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# Quarterly Projection Model for Ukraine

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# QUARTERLY PROJECTION MODEL FOR UKRAINE[1]

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**Abstract**

This paper introduces the Quarterly Projection Model utilized by the National Bank of Ukraine to make its regular macroeconomic forecasts and monetary policy recommendations. The model is a semi-structural representation of an open-economy New-Keynesian general equilibrium model. It captures the transmission mechanism of monetary policy in the context of the Ukrainian economy. Among the economy's key features are the disinflation agenda, heterogeneous prices, imperfect monetary policy credibility, high openness and dollarization.

**Keywords:** National Bank of Ukraine, inflation targeting, monetary policy, projection model, monetary policy transmission mechanism in Ukraine.

**JEL classification:** C52, C53, E37, E52

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## 1. Introduction

The National Bank of Ukraine (NBU) formally adopted inflation targeting (IT) in 2015. As of mid-2019, it aims to decrease inflation to its targeted level, which is 5% in 2019 and thereafter. The main policy instrument for achieving this is the short-term interest rate. In addition, the NBU makes foreign exchange interventions with the goal of mitigating excessive exchange rate volatility and accumulating reserves. At the same time, a floating exchange rate is maintained.

Under IT, the NBU is committed to anchoring inflation and inflation expectations. For that purpose, it strives to enhance the transparency of its policymaking and provide public justifications of monetary policy stance.

Because of transmission lags between monetary policy decisions and their impact on inflation, the need arises for medium-term forecasting to clearly identify how concrete policy decisions impact the future development of the economy. Furthermore, forecasting helps assess how various policy actions influence future inflation. Moreover, the mechanism of influence, referred to as the transmission mechanism, is complex. It requires structured thinking by policymakers, and understanding of the economy.

In this paper, we document the Quarterly Projection Model (QPM) used by the NBU to assist it in making its monetary policy decisions. The model is a part of the Forecasting and Policy Analysis System (FPAS), along with a suite of satellite models[2]. For a number of reasons, the QPM provides the organizational framework for macroeconomic forecasting and story-telling. First, it is very useful for medium-term forecasting and permits inputs from other models, or expert judgments. Second, it describes macroeconomic interrelationships – in particular, how policy choices influence the economy and inflation – thus allowing the exploration of policy options. Finally, the model enables the study of the implications of risks to the baseline forecast, allowing alternative scenarios to be investigated.

This paper explains how the QPM is used in the policy-informing process. Specifically, it explains how the QPM helps organize information from economic data and their analysis. The paper seeks to clarify how the NBU makes monetary policy decisions and enhances the public accountability of monetary policy.

The QPM is a semi-structural, forward-looking New-Keynesian model of a small open economy. It belongs to a broad class of QPM-type models that are successfully used by many central banks and international institutions around the world[3]. These models are reduced-form representations of structural dynamic stochastic general equilibrium (DSGE) models, expanded with data-driven extensions. They combine the strength of the story-

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[2] A similar system for Georgia is outlined in, for example, Tvalodze et al. (2016).
[3] Among others, see De Jager et al. (2015) for South Africa, Beneš et al. (2017) for India and Berg et al. (2006) for the IMF.

telling capability of DSGE models with the flexibility of reduced-form models, which is important for their practical use in a policy making environment. Models of this type lack the rigorous micro-foundations of DSGE models, but they are more flexible, easy to operate, and usually better fit the data. QPMs are often called gap models due to their expressing real variables in terms of gaps, i.e. deviations from their sustainable long-term levels. The QPM used by the NBU has a standard structure, but also possesses Ukraine-specific features.

The coefficients of the model are calibrated – a practice widely adopted among central banks. Calibration is informed by the stylized facts about the Ukrainian economy and peer-economies. It also helps in dealing with short data samples and frequent structural breaks. A recent structural transformation of the Ukrainian economy occurred in 2014-2015 when there was a macroeconomic crisis. The NBU abandoned the pegged exchange rate and consequently adopted IT. The model is further calibrated to match desired characteristics, such as impulse response functions, sacrifice ratio or exchange rate pass-through.

This paper builds on previous versions of the model partially described in Grui and Lepushynskyi (2016) and Grui et al. (2018). Preceding publication, i.e. Petryk and Nikolaychuk (2006), was made much earlier. It featured a rather simpler QPM-type model for Ukraine, which paved the way for a potential transition to IT. Among the important extensions were the role of the labor market, hybrid uncovered interest rate parity, estimations of the neutral interest rate and a bigger influence from commodity markets. During the fixed exchange rate regime, the model had limited utility for forecasting and policy analysis. In contrast, under IT the current version is actively used as an integral part of the FPAS.

The paper is structured as follows. The next section outlines stylized facts – recent structural changes in the Ukrainian economy and its characteristics that the model should capture and replicate. The model’s structure and main equations are provided in section 3. Section 4 presents model calibration. Section 5 discusses the trends of selected variables. Section 6 analyzes model properties. Section 7 is devoted to historical simulations and overviews a typical forecasting exercise at the NBU. Section 8 presents conclusions.

## 2. Ukrainian stylized facts and their implications for the model

While designing the model we refer to specific characteristics of the Ukrainian economy. Even though some may be common to the growing community of developing countries that have adopted an IT regime, some are unique to Ukraine. This section provides an overview of the most important ones differentiating Ukraine’s monetary transmission mechanism from those of peer countries. The specifics include: (i) the change in the monetary policy regime; (ii) shock-specific price responses; (iii) imperfect monetary policy credibility; and (iv) high openness. We further discuss how these specific features affect the QPM structure.

**Monetary policy in Ukraine de facto switched from a fixed exchange rate regime to inflation targeting in 2015.** The regime change included a switch to a floating exchange rate. The maintenance of the fixed exchange rate until 2014 led to the shrinking of reserves and ended with a rapid devaluation of the hryvnia in 2014. Since mid-2015, the nominal exchange rate has demonstrated moderate volatility, which was accompanied by mild and on average positive NBU purchases on the foreign exchange market. Figure 1 plots the nominal exchange rate together with foreign exchange interventions between 2010 and 2018.

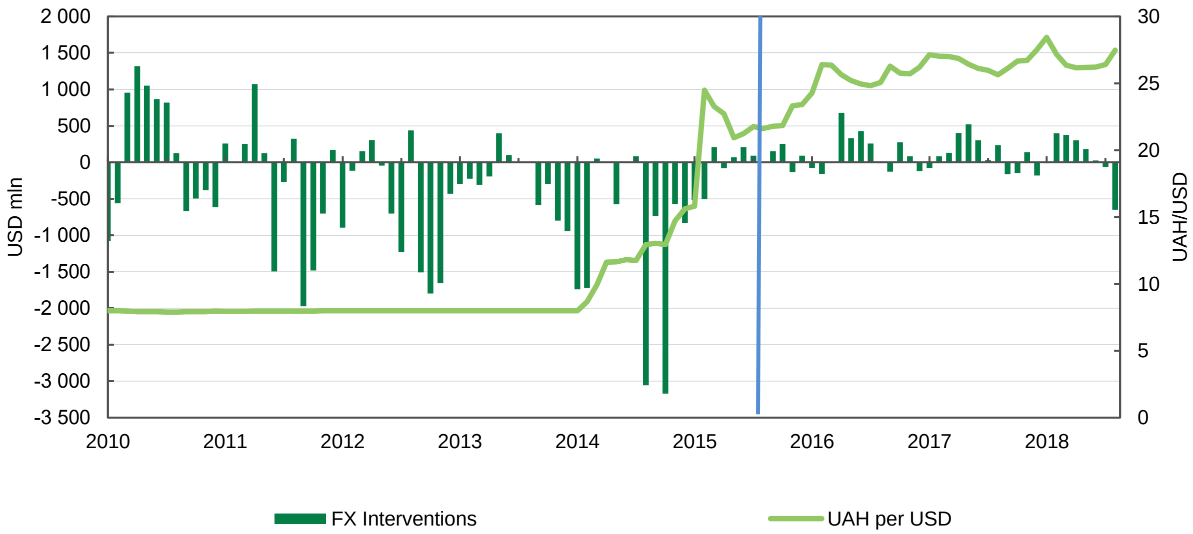


**Figure 1.** Foreign exchange interventions and the exchange rate.
Source: NBU.
Note: Negative FX interventions mean the sale of foreign currencies from reserves. The vertical line marks the formal adoption of the IT regime by the NBU (NBU, 2015). The switch to a floating exchange rate occurred earlier.

Under IT, the interest rate became the key policy instrument. Thus, the monetary policy regime switch is evident from the strengthening of the transmission of the key interest rate to the interbank interest rates. Figure 2 shows how the volatility of interest rates on the interbank credit market declined after the transition to IT. The implementation of this monetary policy anchored the interbank interest rates to the key rate. They float within a corridor defined by the interest rates on overnight credits and certificates of deposits (CDs) set by the NBU. Since 2016, the corridor has been pegged to the key policy rate, which strengthened the interest rate transmission mechanism.

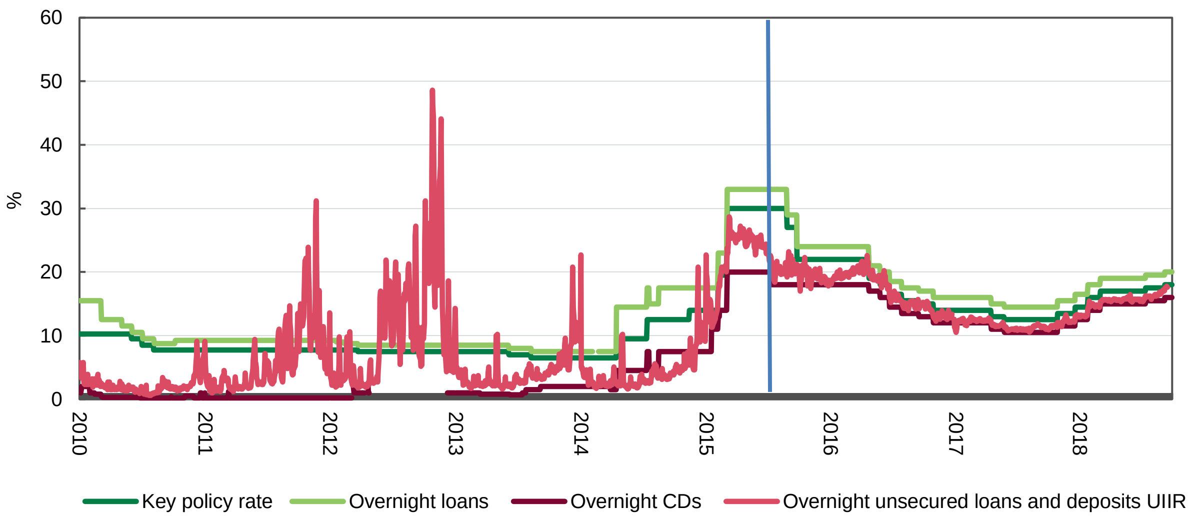


**Figure 2.** Interbank vs. NBUs interest rates (%, p.a.)
Source: NBU
Note: UIIR – Ukrainian Index of Interbank Rates, CD - certificates of deposit. Vertical line marks the formal adoption of the IT regime by the NBU.

The monetary transmission mechanism in Ukraine is developing. This implies that the QPM's structure and parameterization needs to be regularly re-assessed and updated.

**Monetary policy in Ukraine pursues a disinflation agenda in 2016-2019, with a medium-term target of 5%.** The NBU targets Consumer Price Index inflation, and its target for 2019 and afterwards is 5±1%. This is stated in the monetary policy guidelines (NBU, 2017). Since the regime switch in 2015, the NBU has pursued a consistent policy of disinflation, with the inflation target set at 12±3% for 2016, 8±2% for 2017, and 6±2% for 2018, (NBU, 2015). The inflation targets were set in the middle of gradually narrowing bands to give the NBU flexibility during the period of disinflation. This flexibility was needed because the economy of Ukraine was undergoing a period of deep structural transformation, while exposed to external shocks. Additional factors making it difficult to precisely achieve inflation targets during the initial period of disinflation were the increase in utility tariffs due to the introduction of a market-based price-setting mechanism for utility services, and the adjustment of relative prices during the economic recovery following the crisis. The inflation target variable in the QPM decreases from 12% to 5% in 2016-2019, and is stable afterwards.

A number of papers (Gorodnichenko, 2014; IMF, 2014; Petryk and Nikolaychuk, 2007) have discussed the choice of the medium-term inflation target for Ukraine. It should be around 3-5%, given the country's track record of high and volatile inflation. Hammond (2012) argues that inflation targets for developing countries should be higher than their counterparts in advanced economies (often set at 2%) due to a higher level of uncertainty in the course of structural transformations, errors in measuring inflation, and the action of the Balassa-Samuelson effect.

**The NBU takes into account administratively regulated price dynamics in its efforts to target headline inflation.** The consumer basket in Ukraine contains certain items with administered prices[4], which only weakly react to standard monetary policy actions. In recent years, those goods and services accounted for just below one-fifth of the basket. The relatively high share of these items among certain categories of goods and services is a legacy of the long period that the economy was centrally planned in Ukraine.

**Supply-side shocks from the agricultural sector strongly affect consumer prices.** The impact of supply shocks is pronounced for the unprocessed food component (about one-fifth of the consumer basket). Moreover, agricultural production shocks increase food price volatility, while both supply and demand for food market are highly price inelastic. Figure 3 illustrates how changes in the harvest of vegetables can affect vegetable prices. There is clear evidence of prices increasing with poor harvests. The QPM accounts for supply shocks from harvests with agricultural value included in its equation for raw food inflation.

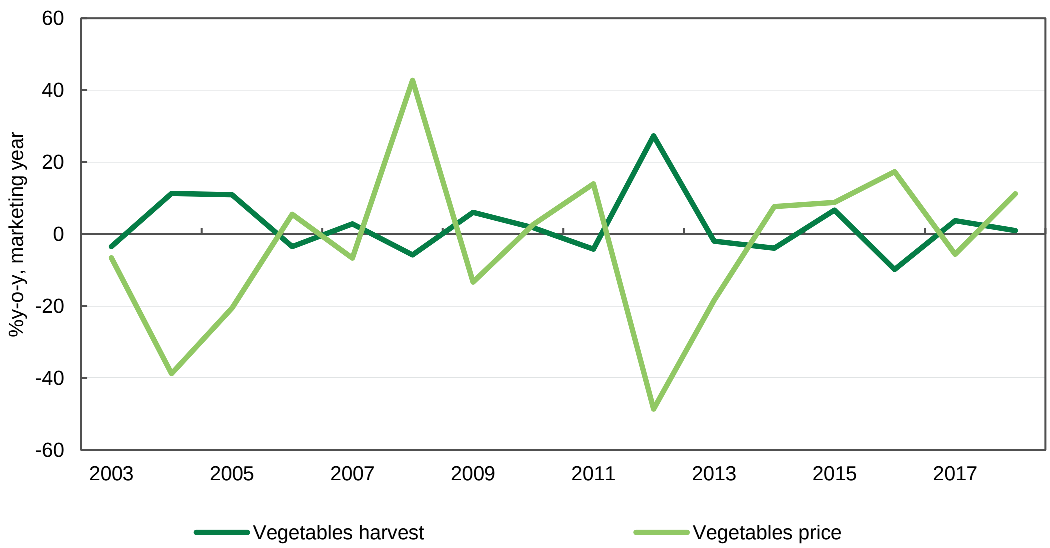


**Figure 3.** Change in dynamics of vegetables harvest and prices (%, y-o-y).
Source: NBU

**Monetary policy in Ukraine operates under less than perfect credibility.** Figure 4 shows that one-year-ahead inflation expectations by banks, businesses and households are considerably above NBU forecasts. However, the expectations of financial analysts are quite close. Economic agents might possess adaptive expectations, as they doubt the NBU's ability to achieve disinflation. In the QPM, we adjust model-consistent inflation expectations by including a backward-looking component to capture this characteristic.

[4] These are mostly utility tariffs, prices of excisable goods and some services (e.g. education).

