European Union and Japan. Each economy is characterized by five behavioural equations capturing output, unemployment, inflation rates, interest rates and exchange rates. Money markets interact via trend exchange rates based on simple random walk processes, while the steady-state inflation rates operate as the constant inflation targets. Later on, Carabenciov et al. (2013) propose an extension of the original model for emerging markets, including also trend currency appreciation and historical changes in inflation targets. Both versions of the model incorporate risk premium only in a form of trend currency premium in the uncovered interest parity (UIP), described as a simple difference between potential interest rates of respective countries adjusted for the trend currency appreciation. Implicitly, these models assume central banks' perfect control over market interest rates.

In contrast, the projection model by Andrle et al. (2014), focusing on the interaction between polish and euro area economies, distinguishes between currency and interbank risk premia and treats them endogenously with autoregressive processes. In addition, the polish interbank premium responds to financial shocks in the euro area, thus capturing the spillovers between the countries via additional risk premium channel. According to this, the authors model a pass-through of the risk premium on the market interest rates, arguing with the interbank premium affecting households, and thus assume imperfect control over domestic money market.

We apply similar principle in the presented model with two exceptions. First, we decompose the interbank premium into trend and cyclical component, where the latter represents actual investors' preferences with relatively high volatility and affects the output gap, while the former operates as the persistent variable with lower volatility and affects the potential output. This is mostly due to the historical evidence and distinguishes from the original specification of Andrle et al. (2014) incorporating only cyclical interbank premia. Second, we define the additional premium on the government bonds that operates as the potential variable and responds to the deviation of government debt from the steady-state value, thus capturing the impact of fiscal policy on potential productivity and long-term economic development. We exclude from the impact of government debt on the interbank premium, since the short-term variables are mostly driven by monetary policy and actual market development. Similarly, the currency premium is modelled independent of fiscal variables, but we incorporate the negative impact of rising debt on the trend appreciation.

From the perspective of domestic research, we should mention the model by Gavura and Reľovský (2005) operating as the open economy gap model based on a small number of behavioural equations and exogenous external environment. In contrast to our solution, the authors applied the method of pre-filtration to distinguish between trend and cyclical variables. Since we focus on the entire region of the Visegrad Group, we propose more complex look on the development of the Slovak economy, while the fiscal block extension is especially important due to the absence of the domestic monetary policy. Next, we should mention the DSGE model by Zeman and Senaj (2009) and the model by Múčka and Horváth (2015) exploring a fiscal policy impact on the Slovak economy.

There are numerous other papers related to our work at least indirectly, for example the projection model by Beneš et al. (2003), formerly applied by the Czech National Bank (CNB), the monetary policy model of the Hungarian National Bank (MNB), developed by Szilágyi et al. (2013), or the model by Lyziak (2016), exploring the role of inflation expectations in Poland.

3 Methodology and data

We propose the medium-scale gap model of the Visegrad Group countries, i.e. Slovakia, Czech Republic, Hungary and Poland, further influenced by the eurozone economy as their most important trading partner. The model is based on the unobserved gaps of real output, unemployment, interest rates and exchange rates, together with the inflation rates, while respecting mutual linkages and spillovers between the economies. Furthermore, we extend the model with the fiscal block for Slovakia. On the other hand, we exclude from financial variables as Carabenciov et al. (2008), due to their importance for small open economies.

Visegrad economies are operating as small open economies affecting each other via two channels. The first one is an effect of exchange rate gap differentials on real economy via changes in real output and inflation rate, capturing the currency depreciation pressure on country competitiveness and higher import prices. The second channel is a direct effect of foreign output gaps weighted by mutual export volumes, affecting the domestic output via pressures of foreign demand. Furthermore, the eurozone operates as a closed economy, due to its relative size with the respect to the Visegrad Group, thus affecting the other countries in the model but not vice versa. In addition to the standard effects via output and exchange rate, the eurozone is also affecting the Visegrad Group via interbank risk premium, since a deviation of the eurozone risk premium puts a pressure on the risk premia of related economies.

We apply five observable variables on quarterly basis for each country, specifically gross domestic product (GDP), harmonised index of consumer prices (HICP), three-months nominal interest rate, interbank risk premium and unemployment rate. Although distinguishing between core and non-core inflation in the model specification, we incorporate only overall price index as the measure for the headline inflation, while the core inflation is identified by the model and not captured by the price index excluding energy and food. In addition, we apply nominal exchange rates of local currencies vis-a-vis Euro for the Visegrad Group countries, government debt and deficit in percentage of the GDP for Slovakia and euro denominated Brent oil prices. We capture also the long end of the eurozone yield curve with the yields on ten-years government bonds and complement with the government bonds for Slovakia to capture the long-term effect of fiscal policy. Finally, we apply also historical targets for inflation and government debt.

Level of the GDP is obtained in chain linked volumes and local currencies to exclude additional effects of inflation and exchange rates. GDP of the eurozone refers to the core twelve countries to exclude the effects of changing composition. HICP index is averaged from monthly data and seasonally adjusted.[2] We obtain these information from the Eurostat together with interest rates, exchange rates and unemployment rates. Information about government debt are also from the Eurostat, while the information about government deficit are from the Statistical Office. Interbank premium is constructed as a simple difference between three-month interest rates and monthly short-rate expectations, approximated by the overnight rates. Brent oil prices are obtained from the Bloomberg database and transformed from US Dollar to Euro. Inflation targets are from the local central banks and target values of government debt equal the observed ones.

Rational expectations are solved via generalized Schur decomposition and model evaluation is performed by the method of Kalman filtering. Time series are additionally smoothed by the modified Bryson-Frazier smoother. Estimation and calibration of the model is performed on the sample period from the first quarter of 2002 to the second quarter of 2017. All computations are performed in Matlab and IRIS Toolbox for macroeconomic modelling.

[2] Gross domestic product and unemployment rate are obtained in the seasonally adjusted form. Price indices are adjusted manually by the method X13-ARIMA-SEATS.

4 Model specification

We proceed with the specification of a generic economy labelled i and time index t. Specification of the eurozone closed economy differs from the open economies of the Visegrad Group, as differs the specification for Slovakia, due to the fiscal block extension. We propose the same equations for the economies of Czech Republic, Hungary and Poland, albeit with different parametrisation. Specification of the model equations is mostly in line with Andrle et al. (2014). Particular equations are described in the subsections.

We follow Carabenciov et al. (2008) in the terms of notation and use capital letters for the observables and small letters for the unobserved gaps between observables and their potential values. Specifically, we define Y as 100 times the log of real GDP level, $\bar{Y}$ as 100 times the log of potential GDP level and y as the output gap in percentage terms, in other words $y = Y - \bar{Y}$. Similarly, we define u as the difference between the actual unemployment rate U and the potential unemployment rate $\bar{U}$, in other words $u = U - \bar{U}$. Next, we define the annualized quarterly rate of inflation π as 400 times the difference of the log HICP in the current quarter from the previous one. Nominal interest rate is denoted I, actual real interest rate is R, potential real interest rate is $\bar{R}$ and the interest rate gap is denoted r. Similarly, 100 times the log of the nominal exchange rate against Euro is denoted S and the gap between the actual real exchange rate Z and its potential value $\bar{Z}$ is denoted z.

4.1 Output block

Structure of the proposed model is based on several behavioural equations and stochastic processes. We start with an aggregate demand of the euro area determined by the dynamic closed economy IS curve, where the output gap is a function of its own lagged and lead values and effective interest rate gap. The lagged output gap allows for the persistency of shocks and the lead term follows the rational expectations forward-looking approach common for the DSGE models. Effective interest rate gap is a weighted average of three-months and ten-years interest rate gaps, while the weight put on the short-term interest rates ρ_1 is set to 0.90. Interest rate component enters the equation with lag, since the channel of rising interest rates affecting the real economy via decline in investments and consumption is empirically lagged. The last term refers to a demand shock to the economy.

$$\boldsymbol{y_{i,t} = \beta_{i1} y_{i,t-1} + \beta_{i2} y_{i,t+1} - \beta_{i3} rr_{i,t-1} + \varepsilon^{y}_{i,t}} \tag{1}$$

We continue with the specification for the Visegrad Group countries, expanding the original equation of the euro area for small open economies as follows. Aggregate output is affected by two additional terms where the first one refers to the effective exchange rate gap and the second one to the aggregate foreign demand. Effective exchange rate gap equals the weighted average of the real exchange rate gap of the country i minus the real exchange rate gaps of its trading partners j, in other words $z_{ij,t} = z_{i,t} - z_{j,t}$. Weights are calibrated as the sum of exports and imports between country i and country j against the sum of exports and imports between country i and all its trading partners, thus taking into consideration relative importance of particular economies. On the other hand, aggregate foreign demand is defined as the weighted average of foreign output gaps, where the particular weights are calibrated as the ratio between export from country i to country j and total export of country i to its trading partners. This term thus captures an upward pressure of foreign demand on domestic export. Both of these terms are empirically lagged.

$$\boldsymbol{y_{i,t} = \beta_{i1} y_{i,t-1} + \beta_{i2} y_{i,t+1} - \beta_{i3} mci_{i,t-1} + \beta_{i5} \sum ex_{ij} y_{j,t-1} + \varepsilon^{y}_{i,t}} \tag{2}$$

$$\boldsymbol{mci_{i,t} = \beta_{i4} rr_{i,t} - (1 - \beta_{i4}) \sum tr_{ij} z_{ij,t}} \tag{3}$$

According to the euro area specification, parameter β_3 captures the monetary-policy pass-through to the real economy, while the values of β_4 and 1-β_4 represent the weights put on interest rates and exchange rates in the monetary condition index. Generally, the more open is the economy, the lower is the value of parameter β_4 and vice versa.

Model specification for Slovakia is similar to the rest of the Visegrad Group with two exceptions. First, since incorporating additional fiscal block, some model equations are extended for additional terms capturing their reactiveness to fiscal variables. Second, due to the adoption of Euro in January 2009, we need to split the model for Slovakia before and after the monetary switch.[3] We continue with the specification of aggregate demand and enrich the open economy IS curve by contemporaneous fiscal impulse.

$$\boldsymbol{y_{i,t} = \beta_{i1} y_{i,t-1} + \beta_{i2} y_{i,t+1} - \beta_{i3} mci_{i,t-1} + \beta_{i5} \sum ex_{ij} y_{j,t-1} + \beta_{i6} d_{i,t}^{imp} + \varepsilon_{i,t}^{y}} \tag{4}$$

Since the government bonds are incorporated only for the euro area, to capture the long end of the euro yield curve, and Slovakia, to model the impact of fiscal policy on the long-term risk premium, effective interest rates for the rest of the Visegrad Group are equal to the short-term interest rates and thus setting of the parameter ρ_1 to 1.00.

Meanwhile, potential output is determined by a local linear trend model where shocks to both level and growth rate are assumed. Shocks to the level are considered as permanent, whereas shocks to the growth rate may result in persistent deviations of the potential growth from its steady-state value. Potential output equals its own lagged value plus the quarterly growth rate and the error term. In contrast to Carabenciov et al. (2008), we allow also for additional impact of potential interest rate change over the last quarter capturing a negative effect of rising interest rates not only on the output gap but also on the potential production. Weights put on the changes in three-months and ten-years potential rates are captured by parameters ρ_1 and 1-ρ_1 respectively. Growth rate of the potential output may temporarily deviate from its steady-state but gradually converges back with the speed of parameter τ_1.

$$\boldsymbol{\bar{Y}_{i,t} = \bar{Y}_{i,t-1} + \Delta\bar{y}_{i,t}/4 - \tau_{i2}(\overline{RR}_{i,t} - \overline{RR}_{i,t-1}) + \varepsilon_{i,t}^{\bar{Y}}} \tag{5}$$

$$\boldsymbol{\Delta\bar{y}_{i,t} = \tau_{i1} \Delta y_i^{ss} + (1 - \tau_{i1}) \Delta\bar{y}_{i,t-1} + \varepsilon_{i,t}^{\Delta\bar{y}}} \tag{6}$$

We exclude from the cross-correlation of model shocks in this version but would like to extend the structure of the model shocks later, similarly to Carabenciov et al. (2008). Specifically, we would like to incorporate a negative correlation between the cost-push shock and the shock to the potential output level, capturing the fact that the productivity shock leads to the growth in aggregate supply implying downward pressure on prices in the economy. On the other hand, expected shock to the potential output growth puts an upward pressure on higher demand not only in the future but also contemporaneously, implying a positive correlation with the demand shock.

However, we should mention that the correlation between potential output and cost-push shocks is driven by additional effects in small open economies. Specifically, although the shock to the potential output leads to higher productivity, this production is mostly exported thus not increasing domestic supply and not putting downward pressure on domestic prices. On the other hand, higher productivity leads to faster real convergence that could be quantified nominally or via the inflation channel, thus leading to an upward pressure on prices in the economy.

We would also like to incorporate persistent and global shocks to the aggregate demand, according to Andrle et al. (2014). While the first one enhances the persistence of domestic demand shocks, the latter captures additional spillovers between the economies and the effect of the economic and financial crisis.

[3] We do not incorporate expectations about entering the monetary union in this version but would like to extend the model for the expectations afterwards.

4.2 Unemployment block

According to the output, unemployment is also decomposed into its trend and cyclical components. While the potential rate of unemployment, or NAIRU, is pinned down by a standard autoregressive process with the speed of steady-state convergence α_3, unemployment gap is captured by a modified version of the Okun's law, where the unemployment gap is a function of its own lagged value and contemporaneous output gap.

$$\boldsymbol{u_{i,t} = \alpha_{i1} u_{i,t-1} - \alpha_{i2} y_{i,t} + \varepsilon^{u}_{i,t}} \tag{7}$$

Although the unemployment is not directly interacting with other model variables, for example in the impulse response analysis, it allows us to exploit the unemployment data and corrects the model historical development. We depart from the original specification of NAIRU with level and growth components, as Carabenciov et al. (2008), and rather apply simple convergence process with properly defined steady-state.

4.3 Inflation dynamics

To capture dynamics and volatility of price development, we distinguish between core and non-core inflation in our model, similarly to Andrle et al. (2014). Specifically, we suppose that the inflation rate is a weighted average of core and non-core components, while the weight of the core inflation is captured by the parameter κ_1 and calibrated by the least squares estimator on the sample period. Non-core component meanwhile refers to the imported oil inflation, thus capturing the spikes in oil prices and exchange rates and their impact on domestic energies. We allow also for high-frequency shocks to the headline inflation that can be explained as either cost-push factors unexplained by fundamentals, as proposed by Andrle et al. (2014), or as a form of measurement errors. Oil price inflation is then captured by an exogenous process and adjusted for the changes in nominal exchange rate and trend real appreciation.

$$\boldsymbol{\pi_{i,t} = \kappa_{i1} \pi^{core}_{i,t} + (1 - \kappa_{i1}) \pi^{oil}_{i,t} + \varepsilon^{\pi}_{i,t}} \tag{8}$$

We depart from the standard definition of core inflation, as headline inflation adjusted for energy and food prices, and rather define it implicitly with the inflation identity. This approach is identical to Andrle et al. (2014) with the core inflation close to trimmed or winsorized time series. We experimented also with the specification of Szilágyi et al. (2013), with endogenously modelled core as well as non-core inflation and observed price index adjusted for energy and food, but decided against, due to the forecasting performance.

Core inflation of the euro area is determined by the hybrid closed economy Phillips curve pinning down the inflation rate as a function of its past and expected value, lagged non-core inflation and lagged output gap. Parameter λ_2 captures the total effect of past and future indexation to core inflation and parameter 1- λ_2 spillovers from the energy prices. Homogeneity of this term is crucial for the model stability. The curve contains both backward-looking and forward-looking elements of agents' expectations. The relative weight of the forward-looking element is captured by the parameter λ_1 measuring the share of price setters who set their expectations about future inflation in a model-consistent way. The backward-looking element includes direct and indirect indexation to past inflation and the 1- λ_1 share of price setters who set their expectations about future inflation based on observed inflation in the past. Again, output gap entering the Phillips curve is empirically lagged and the last term is referring to a supply shock to the economy.

$$\boldsymbol{\pi^{core}_{i,t} = \lambda_{i2} \pi^{exp}_{i,t} + (1 - \lambda_{i2}) \pi^{oil}_{i,t-1} + \lambda_{i3} y_{i,t-1} + \varepsilon^{core}_{i,t}} \tag{9}$$

$$\boldsymbol{\pi^{exp}_{i,t} = \lambda_{i1} \pi^{core}_{i,t+1} + (1 - \lambda_{i1}) \pi^{core}_{i,t-1}} \tag{10}$$

Core inflation of the Visegrad Group is determined by the open economy version of the Phillips curve. The original equation is enriched by the additional term capturing an upward pressure of exchange rate depreciation on domestic inflation via the import channel. In contrast to the specification with the quarterly change of real exchange rate applied by Carabenciov et al. (2008), we base the inflation rate on the real effective exchange rate gap with the weights based on the relative imports from country j to country i. This is to ensure the model stationarity, due to the trend real appreciation of the Visegrad Group economies. Again, this term is empirically lagged.

$$\boldsymbol{\pi_{i,t}^{core} = \lambda_{i2}\pi_{i,t}^{exp} + (1-\lambda_{i2})\pi_{i,t-1}^{oil} + \lambda_{i3}rmc_{i,t-1} + \varepsilon_{i,t}^{core}} \tag{11}$$

$$\boldsymbol{rmc_{i,t} = \lambda_{i4}y_{i,t} + (1-\lambda_{i4})\sum im_{ij}z_{ij,t}} \tag{12}$$

We can represent the parameter λ_3 as the impact of real marginal costs on the inflation rate and the parameters λ_4 and $1-\lambda_4$ as the weights of domestic and foreign components in the real marginal costs. Again, the value of parameter λ_4 depends on the relative openness of the economy. We distinguish between two effects of currency depreciation. First, rising exchange rate leads to higher import oil prices with primary effect on the energy inflation and secondary pass-through to the core inflation. Second, nominal depreciation leads to real depreciation and positive exchange rate gap with direct impact on the core inflation. We exclude from the impact of real oil price gap as Andrle et al. (2014), since it is difficult to either set steady-state level or growth rate of the oil prices, decompose the nominal oil price into real and inflationary components or decompose the real oil price into trend and gap components.

