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Uncovered interest parity with foreign exchange interventions under exchange rate peg and inflation targeting: The case of Ukraine

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Abstract

In this study, I modify the uncovered interest parity condition to account for foreign exchange interventions in the context of a small open economy. This is done in a framework of a semi-structural New Keynesian model. I examine the case of Ukraine, which de facto transitioned to inflation targeting with a managed float in 2015 after a long period of pegged exchange rate. I simulate model-consistent foreign exchange interventions and use them to quantify the effectiveness of those actually observed. The proposed modification is relevant for inflation targeting regimes with foreign exchange interventions as an additional instrument and those in transition.

JEL Codes: E12, E17, E52, F31

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1. Introduction

In 2008:Q4–2014, the National Bank of Ukraine (NBU) was spending on average 5.1% of GDP worth of international reserves every year in order to support the fixed exchange rate regime. It was buying back 1.7% of GDP each year in 2015–2020:Q1 under inflation targeting. Can we really hope to build a macroeconomic model capable of policy advice without foreign exchange interventions? According to Beneš et al. (2015), this is what most central banks do.

Central banks may engage into exchange rate management for a number of reasons. For example, small open emerging market economies have shallow financial markets and great exposure to external shocks. In addition, in the case of high dollarization, the exchange rate can become a shock multiplier. This makes it worthwhile to stabilize exchange rate and use foreign exchange (FX) interventions as a policy tool. Many monetary authorities under inflation targeting (IT) at least informally attempt to control both inflation and the exchange rate with two instruments – the interest rate and FX interventions. Consequently, they require a proper macroeconomic model that describes a monetary policy transmission mechanism and accounts for both instruments.

This paper modifies the uncovered interest parity (UIP) condition in order to model the exchange rate when managed by a central bank. The bank in this case also aims to stabilize inflation and maintain some control over market interest rates. In this regard, the proposed study closely relates to Beneš et al. (2008). However, I apply the model to Ukrainian data to simulate model-consistent FX interventions. For many years until 2014, the National Bank of Ukraine was following a fixed exchange rate regime, while also aiming to transition to IT. Since 2015, it has followed IT while maintaining a managed floating. The proposed framework is applied to both the pre- and post-IT policy regimes.

In this paper, I present a semi-structural model of a small open economy, which features UIP with FX interventions and can be used for policy analysis. Simulated interventions turn out to be highly correlated with the actual ones conducted by the NBU. The former is further used to quantify the effectiveness of the latter.

The rest of the paper is structured as follows. The next section reviews literature on FX interventions and modeling exchange rates with UIP. Section 3 presents the Ukrainian historical background and a triple crisis in 2014–2015. Sections 4 and 5 outline the proposed model's main equations and Bayesian estimations of its parameters respectively. Section 6 discusses the model properties and

Section 7 offers results. Finally, the last section concludes with a discussion of the policy implications and avenues for future research.

2. Literature review

2.1 Literature on foreign exchange interventions

In the aftermath of the Global Financial Crisis of 2007–2009, emerging market economies (EMEs) have increasingly focused on maintaining domestic price and financial stability (BIS, 2019). Many adopted inflation targeting (IT), while also engaging in various degrees of foreign exchange (FX) interventions. The latter are carried out to cushion relatively underdeveloped domestic financial markets against erratic foreign capital movements and related exchange rate fluctuations. Improved domestic macroeconomic stability and low interest rates in developed markets both contributed to net capital inflows (including direct, portfolio and other investments) into EMEs. Their international reserves are consequently increasing. At least, this was the situation before the global COVID-19 pandemic outbreak in early 2020, which triggered capital outflows from the EMEs. Fortunately, accumulated reserves help soften the blow.

Active FX interventions in EMEs are needed to reduce exchange rate volatility, while high reserves may ease possible capital outflows and consequent depreciations (Cavallino, 2019). Normally, flexible exchange rates facilitate necessary real price adjustments in the case of changed external conditions. However, unstable capital flows may cause inefficient exchange rate fluctuations, which are a source of economic disruption, rather than a cure. With a view to stabilizing prices, many IT central banks choose to “lean against the wind” and complement policy interest rate adjustments with FX interventions.

Relatively shallow FX markets with limited volumes of trade increase EMEs' vulnerability to shifts in foreign investors' sentiments. Abrupt exchange rate movements may disrupt macroeconomic stability, as they are passed-through to inflation, affect net export and shape domestic financial conditions. First, EMEs generally import many consumer goods, thus the exchange rate pass-through to inflation is high. Moreover, second-round effects further magnify its impact if inflation expectations are not well anchored.

Second, foreign trade in EMEs is mostly invoiced in foreign currency. Imports do adjust to exchange rate fluctuations, but their effect on the volumes of exports is weak, at least in the short term. Finally, domestic borrowers often rely on borrowing in foreign currency. Furthermore, foreign investors may hold large amounts of domestic assets, including government debt. These factors amplify the financial channel of the exchange rate. For example, appreciation would counteract the effects of tight monetary policy as it improves financial conditions and stimulates domestic demand.

Higher exchange rate pass-through, combined with its weakened effect on net exports and the potent financial channel described above, makes output and inflation less synchronized, thus making it more difficult to stabilize the economy with the interest rate alone. This creates room for FX interventions as a complementary policy instrument able to affect exchange rates directly. Ghosh et al. (2016) regard EMEs as having two instruments – the interest rate and FX interventions. The former is used to deal with lasting economic shocks, while the latter better suits temporary disruptions.

FX interventions can be conducted to counteract the domestic consequences of capital flows and exchange rate fluctuations. In extreme cases, "technical" interventions can even be necessary to sustain market liquidity. With insufficient volumes of trade, an intervening central bank can act as a market maker of last resort. According to Aizenman and Riera-Crichton (2008), FX interventions can cushion the impact of external shocks on the real exchange rate. The effect is important for developing countries and especially for commodity exporters.

Accumulated international reserves provide self-insurance against so-called “sudden stops” – quick reversals of international capital flows. In crisis episodes, FX reserve buffers may mitigate financial stress and moderate currency depreciation. During continuous foreign capital inflows, FX purchases not only absorb appreciation pressures, but also reduce the risk, or at least the magnitude, of a possible reversal.

FX interventions cannot induce a permanent change in the exchange rate if they are inconsistent with other macroeconomic policies. Kriljenko (2003) argues that interventions should only address exchange rate movements caused by temporary shocks. Heavy interventions may provoke a carry trade, which reduces their effectiveness. Persistent currency misalignments raise uncertainty about monetary policy goals and contradict the philosophy of IT. These factors damage policy credibility and investor confidence.