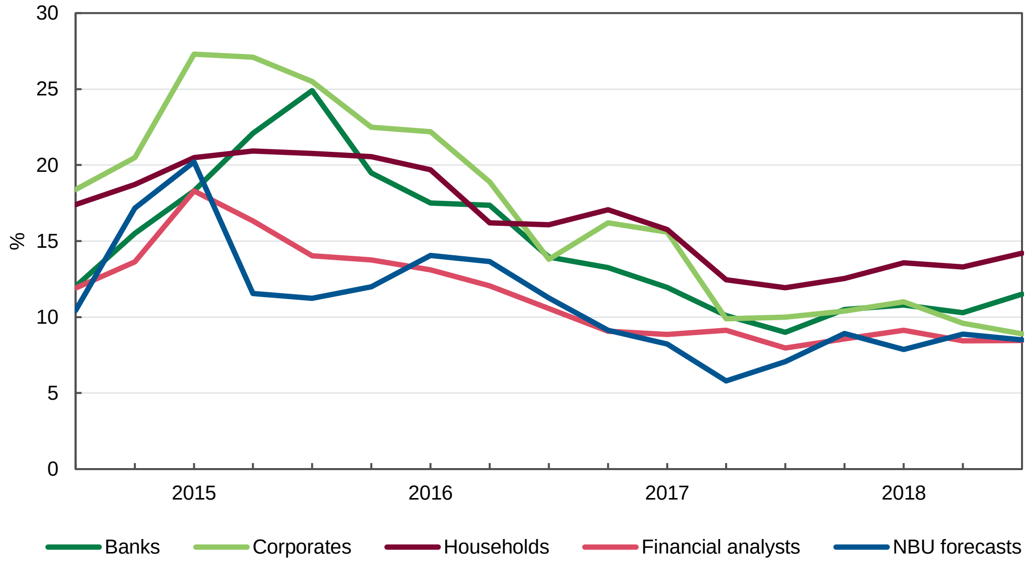


**Figure 4.** One-year inflation expectations and NBU forecasts (%, y-o-y).
Source: NBU

**The sovereign risk premium is important for macroeconomic developments in Ukraine**, since the economy is highly dependent on external sources of funding. The risk premium can be measured as the difference between the average yield of Ukrainian Eurobonds in dollars and the yield of 10-year US Treasuries. The dynamics of the indicator show there are episodes of sharp increases in the cost of external financing for Ukraine. One of these occurred during the global financial crisis in 2008-2009. There was another sharp increase during the macroeconomic crisis of 2014-2015 (Figure 5), which was worsened by Russian military aggression.

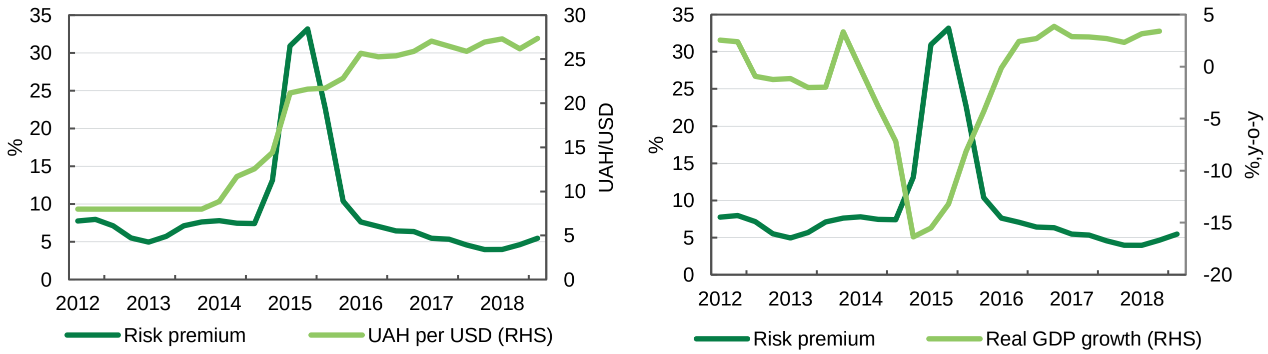


**Figure 5.** Output and exchange rate in times of risk premium hikes.
Source: NBU

Figure 5 hints that the sovereign risk premium has an influence on real output and nominal exchange rate realignment. This influence comes through various channels. First, according to the uncovered interest parity condition, risk premium hikes cause a depreciation of the nominal exchange rate. Second, the negative effect on GDP comes through the financial channel – the increased cost of funding depresses investments, which leads to a slowdown in economic growth. Moreover, the high dollarization of liabilities in both the public and private sectors of the economy means that balance sheet effects are rather strong. The financial channel dominates over the positive effects for external trade from exchange rate depreciation. This is in line with Brito et al. (2018) who claim that countries with less complex economies (a significant share of imports among investment goods) see reduced investment after an exchange rate depreciation.

Additionally, the risk premium has implications for monetary policy because of its effect on the neutral interest rate[5]. An immanent feature of a small open economy is that the price of capital is determined on the global capital markets, with adjustments for a country's fundamentals, including its risk premium. In this way a higher risk premium raises the neutral interest rate, shifting the monetary policy stance, thus making it harder for monetary policy to cope with inflationary pressures.

For these reasons, a risk premium term has been included in the equations of demand curve and uncovered interest parity in the QPM.

**Price dynamics in Ukraine is greatly influenced by imported inflation.** This is due to high trade openness. As shown in Faryna (2016), the pass-through effect in Ukraine is strong[6], which is common for many emerging markets economies. The large share of imported goods in the consumer basket leads to a quick and strong reaction of inflation to exchange rate movements. Figure 6 shows the fast adjustment in prices that followed after rapid nominal exchange rate depreciation in 2014-2015. The monetary policy transmission through the exchange rate in the model is stronger compared to the models for peer inflation targeters[7].

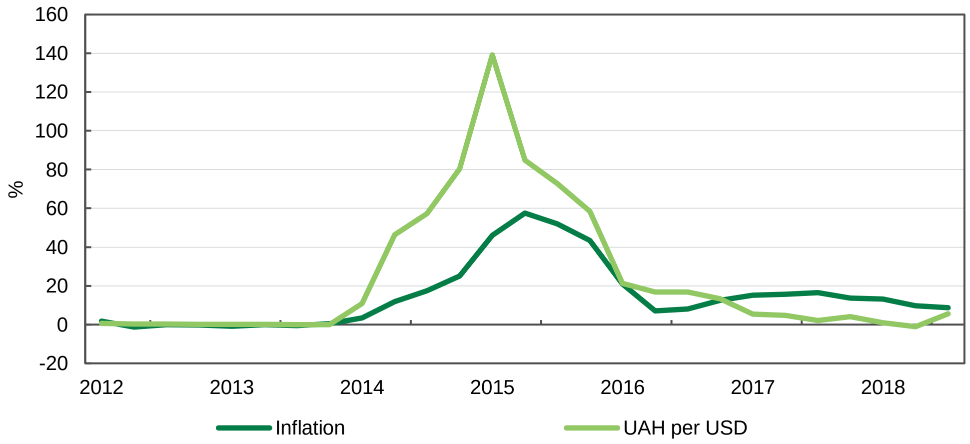


**Figure 6.** Response of inflation to exchange rate growth (%, y-o-y).
Source: NBU

[5] The policy interest rate at its neutral level is neither restrictive nor accommodative.
[6] According to the estimates in Faryna (2016) the pass-through effect in Ukraine is strong and non-linear, which is characteristic for emerging market economies. The average pass-through effect from the devaluation of the NEER is approximately 0.2, while under strong depreciation it rises sharply. Some estimates based on the nominal USD/UAH exchange rate put the pass-through effect within the range of 0.4-0.6.
[7] The QPM for Croatia is calibrated so that the short-term pass-through effect equals to 0.15 (Bokan and Ravnik, 2018). The Serbian model assumes it is equal to 0.2 (Dukić et al, 2010), while for Sri Lanka pass-through is calibrated at the level of 0.15 (Amarasekara et al, 2018).

**Fluctuations on the global commodity markets are highly significant for Ukraine**. The openness of Ukraine's economy, measured as the ratio of exports and imports to GDP, was close to 100% in 2004-2017. Not just the volumes, but also the export structure is important here. Agricultural products and base metals account for the bulk of Ukraine's exports, while imports contain a significant portion of energy products. Overall, Ukraine's commodity trade accounts for 3/4 of total merchandise. This means that commodity prices have a significant impact on GDP, the exchange rate and, resultantly, on inflation through the trade-balance channel.

The terms of trade indicator in Ukraine consists of prices for exported grains and base metals as well as imported crude oil and natural gas. Improving terms of trade are modeled to be consistent with growing GDP and an appreciating exchange rate.

## 3. Model

The NBU's QPM is a semi-structural model. It is a reduced-form New Keynesian model designed to capture the main characteristics of the Ukrainian economy. Monetary policy in this model affects real variables only in the short term because of nominal and real economic rigidities, e.g. sticky prices. In the long term, however, the economy converges to its sustainable growth path, where variables are at their natural levels, e.g. potential output or NAIRU. Monetary policy is considered to have no effect on the dynamics of these natural levels, and thus is neutral in the long term. This next section discusses how monetary policy transmission is included in the QPM model.

### 3.1. Monetary policy transmission in the model

Monetary policy operates through two main transmission channels: the interest rate and the exchange rate. First, interest rates influence an economic agent's choices in consumption and savings, thus regulating domestic demand. We also explicitly model expectations, which strengthen monetary policy transmission. Indeed, as long as higher nominal interest rate decreases inflation expectations, the real interest rate would rise even more. If economic agents expect lower future inflation, this would diminish inflation even today.

Second, monetary policy influences inflation through the exchange rate channel. At the first stage, higher interest rates lead to the appreciation of the local currency via the uncovered interest parity condition. Then, given the open nature of the economy, a change in the exchange rate bears impact on consumer prices in Ukraine through imported inflation. Exchange rate changes also affect economic activity as they influence demand for goods from abroad. Fluctuations in demand then affect inflation.

An analysis of the effectiveness of monetary transmission in Ukraine is outlined in Zholud et al. (2019).

Figure 7 shows a standard representation of the transmission mechanism[8].

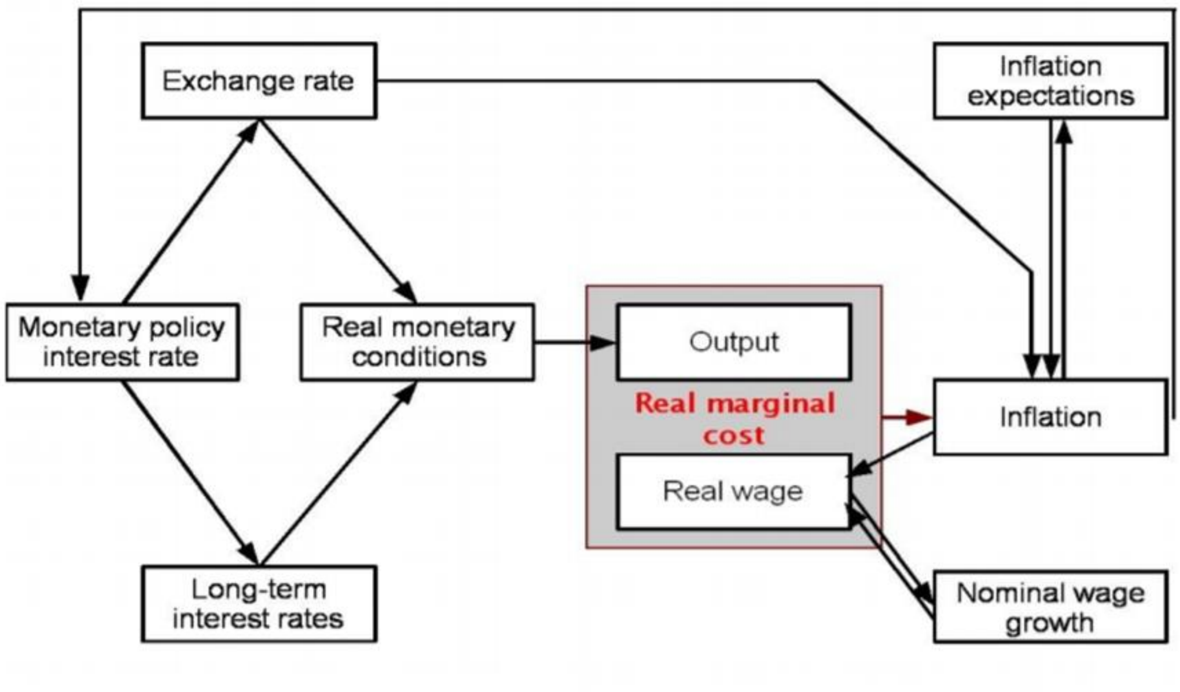


**Figure 7.** Monetary policy transmission mechanism.
Source: Czech National Bank

### 3.2. Main model equations

The following subsection describes the key model equations that govern the core economic predictions. Here we focus on ten equations that are key for modeling the following aspects of the transmission mechanism of monetary policy: aggregate demand, short-term supply (Phillips curves for the main CPI components), uncovered interest parity, monetary policy rule, the neutral interest rate, and the long-term trends of GDP and REER[9].

Behavioral equations are constructed in terms of gaps, i.e. percentage deviations from trends. All the gaps converge to zero in the long term. The trends represent long-term transitory paths to steady states.

***Aggregate demand***

Equation (1) describes output gap ($\hat{y}_t$) in a form of a dynamic IS-type equation. It summarizes the behavior of aggregate demand.

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[8] More detailed version with features specific to Ukraine is given in Appendix 2.
[9] Overall there are more than one hundred equations in the model. Many of them are identities or simple processes for exogenous variables.

$$\hat{y}_t = \alpha_1 \hat{y}_{t-1} + \beta_1 \hat{z}_{t-1} - \gamma_1 \widehat{lr}_{t-1} + \delta_1 \hat{w}_t + \theta_1 \hat{y}_t^W + \mu_1 \widehat{tot}_t + \rho_1 f_t - \sigma_1 \widehat{prem}_t + \varepsilon_{1,t} \quad (1)$$

The first term to influence output gap is its own lagged value ($\hat{y}_{t-1}$). This captures persistency in the business cycle.

The following two terms in the equation are the real credit rate gap ($\widehat{lr}_t$) and real effective exchange rate gap ($\hat{z}_t$). Together they capture real monetary conditions, through which monetary policy affects the real economy. The monetary conditions enter the output gap equation with a lag, modeling the one-quarter delay before monetary policy influences demand.

The real credit rate gap affects aggregate demand through the interest rate channel of monetary policy. Because long-term interest rates are relevant to aggregate demand, a yield curve is constructed. A 1-year credit rate is equal to the average of the current and future expected short-term interest rates adjusted by a term premium. The expectations are model consistent.

In an open economy, the real effective exchange rate influences aggregate demand through its effect on net exports. For example, real depreciation increases the competitiveness of domestic exporters and diverts local consumers from imports. The real exchange rate is not a policy instrument, but it is linked via the nominal exchange rate to interest rates by a modified uncovered interest parity, as shown in equation (5). Thus, monetary policy influences the real economy via the exchange rate channel.

The real wage gap ($\hat{w}_t$) captures demand pressures originating from high consumption of current income and imperfect access to capital markets. Wage growth in the model accounts for inflation expectations and unemployment. The latter, in turn, follows Okun's law, so is fed back by the output gap.

The next two terms, trade partners' output gap ($\hat{y}_t^W$) and terms-of-trade gap ($\widehat{tot}_t$), are determined outside of a small domestic economy. Both reflect external demand for domestic goods. Additionally, trade partners' output affects remittances, which depend on the business cycle abroad and influence domestic demand. Furthermore, the terms of trade impact demand through the income effect, as their fluctuations change the value of output.

The presence of a fiscal impulse ($f_t$) in the demand curve captures the impact of a fiscal authority on economic activity. For example, if it is positive (an increase in structural deficit reflecting fiscal expansion) it increases domestic demand. The impulse is under the fiscal authority's control. It is estimated exogenously[10].

One more important determinant of the output gap is the sovereign risk premium gap ($\widehat{prem}_t$). The idea behind it is that an exogenous increase in the risk premium restricts

[10] Details can be found in Vdovychenko (2018b).

domestic investment activity. Moreover, the price of borrowing in foreign currency simply becomes higher. Both these factors reduce aggregate demand.

Finally, the structural nature of the model allows interpreting the remaining term ($\varepsilon_{1,t}$) as the aggregate demand shock.