In contrast to the euro area specification, inflation targets for the Visegrad Group economies are modelled endogenously as random walk processes and not fixed to actual target values, thus allowing for historical changes in this variable. We further suppose that adopting the European Central Bank (ECB) monetary policy implied changes in Slovakia inflation expectations and set the parameter λ_1 after the monetary switch to the euro area level.

4.4 Monetary policy

Central bank is affecting the economy via changes in the policy rate, considered as a risk-free nominal interest rate that is pinned down by the Taylor-type rule, similarly to the DSGE models. Specifically, we assume that the policy rate is a function of its own lagged value, to smooth the interest rate movement, policy neutral rate and monetary authority responses to the deviations of inflation rate and output gap from their target or steady-state values. We should mention that the steady-state of the euro area inflation is equal to the inflation target of the ECB. We further assume that the monetary authority responses to the annual inflation four quarters ahead. After adopting the ECB monetary policy, policy rate of Slovakia is set to its euro area counterpart.

$$\boldsymbol{I_{i,t} = \gamma_{i1}I_{i,t-1} + (1-\gamma_{i1})\left(\bar{R}_{i,t} + \pi_{i,t+4}^{yoy} + \gamma_{i2}\left(\pi_{i,t+4}^{yoy} - \pi_{i,t+4}^{tar}\right) + \gamma_{i3}y_{i,t}\right) + \varepsilon_{i,t}^{I}} \tag{13}$$

Real interest rate is then determined by the Fisher equation and thus equal to the nominal interest rate minus the inflation expectations one quarter ahead, in other words $R_{i,t} = I_{i,t} - \boldsymbol{\pi}_{i,t+1}$. Definition of potential real interest rate is country-specific and while the euro area potential rate is pinned down by a simple autoregressive process with the speed of steady-state convergence γ_4, potential rates of the Visegrad Group economies are captured by the international interest rate parity, as described in the next subsection.

Government bond yields are determined by the expectations theory, thus as the average short rate expectations over the next ten years on quarterly basis plus the corresponding risk premium. Real government yields and their potential counterparts are defined in the same way, only replacing the nominal short rate expectations by the real and potential ones. Long-term interest rate gap is then defined as a simple difference between real and potential short rate expectations. Weight of the short-term interest rates is captured by parameter ρ_1.

4.5 Uncovered interest parity

Nominal exchange rate is determined by a modified version of the uncovered interest parity, incorporating forward-looking as well as backward-looking expectations about future exchange rate. Specification with the hybrid UIP is according to Adolfson et al. (2008), arguing that this model has an empirical advantage over the standard UIP. Relative weight of the forward-looking element is then captured by parameter ϕ_1, measuring the share of investors with model-consistent expectations, and relative weight of the backward-looking element by 1-ϕ_1, measuring the share of investors with expectations based on observed values of the exchange rate taking into account trend real appreciation and expected inflation differential. This specification is thus similar to the one of Beneš et al. (2003). Finally, the difference between the exchange rate expectations and actual exchange rate is equal to the short-rate differential between the domestic economy and the euro area minus the currency premium, capturing the fact that the investors expecting currency depreciation require additional compensation in the form of higher interest rates.

$$\boldsymbol{S_{i,t} = S_{i,t}^{exp} - I_{i,t}/4 + I_{ea,t}/4 + cp_{i,t}/4 + \varepsilon_{i,t}^{S}} \tag{14}$$

$$\boldsymbol{S_{i,t}^{exp} = \phi_{i1} S_{i,t+1} + (1 - \phi_{i1})\left(S_{i,t-1} + 2\Delta\bar{z}_{i,t}/4 + 2\pi_{i,t+1}/4 - 2\pi_{ea,t+1}/4\right)} \tag{15}$$

In contrast to the specification of Carabenciov et al. (2008), with potential interest rates determined by simple stochastic processes, potential interest rates in our specification are captured by the trend version of the UIP. We thus assume that the potential interest rates of small open economies are not based on economic fundamentals but rather on the potential rate of their most important trading partner, trend real appreciation and potential currency premium.

$$\boldsymbol{\bar{R}_{i,t} = 4\bar{Z}_{i,t+1} - 4\bar{Z}_{i,t} + \bar{R}_{ea,t} + cp_{i,t}} \tag{16}$$

Real exchange rate is defined as the nominal exchange rate minus the price level in the domestic economy plus the price level in the euro area, in other words $Z_{i,t} = S_{i,t} - P_{i,t} + P_{ea,t}$, thus capturing the relative purchase power of the domestic economy. After the Euro adoption, we exclude from the nominal exchange rate growth, real exchange rate growth thus equal to the inflation differential. Potential real exchange rate is then determined by a local linear trend model, similarly to the potential output, taking into account trend real appreciation that gradually converges to its steady-state and shocks to the potential level as well as to the potential growth rate.

$$\boldsymbol{\bar{Z}_{i,t} = \bar{Z}_{i,t-1} + \Delta\bar{z}_{i,t}/4 + \phi_{i4}\left(B_{i,t} - B_{i,t-1}\right) + \varepsilon_{i,t}^{\bar{Z}}} \tag{17}$$

$$\boldsymbol{\Delta\bar{z}_{i,t} = \phi_{i2}\Delta z_i^{ss} + (1 - \phi_{i2})\Delta\bar{z}_{i,t-1} + \varepsilon_{i,t}^{\Delta\bar{z}}} \tag{18}$$

Furthermore, we expand the original equations for the quarterly change in the government debt, thus capturing the fact that rising government debt leads to the trend currency depreciation and that expectation of rising debt puts an upward pressure on the potential interest rates and negatively affects the potential output via interest rate channel.

4.6 Risk premiums

We distinguish between three types of risk premia in the model specification, (i) interbank premium affecting the short-term interest rates, (ii) government bonds premium affecting the long-term interest rates and (iii) currency premium affecting the uncovered interest parity. While the first and second one capture the central banks' imperfect control over domestic interest rates, the third one captures the central banks' imperfect control over exchange rate development. This is in contrast to the specification of Carabenciov et al. (2008), assuming only imperfect control over the exchange rate market and not the domestic one.

We construct the interbank risk premium as a simple difference between three-month money market rates and average short expectations approximated by the overnight rates.[4] Implied policy rate of the euro area is then very close to the three-month Overnight Indexed Swap (OIS), thus really approximating the risk-free interest rate of the economy. Due to the historical evidence, we distinguish between trend and gap component of the interbank premium, while the former shows a higher degree of persistence and affects the potential interest rate and the latter captures actual investors' preferences with relatively high volatility and affects the interest rate gap. This is in contrast to the specification of Andrle et al. (2014) with the interbank premium consisting of only gap component. After entering the monetary union, both trend and gap components of Slovakia interbank premium are set to their euro area counterparts.

We allow for additional spillovers from the euro area to the Visegrad Group countries via risk premium channel. Due to the relative size of respective economies, we expect the spillovers from the euro area premium to the Visegrad Group premia but not vice versa. Interbank premium of the euro area thus follows a simple autoregressive process, while the interbank premia of the Visegrad Group are adjusted by the additional component capturing the euro area spillovers. Potential premium then follows the standard convergence process with persistence ω_1.

$$\boldsymbol{mp_{i,t} = \chi_{i1} mp_{i,t-1} + \chi_{i2} mp_{ea,t} + \varepsilon_{i,t}^{mp}} \tag{19}$$

On the other hand, bonds and currency premia consist of only potential components, following standard convergence processes with persistence ω_2 and ϕ_3 respectively. While the gap component of the bond premium is considered trivial, the gap component of the currency premium is captured by the shocks to the uncovered interest parity. Risk premium on the government bonds is further affected by the expected deviation of government debt from its steady-state value over next ten years, thus capturing the negative effect of excessive government debt on the potential output via interest rate channel. Elasticity of the risk premium to the government debt deviation is meanwhile captured by parameter ω_3-$\omega_2\omega_3$. After entering the monetary union, steady-state value of the bond premium is set to its euro area counterpart, thus lowering the yields on government bonds by half percentage point, and the currency premium is set to zero.

4.7 Fiscal policy

Government debt is a function of actual government deficit and outstanding government debt from the previous period adjusted by the discount factor.[5] We allow also for shocks to the government identity, due to the stock flow adjustment factors, as the formation of the cash reserve or the privatisation effects. On the other hand, target path for the debt is set by the government and pinned down by a simple random walk process.

$$\boldsymbol{B_{i,t} = df_{i,t} B_{i,t-1} + D_{i,t} + \varepsilon_{i,t}^{B}} \tag{20}$$

Consistently with the target debt, we define the sustainable structural deficit, which is adjusted by the expected nominal output growth over the next year, thus approximating the government policy one year ahead. Actual structural deficit then fluctuates around the sustainable one in order to meet the target. This equation might be augmented with the government objective to smooth the output throughout business cycles by adding the term reflecting the deviation of actual nominal output from its potential counterpart. However, since it would be rather inefficient for the government to pursue a countercyclical policy in the small open economy we do not include this feature in the model.

[4] We apply overnight money market rates on monthly basis, due to data availability, and complement with one-month money market rates to reduce the expectations errors.

[5] Discount factor is the sum of the quarterly nominal GDP from time t-4 to time t-1 divided by the sum of the quarterly nominal GDP from time t-3 to time t. This is due to the definition of the debt to GDP ratio as the ratio between cumulative government debt and annual nominal output.

$$\boldsymbol{sd_{i,t}^{tar} = B_{i,t}^{tar} - df_{i,t+4} B_{i,t}^{tar}} \tag{21}$$

$$\boldsymbol{sd_{i,t} = \delta_{i1} sd_{i,t-1} + (1 - \delta_{i1}) sd_{i,t}^{tar} + \varepsilon_{i,t}^{sd}} \tag{22}$$

Overall government deficit then fluctuates around the structural one, depending on a cyclical position of the economy and according to a deviation of government debt from its target one year ahead. The former reflects the impact of automatic stabilizers on government budget whereas the latter follows the policy reactiveness approximating the government policy one year ahead. Finally, fiscal impulse is determined by a quarterly change in the structural deficit, shock to the overall deficit and a quarterly change in the target debt, evaluating the impact of fiscal consolidation.

$$\boldsymbol{D_{i,t} = sd_{i,t} - \delta_{i2} y_{i,t} - \delta_{i3} b_{i,t+4} + \varepsilon_{i,t}^{D}} \tag{23}$$

$$\boldsymbol{d_{i,t}^{imp} = sd_{i,t} - sd_{i,t-1} + \varepsilon_{i,t}^{D} + \delta_{i4} \varepsilon_{i,t}^{tar}} \tag{24}$$

In the future, we would like to extend the fiscal block for additional variables to capture the channels of the fiscal policy. Specifically, we want to incorporate the effects of direct and indirect taxes on the aggregate demand as well as the aggregate supply. In addition, we want to decompose the overall government deficit into primary deficit and interest rate costs to quantify the true impact of the fiscal policy on the real economy and future economic development.

5 Parametrisation

We distinguish between four basic groups of model parameters. First, steady-state parameters determining the long-run convergence of model variables. These parameters are usually calibrated as sample averages from data. Second, structural parameters capturing the model development throughout the business cycles and corresponding policy reactiveness. These are mostly the parameters entering the behavioural equations. Third, trend parameters determining the development and convergence of potential variables, and finally, stochastic parameters describing the behaviour of model shocks. Since we exclude the cross-correlations of the model shocks, these parameters capture only their standard deviations.

Due to the number of model equations, we need to calibrate majority of the parameters. Specifically, we calibrate the steady-state and trend parameters, while estimating the key model elasticities, as the pass-through of the monetary and fiscal policy to the real economy or the elasticity of the inflation rate on the real marginal costs, and the most important model shocks, including shocks to the aggregate demand as well as the aggregate supply. However, most of the structural and stochastic parameters are also calibrated. Estimation procedure is based on the Bayesian techniques of a maximum posterior estimation and Monte Carlo Markov Chain (MCMC) sampling based on the Metropolis-Hastings algorithm.

5.1 Calibration

Steady-state values of the real output growth are calibrated as sample medians on the estimation period from January 2002 to June 2017. We apply median instead of mean for robustness of the results, especially in the period of the economic and financial crisis. We further adjust the results for the emerging economies of the Visegrad Group, since the high-level growths at the beginning of the sample period are not sustainable in the long-term horizon. Steady-state growth of the euro area is thus set to 1.75%, while the steady-state of Czech Republic to 2.75%, Hungary to 2.25%, Poland to 3.25% and Slovakia to 3.00%.

Similarly, we set the steady-state values for the unemployment rate as the average long-term unemployment and adjust the results for the emerging markets, due to the historical development. Specifically, steady-state unemployment of the euro is set to 4.50%, while the steady-state for Czech Republic to 2.25%, Hungary to 2.75%, Poland to 4.25% and Slovakia to 6.75%.

We set the steady-state inflation rates to the actual inflation targets and thus to 2.00% for Czech Republic, 3.00% for Hungary and 2.50% for Poland. Inflation target of the euro area is modelled constant and set to 1.90%. Steady-state inflation of Slovakia is determined by the exchange rate identity and thus equals its euro area counterpart plus the steady-state real appreciation. Equilibrium real appreciation is then calibrated as the difference between the steady-state growths of the Visegrad Group economies and the euro area. Currency premium is set to 0.75% for Czech Republic, 1.25% for Hungary, 1.75% for Poland and 1.00% for Slovakia, following the historical evidence, related literature and volatility in the exchange rates.

We calibrate the steady-state real interest rate of the euro area as the average from January 2002 until December 2007 to exclude the effect of the zero-lower bound and the period of negative real interest rates and set this value to 1.25%. Equilibrium interbank premia are set as the sample medians and thus to 0.10% for the euro area, 0.20% for Czech Republic and Poland, and 0.40% for Hungary and Slovakia before the monetary switch. Bond premium is then set to 0.75% for the euro area and to 1.25% for Slovakia, thus lowering the steady-state yields on government bonds by half percentage point after the monetary switch. Finally, steady-state for the government debt is calibrated to 40.00% following the historical evidence.

We continue with the trend variables and set the potential output convergence (τ_1) to 0.05 and the pass-through of the potential interest rate (τ_2) to 0.10 for all economies. Potential exchange rate convergence (ϕ_2) is country-specific and calibrated due to the historical evidence. Specifically, we set this parameter to 0.05 for Czech Republic and Hungary, since their historical exchange rate growths fluctuate around the steady-state values. On the other hand, Slovakia exchange rate growth historically overcomes its steady-state value, while the opposite holds for Poland. We thus set these parameters to 0.01 to capture the lower degree of convergence. Similarly, potential unemployment convergence (α_3) is set to 0.01 for the euro area, 0.02 for Czech Republic, 0.01 for Hungary and 0.04 for Poland and Slovakia.

Potential interest rate of the euro area also shows a low degree of convergence, we thus calibrate the parameter γ_4 to 0.01. Interbank premium (ω_1) and bond premium (ω_2) persistence is set to 0.90, while the persistence of the currency premium (ϕ_3) is set to 0.80. Finally, persistence of the structural deficit (δ_1) is calibrated to 0.90, impact of the government debt on the potential exchange rate (ϕ_4) to 0.05 and the pass-through of the fiscal consolidation (δ_4) to 0.50.

Persistence of the output gap (β_1), unemployment gap (α_1) and interbank premium (χ_1) are based on the results of the Hodrick-Prescott filter and adjusted due to the related literature and historical development. In addition, we calibrate the elasticity of unemployment to output (α_2) and market premium spillovers from the euro area (χ_2) via the Ordinary Least Squares (OLS). Inflation expectations (λ_1) as well as the exchange rate expectations (ϕ_1) are calibrated due to the related literature, while the former is based on the results of Vašíček (2011). Similarly, calibration of the policy rate persistence (γ_1) follows Andrle et al. (2014). Finally, we set the output expectations parameter (β_2) to 0.10 and the core inflation weight in the hybrid Phillips curve (λ_2) to 0.999, thus limiting the pass-through of oil prices to the core inflation.

Structural parameters of the open economies are calibrated as trade to output ratio (β_4), import to output ratio (λ_4), and export to output ratio (β_5), with the first and second one capturing the total country openness and the last one referring to the pass-through of the model economies. We should mention, that due to the increasing trade openness of the emerging economies, this parameter is in fact non-stationary and should capture rising export to GDP ratio in a fully structural model. Remaining structural parameters of the euro area are calibrated due to the historical development, impulse response functions and the New-Keynesian model of closed economy. We calibrate also the Taylor rule parameters of Slovakia, since they are relevant only for historical development and not actual policy simulations.

Stochastic parameters are calibrated to further advance the structural interpretation of historical data, while taking into account the historical data evidence as well as the structure and particularities of the model economies. For example, shocks to the potential exchange rate growth are based on the degree of historical convergence, while the potential level shocks cover the volatility in the historical data. Again, key stochastic parameters of the euro area are calibrated according to the New-Keynesian model of closed economy.

Finally, parameters capturing the cross-exports and the cross-imports between the model economies are calibrated as the sample averages from historical data.[6] Although the weights of the euro area in the external block are set over 80% for Poland as well as Hungary and over 75% for Czech Republic, relative importance of the euro area for Slovakia is not either 65%. Czech Republic is then second with approximately 20%, followed by Poland and Hungary with 8%. Structural, stochastic and trade parameter values are proposed in Appendix.

[6] Information about the cross-exports and the cross-imports of the model economies are from Comtrade. Data are obtained on annual basis. Euro area covers the core twelve countries.

5.2 Bayesian estimation

We estimate the rest of the model parameters using the Bayesian interface that provides a compromise between the standard estimation and the calibration of the model parameters. The reason is that the standard estimation applied on short data sample usually provides results that are inconsistent with the macroeconomic fundamentals, often estimating effects that are opposite to the standard macroeconomic views. This is especially problematic when these models are applied for policy simulations. On the other hand, calibrated models have no support in data and often reflect nothing more than the modellers' judgement. As the middle ground between these two approaches, Bayesian estimation has a benefit of putting some weights on the prior expectations and some weights on the observed data over the estimation period. These weights are meanwhile captured by the standard deviations of the priors, thus allowing to distinguish between parameters with high and low degree of initial certainty, in other words mostly calibrated and mostly estimated parameters. As the result, posterior distributions of the model parameters are obtained as the weighted average between prior and data generating distributions.

Bayesian approach proposed in this paper consists of a two-step estimator. At first, we apply a maximum posterior estimation to obtain the posterior modes of the model parameters, similarly to Carabenciov et al. (2008). This is in fact nothing else than the standard Maximum Likelihood Estimation (MLE) extended for the deviation of the parameters from their prior modes. We use standard Quasi-Newton method with the BFGS update step for the optimization process. We considered also application of global optimization methods, especially the Differential Evolution algorithm, but decided against, due to the number of estimated parameters.