Earlier research into the effectiveness of FX interventions provided evidence in favor of the greater importance of non-sterilized interventions in comparison to sterilized ones, i.e., those that keep market interest rates unchanged (Geršl and Holub, 2006). The research was based on major floating currencies (US dollar, Deutsche mark, and Japanese yen). However, empirical results were often inconclusive (Schwartz, 2000).

Recent research includes EMEs and demonstrates that sterilized interventions can successfully affect the exchange rate. The rationale is grounded in two key channels – portfolio and signaling (Ribon, 2017). According to the former, interventions change the relative supply of foreign and domestic assets in the economy: Since these are not perfect substitutes, the exchange rate adjusts to restore market equilibrium. The latter states that interventions signal the central bank's objectives and indicate the future monetary policy stance. As a result, the shifted expectations generate actual exchange rate movements.

It is difficult, yet important, to evaluate the effectiveness of FX interventions. They influence the exchange rate, but the decision to intervene itself depends on the behavior of the same exchange rate. This creates an endogeneity bias, which there are several approaches to overcome. Adler and Tovar (2014) and Ribon (2017) use a two-stage estimation approach with instrumental variables. Results for a panel of mostly EMEs and Israel show that FX purchases are effective in slowing down the pace of exchange rate appreciation. The panel data results also demonstrate that the effect is bigger if the capital account is more closed. Humala and Rodrígues (2009) build Markov switching autoregressive (AR) and vector autoregressive (VAR) models to reveal that interventions are consistent with reducing exchange rate volatility. Kuersteiner et al. (2018) identify deviations of sterilized FX interventions from a preannounced rule and estimate their short-term effects on the exchange rate in Colombia.

The effectiveness of FX interventions may differ due to heterogeneous institutional circumstances (Menkoff, 2013). Among the latter are macroeconomic situation, capital controls and central bank communication. Moreover, the effect is found to be generally higher in EMEs, where central banks are relatively bigger market players.

Institutional credibility is an important determinant of the effectiveness of FX interventions. Alichi et al. (2015) describe how the Czech National Bank applied an exchange rate floor as a complementary policy tool under IT. This was done to reduce deflation risks when the interest rate approached the Zero Lower Bound. The authors assess that the strategy worked because of high central bank's credibility. Initial FX interventions were limited. The exchange rate jumped immediately after the strategy was announced, even before actual interventions.

2.2 Literature on modeling exchange rate with uncovered interest parity

Many central banks and international institutions around the world use semi-structural New Keynesian models for regular macroeconomic forecasting and policy analysis (e.g. Beneš et al., 2017). These models are reduced-form representations of Dynamic Stochastic General Equilibrium (DSGE) models augmented with data-driven extensions. While they lack rigorous microfoundations, they are however flexible and easy to operate. New Keynesian models are designed to reflect the current understanding of the monetary policy transmission mechanism and to support consistent policy decisions. Such characteristics make them essential for a typically diverse set of tasks at a central bank.

A standard New Keynesian model explains exchange rate dynamics with an Uncovered Interest Parity (UIP) condition. A version that is adjusted for the sovereign risk premium is shown in the following equation:

$$s_t = s_{t+1} - \frac{i_t - i_t^* - prem_t}{4} + \varepsilon_t$$

Under UIP, the spot exchange rate (s_t) *immediately* appreciates if the risk-adjusted differential between yields on domestic and foreign assets ($\frac{i_t - i_t^* - prem_t}{4}$) is higher than the expected depreciation ($s_{t+1} - s_t$)[2]. It depreciates in the opposite situation. The exchange rate under UIP is a notably forward-looking variable, as it adjusts to the sum of all expected future short-term interest rate differentials.

It is difficult to achieve reasonable impulse response functions in a model with pure UIP, because the exchange rate becomes too volatile (Beneš et al., 2008). Such model properties are inconsistent with stylized facts about much smoother exchange rate movements. These facts complicate the interpretation of economic shocks and reduce usefulness of the model for policy analysis.

Poor performance of UIP in structural models is consonant with its frequent failure in empirical tests. Fama regressions (Fama, 1984) mostly reject the condition on short horizons (up to one year). This result holds for developed and developing countries alike (Aslan and Korap, 2010; Karahan and Çolak, 2012).

Explaining systematic biases in exchange rate expectations is key to reconciling the evidence with the theory (Engel et al., 2007). The literature has come up with several hypotheses. One of the most prominent explanations is that the majority of countries do not work with purely floating exchange rates (Sachsida et al., 2001). UIP is distorted as endogenous monetary policy reactions counteract stochastic foreign exchange market shocks.

[2] Yields are annualized, thus division by four.

Evidence is much more favorable for UIP on longer horizons (Isard, 2006; Jiang et al., 2013). Chinn and Meredith (2004) argue that short-term exchange rate movements are influenced by the "leaning against the wind" policy of a monetary authority, as it reacts to market distortions. Among the latter are shocks to the risk premium and deviations from rational expectations. Instead, over the long term, the fundamental dynamics dominate and UIP performs better.

The exchange rate channel is generally strong in EMEs. Its proper representation is thus crucial for successful use of any model. UIP is often modified by combining model-consistent expectations with backward-looking ones. This reduces the immediate sensitivity of the exchange rate to expected interest rate differentials and makes it more persistent.

Beneš et al. (2008) introduce expectations that are consistent with relative Purchasing Power Parity, if adjusted for real exchange rate trends. In this paradigm, higher inflation leads to a weaker exchange rate. Suggested expectations are myopic in the short term, but converge to the rational ones in the long term.

According to Beneš et al. (2015), common modeling approaches at IT central banks do not capture the practice of FX interventions. Unlike for "pure" IT with one policy instrument, an analytical framework for a so-called hybrid regime is yet to be established. The authors propose constructing a microfounded model that features the portfolio balance effects of interventions.

Several studies have explored ways to integrate FX interventions into reduced-form New Keynesian models. Beneš et al. (2008) interpret a higher weight of myopic expectations in UIP as signifying more active exchange rate management by a central bank. The authors also simulate how much intervention (expressed in the interest rate equivalent) is needed to violate UIP in the short term and limit exchange rate fluctuations. Grui and Lepushynskyi (2016) analyze impulse response functions with various degrees of exchange rate smoothing and conclude that applying FX interventions can help reduce inflation volatility for some economic shocks, but not in the case of the others.