***Price Phillips curves***

The NBU is targeting headline CPI inflation, which is composed of four components: core, raw food, petrol and administratively regulated prices. Each of these components is modeled separately in the QPM. Headline inflation is then set to their weighted average.

Core inflation, equation (2), is modeled with an expectations-augmented, open-economy version of a Phillips curve. Variable $\pi_t^{core}$ captures an annualized quarter-on-quarter percentage change in core prices.

$$\pi_t^{core} = \alpha_2\pi_{t-1}^{core} + \beta_2 E(\pi_{t+1}) + (1-\alpha_2-\beta_2)(\pi_{t-1}^{W} + \Delta s_{t-1} - \Delta\bar{z}_{t-1}) + \gamma_2\hat{y}_t + \delta_2\hat{z}_{t-1} + \theta_2\widehat{w}_t + \mu_2(\pi_t^{food} - \pi_t^{T}) + \varepsilon_{2,t} \quad (2)$$

Inflation is dependent on its lagged values ($\pi_{t-1}^{core}$). With this, we model a phenomena of persistent inflation. Given this feature, inflation reacts to all its determinants only gradually.

Core inflation is influenced by headline-inflation expectations ($E(\pi_{t+1})$), resulting in their dynamics being linked. Inflation expectations are equal to a weighted combination of rational (model consistent, $\pi_{t+1}$) and adaptive (backward looking, $\pi_{t-1}$) expectations[11]. The contribution of the adaptive term reflects imperfect monetary policy credibility[12].

The third term in the equation is imported inflation. It is constructed from weighted trade partners' inflation ($\pi_t^W$), nominal exchange rate depreciation against the USD ($\Delta s_t$), and an adjustment to reflect the higher growth of prices in the non-tradable sector than in tradable one (the Balassa-Samuelson effect approximated by the appreciation of the real effective exchange rate trend, $\Delta\bar{z}_t$). Trade partners' inflation is expressed in dollar terms, thus the nominal exchange rate converts it to domestic currency denominated inflation. The same logic applies to the food price index and global oil prices in equations (3) and (4).

The following three terms capture real marginal costs. The output gap ($\hat{y}_t$) reflects inflationary pressures from the demand side. The real wages gap ($\widehat{w}_t$) adds supply-side costs of domestic producers that arise from the labor market. Finally, the real effective exchange rate gap ($\hat{z}_t$) embodies the real marginal costs of importers.

Given that both nominal depreciation and the real exchange rate gap are present in the equation, both direct and indirect effects of imported inflation are modeled.

[11]Subscript t+1 denotes purely model consistent expectations, while E() stands for weighted average of adaptive and rational expectations.
[12] Some models, e.g. Beneš et al. (2017), have time variant credibility that is defined endogenously.

The last term in the equation ($\pi_t^{food} - \pi_t^T$) implies spillovers from food inflation. These reflect the fact that the basket of the core prices contains many processed food items.

Equation (2) explains the dynamics of core inflation, but says nothing about its steady state. Instead, the task of monetary policy is to define it. A policy commitment to a particular inflation target is described in equation (7).

Equations (3) and (4) show the second and the third inflation components, raw food ($\pi_t^{food}$) and petrol ($\pi_t^{petrol}$), which are modeled similarly to core inflation.

$$\pi_t^{food} = \alpha_3\pi_{t-1}^{food} + \beta_3 E(\pi_{t+1}) + (1-\alpha_3-\beta_3)(\Delta fao_t + \Delta s_t - \Delta\bar{z}_t) + \gamma_3\hat{y}_t + \delta_3\hat{z}_{t-1} - \theta_3\widehat{harv}_t + \mu_3\widehat{fao}_t + \varepsilon_{3,t} \quad (3)$$

$$\pi_t^{petrol} = \alpha_4\pi_{t-1}^{petrol} + \beta_4 E(\pi_{t+1}) + (1-\alpha_4-\beta_4)(\Delta oil_t + \Delta s_t - \Delta\bar{z}_t) + \gamma_4\hat{y}_t + \delta_4\hat{z}_{t-1} - \theta_4\widehat{oil}_t + \varepsilon_{4,t} \quad (4)$$

However, these equations reveal some differences. Among them, imported inflation terms contain changes in the world food price index ($\Delta fao_t$) and oil price growth ($\Delta oil_t$) instead of trade partners' inflation. Moreover, the corresponding marginal costs include gaps in the food price index ($\widehat{fao}_t$) and oil prices ($\widehat{oil}_t$), but they do not include a gap in wages or spillovers from other components. Moreover, raw food prices are assumed to be influenced by the domestic harvest gap ($\widehat{harv}_t$). A higher harvest usually leads to lower food inflation.

The fourth inflation component, administratively regulated prices, is an exogenous process. Its projections are usually made via expert judgments. An equation for administratively regulated inflation is an autoregressive process. It gradually converges with core inflation, while allowing for sizable changes in relative prices in the short term.

The remaining terms ($\varepsilon_{2-4,t}$) are supply shocks.

***Hybrid uncovered interest parity***

Equation (5) shows a modification of the uncovered interest parity (UIP) condition, which explains the dynamics of the nominal exchange rate ($s_t$). An increase in the variable means a nominal depreciation of the hryvnia against the US dollar. The equation follows the assumption that domestic and foreign financial markets should yield the same risk-adjusted effective returns.

$$s_t = s_{t+1} + interv_t + \frac{i_t^W - i_t + prem_t}{4} - \gamma_5\widehat{tot}_t + \varepsilon_{5,t} \quad (5)$$

The UIP condition links the nominal exchange rate with its rational expectations ($s_{t+1}$), nominal foreign ($i_t^W$) and domestic ($i_t$) short-term interest rates, as well as the risk premium ($prem_t$). The spot exchange rate is set by an arbitrage opportunity created when the risk adjusted interest rate spread is not compensated for by the expected depreciation.

In a developing economy with a shallow financial market and less than perfect capital mobility, the UIP condition in its pure form does not hold in the short term. However, the UIP is constructed to converge to its pure form over long horizons.

The equation is modified to account for the use of foreign exchange interventions ($interv_t$) undertaken by the NBU with a goal to smooth excessive exchange rate volatility. The modeled exchange rate is assumed to follow managed floating.

Equation (6) shows how foreign exchange interventions are endogenously defined in order to mitigate exchange rate volatility. Variable $interv_t$ captures the smoothing of excess exchange rate volatility and is scaled in terms of its impact on the exchange rate in percentage points – parameter $\beta_6$.

$$interv_t = \frac{\beta_6}{4}\left(\left((\Delta\bar{z}_t + \pi_t^T - \pi_t^{W,T}) - \Delta s_{t+1}\right) + \left((\Delta\bar{z}_t + \pi_t^T - \pi_t^{W,T}) - \Delta s_t\right)\right) \tag{6}$$

Interventions adjust the expected exchange rate if current ($\Delta s_t$) and/or expected ($\Delta s_{t+1}$) devaluation are not in line with a parity level ($\Delta\bar{z}_t + \pi_t^T - \pi_t^{W,T}$). The parity is consistent with the long-term nominal exchange rate. It accounts for the economic potential represented by the trend of real exchange rate appreciation, adjusted by the targeted inflation differential. The equation models systematic exchange rate management by the central bank.

However, the term $interv_t$ can be seen as an automatic smoother to some extent. The pure UIP condition is often criticized for its poor performance on data, especially over shorter samples. The reason is that the forward-looking element adjusts the exchange level immediately to all future model expected interest rate differentials. This makes the modeled exchange rate jumpy, while empirical observations reveal higher persistence. A commonly suggested modification is to reduce its forward-lookingness. It is implemented in equations (5) - (6). More discussion can be found e.g. in Beneš et al. (2008).

The term $interv_t$ is not an observed variable in the model. The degree to which it correlates with actual interventions by the NBU on the foreign exchange market can be seen in Figure 8. Determining what type of UIP equation offers the best match between the two series could be a prospective research question.

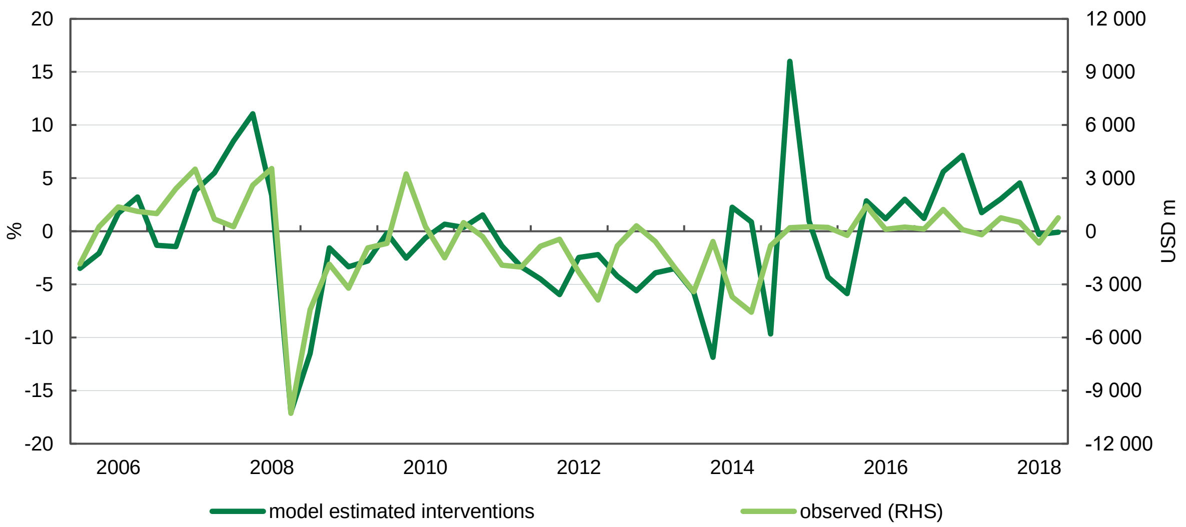



**Figure 8.** Model estimated interventions in comparison to observed series.
Source: NBU.
Note: Negative model estimated interventions mean that the nominal exchange rate was adjusted to strengthen it. Negative observed interventions by the NBU mean that foreign currency was sold on the market.

Equation (5) is further adjusted to allow for the impact of the terms of trade gap ($\widehat{tot}_t$). The effect is significant, given the large share of imports and exports in GDP and the large share of commodities in trade. It is transmitted through the trade balance channel. The impact of the terms of trade on the exchange rate is expected to fall with the further development of the financial markets.

The last term ($\varepsilon_{5,t}$) stands for a temporary shock in the exchange rate.

An important property of the equation is that the nominal exchange rate does not have a unique steady state, contrary to nominal exchange rate depreciation. Instead, the level of the exchange rate depends on historical shocks and initial conditions. The NBU, thus, affects only short-term fluctuations and is not able to determine a particular exchange rate level over the long term.

### *Monetary policy rule*

The central bank's monetary policy follows a rule for short-term interest rates. Equation (7) shows a forward-looking monetary policy rule. It is based on a Taylor-type reaction function, where $i_t^P$ is the domestic nominal short-term policy interest rate.

$$i_t^P = \alpha_7 i_{t-1}^P + (1-\alpha_7)(\overline{r}_t + E(\pi 4_{t+1}) + \beta_7(E(\pi 4_{t+1}) - \pi_{t+1}^T) + \gamma_7 \hat{y}_t) + \varepsilon_{7,t} \qquad (7)$$

The lagged interest rate ($i_{t-1}^P$) represents persistency in the reaction function. It is necessary to capture the conservative behavior typical of a central bank.

The policy interest rate reacts to the next period expected y-o-y headline inflation deviation from the target ($E(\pi4_{t+1}) - \pi^T_{t+1}$). Inflation expectations place some weight on lagged inflation in the same manner as in equation (2). The rule is consistent with achieving the medium-term inflation target. Given that monetary policy has persistence in its reaction and can only influence the real economy with a delay, it is impossible to always set the key policy rate in such a way that one-period-ahead expected inflation is at the target.

Monetary policy also reacts to the output gap ($\hat{y}_t$), which is an indicator of future inflation developments. Note that even if inflation is above target, but the output gap is significantly negative, the policy rule might suggest no increase in the interest rate. This has a twofold interpretation. First, such behavior is a precautionary measure, as the currently depressed demand indicates a slowdown in future inflation. Second, it represents a trade-off between inflation and output stabilization, and the flexible nature of the inflation targeting framework.

In the long term, given that all shocks are dissipated, the policy interest rate moves to its neutral level ($\bar{r}_t + E(\pi4_{t+1})$). It provides both an equilibrium value for the interest rate and additional short-term dynamics. When the interest rate is at its neutral level it means that monetary policy is neither accommodative nor restrictive. The nominal neutral interest rate is determined endogenously as the sum of the real neutral rate and inflation expectations. Equation (8) shows how the former is constructed.[13]

The financial markets are modeled to transmit monetary policy decisions. Both short-term (interbank, entering the UIP equation) and long-term (credit, entering the aggregate demand equation) market interest rates follow the key policy rate, even though they have some exogenous spreads.

Shocks in the monetary policy rule ($\varepsilon_{7,t}$) are interpreted as policy deviations from the rule.

***Real neutral interest rate***

Equation (8) shows long-term real UIP relation, which defines the real neutral interest rate ($\bar{r}_t$) in the model. The rate depends on fundamental factors such as the global price of capital, the sovereign risk premium and real depreciation. Accordingly, all these factors have direct implications for the current monetary policy stance.

$$\bar{r}_t = \bar{r}^W_t + \overline{prem}_t + \Delta\bar{z}_{t+1} \tag{8}$$

Investment in a small open economy is reliant on external funds, and thus the price of capital is determined on the global market. The real neutral interest rate depends on its global counterpart ($\bar{r}^W_t$) adjusted for the sovereign risk premium trend ($\overline{prem}_t$) and the expected trend of real exchange rate depreciation ($\Delta\bar{z}_{t+1}$). In this manner, investors require higher rates of interest in a more risky and vulnerable country. However, they accept lower

[13] While modeling monetary policy, we omit the zero lower bound issue. Interest rates in Ukraine are currently well above zero and are not projected to approach it in the near future.

yields in local currency when its appreciation is expected. More discussion can be found in Grui et al. (2018).

***Potential output and real effective exchange rate trends***

Equations (9) and (10) model movements in trends of output (potential output) ($\Delta\bar{y}_t$) and the real exchange rate ($\Delta\bar{z}_t$) respectively. Unlike the other trends in the model, they possess extensions on top of simple autoregressive processes.

$$\Delta\bar{y}_t = \alpha_9\Delta\bar{y}_{t-1} + (1-\alpha_9)\Delta\bar{y}^{SS} + \beta_9(\Delta\overline{tot}_t - \Delta\overline{tot}^{SS}) + \varepsilon_9 \quad (9)$$

$$\Delta\bar{z}_t = \alpha_{10}\Delta\bar{z}_{t-1} + (1-\alpha_{10})\beta_{10}(\Delta\bar{y}_t^W - \Delta\bar{y}_t) - \gamma_{10}(\Delta\overline{tot}_t - \Delta\overline{tot}^{SS}) + \varepsilon_{10} \quad (10)$$

We model changes in trends to be highly persistent, as they depend on their lagged values (e.g. $\Delta\bar{y}_{t-1}$). Both are assumed to approach long-term levels (e.g. $\Delta\bar{y}^{SS}$). For the real exchange rate, the long-term level is time-variable and is defined by the trend for relative output growth ($\Delta\bar{y}_t^W - \Delta\bar{y}_t$). Trends are also affected by spillovers from the terms of trade ($\Delta\overline{tot}_t - \Delta\overline{tot}^{SS}$). Conditions on the commodity markets are an important determinant of the country's trade balance. Improvements contribute positively to potential output growth, as well as trend for real appreciation.

***Foreign sector***

The variables in the foreign sector are the following: trade partners' output, inflation and bilateral exchange rates, foreign nominal short-term and real neutral interest rates, commodity terms of trade, the fiscal impulse, the sovereign risk premium, the food price index and the domestic harvest (all variables can be treated as foreign, as they are completely exogenous). The equations for the variables are either autoregressive or white noise (fiscal impulse), or random walk (exchange rates). Autoregressive coefficients are estimated outside the model.