Application of the maximum posterior estimator has two main disadvantages. First, estimation of the posterior modes is performed under the true/false loss function, in contrast to the standard quadratic loss function applied for the posterior means. Second, we obtain only the point estimates and not the entire distributions of the posterior parameters. Therefore, we apply an additional estimation step where we sample from the posterior distributions using the MCMC sampling algorithm based on the random walk Metropolis-Hastings simulation. As the result, we obtain an approximation of the posterior distributions and thus information about the means, standard deviations and confidence intervals of the estimated parameters.

Prior distributions of the structural parameters are set according to the impulse response analysis and related literature. Priors of the stochastic parameters are then based on the historical data development. Structural parameters are from the gamma distributions and the stochastic ones from the inverse gamma distributions, according to the related literature. Priors as well as posteriors of the estimated parameters are proposed in Appendix.

While the posterior mean of the monetary policy pass-through (β_3) is estimated higher than the prior for Czech Republic, the opposite holds for the rest of the economies. On the other hand, posterior estimator of the fiscal policy pass-through (β_6) for Slovakia is close to the prior. Posteriors of the real marginal costs pass-through (λ_3) are estimated below the priors for all economies, with the most significant decline for Slovakia. Taylor rule parameters are also estimated below the priors, mostly for Poland. While the overall deficit elasticity on the government debt (δ_3) overcomes the prior, the opposite holds for the government bonds premium (ω_3). Finally, automatic stabilizers of the fiscal policy (δ_2) are significantly below the prior setting. Posterior standard deviations were reduced for all parameters except the government policy reactiveness.

While the standard deviations of the aggregate demand shocks are estimated higher than the priors, posterior standard deviations of the monetary and fiscal policy shocks are significantly below the prior settings. Standard deviation of the aggregate supply shock of Slovakia is estimated higher than the prior, while the estimations for Czech Republic, Hungary and Poland are close to the prior settings. Again, posterior volatility is reduced for all parameters except the cost-push shock of Slovakia.

6 Model evaluation

Evaluation of the model performance is based on the impulse response functions and the historical decomposition of the model variables. We propose the impulse response functions to the most important domestic and external shocks, including shocks to the domestic and foreign demand, cost-push shocks, shocks to the policy rate, risk premium and exchange rate and shocks to the government deficit and target debt. All shocks have magnitude equalling one percentage point as common in the related literature, except the oil price shock with the magnitude of ten percentage points, due to the volatility of the oil prices. Impulse response functions are presented in percentage points. On the other hand, we propose the historical estimation of the core inflation, output gap and potential variables.

We propose also simple fiscal policy simulation based on the positive shock to the target debt and different government policies and unconditional as well as conditional forecast based on the estimated historical time series and pre-set path for the target debt.[7] Model evaluation together with the fiscal policy simulation is proposed in Appendix.

6.1 Impulse response functions

Starting with the domestic demand shock, output gap puts an upward pressure on the core inflation multiplied by the rational expectations. Reaction of the monetary policy follows the output and inflation development putting an upward pressure on the real interest rates and thus leading to the appreciation of the nominal as well as the real exchange rates. On the other hand, due to the absence of the monetary policy reaction, we observe initial decline in the real interest rates for Slovakia. Rising output gap is then followed by the automatic stabilizers and thus leads to the decline in the government deficit as well as the government debt. Latter is further reduced through the nominal output growth.

On the other hand, external demand shock puts an upward pressure on the domestic output gap followed by the core inflation and the nominal as well as the real interest rates. Since the reaction of the domestic monetary policy overcome the external one, euro area demand shock leads to the nominal and real appreciation of the Visegrad Group countries. However, due to the absence of the exchange rate appreciation against the euro area, real exchange rate of Slovakia effectively depreciates. After initial increase of the structural deficit based on the forward-looking inflation pressure, we observe the decline in the government deficit as well as the government debt.

We continue with the cost-push shock, when rising inflation puts a downward pressure on the real interest rates together with the real exchange rate appreciation, followed by the monetary policy reaction and decline in the output gap. Reaction of the nominal exchange rate is uncertain and depends on the rigidity of domestic prices and monetary policy reactiveness. Specifically, the more active is the monetary authority, the more likely the currency appreciates. In addition, due to the forward-looking nature of the policy rule, more persistent inflation leads to the increase in the policy rate and thus to the currency appreciation. Higher nominal output growth puts an upward pressure on the government deficit and reduces the government debt.

Similarly, oil price shock leads to the increase in the headline inflation (blue line) slightly followed by the core one (red line) with the corresponding policy and economic reaction. In addition, decline in the real interest rates together with the real exchange rate depreciation produce positive output gap for Slovakia. Exchange rate shock leads to the nominal and real depreciation affecting the headline inflation (blue line) as well as the core one (red line) and putting an upward pressure on the output gap. Rising inflation and output gap activate the monetary policy and thus lead to the decline in the nominal as well as the real interest rates.

[7] Target path for the government debt is set according to the published forecast of the Ministry of Finance.

Monetary policy shock leads to the decline in the inflation rate and the output gap, increase in the real interest rates and nominal as well as real appreciation. On the other hand, shock to the interbank premium leads to the decline in the policy rate and nominal as well as real depreciation. Shocks to the policy rate and interbank premium for Slovakia refer to their euro area counterparts. Both of them lead to the increase in the government deficit and debt to compensate the output loss, thus pushing the potential exchange rate towards depreciation.

We present also impulse response functions to the additional external shocks for Slovakia, including shock to the external monetary policy and shock to the external interest rate parity. Due to the dynamics and magnitude of the impulse response functions, we propose only shocks for Czech Republic, with similar development for Poland and Hungary.

Shock to the external policy rate leads to the external exchange rate appreciation and thus to the depreciation of the domestic exchange rate. Output gap and core inflation initially increase, due to the exchange rate development, but decline afterwards through the external demand channel. Real interest rates follow the inflation dynamics, while the government deficit and debt react to the output gap development. On the other hand, shock to the external exchange rate leads to the domestic exchange rate appreciation, thus initially lowering the output gap as well as the core inflation, followed by the increase in the external and domestic demand. Again, real interest rates follow the inflation dynamics and the fiscal variables react to the output gap development.

Shock to the government deficit positively affects the output gap via contemporaneous fiscal impulse and increases the government debt, thus leading to the potential exchange rate depreciation. On the other hand, the government debt is expected to decline in the future, thus pushing the future potential exchange rate towards appreciation, lowering the potential interest rates and increasing the potential output growth. However, potential output is then negatively affected by the government debt through the bond premium channel. Gap components of the real interest and exchange rates compensate the development of their potential counterparts. Initial increase in the core inflation implied by the rising output gap is thus overcome by the exchange rate effects afterwards.

Finally, shock to the target debt leads to the increase in the government deficit, rising government debt and positive reaction of the output gap via the fiscal stimulation channel. On the other hand, actual and expected increase in the government debt pushes the potential exchange rate towards depreciation immediately and also in the future, thus increasing the potential interest rates and lowering the potential output growth. Again, gap components of the real interest and exchange rates compensate their potential counterparts.

6.2 Historical decomposition

Decomposition of the model variables is performed on the sample period from the first quarter of 2002 to the second quarter of 2017 with the Kalman filter and smoother. We propose the estimation of the core inflation, output gap and potential variables, including real interest rates, real exchange rates, interbank and bond premia and potential unemployment.

Core inflation (red line) is proposed against its headline counterpart (blue line) with the estimated time series close to the trimmed or winsorized inflation rates, similarly to Andrle et al. (2014). The only exception is the core inflation of Slovakia before the Euro adoption with high volatility and low co-movement with the output gap. Output gap (blue line) is then proposed against the external demand (red line) for the Visegrad Group and against the interest rate gap (red line) for the euro area, as the key drivers of the output gap development. While the domestic and the external demand of Poland show a similar degree of volatility, domestic demand of Slovakia fluctuates around the external one with significantly higher volatility, due to a number of one-off effects. Spike in the domestic demand of Slovakia in the last quarter of 2007 is driven by the prepositioning of cigarettes by tobacco firms, due to the expected increase in the taxes on tobacco.

Potential real interest rate of the euro area decreases on the sample period resulting into negative real interest rates in the recent years. Similarly, potential real interest rates of the Visegrad Group countries have mostly decreasing tendencies. Potential real exchange rate, proposed as 100 times the log of the original variable, decreases for all economies except Poland, with the most significant decline for Slovakia. Potential unemployment of the euro area has significantly increased after the economic and financial crisis, especially during the debt crisis of the eurozone. Although the potential unemployment dynamics of Hungary has changed in time, unemployment rates of the rest of the Visegrad Group countries have significantly decreasing tendencies. Structural deficit of Slovakia has declined after the economic and financial crisis, due to the decline in the nominal output growth, but increased in the recent years.

While the interbank premium of Czech Republic is driven mostly by the gap component, potential premium of Hungary has significantly increased after the economic and financial crisis, according to the issues with currency depreciation, thus affecting the interbank premium dynamics. Government bond premium of Slovakia (blue line) and its euro area counterpart (red line) show a high degree of co-movement, with higher levels of the Slovakia premium. However, in the recent years we observe the convergence of the Slovakia premium to its euro area counterpart. Sharp decline in the recent years is according to the effect of the Quantitative Easing (QE).

6.3 Fiscal simulations

We propose the impulse response functions to the positive target debt shock for three different government policies. While the baseline policy (black line) is according to the original model parametrisation, we experiment also with more pro-active government by (i) increasing the reactiveness to the government debt deviation from the target value (blue line), thus assuming the government wants to meet the target more aggressively, and (ii) increasing the effect of the fiscal stimulations (red line), thus increasing the impact of the target debt shocks on the fiscal impulse and the real economy. The first scenario corresponds to the increase of parameter δ_3 to 0.50 and the second one to the increase of parameter δ_4 to 1.00, thus assuming the Keynesian one-to-one impact of the fiscal stimulations.

The first scenario with more reactive government shows significant differences for the fiscal variables, with higher initial deficit and more sharply rising debt, and potential exchange and interest rates, with the first one pushed towards depreciation and the second one rising through the expectations about future development. On the other hand, the second scenario with more effective fiscal stimulations significantly increases the output gap, implying the initial increase in the output growth and the core inflation, and decreases the structural deficit, due to the decline in the expected future output growth.

6.4 Conditional forecast

Finally, we propose the unconditional and the conditional forecast from the third quarter of 2017 to the last quarter of 2020 starting from the estimated historical values, while the latter captures the pre-set path for the target debt according to the Ministry of Finance. While lowering the output gap, output growth and structural deficit via the fiscal impulse channel, we decline also the government debt (blue line) in order to meet the target (red line), through the decline in the government deficit, and the risk premium on government bonds that declines by approximately half percentage point at the end of the forecast period. We should also mention that we underestimate the future output growth, since not incorporating the one-off investment effects of Volkswagen and Jaguar.

7 Concluding remarks

In this paper, we proposed the medium-scale gap model of the Visegrad Group, based on the behavioural equations for output gap, unemployment gap, inflation rates, interest rates and exchange rates, together with the underlying stochastic processes, that was further extended with the fiscal block for Slovakia. In addition, we approximated the term structure of interest rates by incorporating the yields on ten-years government bonds. Spillovers between the economies are captured by three macroeconomic channels, (i) impact of the external demand on the domestic output, (ii) impact of the exchange rates via relative competitiveness and import prices and (iii) correlation of the interbank risk premia. On the other hand, government deficit and debt are affecting the economy via fiscal impulse, government bond premium and trend real appreciation.

There is a number of potential extensions of our work. First, we want to incorporate the expectations about the monetary switch thus better capturing the historical development of the model variables. Second, we want to extend the original model according to Szilágyi et al. (2013) and decompose the output gap and the inflation rate into their main components to obtain additional information about domestic consumption, investment, government expenditure and trade variables together with core and non-core inflation. Third, we want to extend the structure of the model shocks for basic cross-correlations according to Carabenciov et al. (2008) and complex demand shocks, including persistent and global shocks, according to Andrle et al. (2014). Finally, we want to extend the fiscal block for additional variables, as direct and indirect taxes and interest rate costs, to better capture the impact of the fiscal policy.

Bibliography

Adolfson, M., Laséen, S., Lindé, J., Villani, M. (2008): *Evaluating an estimated new Keynesian small open economy mode*l, Journal of Economic Dynamics and Control, Elsevier, Vol. 32 (8), 2690-2721

Andrle, M., Garcia-Saltos, R., Ho, G. (2014): *A Model-Based Analysis of Spillovers: The Case of Poland and the Euro Area*, Working paper, International Monetary Fund

Beneš, J., Hlédik, T., Vávra, D., Vlček, J. (2003): *The Quarterly Projection Model and it Properties*, The Czech National Bank's Forecasting and Policy Analysis System, Czech National Bank

Carabenciov, I., Ermolaev, I., Freedman, Ch., Juillard, M., Kamenik, O., Korsunov, D., Laxton, D., Laxton J. (2008): *A Small Quarterly Multi-Country Projection Model*, Working paper, International Monetary Fund

Carabenciov, I., Freedman, Ch., Garcia-Saltos, R., Laxton, D., Kamenik, O., Manchev, P. (2013): *GPM6 – The Global Projection Model With 6 Regions,* Working paper, International Monetary Fund

Gali, J., Monacelli, T. (2005): *Monetary Policy and Exchange Rate Volatility in a Small Open Economy*, Working paper, National Bureau of Economic Research

Gavura, M., Reľovský, B. (2005): *A Simple Model of the Transmission Mechanism of Slovakia's Economy, Its Structure and Properties*, Working paper, National Bank of Slovakia

Lyziak, T. (2016): *Do inflation expectations matter in a stylised New Keynesian model? The case of Poland*, Working paper, Narodowy Bank Polski

Múčka, Z., Horváth, M. (2015): *Fiscal Policy Matters A New DSGE Model for Slovakia*, Discussion paper, Council for Budget Responsibility

Smets, F., Wouters, R. (2003): *An Estimated Stochastic Dynamic General Equilibrium Model of the Euro Area*, Journal of the European Economic Association, Vol. 1 (5), 1123-1175

Szilágyi, K., Baksa, D., Beneš, J., Horváth, A., Kober, C., Soós, G.D. (2013): *The Hungarian Monetary Policy Model*, Working paper, Magyar Nemzeti Bank

Vašíček, B. (2011): *Inflation Dynamics and the New Keynesian Phillips Curve in Four Central European Countries*, Emerging Markets Finance and Trade, Vol. 47 (5), 71-100

Zeman, J., Senaj, M. (2009): *DSGE model – Slovakia*, Working paper, National Bank of Slovakia

Appendix

Table 1: Structural model parameters

Description		Euro Area	Czech Republic	Hungary	Poland	Slovakia
			Output gap			
Persistence	β_1	0.7000	0.7000	0.6750	0.6250	0.6000
Expectations	β_2	0.1000	0.1000	0.1000	0.1000	0.1000
Monetary policy	β_3	0.1250	0.1816	0.1669	0.1399	0.1578
Domestic weight	β_4	-	0.4700	0.3950	0.6650	0.2900
External demand	β_5	-	0.4850	0.4400	0.2050	0.5550
Fiscal policy	β_6	-	-	-	-	0.2033
			Unemployment gap			
Persistence	α_1	0.8000	0.7750	0.7500	0.7750	0.7750
Output gap	α_2	0.1250	0.1250	0.1000	0.2000	0.1500
			Headline inflation			
Core inflation	κ_1	0.9850	0.9900	0.9775	0.9875	0.9875
			Core inflation			
Expectations	λ_1	0.7500	0.5000	0.3750	0.4750	0.4250
Core inflation	λ_2	0.9990	0.9990	0.9990	0.9990	0.9990
Marginal costs	λ_3	0.0750	0.1064	0.1143	0.0999	0.0643
Domestic weight	λ_4	-	0.4750	0.3950	0.6550	0.2800
			Monetary policy rule			
Persistence	γ_1	0.7500	0.7500	0.7500	0.7500	0.7500
Inflation gap	γ_2	2.0000	2.9503	2.9835	2.9179	3.0000
Output gap	γ_3	0.2500	0.1975	0.1865	0.1656	0.1500
			Interbank premium			
Persistence	χ_1	0.5000	0.4000	0.4000	0.6000	0.5000
Euro spillovers	χ_2	-	0.5000	0.1000	0.5000	0.5000
			Uncovered interest parity			
Expectations	ϕ_1	-	0.7500	0.7500	0.7500	0.7500
			Fiscal policy rule			
Output gap	δ_2	-	-	-	-	0.3640
Debt deviation	δ_3	-	-	-	-	0.2200
Consolidation	δ_4	-	-	-	-	0.5000
			Government bonds			
Debt deviation	ω_3	-	-	-	-	0.1172

Table 2: Stochastic model parameters

Description	Euro Area	Czech Republic	Hungary	Poland	Slovakia
Output block					
Output gap	0.5000	0.6270	0.8547	0.6503	1.0963
Potential level	0.0750	0.1500	0.1500	0.1250	0.2000
Potential growth	0.0750	0.2000	0.2000	0.1250	0.2500
Unemployment block					
Unemployment gap	0.1500	0.2000	0.2500	0.4000	0.4000
Potential rate	0.1000	0.1000	0.2000	0.1500	0.1500
Inflation block					
Headline inflation	1.0000	1.5000	2.0000	1.5000	2.0000
Core inflation	0.3000	0.6098	0.7883	0.3948	0.9779
Oil price inflation	15.0000	-	-	-	-
Interest rate block					
Taylor rule	0.4000	0.6599	0.8573	0.7219	1.0000
Potential rate	0.0250	-	-	-	-
Exchange rate block					
Uncovered parity	-	4.0000	6.0000	7.0000	5.0000
Potential level	-	0.5000	0.7500	0.7500	0.5000
Potential growth	-	0.0500	0.0500	0.1000	0.1000
Risk premium block					
Premium gap	0.2000	0.1500	0.4000	0.2000	0.3000
Potential premium	0.0500	0.0500	0.1000	0.0750	0.0500
Bond premium	0.1000	-	-	-	0.1000
Currency premium	-	0.1500	0.3000	0.4000	0.2000
Fiscal block					
Government identity	-	-	-	-	1.5000
Overall deficit	-	-	-	-	0.8789
Structural deficit	-	-	-	-	0.0750