3. Ukrainian historical background

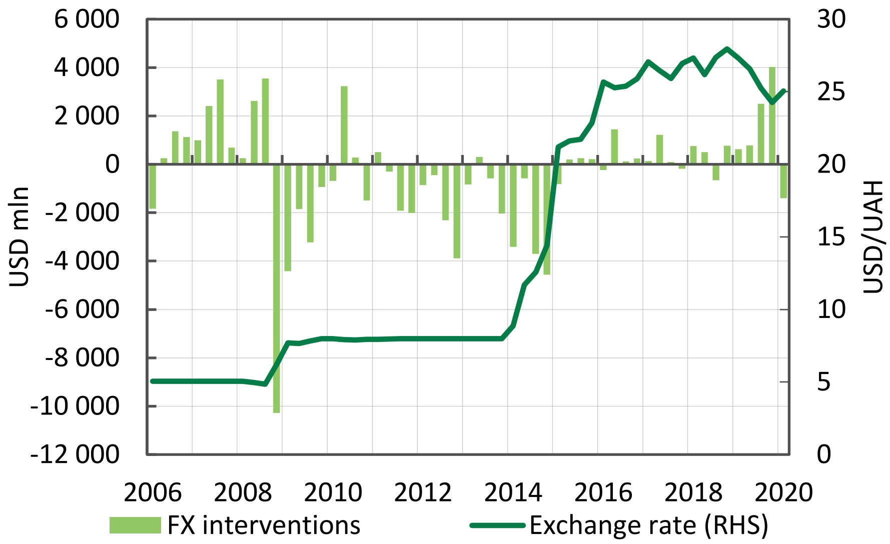
Monetary policy in Ukraine abandoned the fixed exchange rate regime and de facto adopted inflation targeting in 2015. FX interventions used to be the main policy tool aimed at keeping nominal Ukrainian hryvnia (UAH)/United States dollar (USD) exchange rate fixed (Figure 1). Interventions were absorbing all economic shocks, adverse and favorable alike. Until 2008:Q3, FX interventions were positive, thus the exchange rate was protected against appreciation. However, the global financial crisis brought a major depreciation. Maintaining the fixed exchange rate in 2009–2014 required massive foreign currency sales.

Since 2015, the nominal exchange rate has followed a managed float. FX interventions have been mostly positive and of comparatively low magnitude. They are used as an additional monetary policy instrument with a view to smooth exchange rate volatility and accumulate international reserves. The NBU does not aim to achieve any predetermined level of the exchange rate.

In 2019, Ukraine experienced an influx of foreign capital into domestic government debt securities denominated in hryvnia. The surplus of foreign currency was mostly bought by the NBU. Yet, the nominal exchange rate considerably appreciated. In contrast, the exchange rate depreciated in 2020:Q1 amid coronavirus fears. This depreciation was softened by interventions.

The proposed model features two policy regimes for the fixed exchange rate and inflation targeting periods. Coefficients of the model differ (and are estimated separately) on respective horizons. Furthermore, the same amount of FX interventions can have different effects on the exchange rate on the two historical periods due to the changed policy regime and other institutional circumstances.

Figure 1. Foreign exchange interventions and exchange rate



Source: National Bank of Ukraine.

Note: negative FX interventions mean that foreign currency was sold by the NBU on the market.

In 2014–2015 Ukraine went through a "perfect storm". First, a macroeconomic crisis was fueled by Russian military aggression. Exports declined and the economy fell into a recession. Second, lower exports, challenges to state sovereignty, and a public finance deficit created a currency crisis. Low confidence in the hryvnia exacerbated the devaluation that led to an inflation outbreak. Third, the panicked withdrawal of bank deposits coincided with an increase in arrears. This exposed the corrupt corporate management of many banks, triggering a banking crisis and stopping further lending to the economy. The three components of the crisis intensified each other.

In 2016–2019, the economy was recovering. The banking system was cleaned and lending was slowly resuming. Output was steadily growing, but the risks associated with the escalation of the military conflict remain[3].

Monetary policy focused on controlling market interest rates as of 2015. Under IT, the short-term interest rate turned into the main policy instrument. At the key policy rate, the NBU carries out transactions that most affect the price of funds in the interbank market[4], which the market interest rates follow closely.

The interbank interest rate became an operational target of monetary policy. It used to be highly volatile under unsterilized FX interventions before 2015. However, its volatility greatly decreased as the rate became tightly linked to the key policy rate (Figure 2). Similar results apply to other market interest rates, namely those of domestic government debt securities, credits and deposits of non-financial corporations, and deposits of households. These started to correlate with the policy interest rate[5].

I account for the policy regime switch with changes in several model parameters, which reflect the willingness of the NBU to intervene on the FX market and its preferences in the interest rate reaction function.

In July 2019, the NBU became the eighth IT central bank to start publishing its projected policy interest rate trajectory in its *Inflation Reports*[6]. The move augmented verbal forward guidance and was meant to improve policy control over longer-term market interest rates. It is not explicitly modeled, however, its effectiveness might become a good research question.

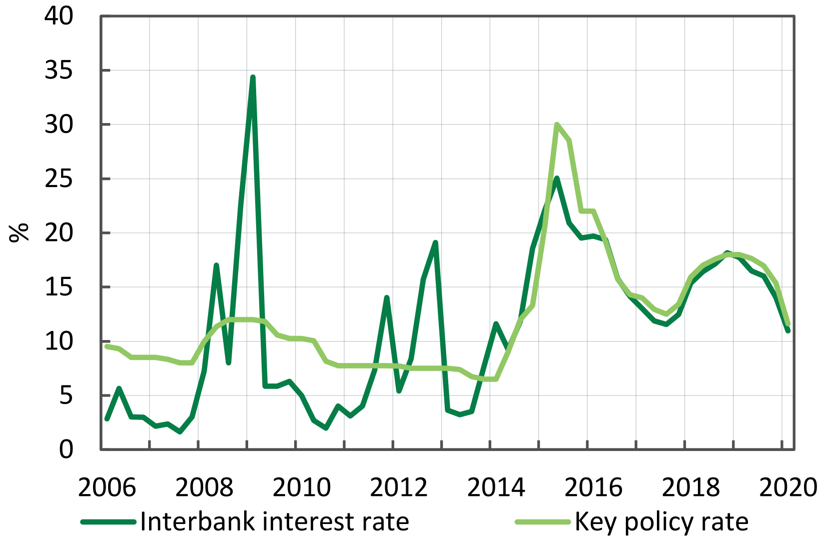
[3] The NBU publishes *Inflation Reports* and *Financial Stability Reports*, where more details are available.

[4] As of 2019, the NBU both absorbed and provided liquidity to the banking system for a period of two weeks. It used to only absorb liquidity at the beginning of IT.

[5] Zholud et al. (2019) provide an overview of the monetary policy transmission in Ukraine.