Several variables are built inside the model as weighted averages of their subcomponents (foreign inflation, terms of trade). Weights are calibrated based on shares of foreign trade. Some variables (terms of trade, food price index and sovereign risk premium) are decomposed into trend and gap inside the model, while others (trade partners' output and domestic harvest) are detrended externally. These conventions make the model practical for everyday use, but can be changed.

## 4. Calibration

This section lists key QPM parameters that are calibrated. The calibration is based on expert judgments, benchmarks from similar models, as well as a need to form satisfactory steady states and sound model properties to fit characteristics of the Ukrainian economy. These are confirmed by the literature and empirical evidence from peer economies[14].

[14] Direct estimation of the model parameters is problematic due to a number of factors common for transition economies. These include macroeconomic vulnerability to external shocks and structural breaks. A recent example is the crisis in 2014-2015 and the consequent switch from a fixed exchange rate to an IT regime.

***Output gap***

The aggregate demand curve (equation (1), table 1) contains an autoregressive component with the coefficient $\alpha_1$, which reflects the inertia of the GDP gap. This parameter is close to values in similar models, e.g. those of the Bank of Serbia (Dukić et al, 2010), the Bank of Croatia (Bokan and Ravnik, 2018), the Reserve Bank of India (Beneš et al, 2017) and the Czech National Bank (Beneš et al, 2003), but in the lower segment of the value range. This reflects our judgment that projected GDP growth in Ukraine is slightly more volatile.

The pass-through from real monetary conditions (sum of coefficients $\beta_1$ and $\gamma_1$) is suggested by Laxton and Scott (2001) to be set in the range of 0.1 to 0.4. In the QPM, it is on the lower bound of this range, which means there is a relatively low impact of monetary policy. Parameter $\beta_1$ is higher than $\gamma_1$. This is consistent with the greater importance of the exchange rate channel in the open Ukrainian economy.

The parameter modifying the real wage gap ($\delta_1$) was calibrated according to independent estimations and expert judgments. The spillover from the world output gap (parameter $\theta_1$) was calibrated in accordance to the share of exports in GDP. The terms-of-trade coefficient ($\mu_1$) was derived on the basis of historical simulations, with the objective of it fitting the data during episodes of commodity slumps and booms. Parameter $\rho_1$ identifies the impact of fiscal policy and was calibrated on the basis of the results of a SVAR analysis (Vdovychenko, 2018a). The calibration of $\sigma_1$ reflects episodes of risk premium shocks in 2008 and 2014 and their impact on GDP.

**Table 1.** Calibration of the aggregate demand curve.

| Parameter | $\alpha_1$ | $\beta_1$ | $\gamma_1$ | $\delta_1$ | $\theta_1$ | $\mu_1$ | $\rho_1$ | $\sigma_1$ |
|---|---|---|---|---|---|---|---|---|
| Value | 0.7 | 0.065 | 0.035 | 0.07 | 0.5 | 0.07 | 0.2 | 0.1 |

***Inflation dynamics***

Modified Phillips curves for the components of inflation are described by equations (2)-(4) with the parameters presented in table 2. Coefficients $\alpha_2 - \alpha_4$ indicate a relatively low weight of the autoregressive components, which is consistent with historical inflation volatility. Parameters $\beta_{2-4}$ capture the importance of expectations. In the QPM, these coefficients are relatively high. However, inflation expectations are formed in the model as a weighted average of past (with a weight of 0.25) and model- Thus, the effective measure of how much the inflation is forward-looking becomes lower

Price elasticity with respect to import prices (adjusted for the Balassa-Samuelson effect) is calculated as $(1 - \alpha_{2-4} - \beta_{2-4})$. Inflationary pressures from the economy's position in the business-cycle (coefficients $\gamma_{2-4}$) are calibrated to be comparatively small, with a higher coefficient for policy-relevant core inflation, but a lower one for supply-driven raw food and for petrol, which is mostly imported. The other terms of the equations represent the supply side of inflation, which is transmitted through the real marginal costs of domestic producers

This induces changes in model parameters as long as the QPM is not fully micro-founded. The estimation thus lacks observations. Among plans for future actions is to conduct a Bayesian estimation, which could potentially overcome this handicap.

and importers. The parameters were calibrated on the basis of an analysis of stylized facts and the cost structure of the Ukrainian economy.

**Table 2.** Calibration of Phillips curves.

| Core | | | | | | |
|---|---|---|---|---|---|---|
| Parameter | $\alpha_2$ | $\beta_2$ | $\gamma_2$ | $\delta_2$ | $\theta_2$ | $\mu_2$ |
| Value | 0.25 | 0.7 | 0.18 | 0.06 | 0.06 | 0.09 |
| Raw food | | | | | | |
| Parameter | $\alpha_3$ | $\beta_3$ | $\gamma_3$ | $\delta_3$ | $\theta_3$ | $\mu_3$ |
| Value | 0.4 | 0.55 | 0.1 | 0.05 | 0.3 | 0.05 |
| Petrol | | | | | | |
| Parameter | $\alpha_4$ | $\beta_4$ | $\gamma_4$ | $\delta_4$ | $\theta_4$ | |
| Value | 0.3 | 0.4 | 0.04 | 0.18 | 0.18 | |

### *Uncovered interest rate parity (UIP) condition*

Table 3 comprises coefficients from equations (5)-(6), which constitute the modified UIP condition in the QPM. Both parameters were calibrated on the basis of an analysis of impulse responses and historical simulations, with the goal of obtaining reasonable predictions and an acceptable fit to the data. Coefficient $\gamma_5$, although small, allows the nominal exchange rate to depend on commodity terms of trade. This term can be found in models for net commodity exporters, for example see the QPM for the South African Reserve Bank in de Jager et al (2015). Parameter $\beta_6$ smoothes exchange rate volatility and measures the degree to which a central bank intervenes on the FX market[15]. It is slightly above the respective coefficients in peer economies, as the NBU actively engages into mitigating excessive exchange rate volatility.

**Table 3.** Calibration of the UIP condition.

| Parameter | $\gamma_5$ | $\beta_6$ |
|---|---|---|
| Value | 0.05 | 0.6 |

### *Monetary policy rule*

The policy reaction function should reflect the preferences of NBU policymakers (equation (7), table 4). Parameter $\alpha_7$ defines how persistent the monetary policy is. A value close to one indicates a “wait-and-see” approach, while zero means no persistence at all. The rule is calibrated to have moderate persistence, with about 87% of the “desired” response coming within a year. Coefficients $\beta_7$ and $\gamma_7$ define the strength of the monetary policy response to the deviations of inflation and output from their targeted and potential levels respectively. According to the Taylor principle, it is sufficient that the former is positive for monetary policy to help to stabilize the economy. The latter is non-negative so that actual GDP converges to its potential level. The policy rule in the QPM pays more attention to inflation stabilization and is relatively aggressive in comparison with inflation-targeting peers. It reflects the need to gain credibility at the initial stage of the IT regime.

[15] Detailed discussion for Ukraine can be found in Grui and Lepushynskyi (2016).

**Table 4.** Calibration of monetary policy rule.

| Parameter | $\alpha_7$ | $\beta_7$ | $\gamma_7$ |
|---|---|---|---|
| Value | 0.6 | 2 | 0.4 |

### *Potential output and trend REER*

The trends for the growth rates of GDP and REER (equations (9)-(10), table 5) have high inertia ($\alpha_{9-10}$), which reflects their rigid nature. Parameters $\beta_9$ and $\gamma_{10}$ define how sensitive they are to changes in the trend of commodity terms of trade. They are calibrated to provide a reasonable historical fit. The last coefficient, $\beta_{10}$, defines the relation between steady states and is set by expert judgments.

**Table 5.** Calibration of output and REER trends.

| Potential output | | | |
|---|---|---|---|
| Parameter | $\alpha_9$ | $\beta_9$ | |
| Value | 0.85 | 0.05 | |
| REER trend | | | |
| Parameter | $\alpha_{10}$ | $\beta_{10}$ | $\gamma_{10}$ |
| Value | 0.75 | 0.5 | 0.2 |

### *Steady states*

In the model, steady states are explicitly calibrated in accordance with the NBU's targets and theoretically consistent relationships among variables (table 6). Steady state inflation ($\pi^{SS}$) is equal to the medium-term policy target in Ukraine. Zero steady state growth of terms of trade ($\Delta\overline{tot}^{SS}$) indicates the conservative assumption of no changes in the long-term conditions for Ukrainian external trade. Potential GDP growth ($\Delta\bar{y}^{SS}$) in the steady state is conservatively below average growth in emerging and developing Europe (4.5% in 2011-2018[16]). It is above the recent historical average in Ukraine (2.9% in 2017-2018), but our view stems from ongoing and expected structural reforms, as well as real convergence. The steady state for sovereign risk premium ($\overline{prem}^{SS}$) is based on data for peers and expert judgments.

Steady states for REER trend appreciation and neutral real interest rate are implicitly derived, as they depend on the calibration of other parameters in the model. The former is proportional to the difference between Ukrainian and foreign steady state GDP growth. Moderate steady state REER trend appreciation ($\Delta\bar{z}^{SS}$) reflects the Balassa-Samuelson effect and estimates for Central and Eastern Europe (Beneš et al, 2003). The latter accounts for steady states of global real interest rate, risk premium and real appreciation[17]. Estimation for the neutral real interest rate ($\bar{r}^{SS}$) is consistent with the long-term UIP condition in real terms.

**Table 6.** Calibration of steady states.

| Parameter | $\pi^{SS}$ | $\Delta\overline{tot}^{SS}$ | $\Delta\bar{y}^{SS}$ | $\Delta\bar{z}^{SS}$ | $\overline{prem}^{SS}$ | $\bar{r}^{SS}$ |
|---|---|---|---|---|---|---|
| Value | 5 | 0 | 4 | -1 | 4 | 3 |

[16] According to IMF World Economic Outlook, April 2019.
[17] Details can be found in Grui et al. (2018).

## 5. Trends and gaps of basic variables

Real variables[18] are decomposed into trends and gaps in the model. This allows the position of the economy in the business cycle to be gauged, revealing inflationary pressures and possible misalignments. Moreover, trends and gaps serve as the initial conditions for forecasting. They are unobservable, and their estimation requires the application of filtration. For that, the QPM employs a Kalman filter. This is a multivariate filter, which uses a state-space presentation of the model's equations and estimates unobserved components of variables based on their prescribed statistical properties. There is an important advantage of the Kalman filter over univariate filters, for example the Hodrick-Prescott filter – the Kalman filter is able to incorporate a data-generating structure that follows economic intuition and statistical logic, and thus the identification of trends and gaps should be more accurate.

In this section, we present estimates of the trends as of late-2018. The estimates are subject to uncertainty and may be revised. Such revisions can alter policy views at a particular stage of the business cycle. In practice, provided the model is well-structured and well-calibrated, the revisions of trends are usually marginal from one forecasting round to the next. A significant trend revision would typically take place only if a sizable structural change were to happen in the economy and had to be reflected in the estimation. The estimates of the trends are used to condition historical forecasts in the exercise in section 7.

The estimates may include expert judgments, e.g. a drop in potential GDP in early 2015. These are meant to instruct the filter about structural changes in the economy that are not captured by the model.

GDP and REER gaps are among the most important variables in a small open economy, as they define marginal costs in Phillips curves and drive the inflation dynamic. Thus, they affect monetary policy decisions to a large degree. Respective trends and gaps are presented in Figure 9[19].

The figure for GDP demonstrates the overheating of the Ukrainian economy in 2007-2008 – mostly fueled by a boom on the commodity markets. In contrast, the two large GDP drops seen reflect the global financial crisis in 2008-2009 and the Ukrainian macroeconomic crisis in 2014-2015. The negative output gap in 2015-2016 contributed to rapid disinflation. Annual inflation was 12.4% in 2016 after hitting 43.3% in 2015. As of 2018, the output gap is close to zero.

Two long periods of negative REER gaps (2005-2008 and 2010-2014) testify to the overvaluation of the REER. These reflect periods of a fixed exchange rate regime in Ukraine and the respective accumulation of imbalances. The significant overvaluation in 2012-2013 is in line with the close to zero inflation in those years. The REER quickly reverted to its trend twice during the crises. The corrections happened by means of

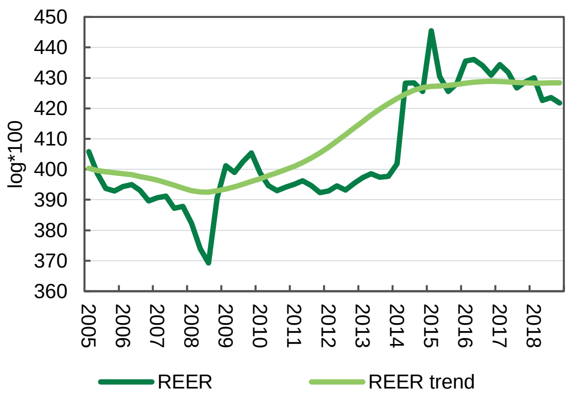
[18] Appendix 1 provides information about raw data.
[19] Time series are in logs multiplied by 100 so that gaps can be interpreted as deviations from trends in percent.

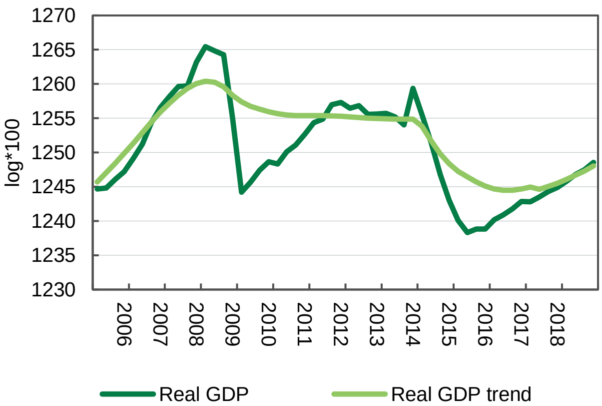
nominal devaluations, as the NBU was not able to confront these pressures on the FX market. After 2015, the REER appears to be closer to the trend on the back of the IT regime and floating exchange rate.

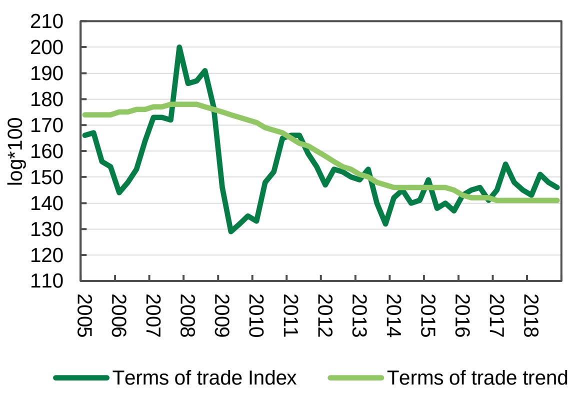
Filtrations of Ukrainian terms of trade and trade partners' output reveal boom and bust around the global financial crisis in 2008. This captures effects from both the commodity markets and the global economy. The continuous worsening of terms of trade contributed to the trend for REER devaluation.

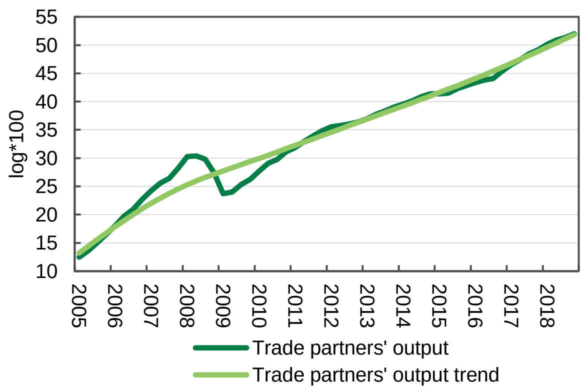
In line with the Okun's law, the unemployment gap roughly follows the output gap moving in opposition to each other. The trend of growing unemployment shows the effects of increased structural mismatches in the supply and demand for labor, as well as outward migration after the crisis of 2014-2015. The real wage gap also correlates with the output gap. Wages were swift to recover after the crisis of 2014-2015. This was at least partially due to the necessity to retain workers at home while outward labor migration intensified.