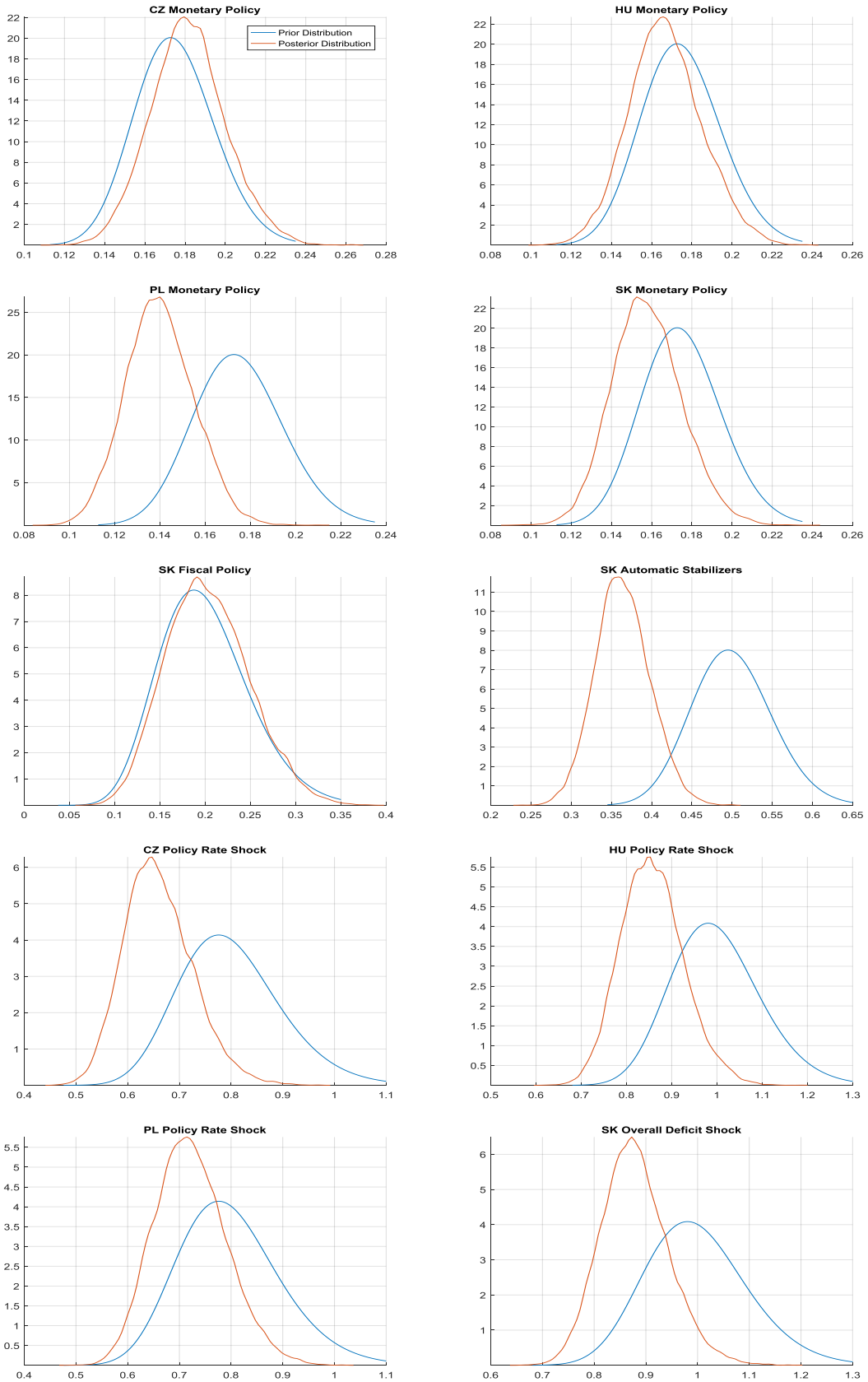
Table 3: Trade model parameters

Country	Euro Area	Czech Rep.	Hungary	Poland	Slovakia
			Trade parameters		
Czech Rep.	0.7721	-	0.0364	0.0875	0.1040
Hungary	0.8207	0.0540	-	0.0614	0.0639
Poland	0.8488	0.0781	0.0380	-	0.0352
Slovakia	0.6410	0.1933	0.0798	0.0859	-
			Export parameters		
Czech Rep.	0.7698	-	0.0360	0.0777	0.1166
Hungary	0.8268	0.0522	-	0.0550	0.0660
Poland	0.8327	0.0892	0.0424	-	0.0356
Slovakia	0.6499	0.1780	0.0806	0.0914	-
			Import parameters		
Czech Rep.	0.7743	-	0.0371	0.1005	0.0880
Hungary	0.8141	0.0559	-	0.0682	0.0618
Poland	0.8662	0.0659	0.0333	-	0.0347
Slovakia	0.6288	0.2140	0.0791	0.0781	-

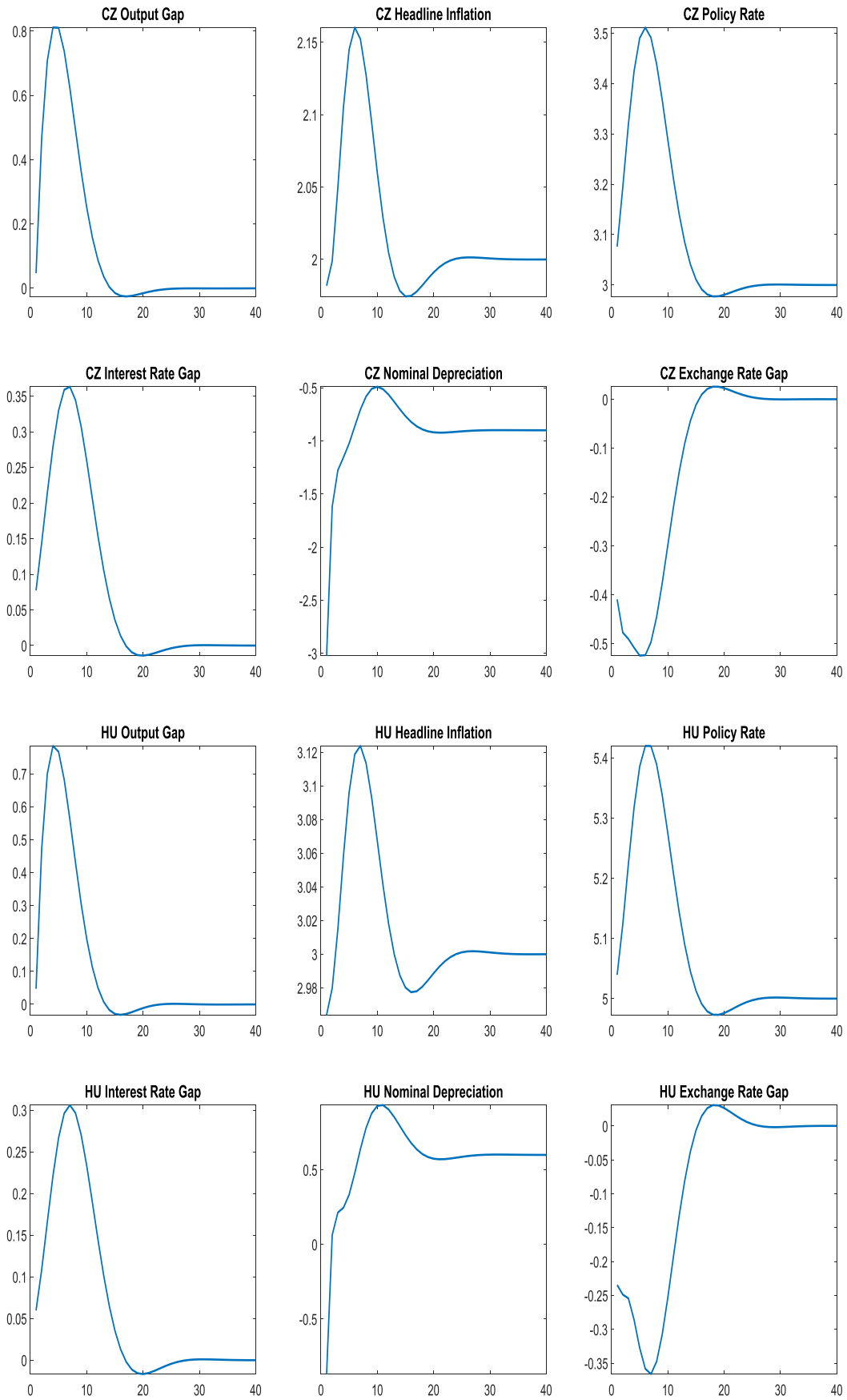
Table 4: Estimation procedure results

Country	Prior Mean	Prior St. Dev.	Posterior Mode	Posterior Mean	Posterior St. Dev.
Monetary policy pass-through					
Czech Rep.	0.1750	0.02	0.1803	0.1816	0.0188
Hungary	0.1750	0.02	0.1656	0.1669	0.0182
Poland	0.1750	0.02	0.1381	0.1399	0.0150
Slovakia	0.1750	0.02	0.1549	0.1578	0.0174
Fiscal policy pass-through					
Slovakia	0.2000	0.05	0.1944	0.2033	0.0457
Marginal costs pass-through					
Czech Rep.	0.1250	0.01	0.1049	0.1064	0.0084
Hungary	0.1250	0.01	0.1141	0.1143	0.0088
Poland	0.1250	0.01	0.0992	0.0999	0.0076
Slovakia	0.1250	0.01	0.0630	0.0643	0.0084
Inflation gap reactiveness					
Czech Rep.	3.0000	0.1	2.9431	2.9503	0.0977
Hungary	3.0000	0.1	2.9825	2.9835	0.0976
Poland	3.0000	0.1	2.9183	2.9179	0.0947
Output gap reactiveness					
Czech Rep.	0.2000	0.05	0.1866	0.1975	0.0482
Hungary	0.2000	0.05	0.1749	0.1865	0.0450
Poland	0.2000	0.05	0.1551	0.1656	0.0406
Automatic stabilizers					
Slovakia	0.5000	0.05	0.3601	0.3640	0.0338
Debt to government deficit					
Slovakia	0.2000	0.02	0.2188	0.2200	0.0212
Debt to government bonds					
Slovakia	0.2000	0.01	0.1166	0.1172	0.0053
Output gap shocks					
Czech Rep.	0.6000	0.05	0.6229	0.6270	0.0398
Hungary	0.8000	0.05	0.8473	0.8547	0.0484
Poland	0.6000	0.05	0.6435	0.6503	0.0437
Slovakia	1.0000	0.05	1.0938	1.0963	0.0474
Core inflation shocks					
Czech Rep.	0.6000	0.05	0.6040	0.6098	0.0443
Hungary	0.8000	0.05	0.7823	0.7883	0.0461
Poland	0.4000	0.05	0.3853	0.3948	0.0442
Slovakia	0.8000	0.05	0.9727	0.9779	0.0625
Policy rate shocks					
Czech Rep.	0.8000	0.1	0.6482	0.6599	0.0664
Hungary	1.0000	0.1	0.8448	0.8573	0.0695
Poland	0.8000	0.1	0.7099	0.7219	0.0697
Overall deficit shocks					
Slovakia	1.0000	0.1	0.8680	0.8789	0.0654

Priors and posteriors



External demand shock



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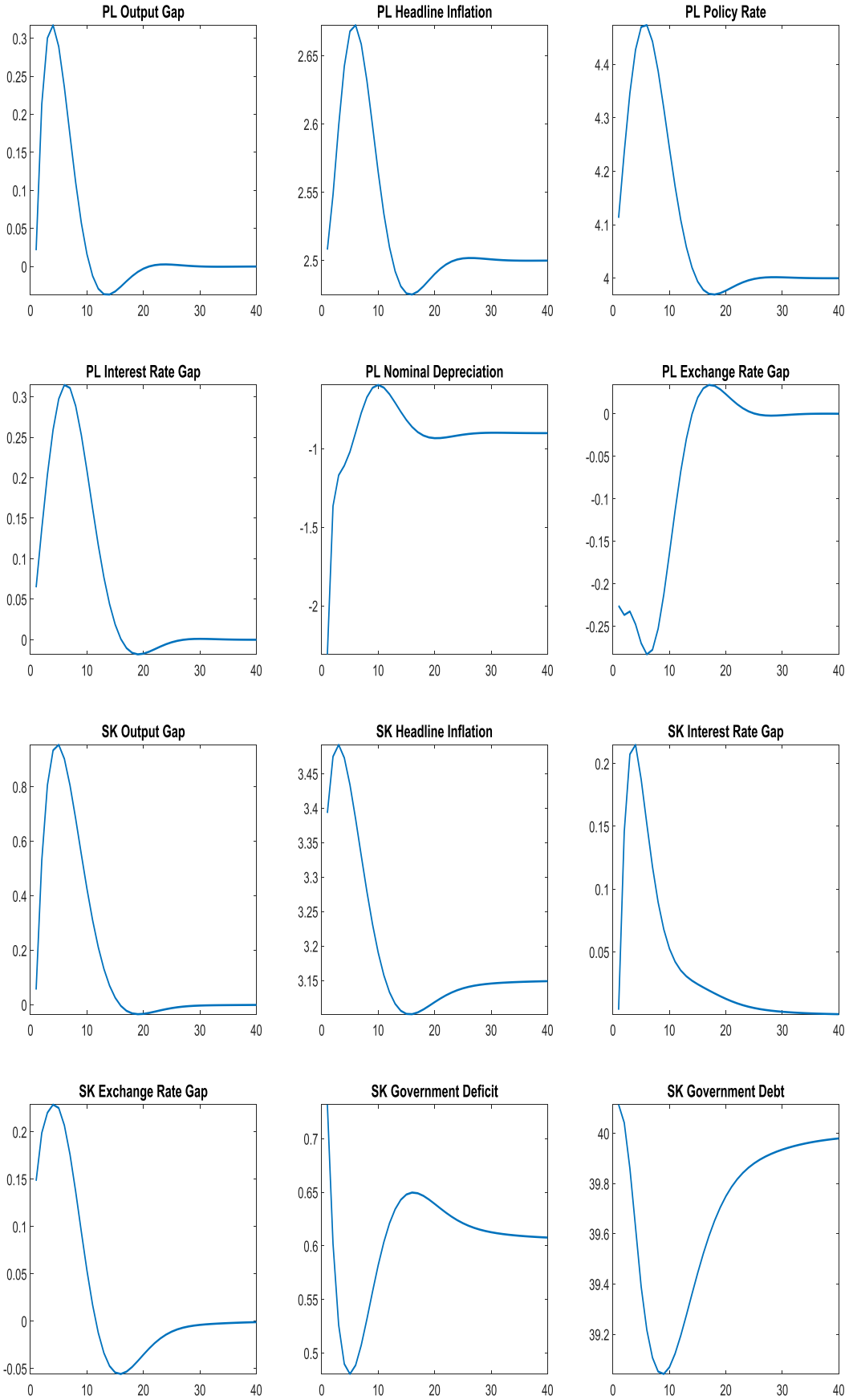
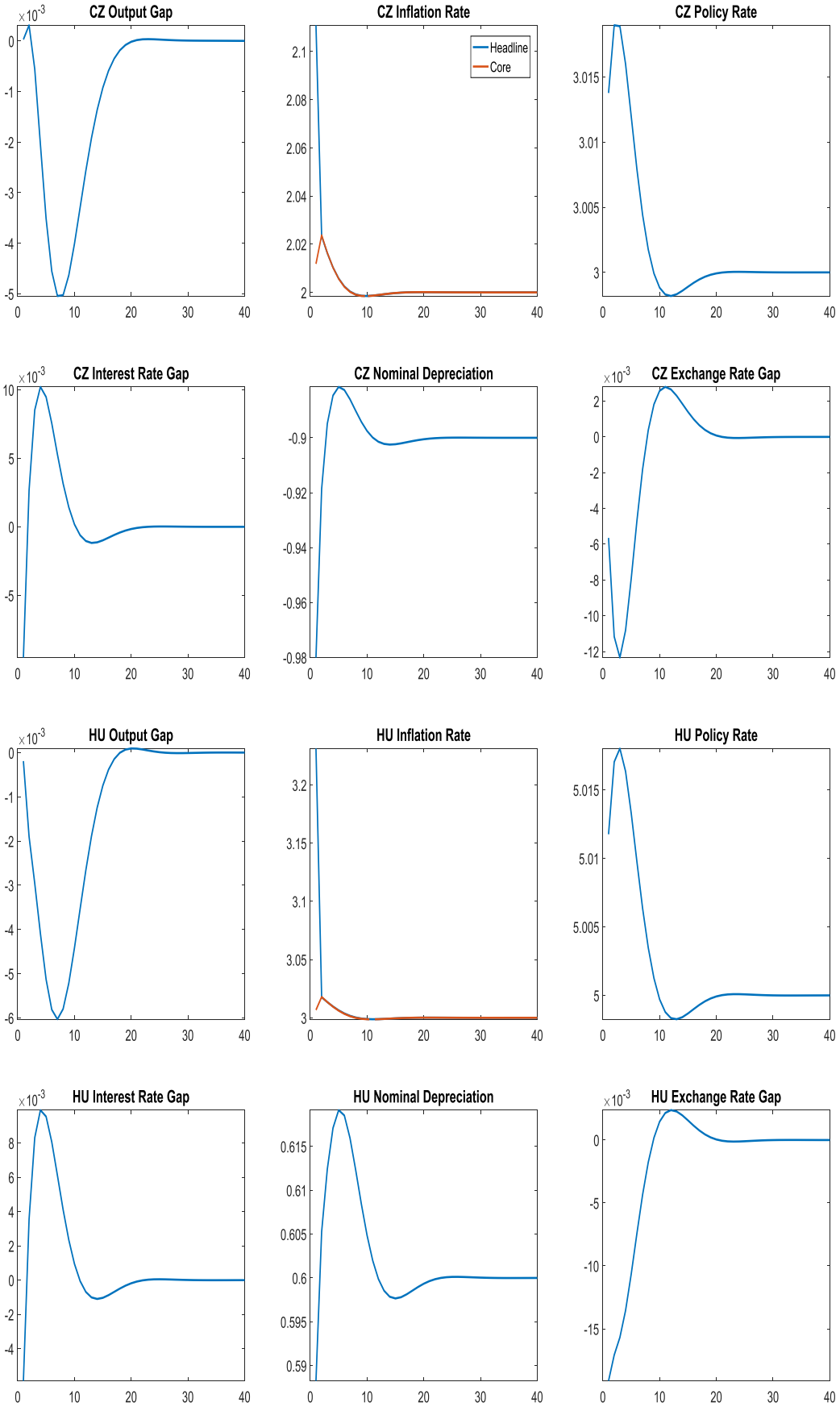