[6] The other seven IT central banks are the National Bank of Georgia, the Reserve Bank of New Zealand, Norges Bank, the Bank of Israel, the Central Bank of Iceland, Czech National Bank, and Sveriges Riksbank

Figure 2. Interbank and key policy interest rates



Source: National Bank of Ukraine.

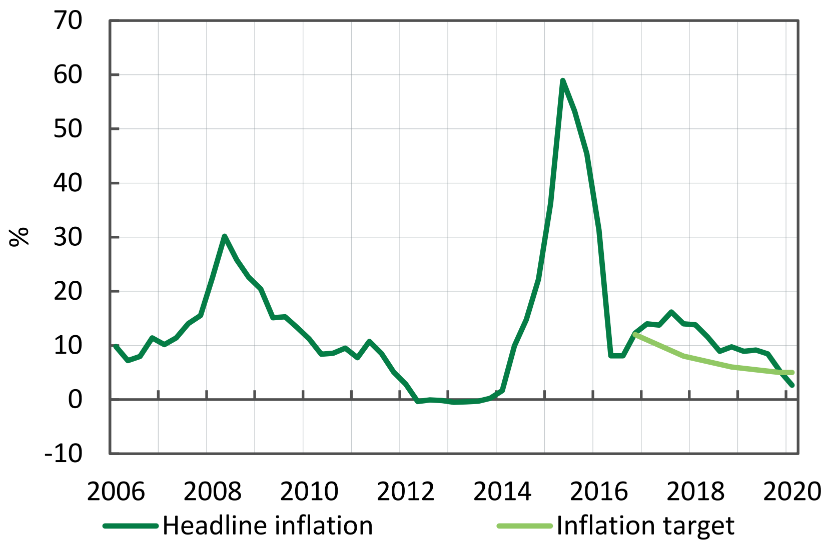
Monetary policy pursued a disinflation agenda in 2016–2019 with a medium-term target of 5%. The targets descended from 12±3% to 5±1% (Figure 3). The disinflation was gradual, which was meant to minimize the negative consequences for economic growth. It also accounted for the need to adjust administratively-regulated prices to market-justified levels.

The medium-term inflation target in Ukraine is above usual values for developed inflation targeters. First, this is linked to historically high and volatile inflation, as well as initially low monetary policy credibility. Higher inflation goals are easier to achieve with a view to enhance credibility and anchor inflation expectations. Second, due to the Balassa-Samuelson effect, it is optimal for EMEs to have higher inflation rates, as they grow and increase their productivity. Finally, higher inflation is consistent with higher domestic nominal interest rates. In case of headwinds, this allows monetary policy more room to stimulate economy without hitting the zero lower bound.

The adoption of IT helped stabilize the Ukrainian economy. Inflation used to be volatile in the past. However, it became much less so since 2016. The same is also true for output growth.

The inflation target variable in the model follows official targets in 2016–2020:Q1. However, there were no official targets on the preceding horizon. While estimating the model coefficients, I approximate historical inflation targets with a Hodrick-Prescott (HP) filter.

Figure 3. Annual inflation and inflation target



Source: National Bank of Ukraine.

Ukraine is exposed to fluctuations in global investor sentiments. The economy relies on external sources of funding, the cost of which may grow with the sovereign risk premium. The latter is measured as a spread between the average yield of Ukrainian Eurobonds in US dollars and the yield of 10-year US Treasury bonds (dubbed as a risk free instrument). The premium peaked in early 2009 amid the global financial crisis and then in the first half of 2015 during the domestic triple crisis (Figure 4).

Investor sentiments affect the nominal exchange rate and real output through two channels. First, according to the UIP condition, an increased risk premium leads to depreciation. Second, an increased cost of funding depresses spending and slows down output growth. The effect might be particularly strong in a country with dollarized liabilities. This channel dominates over the positive effects that are brought to external trade by depreciation.

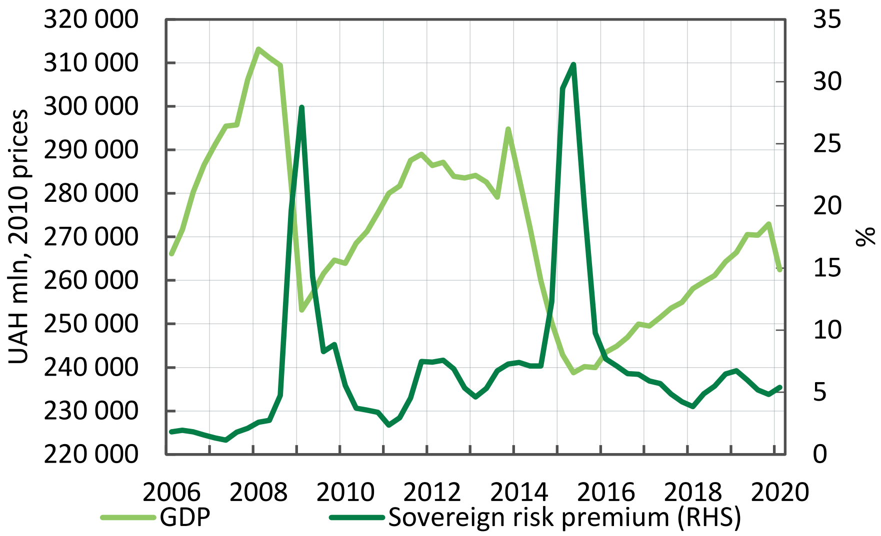
Furthermore, investor sentiments affect the neutral interest rate, which has implications for the monetary policy stance[7]. As the supply of funds for a small open economy is perfectly elastic, the equilibrium price of capital is given by its global counterpart adjusted by the country's fundamentals, such as the sovereign risk premium. During the crisis periods in Ukraine, the worsened perception of foreign investors used to increase the neutral interest rate, which made monetary policy stance more accommodative and handicapped its ability to tame inflation[8].

[7] If policy interest rate is at its neutral level, monetary policy is neither restrictive nor accommodative.
[8] Discussion on the methodology and estimates for Ukraine can be found in Grui et al. (2018).

The risk premium is present in equations for the nominal exchange rate, the output and the neutral interest rate.

Investor sentiments in Ukraine tend to improve with growing international reserves and vice versa. This might serve as an incentive for their accumulation. However, modeling the relationship between international reserves and the sovereign risk premium remains beyond the scope of this paper, but could become a good question for further research.

Figure 4. GDP and sovereign risk premium



Source: National Bank of Ukraine.