A comparison of real market short-term interest rates, and the policy neutral interest rate, allows judgments about the monetary policy stance to be made. The mostly negative historical real interest rate gap testifies to long spans of an accommodative monetary policy. This finding matches with the high average inflation. Since 2018 the policy has been restrictive, with a view to bringing inflation to the target.



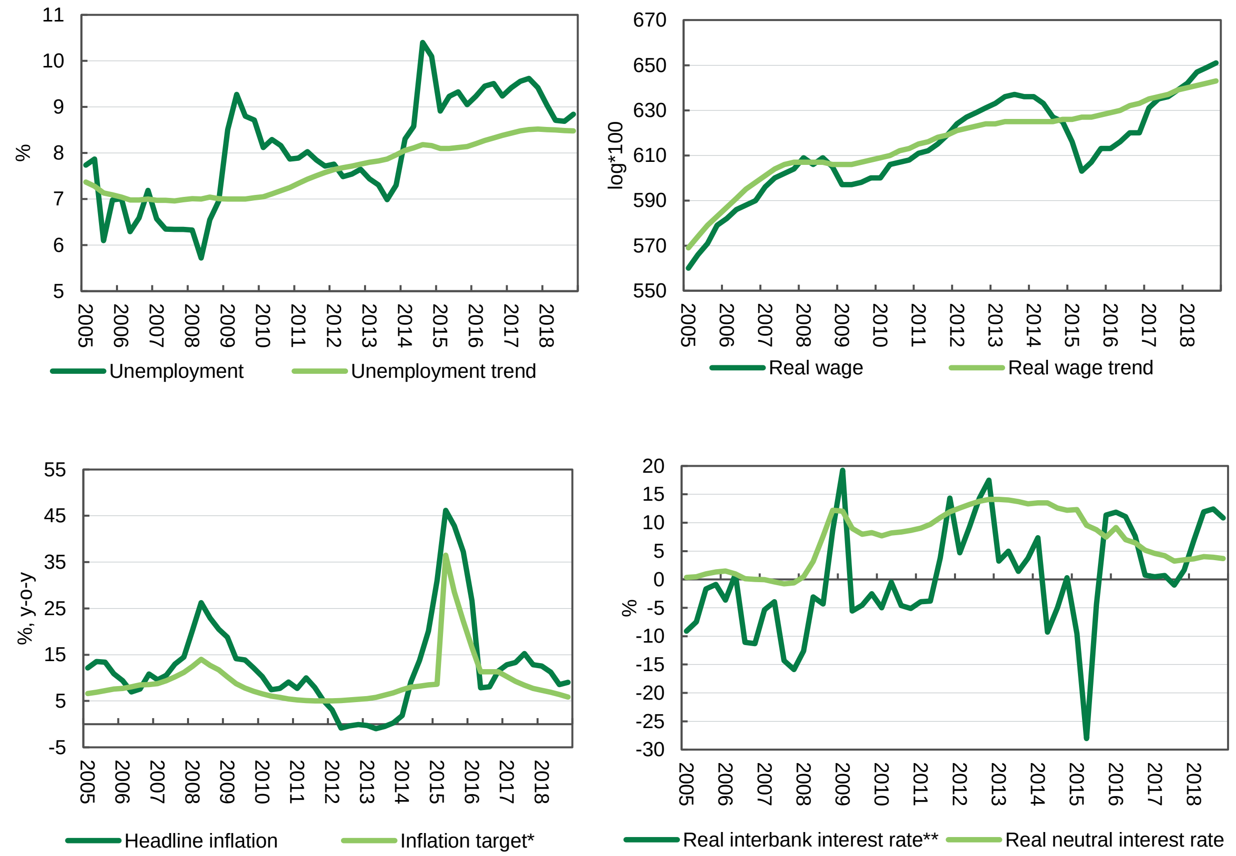



**Figure 9.** Trends and gaps of basic variables.
Source: NBU staff estimates.
Note: * The inflation target until 2016 is filtered and contains expert judgments, while after 2016 it is the official target of the NBU; ** The nominal interbank rate is adjusted with model-consistent one-quarter-ahead inflation expectations.

## 6. Model Properties

With a view to examining the model's properties, we employ an impulse response analysis. In this section, we show the simulated impulse responses of the main macroeconomic variables to selected shocks. All of the analyzed shocks are temporary, except for the disinflation shock, which is permanent. All variables start at their equilibria before the shock happens and return to them after the impact of the shock dissipates. All shocks are assumed to be identified by the central bank at the time of their occurrence, which means that the central bank takes them into account in its policy decisions. The impulse response functions are given in Appendix 3, in Figures 10 to 15, where the periods represent quarters.

### *Demand shock*

A positive demand shock is simulated as a 1 p.p. shock to the GDP gap equation and generates positive inflationary pressures (see Figure 10.). Inflation accelerates by 0.06 p. p. in the third quarter after the shock. In line with the NBU's reaction function, monetary policy reacts by raising the key policy rate by 0.3 p.p. The growth of the nominal interest rate leads to an increase in the real short-term interest rate, calculated as the difference between the nominal rate and expected inflation. Real interest rate growth means that the nominal interest rate is set to a level well above inflation expectations. Inflation is consequently mitigated. This is the interest rate channel of the monetary policy transmission mechanism.

The UIP reaction leads to an appreciation of the nominal exchange rate by 0.7 percent in one year, given increased returns and thus demand for hryvnia-denominated assets. The higher inflation and nominal appreciation create a negative REER gap. Both the nominal and real appreciation help return inflation to the target, as imported inflation and marginal costs go down. The importance of the exchange rate channel for inflation stabilization is relatively high, due to the decidedly open nature of Ukrainian economy. Furthermore, tight monetary conditions in terms of real interest rates and REER contribute to the dissipation of the GDP gap.

As opposed to the real variables, which return to their long-term equilibrium, the level of the nominal exchange rate is not anchored. This follows from the UIP and the Phillips curve. The nature of the Phillips curve equations states that the price level (aka accumulated inflation) will always adjust until the real marginal costs (in particular the REER gap) diminish to zero. As long as trend REER does not react to temporary shocks, the nominal exchange rate needs to settle at a new steady state in order to compensate for the new price level.

A decisive reaction by the central bank quickly mitigates the responses of both inflation and GDP. After some fluctuation, caused primarily by partially backward-looking expectations, inflation returns to target, and the remaining variables settle at their steady state levels. Monetary policy reacts rather forcefully, given the presence of the GDP gap in its reaction function, and also due to the fact that the model assumes non-perfect monetary policy credibility (modeled as a share of adaptive expectations, see Main Equations section) of the NBU. Therefore, in order to overcome the lack of confidence in the intentions and ability of the central bank to bring inflation to its target, the rate is raised aggressively. This gives a clear signal to economic agents that the central bank is committed to the price stabilization objective.

***Supply shock***

A supply shock (2 p.p. q-o-q, annualized) is simulated as an unexpected increase in core inflation. Figure 11 shows the central bank reacting to an expected deviation of inflation from the target by raising the policy rate by 0.4 p.p. The nominal exchange rate appreciates by 1.3 p.p. after a year because hryvnia assets become more attractive to foreign investors, which stimulates short-term capital inflow. Both elevated inflation and nominal appreciation contribute to real appreciation. Tight monetary conditions subdue aggregate demand, reducing output by 0.3 percent over a one-year horizon. In turn, the combination of diminished demand with an appreciated currency slow inflation.

Similar to the case of the demand shock, monetary policy overreacts with a view to overcoming its non-perfect credibility. Adaptive expectations subsequently generate volatility.

### *Risk premium shock*

A risk premium shock of 2 p.p. increases country's sovereign risk premium. This shock is an important driver of exchange rate fluctuations, because small open economies, like that of Ukraine, are highly dependent on external funding. That is why risk premium shocks are of a great impact and have much in common with supply ones. The effect of the risk premium is propagated through the exchange rate into domestic prices. Adverse risk premium shocks can also be used to simulate the impact of sudden capital flows stops.

The risk premium, which is an observable variable in the model, features in the GDP gap equation (as $\widehat{prem}$) and both long-term and short-term versions of the UIP condition (as $prem$ and $\overline{prem}$ respectively). Accordingly, the risk premium shock applied to the model opens up a negative output gap of 0.2 percent (due to a sharp slowdown in externally funded investment) and leads to nominal exchange rate depreciation of about 1 percent (Figure 12). However, long-term UIP is not affected, as the shock is temporary. Due to the large share of imported goods, depreciation pushes up inflation by almost 0.4 p.p. after a year and elevates inflation expectations. This implies a temporary decline of the short-term real interest rate, even though the nominal interest rate has already increased.

The central bank prioritizes a response to heightened inflation expectations over subdued demand, with the key policy rate rising by 0.7 p.p. after 4 quarters. This reduces initial nominal depreciation. However, the high real interest rate slows down economic recovery. Meanwhile, as prices do not adjust to nominal depreciation immediately, the REER gap that opens is positive. This creates more favorable conditions for GDP growth.

### *Terms of trade shock*

A positive terms of trade shock is simulated as a temporary 10 p.p. increase in prices for ferrous metals. Figure 13 shows the responses: As the price of the exported commodity increases, the improved current account creates a positive GDP gap of 0.4 percent over the first year. The inflow of foreign currency due to higher exports leads to an appreciation of the nominal exchange rate (1 percent after four quarters). This lowers inflation by 0.25 p.p. in year-over-year numbers, through the effect of its imported component. The monetary policy pays more attention to low inflation than to a positive GDP gap. As a result, the key interest rate is decreased by 0.3 p.p. after one year. The prevailing effect of nominal appreciation leads to a negative REER gap, which worsens the price competitiveness of domestic goods on the international markets and gradually reduces the GDP gap back to zero.

The short-term real interest rate increases only over the first two quarters, as inflation expectations decline quickly. After that, the real rate mimics its nominal counterpart.

### *Monetary policy shock*

The monetary policy shock is modeled as an unexpected 1 p.p. shock to the key interest rate. The central bank quickly acknowledges the deviation from its policy rule and reverts to the rule in the next quarter. The simulation demonstrates the policy transmission mechanism well. Moreover, it is useful for comparison purposes, as monetary policy shocks have been well identified across a set of various models. Figure 14 demonstrates the responses of key macroeconomic variables.

A higher nominal interest rate leads to nominal appreciation by 0.4 p.p. on impact, which transmits into a negative REER gap amid a sluggish reaction by inflation. Expectations of future inflation fall quickly in response to the tight monetary policy stance, however. Thus, the real interest rate increases even more than nominal one. Restrictive monetary conditions slow down aggregate demand, and output declines by about 0.1 percent at the end of the year. Inflation slows as well. The negative output gap and lower inflation push monetary policy to reverse its stance, so the interest rate plunges. Afterwards, monetary policy is normalized.

***Disinflation scenario***

Disinflation engineered by the central bank is modeled as a permanent shock to the inflation target, which is decreased by 1 p.p. (Figure 15). In order to achieve the new target, the central bank first briefly increases the key policy rate by 0.4 p.p. on impact. The short-term real interest rate also increases, and with a larger magnitude. This is due to the fact that inflationary expectations are reduced in response to an announced cut in the inflation target. This implicitly signifies that economic agents believe that the central bank can achieve its inflation targets.

The rise in the nominal interest rate leads to both nominal (2.2 percent after a year) and real appreciations, and as a consequence a decrease in imported inflation. Tight monetary conditions lead to a reduction in aggregate demand and a negative GDP gap, which falls to (-2.2) percent in the fourth quarter after the shock. The reduction of imported inflation and the negative GDP gap create disinflationary pressure in the economy, which help re-anchor inflation and inflation expectations at the new target.

The disinflation comes with economic costs. The sacrifice ratio, measured as an annual loss in economic output, reaches 0.4 percent of GDP. That means that, for every 1 p.p. of permanently diminished inflation, the economy “pays” with a loss of GDP of 0.4 percent. This value is similar to those seen in peer economies during the early stages of their IT regimes. However, it is relatively small because of Ukraine’s high trade openness, which makes the disinflation work more through the exchange rate channel and less through the interest rate channel.

After an initial monetary policy tightening, the central bank starts to decrease the interest rate, as inflation declines while the GDP gap is negative. The decline in rates and shrinking REER gap lead to a recovery of demand. As a result of the disinflation, the steady states of inflation and the nominal interest rate are reduced.

Permanently lower domestic inflation leads to a faster pace in the nominal appreciation of the hryvnia. Since the disinflation shock is purely nominal, REER comes back to an unchanged steady state after the shock’s dissipation. Permanently lower inflation and unchanged long-term REER require nominal appreciation. The pace of nominal exchange rate depreciation decreases permanently by the size of the disinflation shock.

## 7. Forecasting with the model

The QPM is mainly used at the NBU for medium-term forecasting of main macroeconomic variables as well as augmenting it with consistent narratives. The model has to provide theoretically coherent projections and be reasonably practical to use. This section provides a brief overview of how forecasting with the QPM is done.

### 7.1. Pseudo-real-time forecasting

In this subsection, a pseudo-real-time forecasting performance of the QPM is illustrated. The forecasting simulations are made and assessed on a sample from 1Q 2016 to 4Q 2018. Sequential forecasts start from each quarter except of the last one on the interval (eleven periods in total) and are eight quarters ahead. Figure 16 plots the results, where the black line is the observed reality.

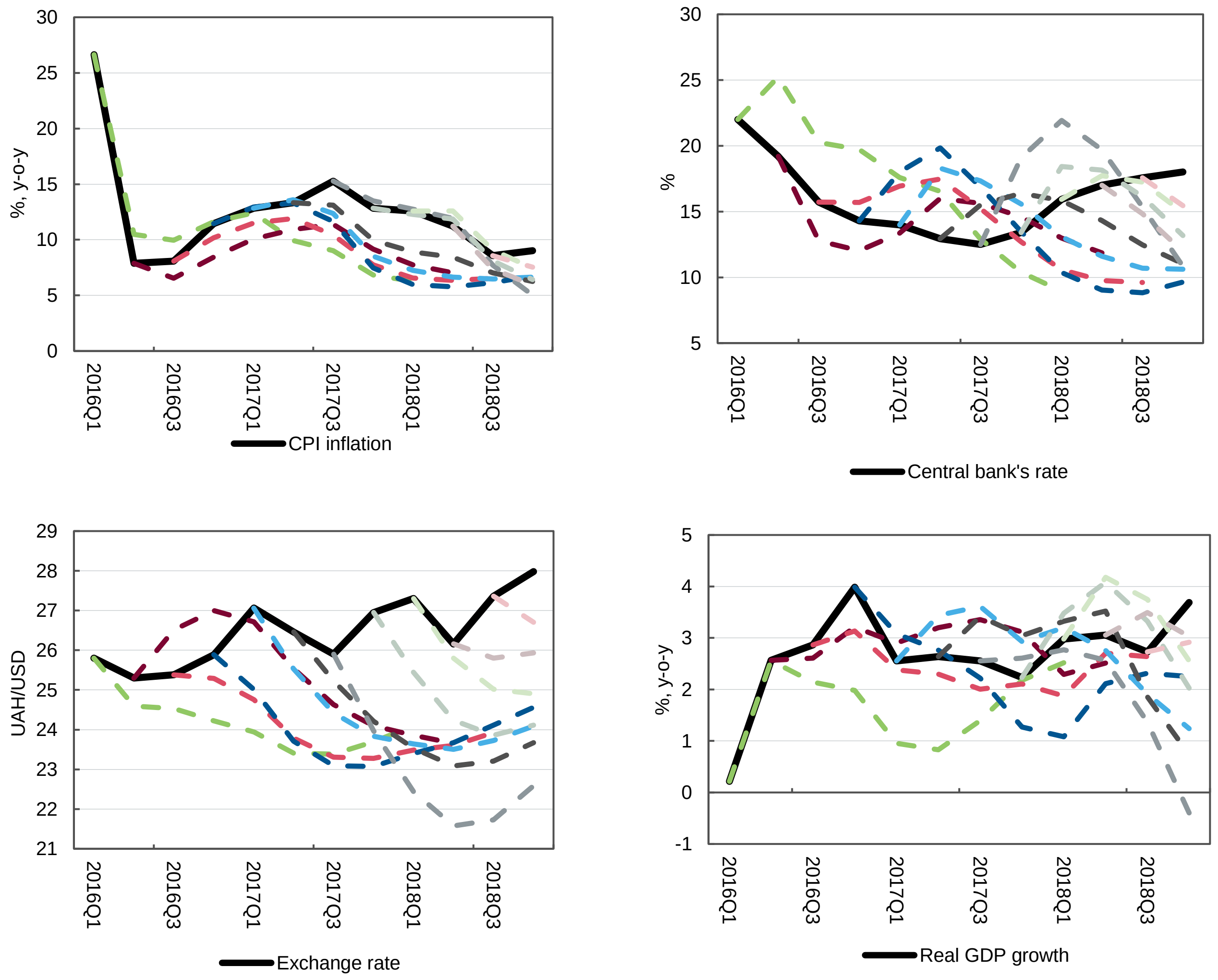



**Figure 16.** Historical simulations of key economic variables.

The pseudo-real-time forecasts differ from a typical out-of-sample forecasting exercise at the NBU (we talk about the latter in the following subsection). This is for a number of reasons.