Oil price shock



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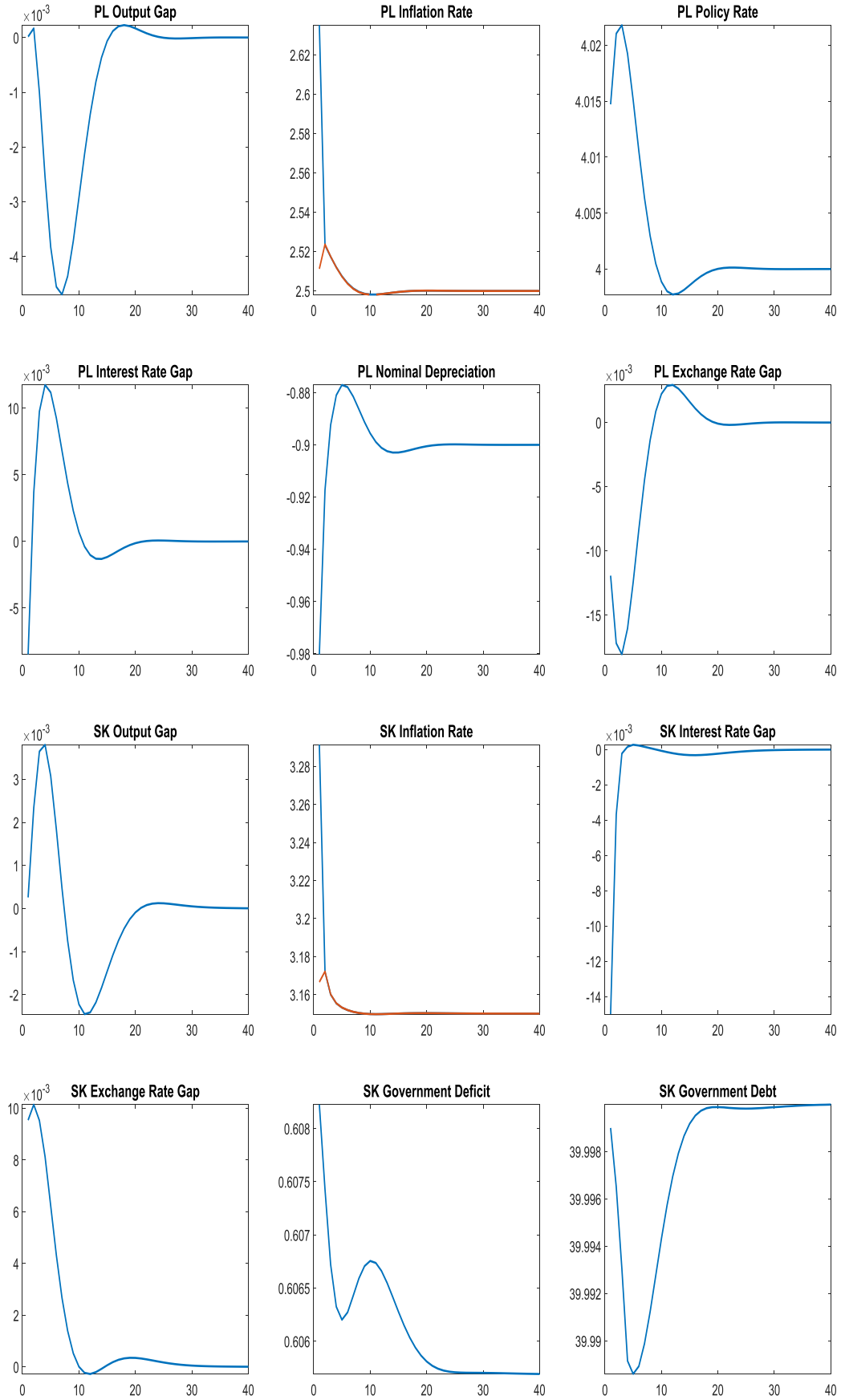
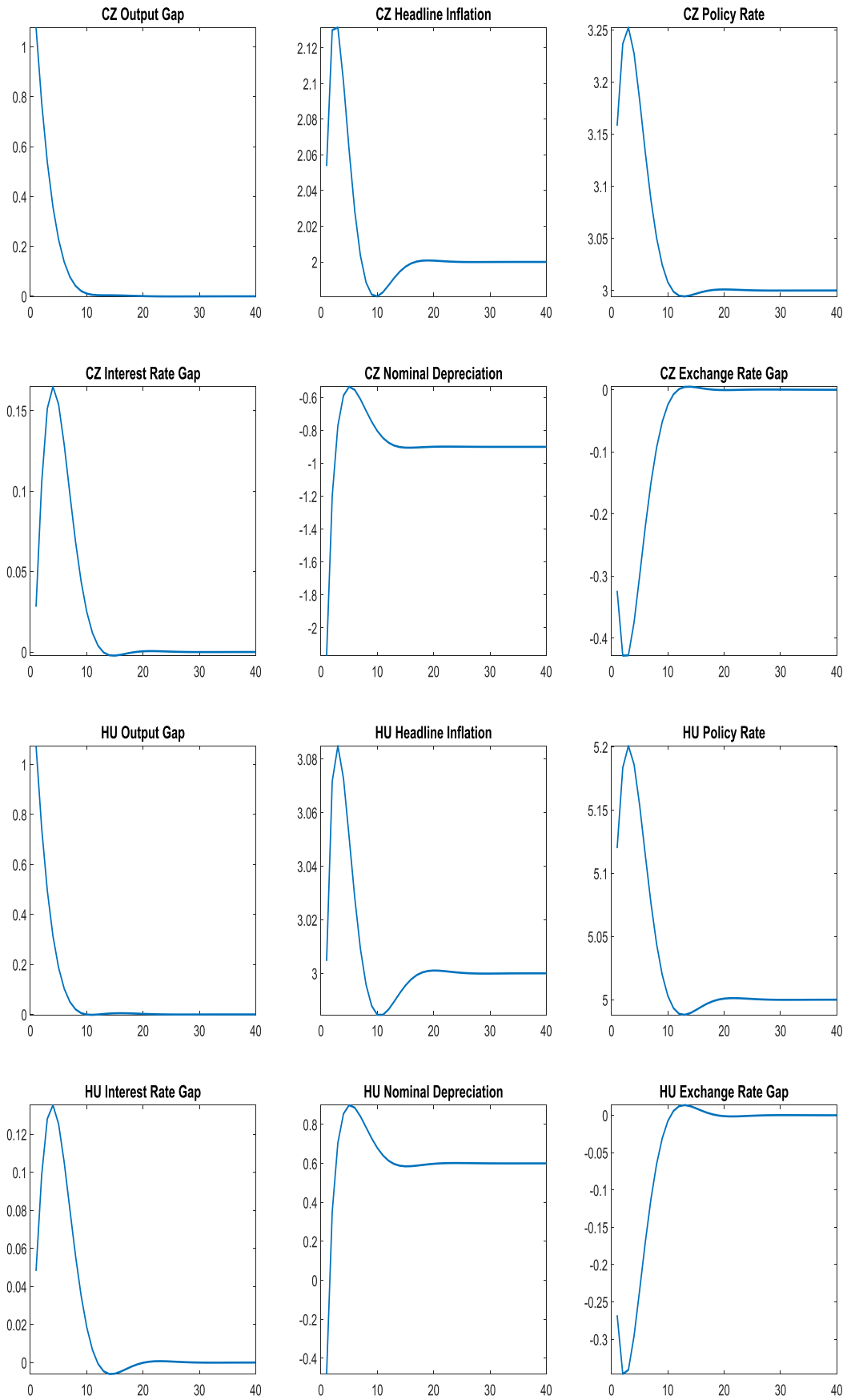


Domestic demand shock



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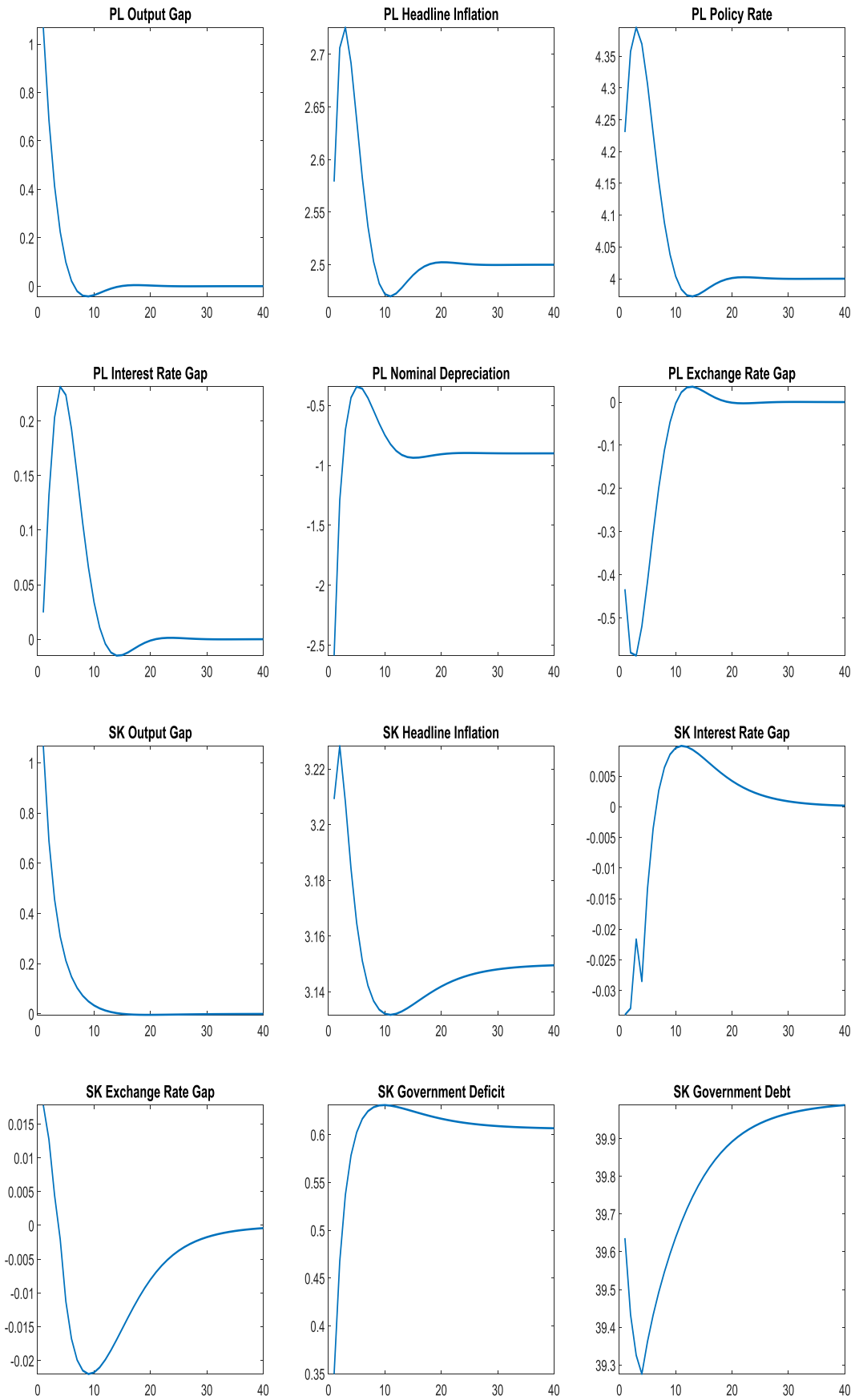
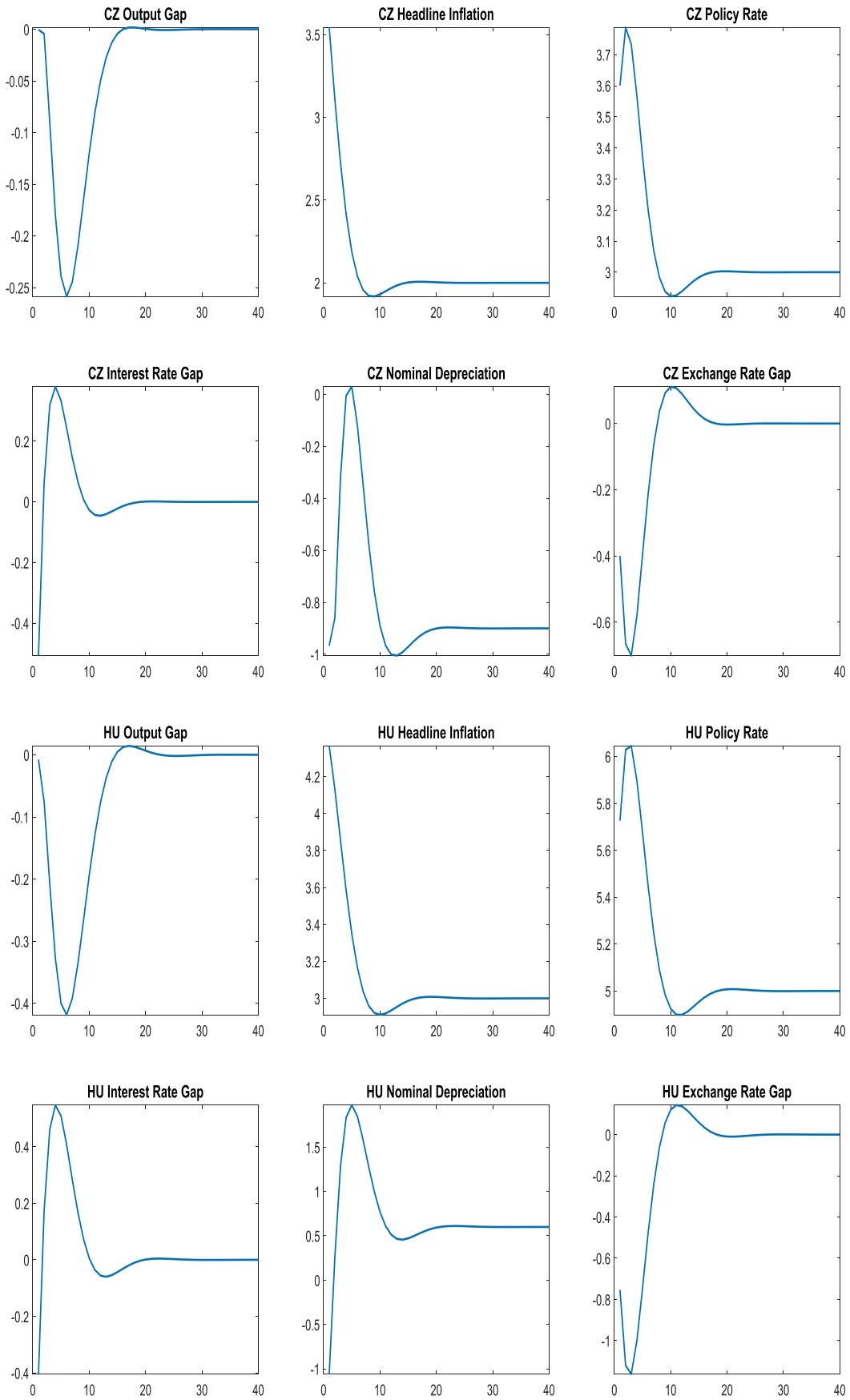