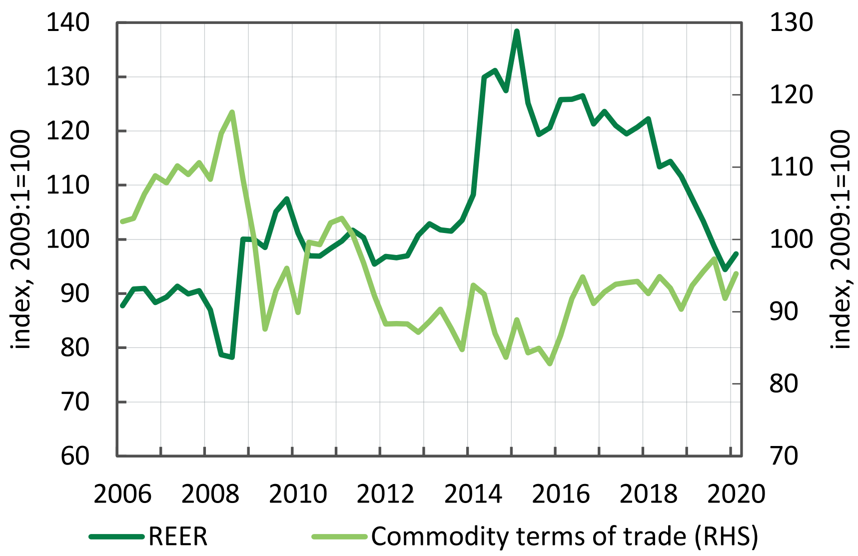
Global commodity prices are important for Ukraine. The economy is quite open as the ratio of imports and exports to GDP averaged close to 90% in the last decade. Furthermore, around 43% of the foreign trade is in commodities. Prices on global markets affect the currency valuation and the output growth.

The commodity terms of trade indicator for Ukraine comprises prices for the main traded commodities. Among the exported ones are mostly base metals and agricultural products; among imports, oil products and natural gas.

The indicator seems to correlate with the real exchange rate, FX interventions and the output growth in Ukraine. For example, favorable terms of trade in 2006–2008 were the major cause of real appreciation (Figure 5), positive FX interventions (Figure 1) and economic expansion (Figure 4). However, their deterioration after the global financial crisis contributed to both depreciation and recession.

In the proposed model, I use commodity terms of trade to help explain fluctuations of the nominal exchange rate and output.

Figure 5. Commodity terms of trade and the real effective exchange rate (REER)



Source: National Bank of Ukraine.

4. Main equations

This section presents a semi-structural forward-looking New-Keynesian model of a small open economy. It focuses on monetary policy transmission mechanism. The NBU employs a similar though more complex model for regular forecasting and policy analysis, which is presented in Grui and Vdovychenko (2019). Similar models are widely used by many central banks and international institutions around the world.[9]

The monetary policy in this model affects real variables only in the short to medium term. In the long term, variables are modeled to converge to their sustainable natural levels, e.g. potential output and equilibrium real exchange rate. The natural levels are approximated with trends that are estimated by the Kalman filter. Percentage deviations from trends are called gaps.

[9] 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.

4.1 Open economy IS curve

$$\hat{y}_t = \alpha_1\hat{y}_{t-1} + \beta_1\left(\gamma_1\left(-\widehat{lr}_t\right) + (1-\gamma_1)\hat{z}_t\right) + \delta_1\hat{y}_t^* + \theta_1\widehat{tot}_t - \mu_1\widehat{prem}_t + \varepsilon_{1,t} \qquad (1)$$

Equation (1) outlines the behavior of aggregate demand. It models output gap ($\hat{y}_t$) in a form of an open-economy dynamic investment-savings (IS) curve.

First, output gap depends on its own lagged value ($\hat{y}_{t-1}$), which captures business cycle persistency.

The following two terms reflect real monetary conditions, through which monetary policy affects the real economy: (i) the real credit rate gap ($\widehat{lr}_t$) influences domestic demand through the interest rate channel of monetary policy; and (ii) the real effective exchange rate gap ($\hat{z}_t$) has an effect on external demand through the relative prices of exports and imports.

The next two terms are determined outside of the small open economy. Trade partners' output gap ($\hat{y}_t^*$) reflects external business cycle and remittances, while the commodity terms-of-trade gap ($\widehat{tot}_t$) directly affects the value of net exports and influences domestic demand through the income effect.

The output gap is also influenced by the sovereign risk premium gap ($\widehat{prem}_t$). A worsened risk perception increases the cost of borrowing in foreign currency and reduces domestic investment.

Due to the semi-structural nature of the model, the final term ($\varepsilon_{1,t}$) can be interpreted as an aggregate demand shock.

4.2 Phillips curve with rational expectations

$$\pi_t = \alpha_2\pi_{t-1} + (1-\alpha_2)\pi_{t+1} + \beta_2(\gamma_2\hat{y}_t + (1-\gamma_2)\hat{z}_t) + \varepsilon_{2,t} \qquad (2)$$

Equation (2) reveals an expectations-augmented open-economy version of the Phillips curve, which is used to model quarterly inflation (π_t).

Persistency in inflation is modeled with its dependence on lagged values (π_{t-1}), while the next term (π_{t+1}) represents model-consistent rational expectations.

The real marginal costs are modeled with the following two terms: The output gap ($\hat{y}_t$) represents the costs of domestic producers; and the real effective exchange rate gap ($\hat{z}_t$), those of importers.

The remaining term ($\varepsilon_{2,t}$) stands for a supply shock.

4.3 Taylor-type reaction function

$$i_t^P = \alpha_3 i_{t-1}^P + (1-\alpha_3)(\bar{r}_t^P + \pi_{t+1} + \beta_3(\pi_{t+1} - \pi_{t+1}^T) + \gamma_3 \hat{y}_t) + \varepsilon_{3,t} \quad (3)$$

The central bank defines nominal short-term policy interest rates (i_t^P) following a Taylor-type reaction function, reflected in equation (3).

The lagged interest rate (i_{t-1}^P) is necessary to capture a typical central bank's conservative behavior.

Monetary policy reacts to expected inflation deviations from the target ($\pi_{t+1} - \pi_{t+1}^T$). Such behavior is consistent with a desire to achieve a targeted level of inflation in the medium term. The policy rate also responds to the output gap ($\hat{y}_t$). On the one hand, this can be viewed as a precautionary measure, as current demand fluctuations indicate incoming inflationary pressures. On the other hand, it represents a trade-off between inflation and output stabilization.

In the long term, when all the shocks dissipate, the policy interest rate settles at its neutral level ($\bar{r}_t^P + \pi_{t+1}$). Such an interest rate is neither accommodative nor restrictive. The real neutral interest rate ($\bar{r}_t^P$) is equal to a sum of its foreign counterparts and the sovereign risk premium trend reduced by equilibrium REER appreciation.