First, factual forecasts often incorporate expert judgments and include short-term tunes coming from satellite models. These models are typically multivariate econometric models (e.g. VAR, VECM), which are normally considered to demonstrate better short-term forecasting performance.

Second, the simulations in the pseudo-real-time forecasting exercise contain some information that is not actually available in real time. Specifically, unobserved trends are fixed at their most recent estimates. While in practice these trend estimates do not change much from iteration to iteration, the revisions might be substantial in economies that are undergoing structural changes. Additionally, actual realizations of foreign variables in the current exercise play the role of forecast assumptions. In reality, however, no perfect outlook of the global economy is available at the time of forecasting, and assumptions change regularly from one round to the next – sometimes significantly. The QPM is not designed to forecast foreign variables, and the domestic variable forecasts are each time-conditioned to the best assumptions available from third parties. We therefore should not judge the model's performance by errors generated because of inaccurate exogenous assumptions.

Finally, the simulations are made with the most recent version of the model, which includes recent recalibration of some coefficients. As the QPM is tasked with forecasting, its equations should reflect the most up-to-date views of the economy's mechanics. However, the Ukrainian economy and monetary policy have undergone a structural transition over the few years since IT was announced in 2016. Moreover, the economy has been recovering from the preceding crisis of 2014-2015. For example, a change in calibration is well demonstrated by the policy interest rate forecasts in Figure 16. The model tends to suggest a hawkish policy reaction occurring earlier than it in fact happened. To a large extent, this can be explained by the changed perception of inflation expectations, namely the introduction of a backward-looking component. Furthermore, the monetary policy rule was updated – in particular, it gained more focus on inflation.

Given their limitations, pseudo-real-time forecasts do not reveal the true forecasting performance of the model. However, they show how it can provide a coherent outlook and provide recommendations for monetary policy. Knowing its strengths and weaknesses, the QPM can and should be used for medium-term forecasting.

Table 7 shows the root mean squared errors (RMSEs) of the forecasts. The number of observations is 11 for 1-quarter-ahead forecasts, though this diminishes to four for 8-quarter-ahead ones. The numbers are shown relative to naive random-walk forecasts, thus RMSEs below unity mean better than random-walk precision.

Simulations suggest good forecasting performance for both headline inflation and GDP growth. Deviations can be attributed to shocks that were identified in many cases only expost. In practice, some of them are largely taken into account by imposed expert judgments. Slower disinflation in 2017 is connected to unexpected supply shocks linked to bad weather and an increase in the minimum wage (NBU Inflation Report, January 2018). Higher than projected GDP performance in 2018 in official forecasts was captured by sectoral experts' judgments.

The forecasts of the policy interest rate and nominal exchange rate are less precise. Monetary policy is on average projected to be more aggressive. Inflation in 2017-2018 comes in above target, so tightening could have been a consistent and reasonable suggestion. The nominal exchange rate in turn is forecasted to be stronger. First, this is consistent with higher interest rates. Second, the model does not account for the positive average in foreign exchange interventions implemented by the NBU (more FX bought than sold), with the goal of replenishing international reserves. Interventions are able to influence the exchange rate significantly on the relatively shallow Ukrainian market with its non-perfect capital mobility. In practice, this feature is captured by expert judgments.

**Table 7.** Relative RMSEs of the QPM forecasts.

| | 1q | 2q | 3q | 4q | 5q | 6q | 7q | 8q |
|---|---|---|---|---|---|---|---|---|
| GDP growth, % y-o-y | 0.71 | 0.67 | 0.62 | 0.90 | 1.68 | 1.34 | 0.97 | 0.57 |
| Key policy rate | 2.19 | 1.38 | 0.79 | 0.64 | 0.91 | 1.06 | 1.33 | 1.88 |
| Exchange rate, UAH/USD | 1.87 | 2.35 | 3.86 | 3.64 | 2.88 | 2.74 | 2.47 | 1.88 |
| Headline inflation, % y-o-y | 0.24 | 0.31 | 0.41 | 0.55 | 0.65 | 0.79 | 0.62 | 0.56 |

### 7.2. Regular forecasting exercise

This subsection offers a quick glance at a typical macroeconomic forecasting exercise at the NBU using the QPM. The QPM provides the framework for the NBU’s forecasting and policy analysis system. It helps to organize the work of staff and the formulation of their advice to policymakers. A regular forecast, published in the NBU’s Inflation Report, is produced four times a year and has a horizon of two to three years. An assessment of the actual deviations from previous published forecasts can be found in the NBU Inflation Reports from April 2019 (NBU, 2019a) – for GDP growth and inflation, and from July 2019 (NBU, 2019b) – for the policy interest rate.

The QPM is utilized to enhance the narrative and ensure consistency in the forecasts of the main macroeconomic variables. First, the model provides an organizational framework used to account for various sources of views about economic developments. Second, it combines external information with structural driving forces that are seen to be relevant predictors of medium-term dynamics.

During the forecasting exercise, some variables are treated exogenously and are given over the forecasting horizon. Among these are administratively regulated prices and global indicators such as commodity prices, foreign inflation, trading partners’ bilateral exchange rates and their GDP, and the benchmark global interest rate. External sector variables are projected outside of the QPM. Thus, the model's forecasts are made on the basis of exogenous assumptions.

The Kalman filter is used to decompose variables into unobservable trends and gaps. The filtration range spans both historical and forecasting time horizons. For the latter, external assumptions about commodity prices enable judgments to be made about the medium-term trend and cycle in commodity terms of trade. The resulting estimated unobserved variables are taken as initial conditions for model-based forecasts.

In addition to external sector variables, a typical forecasting exercise requires to exogenise (i.e. treat as exogenously given) some of the domestic variables over particular horizons. First, short-term judgments (also called tunes) are usually imposed to reflect forecasts made by satellite models or expert assessments. These include nowcasts (forecasts for the current quarter), where available, and backcasts (forecasts for the previous quarter) of variables that are published with a delay, such as GDP. These also include several quarters of some forecasts of inflation components, such as volatile raw food inflation. Such expert tunes usually improve short-term forecasting performance. However, structural driving forces are more important over the medium term. Second, for scenario analysis it is possible to exogenise some variables, e.g. the nominal exchange rate, over the whole forecasting horizon. In such case, the forecast becomes conditional on a specific exchange rate path. Finally, the forecast may include add-factors – shocks of a particular size that are added to a variable at some period in the future. These are intended to capture some additional information that is not explicitly modeled in the QPM.

The forecast conditional on the tunes from experts and satellite models is not taken mechanically but is discussed by an expert panel. At this stage, potential inconsistencies are revealed, and a narrative is discussed. After the discussion, additional adjustments may be required. The iterative procedure continues until a consensus among experts and policy makers is reached.

## 8. Conclusions

This paper presents the QPM for Ukraine, which is the workhorse model for macroeconomic forecasting and monetary policy analysis at the NBU. The model produces consistent medium-term forecasts and allows for inputs from other (satellite) models, as well as expert judgments. Moreover, it gives an opportunity for forecast scenarios to be developed and counterfactual analyses to be conducted. These characteristics make it an essential tool for monetary policy decisions and analyses.

The QPM is a medium-scale, semi-structural model of a small open economy. It follows standard New-Keynesian logic with some modifications aimed at capturing Ukrainian stylized facts. Among other things, we model the disinflation agenda, the heterogeneity of inflation components, non-perfect monetary policy credibility, and the comparatively high importance of exchange rate channel.

The parameters of the model are calibrated, which overcomes structural breaks and the relatively short experience with the inflation targeting (IT) regime in Ukraine. The calibration is set to be in line with peers, but also to provide sound model properties, e.g. impulse-response functions. The parameterization of the model is subject to updates, as IT in Ukraine is still at its early stages and the transmission mechanism has been improving gradually.

Model simulations reveal that the QPM outperforms a benchmark random walk model in forecasting inflation and output growth. They also demonstrate the usefulness of external judgments for exchange rate forecasting and show how recalibration can call into question past policy decisions.

Further development of the QPM presumes it will be extensively validated with supplementary research. This will include external assessment of trends and steady states. Calibration needs to be supported by new empirical findings. There is also a room for a Bayesian estimation of model parameters. Forecasting performance should be revisited with more data and challenged by more sophisticated models, e.g. BVARs and VECMs. The way uncertainty is handled in this model (i.e. standard deviations of the shocks, fan charts) was not addressed in this paper, and may fall into the scope of future studies. Possible satellite QPM-type models could be devoted to expanding the UIP with interventions for reserves accumulation, implementing an ample fiscal block, and accounting for endogenous policy credibility.

## 9. References

Amarasekara, C., Anand, R., Ehelepola, K., Ekanayake, H., Jayawickrema, V., Jegajeevan, S., Kober, C., Nugawela, T., Plotnikov, S., Remo, A., Venuganan, P., Yatigammana, R. (2018). An open economy quarterly projection ьodel for Sri Lanka. IMF Working Papers, 18/149. International Monetary Fund. https://doi.org/10.5089/9781484361511.001

Beneš, J., Clinton, K., George, A., Gupta, P., John, J., Kamenik, O., Laxton, D., Mitra, P., Nadhanael, G.V., Portillo, R., Wang, H., Zhang, F. (2017). Quarterly projection model for India: key elements and properties. IMF Working Papers, 17/33. International Monetary Fund. https://doi.org/10.5089/9781475578706.001

Beneš, J., Hledik, T., Vavra, D., Vlcek, J. (2003). The quarterly projection model and its properties, in Coats W., Laxton D., Rose D. (ed.) The Czech National Bank's Forecasting And Policy Analysis System, pp. 63-99. Czech National Bank.

Beneš, J., Hurnik, J., Vavra, D. (2008). Exchange rate management and inflation targeting: modeling the exchange rate in reduced-form new keynesian models. Czech Journal of Economics and Finance, 3-4, pp. 166-194. Retrieved from http://journal.fsv.cuni.cz/mag/article/show/id/1128

Berg, A., Karam, P., Laxton, D. (2006), Practical model-based monetary policy analysis – a how-to guide. Working paper, 06/81. International Monetary Fund. https://doi.org/10.5089/9781451863413.001

Bokan, N., Ravnik, R. (2018). Quarterly projection model for Croatia. Surveys, S-34. Croatian National Bank, Zagreb. Retrieved from https://www.hnb.hr/documents/20182/2569513/s-034.pdf

Brito, S., Magud, N., Sosa, S. (2018). Real exchange rates, economic complexity, and investment. IMF Working Papers, 18/107. International Monetary Fund. https://doi.org/10.5089/9781484354834.001

De Jager, S., Johnston, M., Steinbach, R. (2015). A revised quarterly projection model for South Africa. Working Paper Series, 15/03. South African Reserve Bank. Retrieved from https://www.resbank.co.za/Lists/News%20and%20Publications/Attachments/6839/WP1503.pdf

Đukić, M., Momčilović, J., Trajčev, L. (2010). Medium-term projection model of the National Bank of Serbia. Working Papers, 17. National Bank of Serbia, Belgrade. Retrieved from https://www.nbs.rs/internet/english/90/90_0/2010_17_MDj_JM_LjT_e.pdf

Faryna, O. (2016). Nonlinear exchange rate pass-through to domestic prices in Ukraine. Visnyk of the National Bank of Ukraine, 236, 30-42. https://doi.org/10.26531/vnbu2016.236.030

Gorodnichenko, Y. (2014). Inflation target for Ukraine, VoxUkraine Blog. Retrieved from http://voxukraine.blogspot.com/2014/05/IT.html

Grui, A., Lepushynskyi, V. (2016). Applying foreign exchange interventions as an additional instrument under inflation targeting: the case of Ukraine. Visnyk of the National Bank of Ukraine, 238, 39-56. https://doi.org/10.26531/vnbu2016.238.039

Grui, A., Lepushynskyi, V., Nikolaychuk, S. (2018). A neutral real interest rate in the case of a small open economy: application to Ukraine. Visnyk of the National Bank of Ukraine, 243, 4-20. https://doi.org/10.26531/vnbu2018.243.004

Hammond, G. (2012). State of the art of Inflation targeting. Handbook, 29. Bank of England, Centre for Central Banking Studies. Retrieved from https://www.bankofengland.co.uk/-/media/boe/files/ccbs/resources/state-of-the-art-inflation-targeting

International Monetary Fund (2014). Ukraine: request for a stand-by arrangement – staff report; supplement; staff statement; press release; and statement by the executive director for Ukraine. IMF Country Report, 14/106. International Monetary Fund. https://doi.org/10.5089/9781484340370.002

International Monetary Fund (2019). World Economic Outlook, April 2019: Growth Slowdown, Precarious Recovery. https://doi.org/10.5089/9781484397480.081

Laubach, T., Williams, C. (2003). Measuring the natural rate of interest. Review of Economics and Statistics, 4, 1063-1070. https://www.jstor.org/stable/3211826

Laxton, D., Scott, A. (2000). On developing a structured forecasting and policy analysis system designed to support inflation-forecast-targeting in *Inflation Targeting Experiences: England, Finland, Poland, Mexico, Brazil, Chile,* pp. 6–63. The Central Bank of Turkey, Ankara.

National Bank of Ukraine (2015). Main Principles of Monetary Policy for 2016-2020. Retrieved from https://bank.gov.ua/doccatalog/document?id=28745297

National Bank of Ukraine (2017). Monetary Policy Guidelines for 2018 and Medium Term. Retrieved from https://bank.gov.ua/doccatalog/document?id=87678840

National Bank of Ukraine (2018). Inflation Report, January 2018. Retrieved from https://bank.gov.ua/doccatalog/document?id=63442011

National Bank of Ukraine (2019a). Inflation Report, April 2019. Retrieved from https://bank.gov.ua/doccatalog/document?id=93772770

National Bank of Ukraine (2019b). Inflation Report, July 2019. Retrieved from https://bank.gov.ua/admin_uploads/article/IR_2019-07_eng.pdf

Petryk, O., Nikolaychuk, S. (2006). Structural model of monetary policy transmission mechanism in Ukraine (in Ukrainian). Visnyk of the National Bank of Ukraine, 3, 19-20. Retrieved from https://old.bank.gov.ua/doccatalog/document?id=42102

Petryk, O., Nikolaychuk, S. (2007). Determination of the optimal inflation rate for Ukraine (in Ukrainian). Visnyk of the National Bank of Ukraine, 6, 10-22. Retrieved from https://old.bank.gov.ua/doccatalog/document?id=46277

Tvalodze, S., Mkhatrishvili, S., Mdivnishvili, T., Tutberidze, D., Zedginidze, Z. (2016). The National Bank of Georgia's Forecasting and Policy Analysis System. National Bank of Georgia. Retrieved from https://www.nbg.gov.ge/uploads/publications/fpas/FPAS%20Documentation.pdf

Vdovychenko, A. (2018a). How does fiscal policy affect GDP and inflation in Ukraine? Visnyk of the National Bank of Ukraine, 244, 25-43. https://doi.org/10.26531/vnbu2018.244.02

Vdovychenko, A. (2018b). Estimating the fiscal impulse in Ukraine. Visnyk of the National Bank of Ukraine, 245, 45-63. https://doi.org/10.26531/vnbu2018.245.03

Zholud, O., Lepushynskyi, V., Nikolaychuk, S. (2019). The Effectiveness of the monetary transmission mechanism in Ukraine since the transition to inflation targeting. Visnyk of the National Bank of Ukraine, 247, 19-37. https://doi.org/10.26531/vnbu2019.247.02

## Appendix 1. Raw data description

**Table 8.** Raw data description

| Variable | Raw Units | Note | Model transformations | Source |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |
| Real GDP | UAH millions in 2010 prices | Gross Domestic Product of Ukraine at constant prices. | ln*100 | State Statistic Service of Ukraine (SSSU) |
| Agriculture shocks | UAH millions in 2010 prices | Agriculture value added | – ln*100<br>– HP filter to decompose the time series on gap and trend[20] | SSSU |
| Unemployment | % of economically active population aged 15-70 | Unemployed as a share of the labor force based on International Labor Organization methodology | Seasonal adjustment by X13-ARIMA-SEATS | SSSU |
| Nominal wage | UAH | Monthly data on average wage of staff employees | – Seasonal adjustment by X13-ARIMA-SEATS<br>– Aggregation to quarterly frequency by computing the mean<br>– ln*100 | SSSU |
| Headline CPI | Index | Monthly data on Consumer Price Index (CPI), | – Seasonal adjustment by X13-ARIMA-SEATS<br>– ln*100<br>– Aggregation to quarterly frequency by computing the mean | SSSU |
| Core CPI | Index | Monthly data on core prices index | – Seasonal adjustment by X13-ARIMA-SEATS<br>– ln*100<br>– Aggregation to quarterly frequency by computing the mean | SSSU, NBU calculations |
| Food CPI | Index | Monthly data on food prices | – Seasonal adjustment by X13-ARIMA-SEATS<br>– ln*100<br>– Aggregation to quarterly frequency by computing the mean | SSSU, NBU calculations |
| Administratively regulated CPI | Index | Monthly data on administrative prices | – ln*100<br>– Aggregation to quarterly frequency by computing the mean | SSSU, NBU calculations |
| Fuel CPI | Index | Monthly data on fuel prices | – ln*100<br>– Aggregation to quarterly frequency by computing the mean | SSSU, NBU calculations |

[20] Transformations are applied in the order as they appear in the list.