Domestic supply shock



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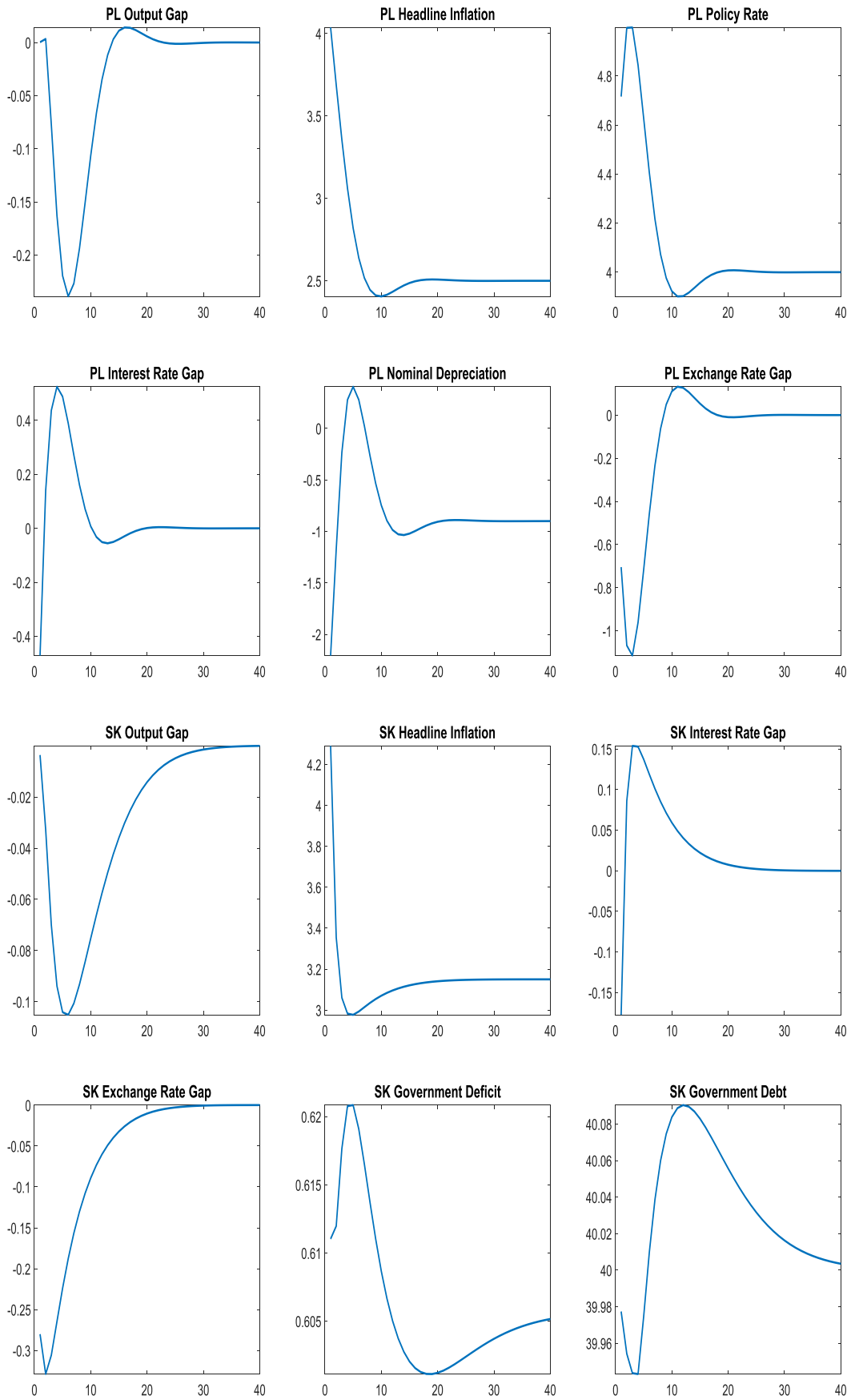
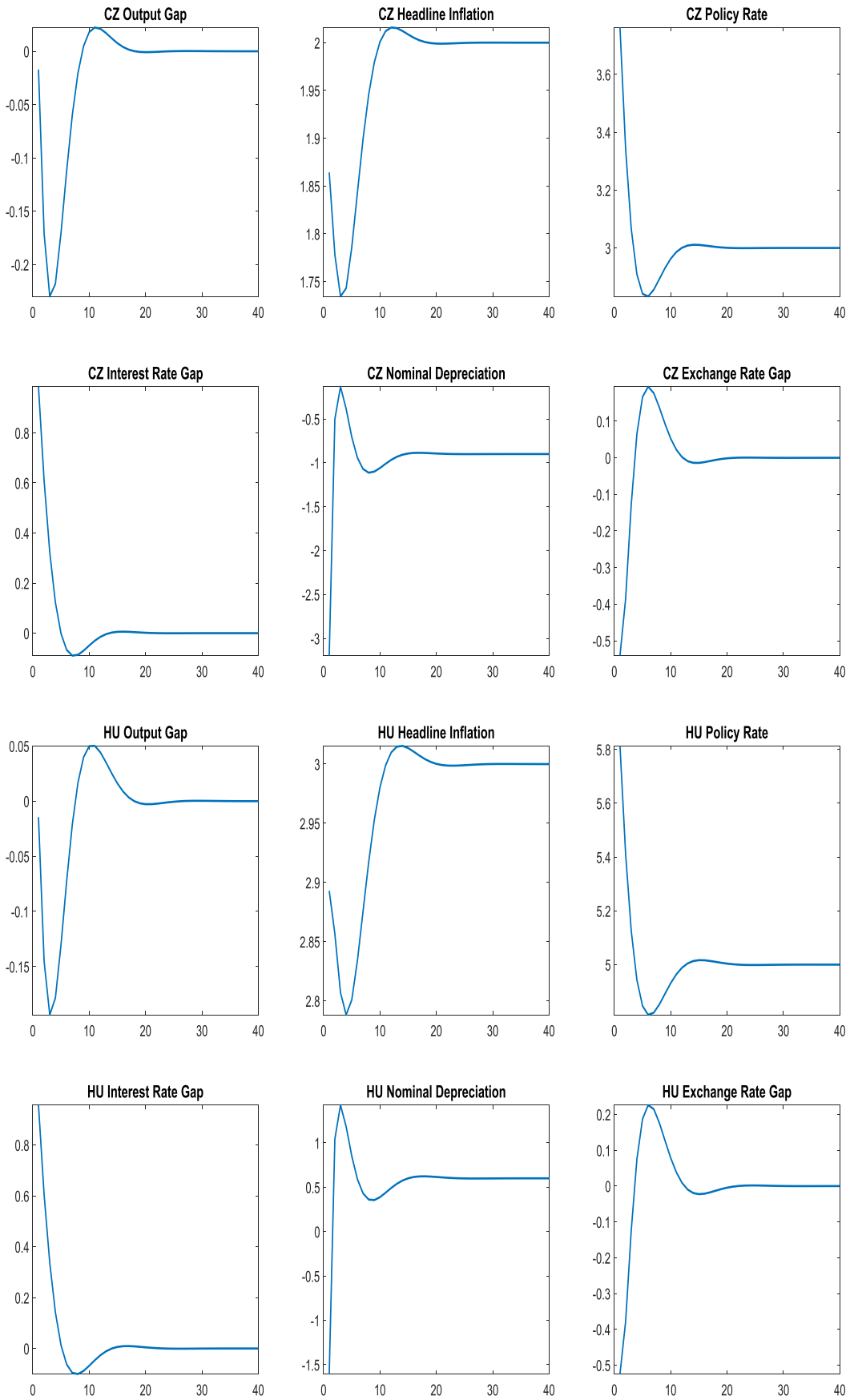
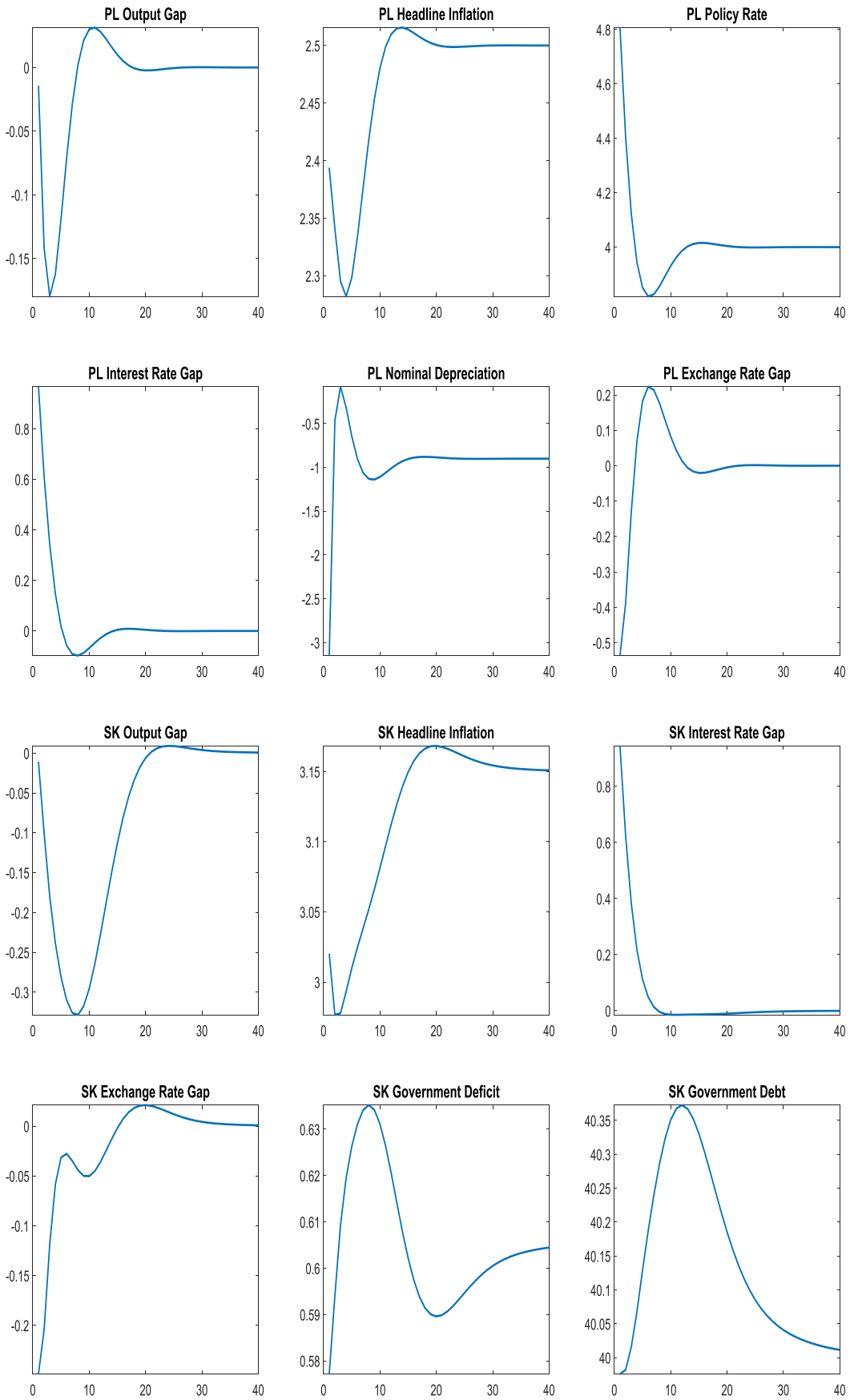