Deviations from the reaction function ($\varepsilon_{3,t}$) are monetary policy shocks.

4.4 Hybrid uncovered interest parity

$$s_t = s_{t+1} + interv_t + \frac{i_t^* - i_t + prem_t}{4} - \gamma_4 \widehat{tot}_t + \varepsilon_{4,t} \quad (4)$$

Equation (4) displays a modification of the uncovered interest parity (UIP) condition. An increase in the nominal exchange rate (s_t) means depreciation of the Ukrainian hryvnia against the US dollar.

The spot exchange rate is defined by the market so that it removes possible arbitrage opportunities. The latter arise when the difference between short-term nominal domestic (i_t) and foreign (i_t^*) interest rates, adjusted by a sovereign risk premium ($prem_t$), is not compensated by expected depreciation ($s_{t+1} - s_t$).

The UIP condition is modified to account for systematic exchange rate management by the NBU. Equation (5) shows how foreign exchange interventions ($interv_t$) are endogenously defined with a view to smoothing exchange rate volatility:

$$interv_t = \frac{\beta_5}{4}\left(\left(\left(\Delta\bar{z}_t + \pi_t^T - \pi_t^{*,T}\right) - \Delta s_{t+1}\right) + \left(\left(\Delta\bar{z}_t + \pi_t^T - \pi_t^{*,T}\right) - \Delta s_t\right)\right) \tag{5}$$

Interventions are applied when current (Δs_t) and/or expected (Δs_{t+1}) devaluations deviate from some parity-implied value ($\Delta\bar{z}_t + \pi_t^T - \pi_t^{*,T}$). This value represents relative purchasing power parity, when adjusted for a real exchange rate trend. In this paradigm, higher inflation is consistent with nominal depreciations, unless offset by a real trend appreciation. The latter reflects the long-term economic potential, i.e. the real exchange rate should steadily appreciate with real convergence. Growth rates in this model are annualized, hence a coefficient in front of the whole term is divided by four.

Equation (5) does not rule out the possibility of using interventions for continuous accumulation or divestment of reserves. Nominal exchange rate movements can permanently deviate from parity-implied values.

Equation (4) is further adjusted to include the impact from the terms of trade ($\widehat{tot}_t$). Global commodity prices are important exchange rate determinants for any developing country with a large share of commodities in trade.

The residual term ($\varepsilon_{4,t}$) stands for a temporary shock in the exchange rate.

The term $interv_t$ can at least partially be seen as an automatic smoother. It reduces the high forward-looking dimension of the pure UIP condition, for which the latter is often criticized[10]. Equations (4) and (5) can be combined to obtain the following:

$$s_t = (1-\beta_5)s_{t+1} + \beta_5\left(s_{t-1} + \frac{2}{4}\left(\Delta\bar{z}_t + \pi_t^T - \pi_t^{*,T}\right)\right) + \frac{i_t^* - i_t + prem_t}{4} - \gamma_4\widehat{tot}_t + \varepsilon_{4,t} \tag{4*}$$

The first two terms in equation (4*) represent the modified expected exchange rate. It is constructed as a weighted average of model-consistent rational expectations and adaptive parity-implied ones. The latter account for the long-term economic potential as they extrapolate the past nominal exchange rate with the real exchange rate trend growth and inflation differential. Adaptive expectations are myopic in the short term, but consistent with rational expectations in the long term.

[10] More discussion can be found e.g. in Beneš et al. (2008).

4.5 Market interest rate

$$i_t = \alpha_6 i_{t-1} + (1 - \alpha_6) i_t^P + \varepsilon_{6,t} \quad (6)$$

The market interest rate (i_t) converges to the policy rate (i_t^P) in the long term, but can deviate from it in the short term. Equation (6) leaves the sources of such deviations unspecified.

4.6 Domestic trends

Domestic trends in the model feature potential GDP, equilibrium REER and inflation targets. The former two have equations in growth rates and the latter in levels. All of them follow very persistent autoregressive processes that converge to their calibrated steady states.

4.7 Foreign sector

The foreign sector consists of the sovereign risk premium, foreign interest rates, output gap and inflation rate, as well as commodity terms of trade. All are modeled as autoregressive processes with calibrated steady states, while the sovereign risk premium is also decomposed into a trend and a gap.

5. Bayesian estimation

There are 44 coefficients in the model, including standard deviations of the shocks; 38 of them are estimated with Bayesian techniques and the other 6 are calibrated. This section focuses on 20 coefficients from the main equations. The whole parametrization is shown in Appendix 1 (Table 5).

Coefficients in equations (1) – (6) are estimated with Bayesian techniques. The practice allows accounting for both expert judgment and suggestions from the data. Bayesian estimation is particularly relevant for Ukraine as it helps overcome structural breaks and short data series.

Prior means are calibrated. Many of them are informed by benchmarks from similar models. Calibration of parameters is widely used among central banks. Normally, it is designed to reflect stylized facts about the economy and provide desired model characteristics, e.g. impulse response functions.

The calibrated coefficients are mostly set within the range of values for Ukrainian peer economies, if such information is available. Among similar models are those of the Czech National Bank (Beneš et al, 2003), the Bank of Serbia (Đukić et al, 2010), the South African Reserve Bank (De Jager et al, 2015), the Reserve Bank of India (Beneš et al, 2017) and the Central Bank of Sri Lanka (Amarasekara et al, 2018). The calibration also considers the models for the National Bank of Georgia (Tvalodze et al, 2016) and the Central Bank of Chile (Marioli et al, 2020). Standard deviations of shocks prior to estimation are calibrated to be equal and normalized to unity. Table 1 summarizes the reasoning behind calibration.