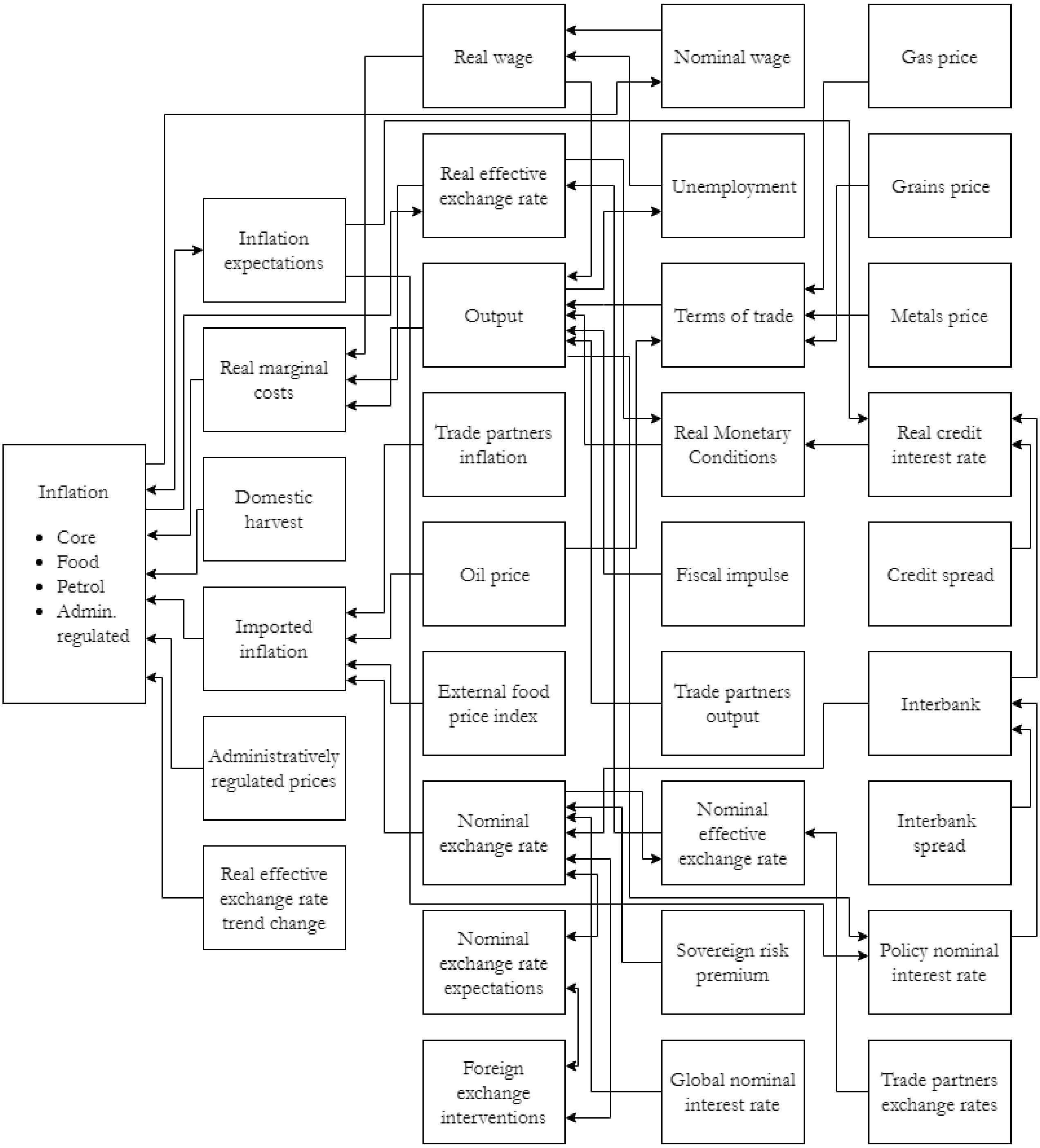
| 1 | 2 | 3 | 4 | *5* |
|---|---|---|---|---|
| Inflation target | %, y-o-y | Official target of the NBU | | NBU |
| Fiscal impulse | % of potential GDP | Changes in structural deficit, computed based on Vdovychenko (2018b). | | *SSSU, State Treasury Service of Ukraine, NBU calculations* |
| NBU policy rate | %, p.a. | Monthly data on Interest rates on two-week deposit certificates and (since 2019) also refinance activities. | Aggregation to quarterly frequency by computing the mean | *NBU* |
| Interbank rate | %, p.a. | Monthly data on weighted average of interbank interest rates for credits without overdrafts. | Aggregation to quarterly frequency by computing the mean | *NBU* |
| Credit rate | %, p.a. | Monthly data on weighted average of interest rates for credits to non-financial corporations without overdrafts | Aggregation to quarterly frequency by computing the mean | *NBU* |
| Terms of trade, incl.: | Index | Weighted average of prices of exported (metals and wheat) and imported goods (oil and natural gas with minus sign) | ln*100 | *Thomson Reuters Datastream* |
| • *Export steel price* | US dollars per ton | Volume weighted average export price for 4 basic groups of ferrous metals | ln*100 | *Thomson Reuters Datastream* |
| • *Export wheat price* | US dollars per ton | Volume weighted average export price for cereals | ln*100 | *Thomson Reuters Datastream* |
| • *Brent oil price* | US dollars per barrel | Brent crude oil price | ln*100 | *Thomson Reuters Datastream* |
| • *Natural gas price* | US dollars per cubic meter | Volume weighted average import price for natural gas | ln*100 | *Thomson Reuters Datastream* |
| Food price | Index | Food and Agriculture Organization (FAO) price index | ln*100 | *FAO* |
| Foreign interest rate | %, p.a. | One-month LIBOR rate | | *Thomson Reuters Datastream* |

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| World demand gap | Index | Real GDP of main trading partners | – ln*100<br>– HP filter to decompose the time series on gap and trend | *national statistical offices, NBU calculations* |
| World natural rate of interest | % | Estimates of Federal Reserve Bank of New York based on Laubach and Williams (2003) methodology | | *New-York FED*[21] |
| World inflation, incl.: | Index | Weighted by import shares inflation in main trading partners, expressed in US dollar terms. | ln*100 | *IMF (IFS)* |
| • *US CPI* | Index | CPI urban consumers of the US | ln*100 | *IMF (IFS)* |
| • *EU CPI* | Index | Harmonized Index of Consumer Prices of EU | ln*100 | *IMF (IFS)* |
| • *RU CPI* | Index | CPI of Russian Federation (as a proxy for CIS trade partners) | ln*100 | *IMF (IFS)* |
| • *UAH/USD exchange rate* | UAH | Official bilateral nominal exchange rate UAH per USD. | ln*100 | *NBU* |
| • *RUR/USD exchange rate* | Rubles | Bilateral nominal exchange rate RUR per USD. | ln*100 | *NBU* |
| • *USD/EUR exchange rate* | US dollars | Bilateral nominal exchange rate USD per EUR. | ln*100 | *NBU* |
| Risk premium | % | Spread between yield to maturity of Ukrainian Eurobonds and 10Y US Treasuries | | *cbonds.com* |