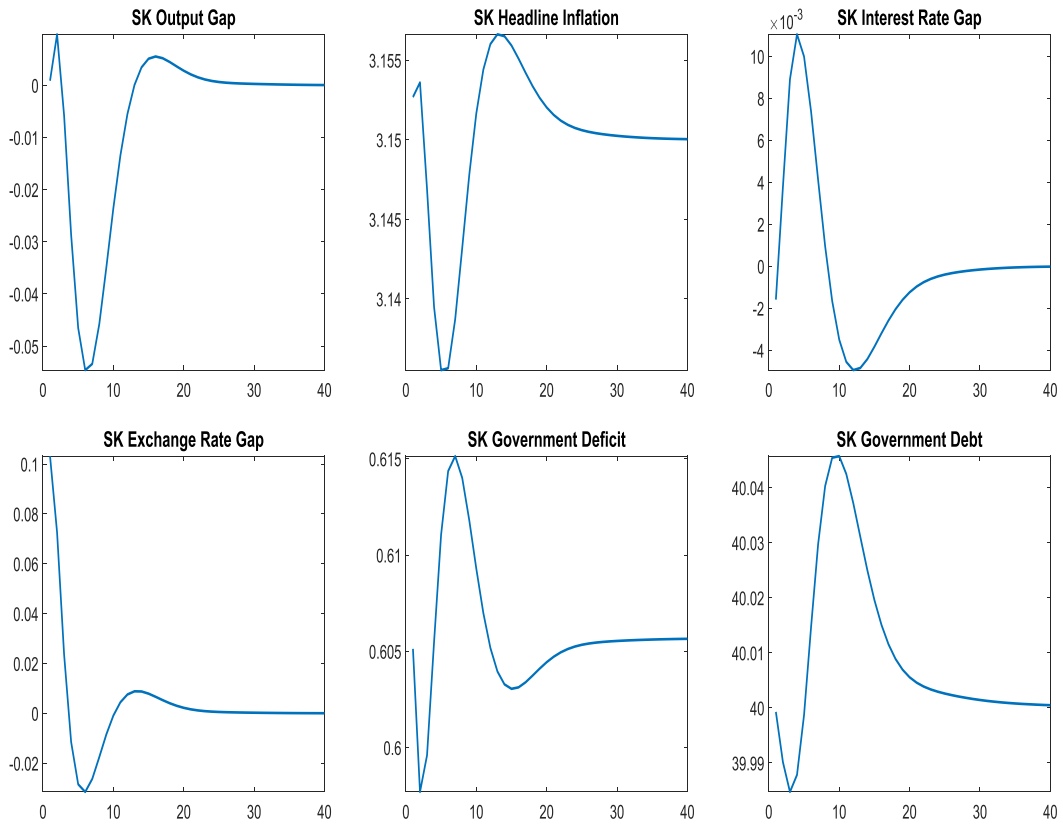
Monetary policy shock



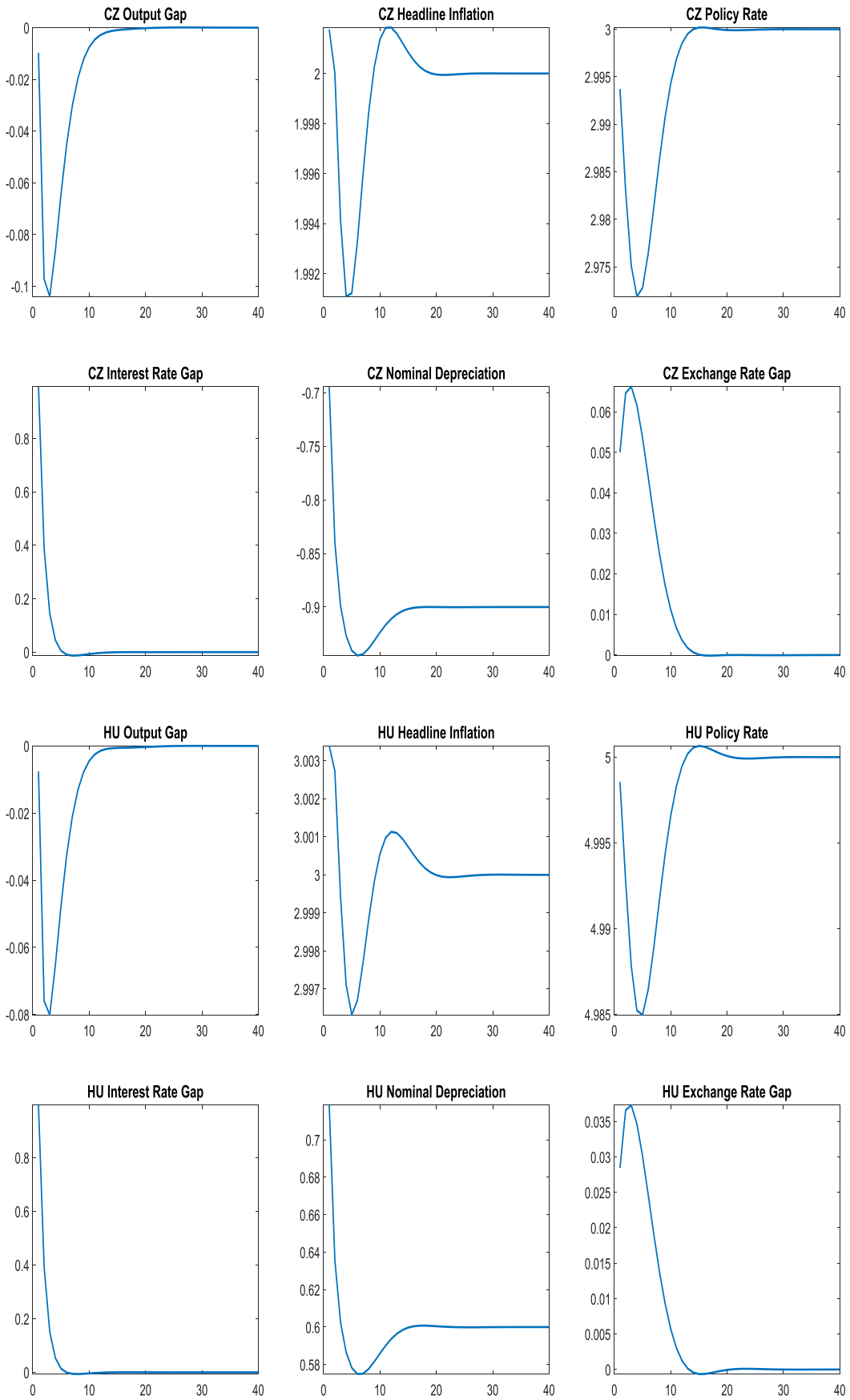
Monetary policy shock



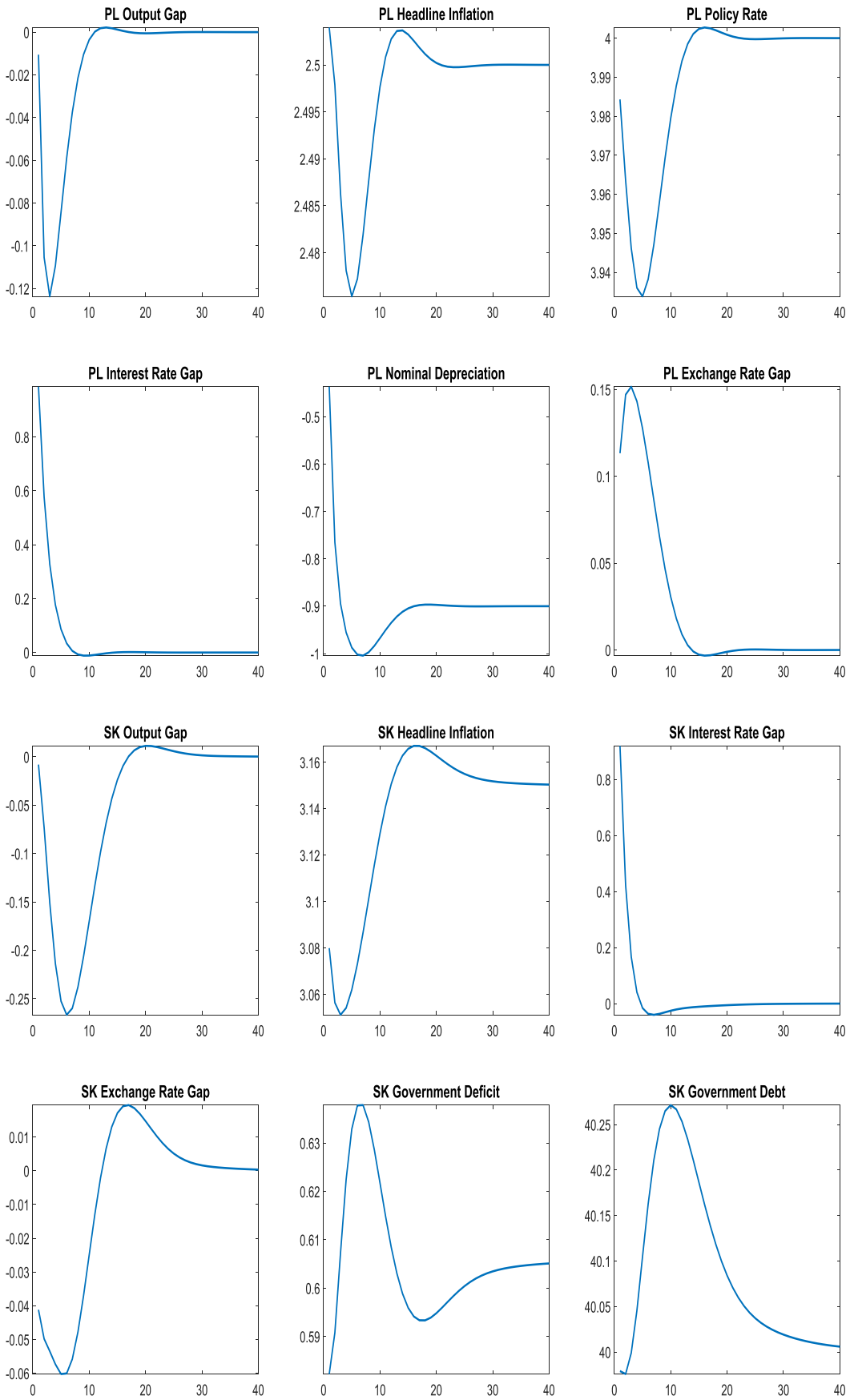
External policy shock



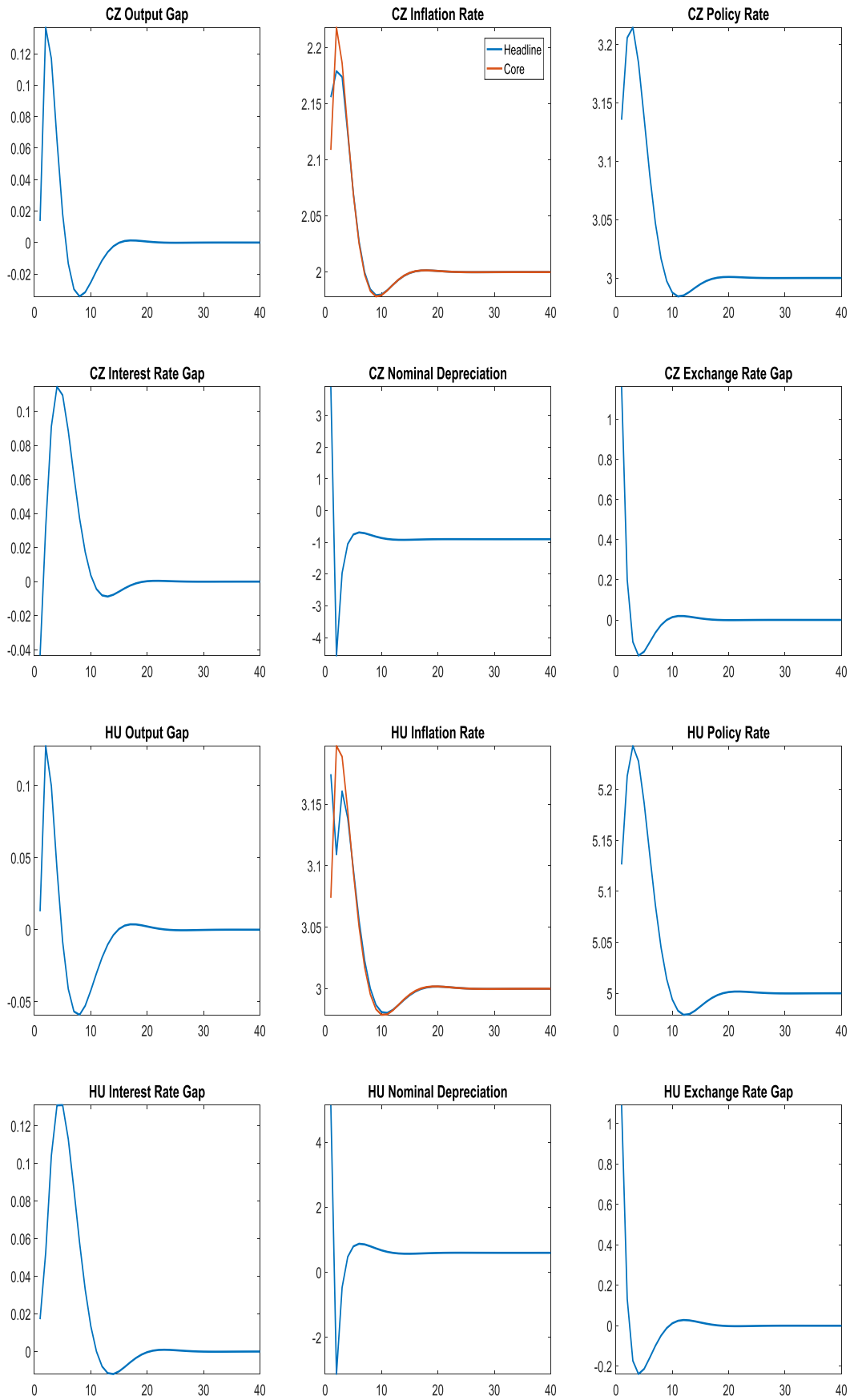
Risk premium shock



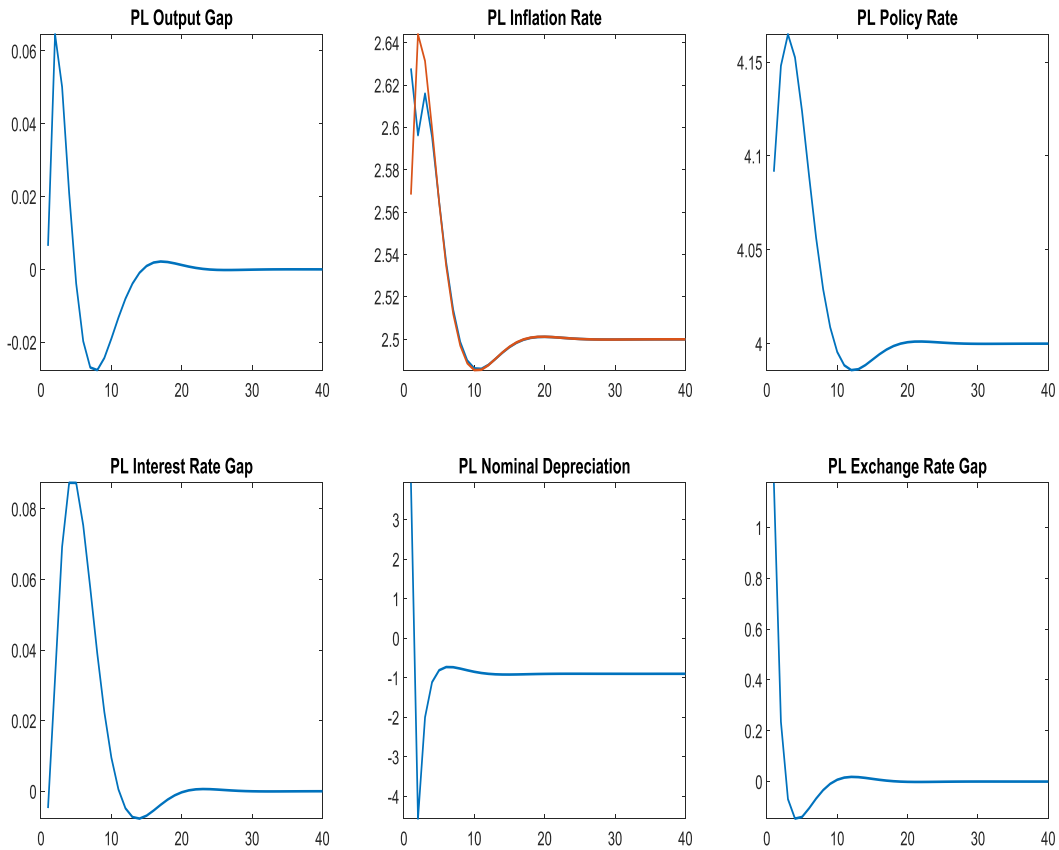
Risk premium shock



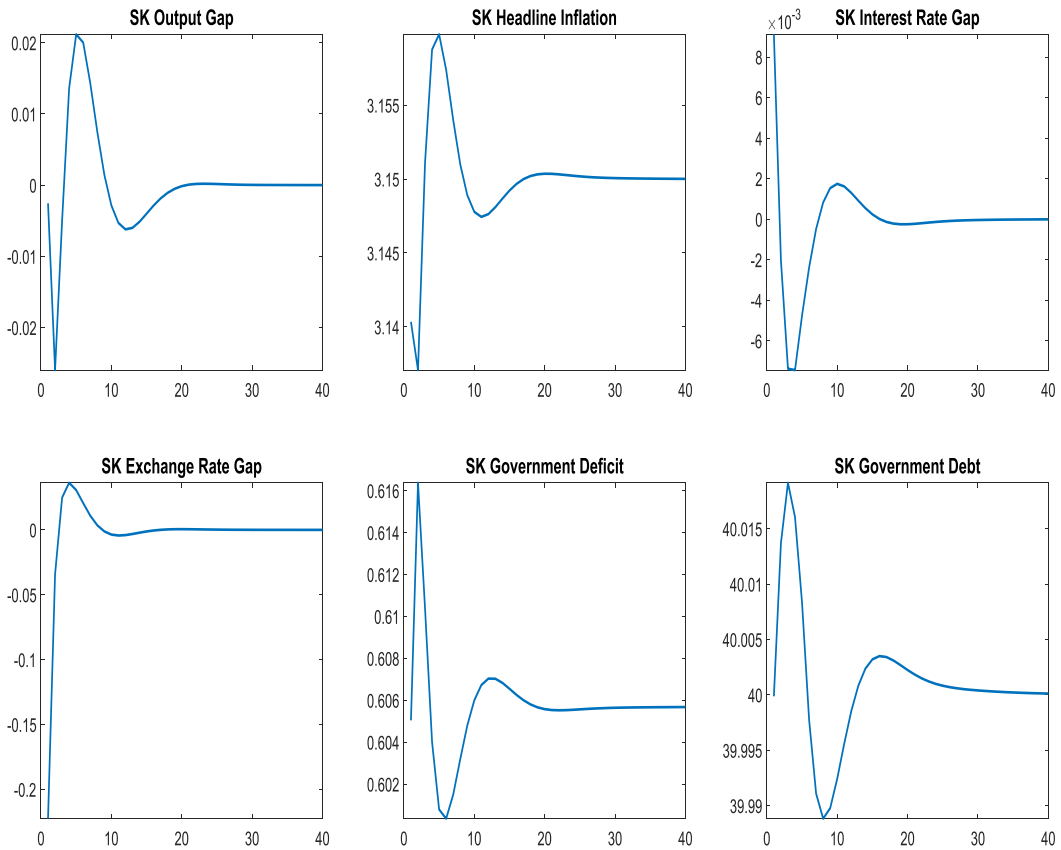
Exchange rate shock



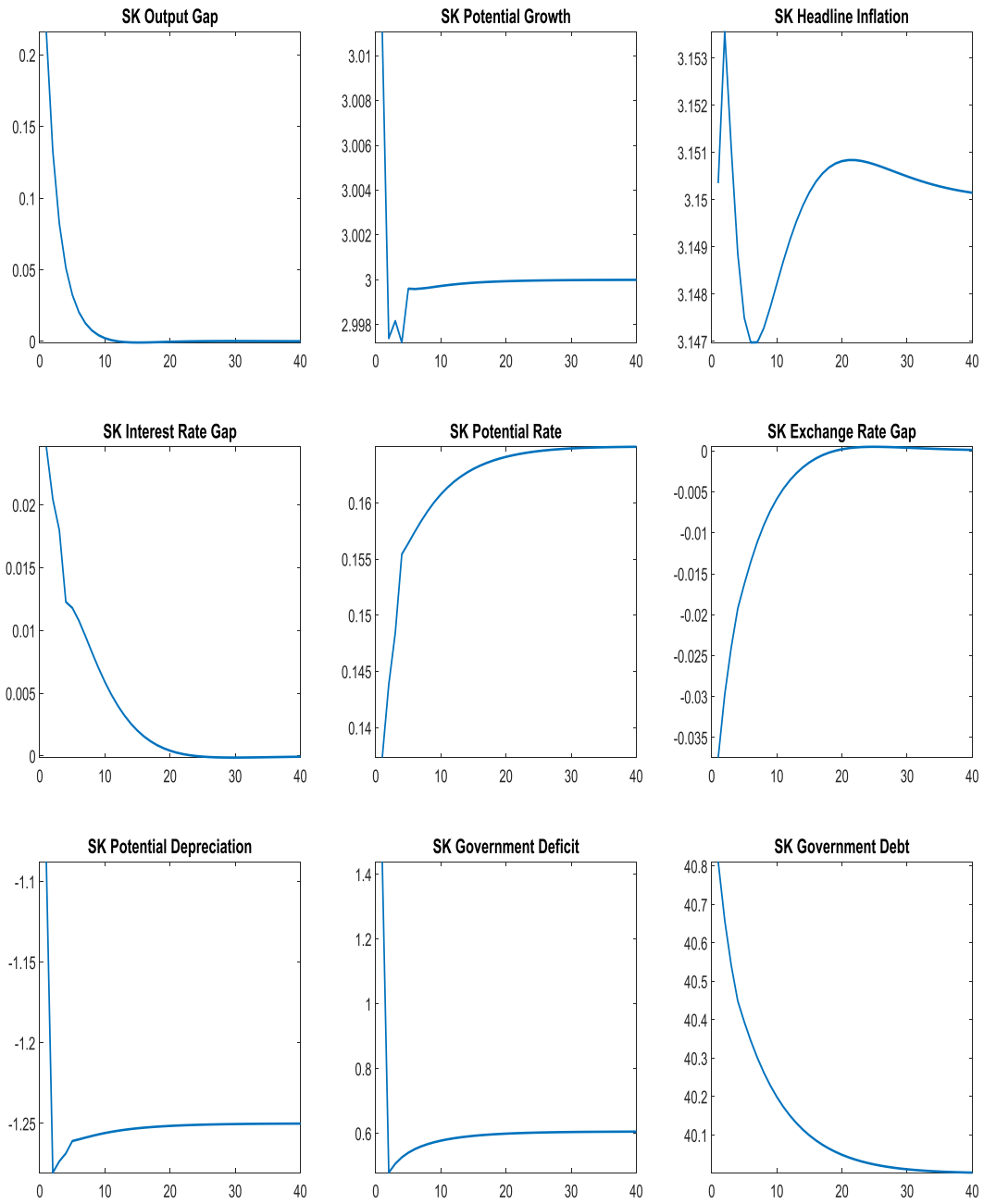
Exchange rate shock



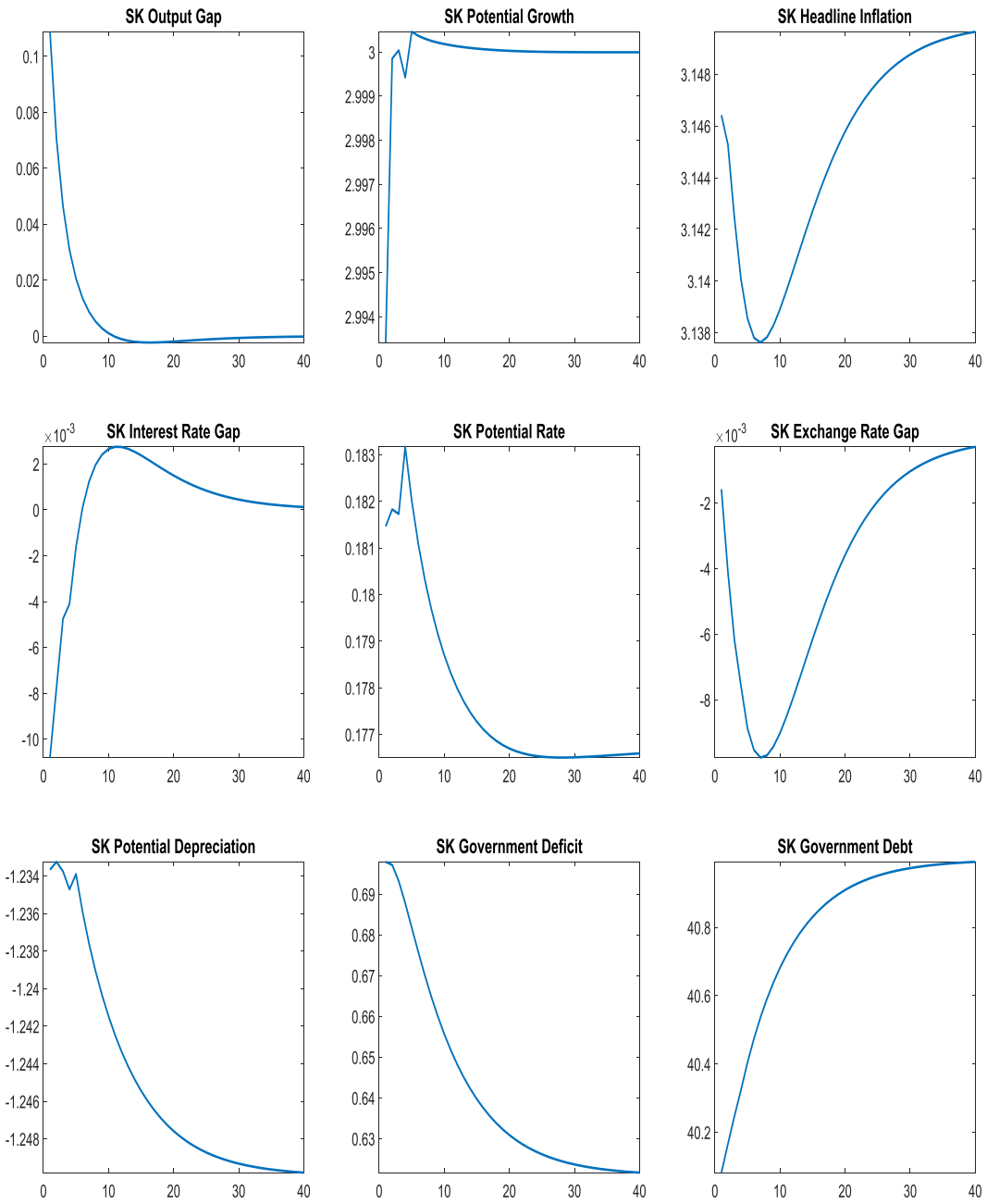