Table 1. Calibrated coefficients

Parameter	Range for peers or other benchmark	Calibrated value	Rationale
Open economy IS curve			
α_1	0.55 – 0.9	0.7	Comparatively small degree of business-cycle inertia reflects volatile Ukrainian output.
β_1	0.1 – 0.5	0.1	Weak monetary policy transmission to the real economy is common for EMEs as transmission mechanisms are less developed, e.g. low financial depth in Ukraine.
γ_1	0.2 – 0.63[11]	0.4	The interest rate channel in a small open economy is less important than the exchange rate channel. Its effectiveness can be further reduced by dollarization (or euroization).
δ_1	0.04 – 0.8	0.5	The spillover from the foreign output gap reflects the elasticity of GDP to foreign demand.
θ_1	0.01[12]	0.15	The effects from commodity terms of trade and the sovereign risk premium are calibrated with event analysis.
μ_1	–[13]	0.1	
σ_1^{ε}	–	1	–
Phillips curve with rational expectations			
α_2	0.55[14]	0.6	Relatively high inflation persistence indicates a large share of backward-looking economic

[11] One outlier of 0.998 from De Jager et al. (2015) is discarded.
[12] An analogous term is present only in Marioli et al. (2020), however, the overall IS curve specification is different.
[13] An analogous term is present only in Tvalodze et al. (2016), however, the coefficient size is not specified.
[14] Benchmark values for the Phillips curve are estimated with an OLS on the whole horizon. The forward-looking component is approximated with actual one-quarter-ahead inflation. The output and REER gaps are extracted with an HP filter.

			agents and requires more pronounced policy responses to economic shocks.
β_2	0.62	0.4	The monetary policy pass-through to inflation is calibrated to be quite strong.
γ_2	0.37	0.4	Real marginal costs of domestic producers are relatively less important than those of importers due to the high openness of Ukrainian economy.
σ_2^{ε}	–	1	–
Taylor-type policy reaction function			
α_3	0.5 – 0.93	0.6	Comparatively small degree of persistence in monetary policy allows for aggressive policy responses.
β_3	0.77 – 5	2	Strong policy reaction to inflation deviations from the target reflects preferences for quick inflation stabilization.
γ_3	0 – 1	0.4	The interest rate is less responsive to the output gap as inflation stabilization takes precedence.
σ_3^{ε}	–	1	–
Hybrid uncovered interest parity & Interventions			
γ_4	0.0006[15]	0.1	The effect from commodity terms of trade is calibrated with event analysis.
σ_4^{ε}	–	1	–
β_5	0.15 – 0.5[16]	0.5	High willingness of the NBU to intervene is consistent with a managed exchange rate.
Market interest rates			
α_6	0 – 0.19[17]	0.4	Volatile interbank rate is consistent with its pronounced deviations from the policy interest rate.
σ_6^{ε}	–	1	–

Ranges for peers are not available, because core macroeconomic projection models at central banks typically decompose headline inflation into components and contain several Phillips curves (e.g. energy, raw food, administratively regulated and core inflation). Equations for each of these are different and can become quite complex.

[15] An analogous term is present only in De Jager et al. (2015), however, the coefficient is oddly small.

[16] The models for peers do not explicitly contain interventions variable, however, they make exchange rate more backward-looking, with specifications that resemble equation (4*).

[17] Short-term market interest rates under IT regimes are usually set to be equal to the policy rate, which effectively sets the coefficient at zero. Amarasekara et al. (2018) offers an exception, however, the overall specification is different.

I estimate coefficients separately on the 2006–2014 and 2015–2020:Q1 historic horizons, as the triple crisis and consequent policy regime change introduced a major structural break. The priors are kept the same, thus all obtained differences are dictated by the data.

Most of the priors are considerably lax, which allows the data to reflect structural changes in Ukrainian economy. The priors in equations (3) – (6) are kept tighter as the data seems to be less reliable in judgments about the policy regime change. For the coefficients bounded between zero and unity, I use Beta distributions, for others – an Inverse Gamma distribution.

Table 2 presents the priors and resulting posterior means for all estimated coefficients on the respective historic horizons.

Table 2. Estimated coefficients

Parameter	Prior			Posterior	
	Distribution	Mean	Std. dev.	Mean	
				2006–2014	2015–2020:Q1
Open economy IS curve					
α_1	Beta	0.7	0.10	0.60	0.79
β_1	Inv. Gamma	0.1	0.10	0.04	0.05
γ_1	Beta	0.4	0.10	0.38	0.40
δ_1	Inv. Gamma	0.5	0.10	0.57	0.45
θ_1	Inv. Gamma	0.15	0.10	0.08	0.09
μ_1	Inv. Gamma	0.1	0.10	0.25	0.06
σ_1^ε	Inv. Gamma	1	1.0	0.33	0.20
Phillips curve with rational expectations					
α_2	Beta	0.6	0.10	0.41	0.44
β_2	Inv. Gamma	0.4	0.10	0.36	0.39
γ_2	Beta	0.4	0.10	0.42	0.41
σ_2^ε	Inv. Gamma	1	1.0	0.87	1.24
Taylor-type policy reaction function					
α_3	Beta	0.6	0.05	0.79	0.70
β_3	Inv. Gamma	1.5	0.5	1.00	1.00
γ_3	Inv. Gamma	0.4	0.05	0.39	0.39
σ_3^ε	Inv. Gamma	1	1.0	0.70	0.94
Hybrid uncovered interest parity & Interventions					
γ_4	Inv. Gamma	0.1	0.05	0.06	0.07
σ_4^ε	Inv. Gamma	1	1.0	1.01	0.80
β_5	Beta	0.5	0.05	0.61	0.57
Market interest rates					
α_6	Beta	0.4	0.05	0.33	0.39
σ_6^ε	Inv. Gamma	1	1.0	1.02	0.33

The estimated IS curve reveals that the output gap is less persistent (α_1) under the fixed exchange rate than under IT. The influence from real monetary conditions (β_1) appears to be even lower than when calibrated on both horizons. The weight of the real interest rate (γ_1) is kept almost the same. Sensitivity to foreign output (δ_1) and the sovereign risk premium (μ_1) turns out to be higher in 2006–2014 than in 2015–2020:Q1. The elasticity to commodity terms of trade (θ_1) is evenly adjusted downwards on both horizons. Low standard deviations of shocks (σ_1^ε) mean that they are relatively less volatile than those of other variable.

On both historic horizons, inflation is less persistent (α_2) than originally calibrated. Lower persistence is especially pronounced in 2006–2014. During that period, inflation also demonstrates a lower sensitivity to real marginal costs (β_2), but a similar sensitivity to the costs of internal producers (γ_2). The higher volatility of shocks (σ_2^ε) in 2015–2020:Q1 can be explained by the inflation peak in 2015.

The estimated policy reaction function provides evidence in favor of a more persistent (α_3) and less aggressive (β_3 and γ_3) interest rate on both historic horizons. However, the rate is more responsive in 2015–2020:Q1. This is to be expected, because under IT, the interest rate serves as the main policy instrument. Under the fixed exchange rate regime, the interest rate was not used as an important policy instrument. Monetary policy shocks are more volatile (σ_3^ε) in 2015–2020:Q1 under a more active policy reaction function.

The estimation proves that the exchange rate is less sensitive to commodity terms of trade (γ_4) than originally calibrated. The shocks (σ_4^ε) have a higher standard deviation in 2006–2014 as Ukraine experienced two major devaluations during that period.