[21] Link to the estimates: https://www.newyorkfed.org/research/policy/rstar

## Appendix 2

## Detailed model structure



## Appendix 3

## Impulse response functions of the QPM

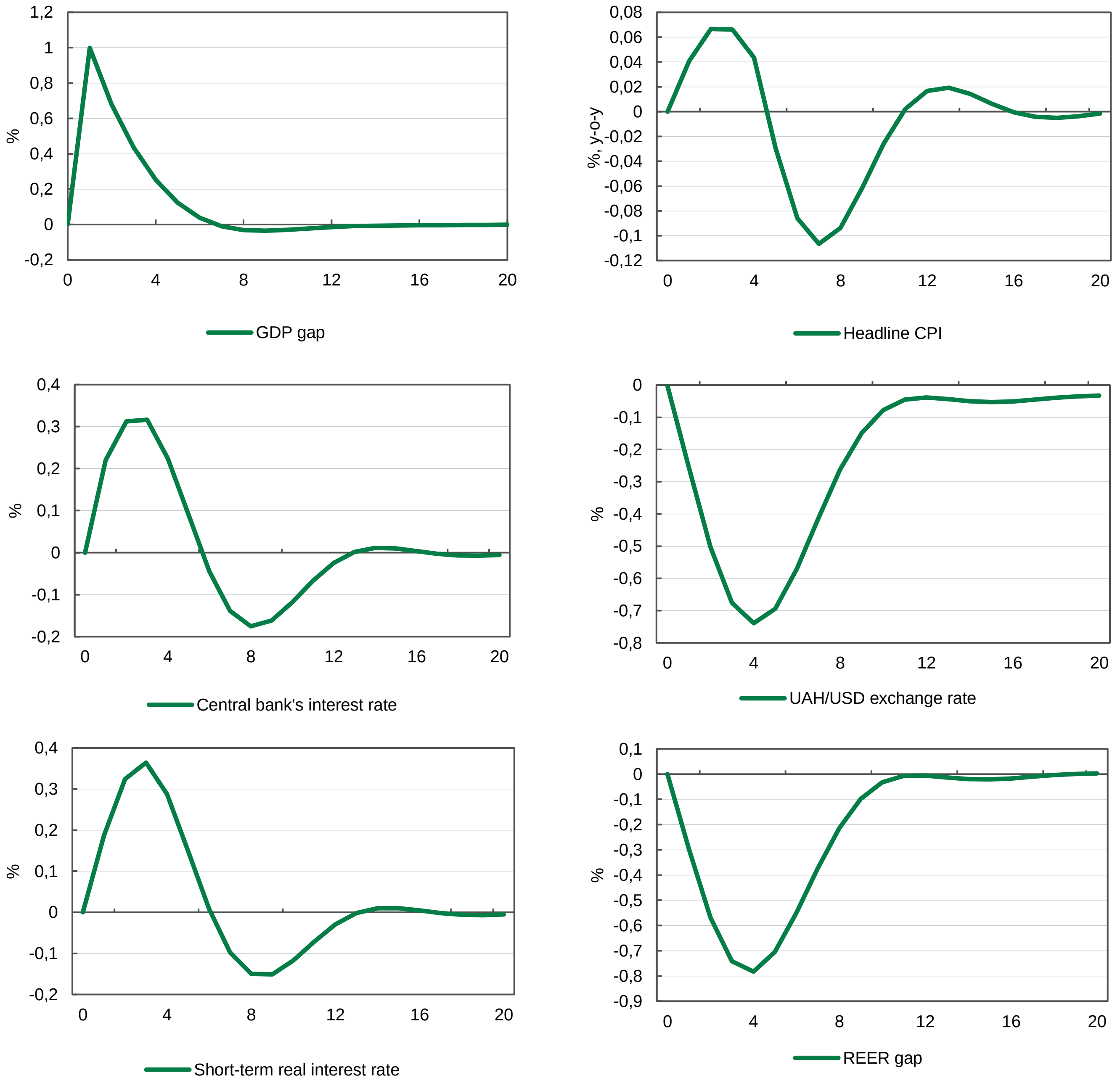



**Figure 10.** IRFs to demand shock.

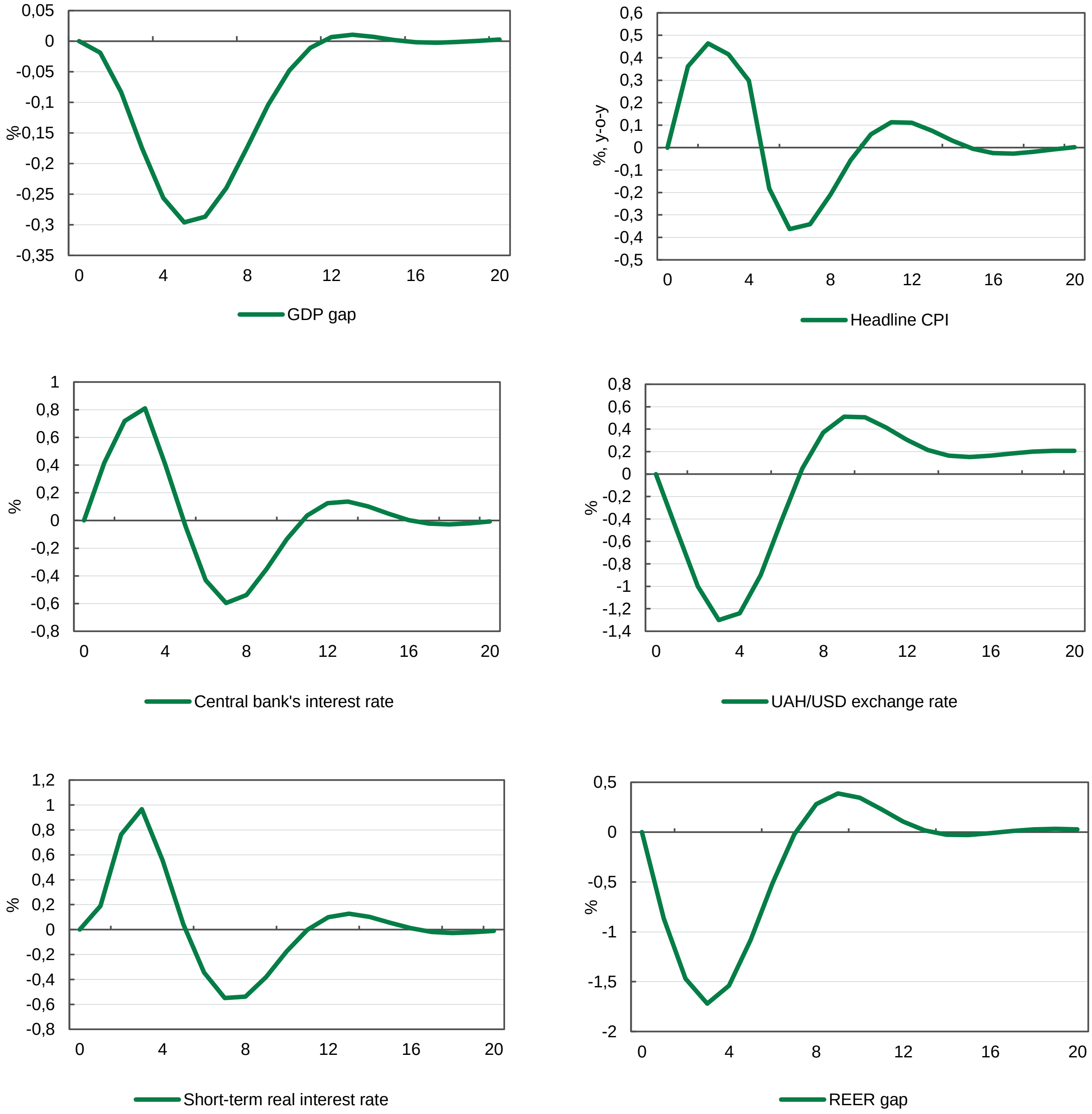



**Figure 11.** IRFs to supply shock.

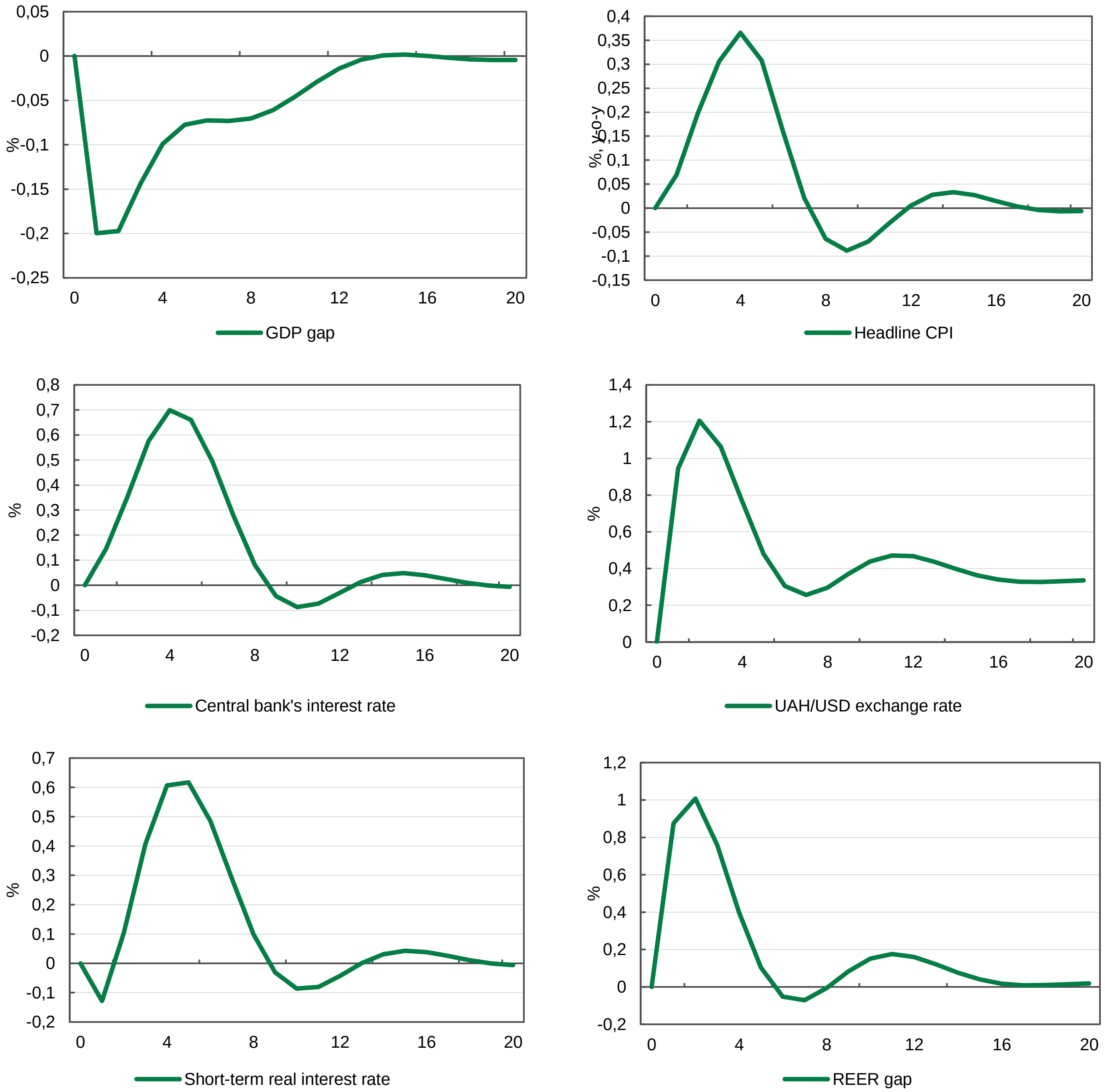



**Figure 12.** IRFs to risk premium shock.

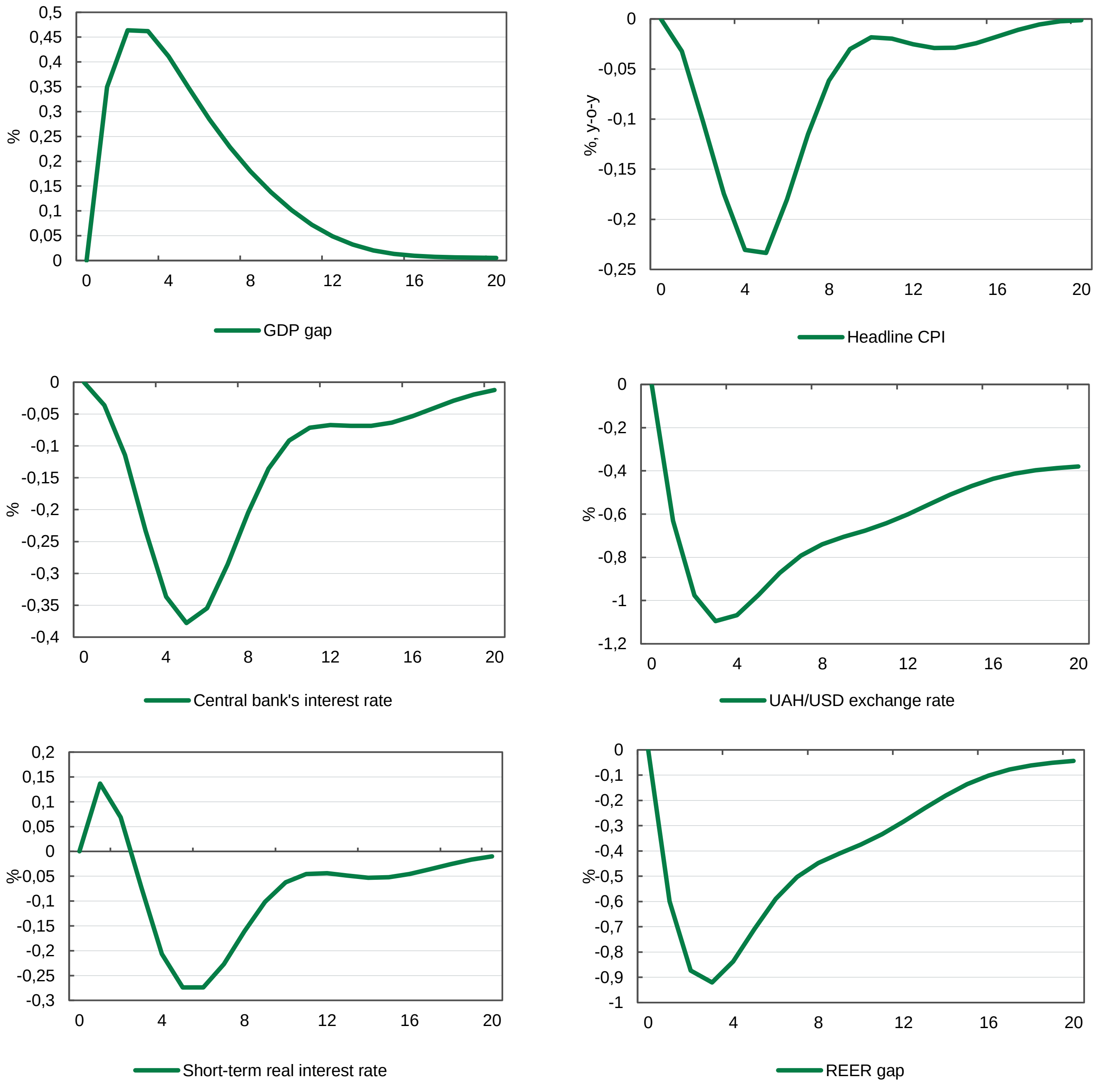



**Figure 13.** IRFs to terms of trade shock.

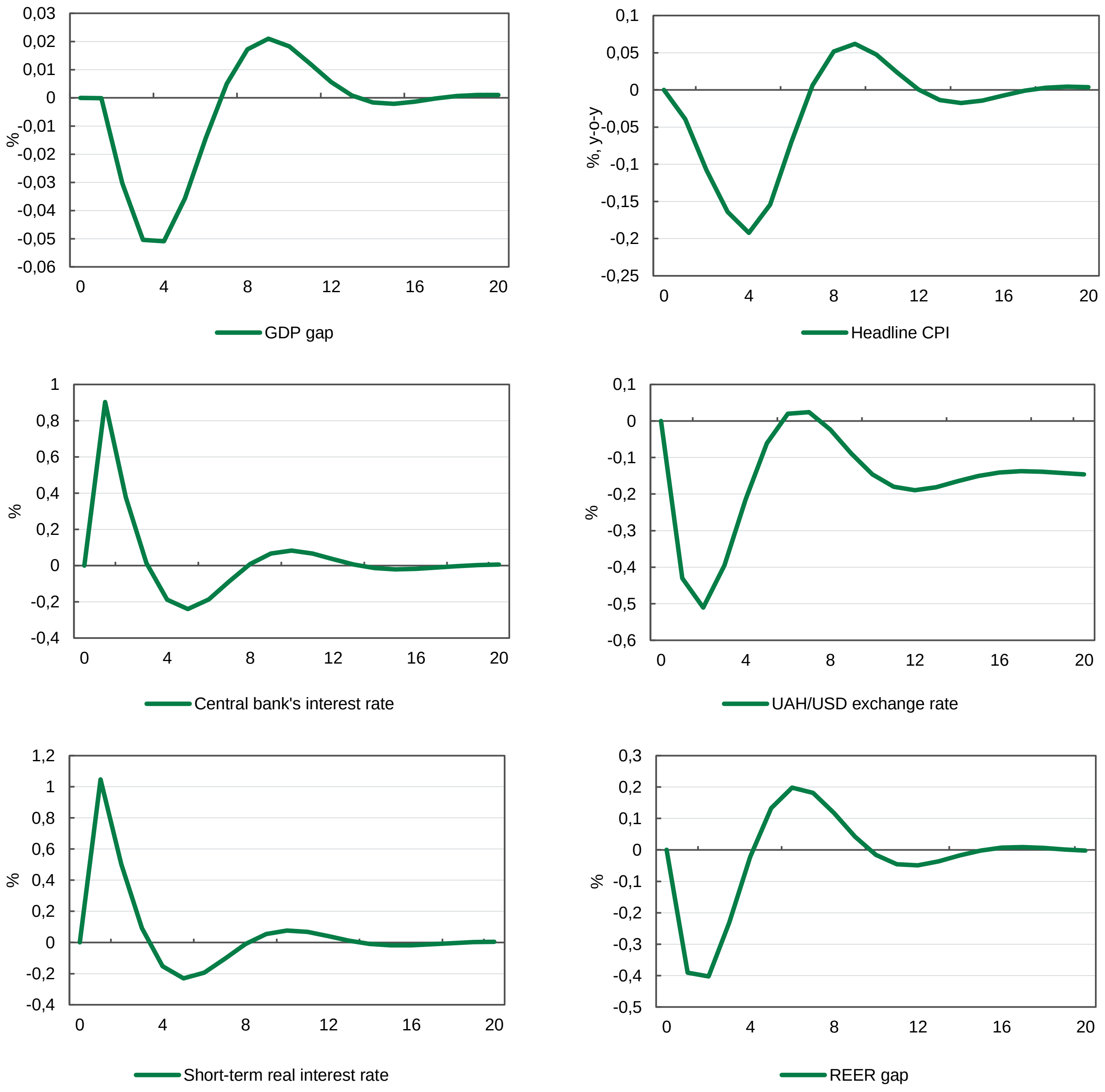



**Figure 14.** IRFs to monetary policy shock.

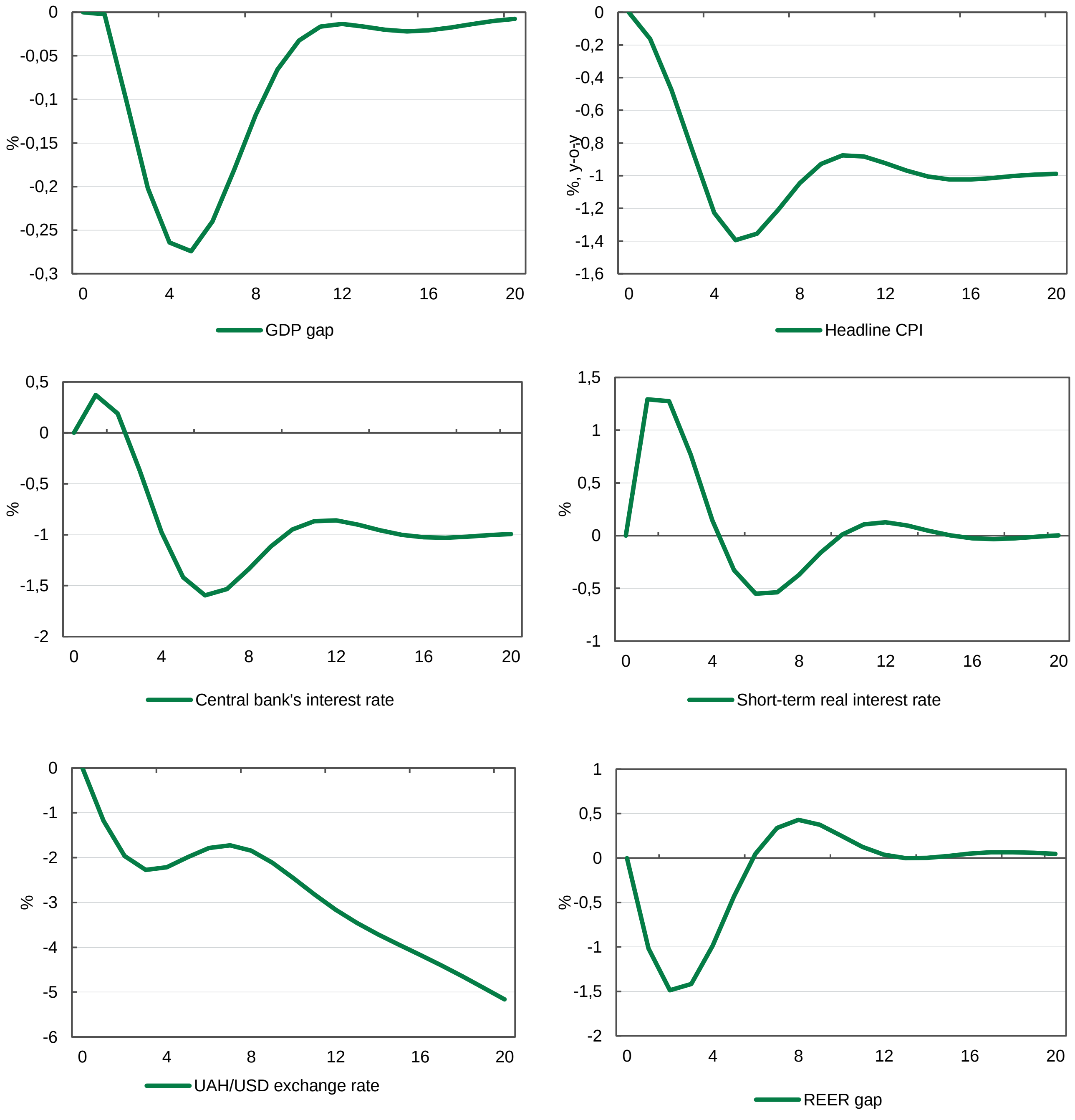



**Figure 15.** IRFs to disinflation shock.