External parity shock



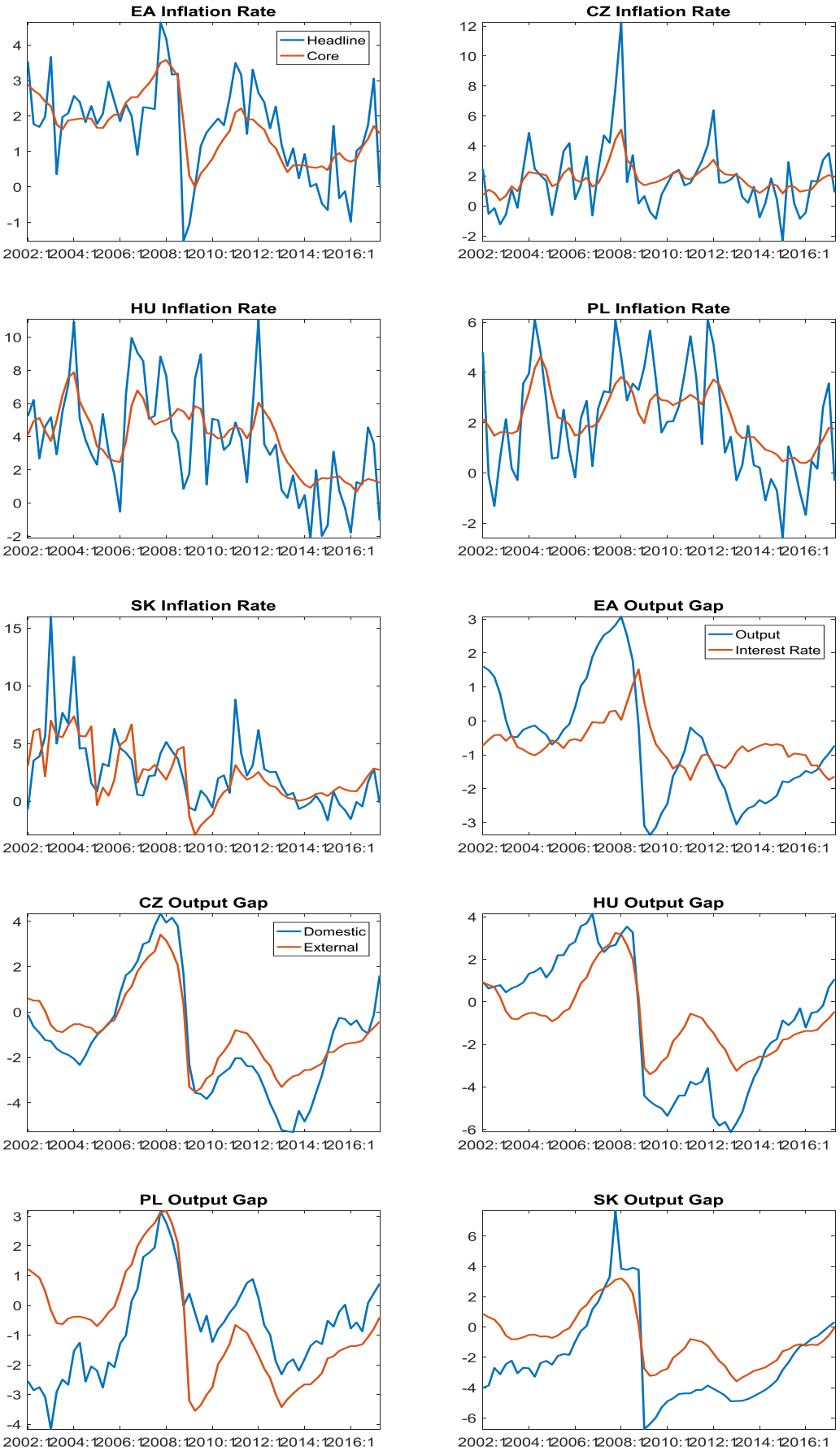
Government deficit shock



Target debt shock



Historical decomposition



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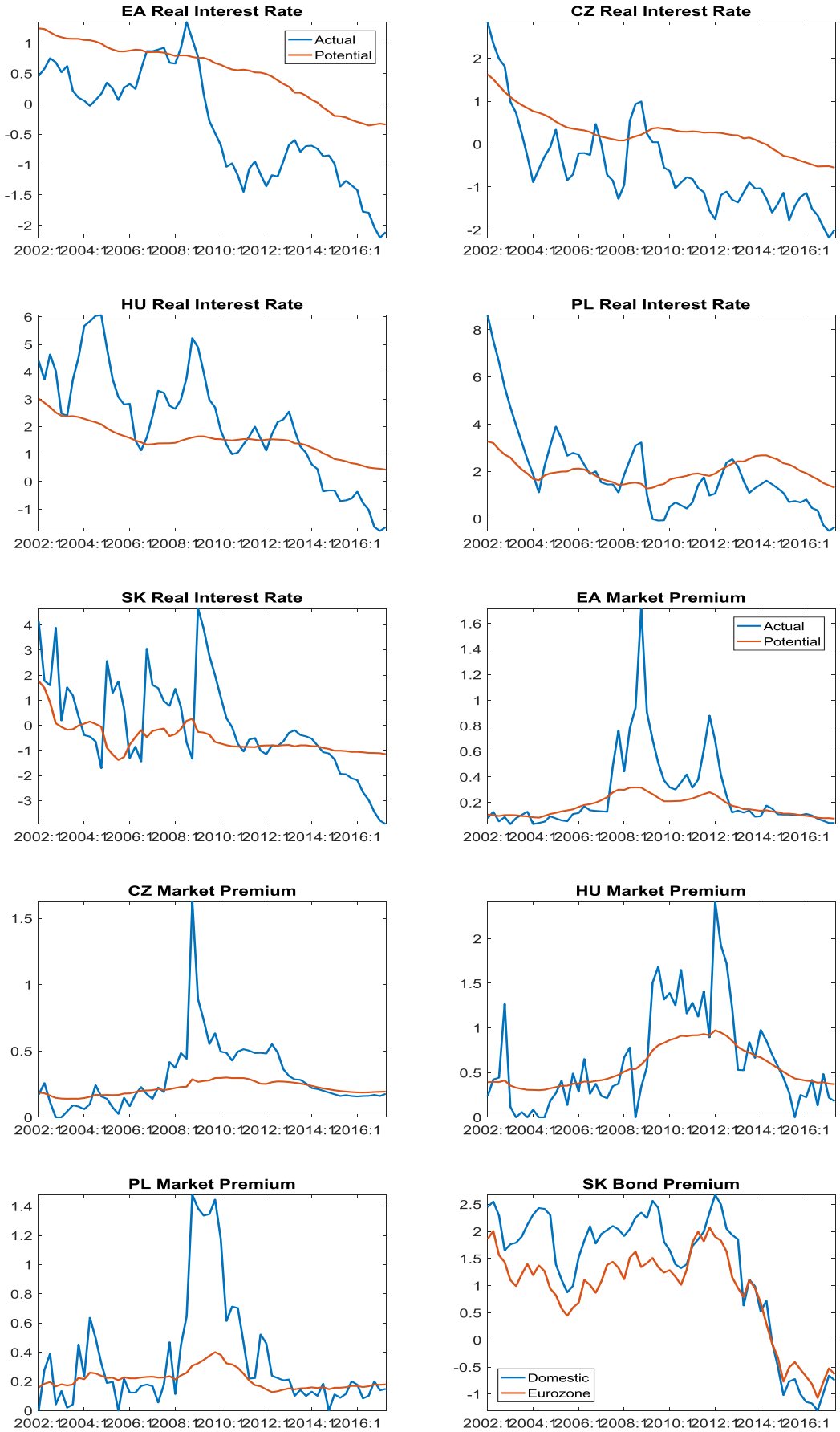
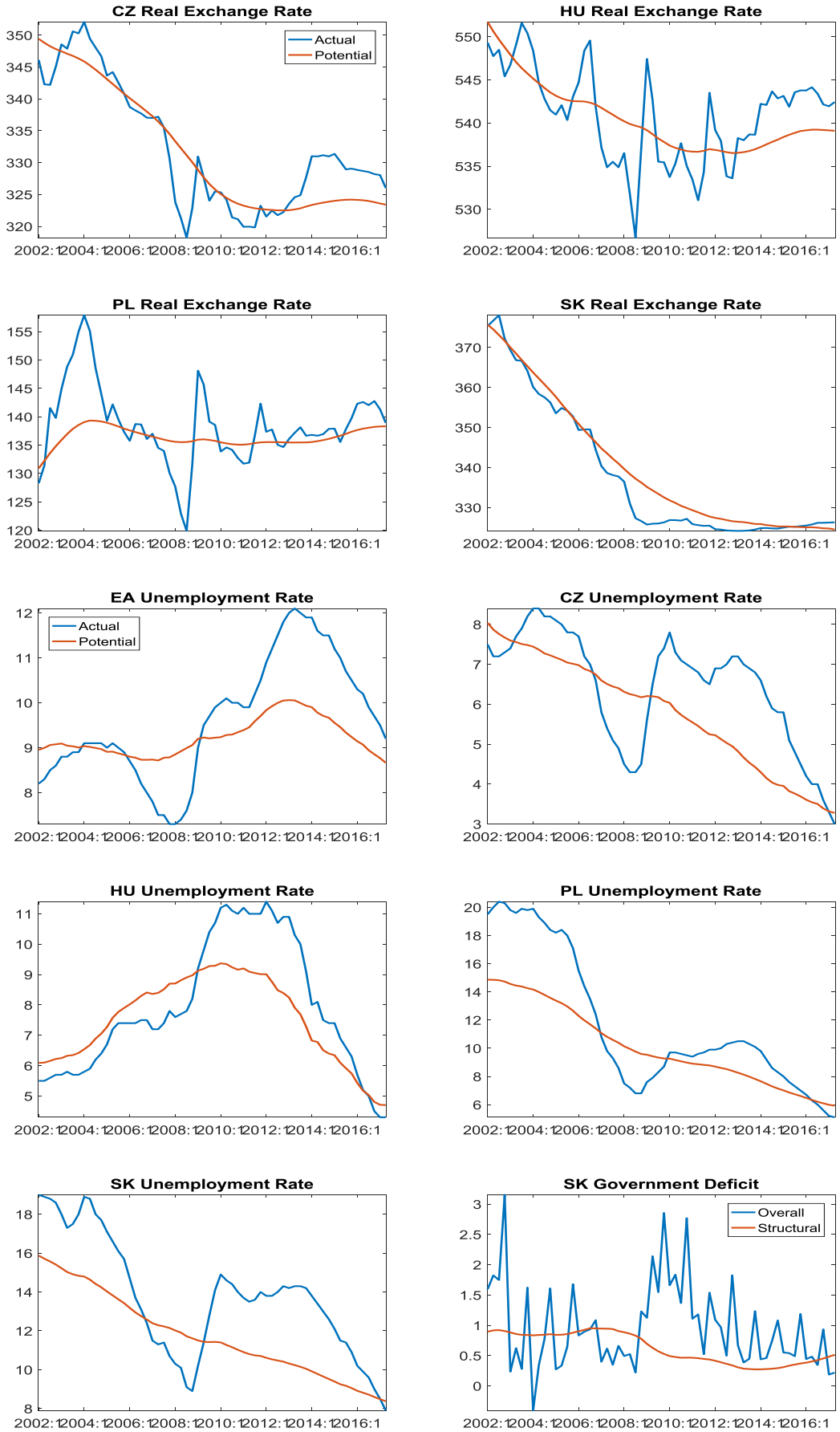
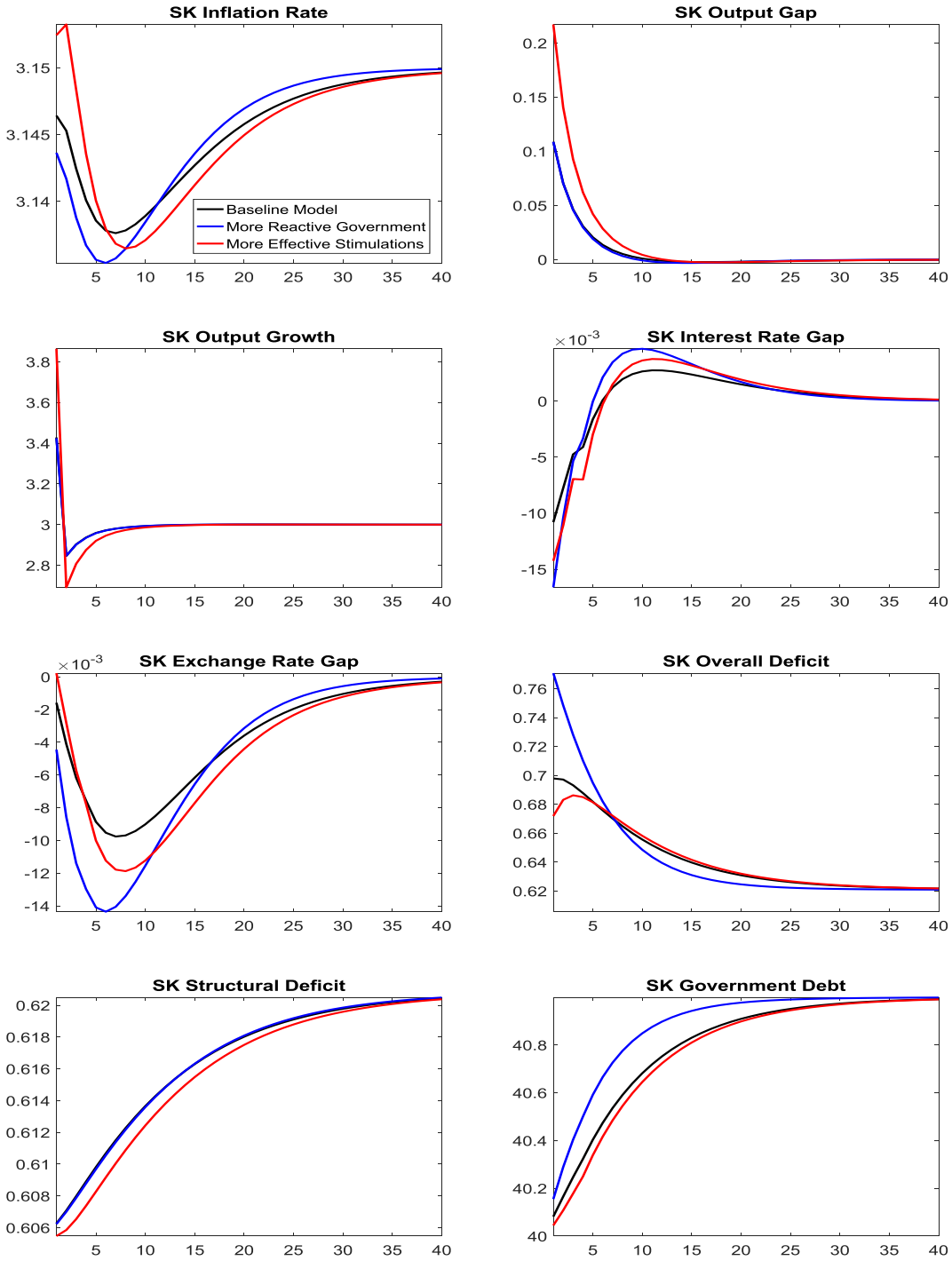


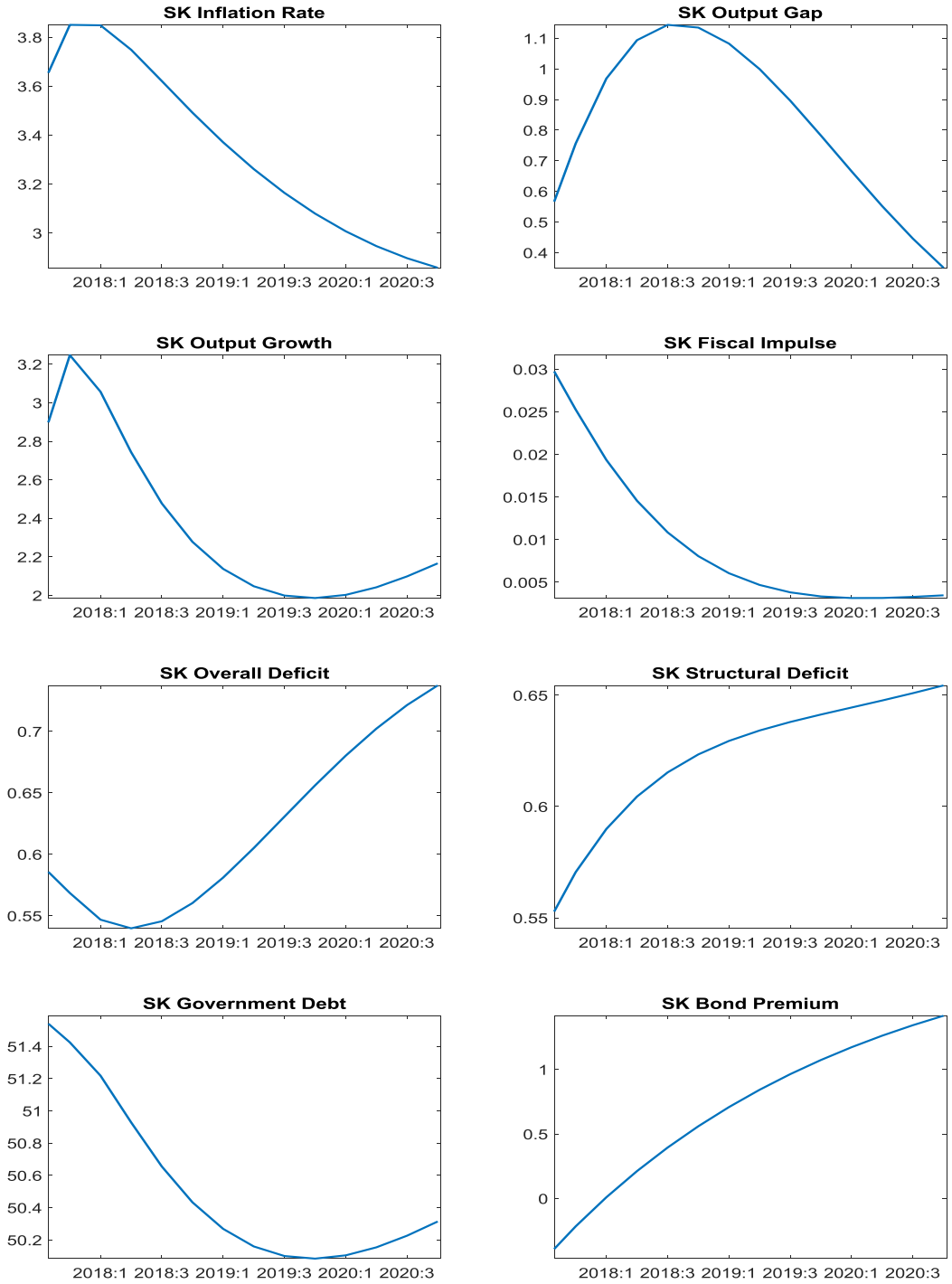
Historical decomposition



Fiscal policy simulation



Unconditional forecast



Conditional forecast