The willingness of the NBU to intervene on the FX market (β_5) is expectedly estimated to be higher during the fixed exchange rate regime. Furthermore, the estimation puts both coefficients above their calibrated values, which reflects the managed exchange rate in Ukraine on both historic horizons.

Finally, the interbank interest rate persistence (α_6) is higher under IT. Moreover, shocks are more volatile (σ_6^ε) under the fixed exchange rate regime.

6. Model properties

The two parametrizations yield models with differing properties. Yet, both feature the nominal exchange rate stabilization mechanism, which is suggested in equations (4) – (5). The scope of stabilization is reflected by the coefficient β_5.

The models with parametrizations estimated for the 2006–2014 and 2015–2020:Q1 historic periods bear distinct impulse response functions: these are shown in Appendix 2 (Figures 7 and 8). It is difficult to pinpoint the exact sources of the differences between them due to the many changed parameters. Moreover, the monetary policy regime switch in 2014–2015 cannot be treated as exogenous, because it came along with a structural break in economic fundamentals.

Simulations for the 2006–2014 parametrization reveal that the nominal exchange rate was not constant in response to economic disturbances. In fact, impulse response functions with constant nominal exchange rate are possible only if β_5 approaches infinity. In such a case, equation (4*) gets reduced to:

$$s_{t+1} = s_{t-1} + \frac{2}{4}\left(\Delta\bar{z}_t + \pi_t^T - \pi_t^{*,T}\right).$$

The nominal exchange rate then becomes unresponsive to temporary shocks and reacts solely to the REER trend and inflation target differential. The nominal exchange rate path becomes determined by the latter. While the REER trend is time-variant in general, an appropriate choice of the inflation target allows for modeling the fixed exchange rate regime.

Given the 2015–2020:Q1 parametrization, it is possible to model a hybrid IT regime with exchange rate management using a reasonably sized coefficient β_5. Higher values of the coefficient are consistent with the smoother exchange rate. The corresponding impulse response functions are shown in Appendix 2 (Figures 9 and 10).

Exchange rate changes become more stabilized around the parity level and also less volatile with higher β_5 values (Table 3). To show this, I calculate the model-implied standard deviations of a set of variables using estimated standard deviations of shocks and the model structure[18]. All parameters, except for β_5, are taken from the 2016–2020:Q1 parametrization and kept constant.

[18] Simulations assume that relative volatilities of economic shocks are kept the same as dictated by the 2016–2020:Q1 data. However, standard deviations of shocks can be set with expert judgment. It allows one to investigate the policy options in response to a particular set of disturbances or even to one predominant shock.

Table 3. Model implied unconditional standard deviations

	Nominal exchange rate deviations from parity	Model-implied interventions	Output gap	Inflation	Policy interest rate
	$\Delta s_t - (\Delta\bar{z}_t + \pi_t^T - \pi_t^{*,T})$	$interv_t$	$\hat{y}_t$	π_t	i_t^P
$\beta_5 = 0$	1.32	0.00	1.00	1.07	1.16
$\beta_5 = 0.57$	1.00	1.00	1.00	1.00	1.00
$\beta_5 = 1$	0.64	1.16	1.00	1.08	1.32
$\beta_5 = 100$	0.01	1.24	0.99	1.22	2.01

Note: values are normalized for each variable to a baseline case of $\beta_5 = 0.57$

Stronger management achieves lower exchange rate volatility at an expense of large FX interventions. The latter is indicated by the implied standard deviation of the $interv_t$ variable. In contrast, the case of $\beta_5 = 0$ means no management, which is consistent with absent interventions and higher exchange rate volatility.

Moderate exchange rate management ($\beta_5 = 0.57$) is able to reduce inflation volatility in comparison with the no management case. However, smoother exchange rate does not always guarantee improved macroeconomic stability. In fact, further increasing β_5 leads to more volatile inflation and policy interest rate. Moreover, the output gap exhibits seemingly no variation in volatility in response to changing degrees of exchange rate management. Given inelastic aggregate demand, it becomes very painful to peg the exchange rate and strip monetary policy from yet another important transmission channel.

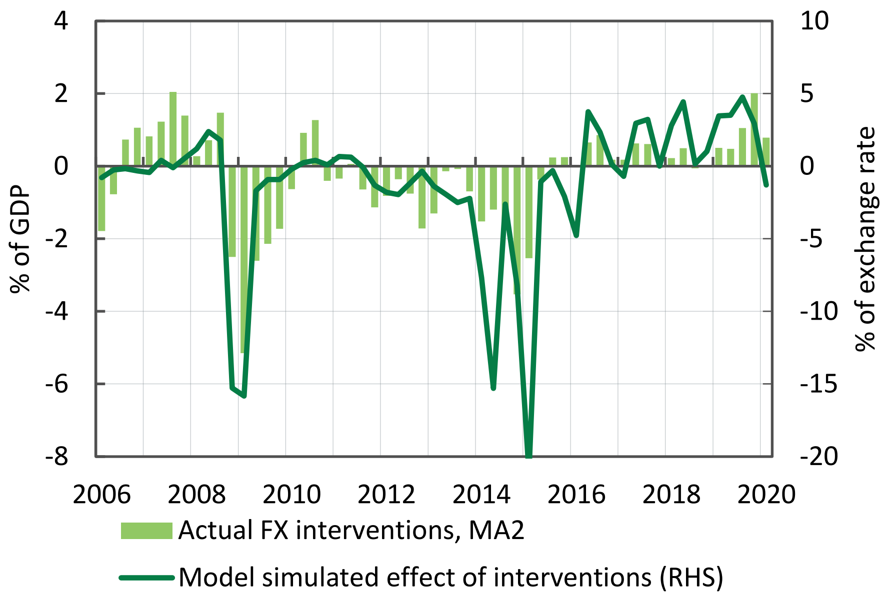
7. Results

With the two model parametrizations in place, I use the Kalman filter to estimate the $interv_t$ variable from equation (4) on the whole historic horizon. The variable measures the impact on the exchange rate due to its management. I further compare the obtained series with actual FX interventions by the NBU and discuss the effectiveness of the latter.

The term $interv_t$ represents systematic deviations of the nominal exchange rate from the UIP condition, even after correction for the terms of trade. It is not an observable variable in the model, but can be estimated with the Kalman filter. The latter uses a state-space representation of the model's equations and simulates unobserved variables taking into account observed ones. I filter the variable separately on the 2006–2014 and 2015–2020:Q1 historic periods, and then merge the resulting series for further analysis.

Systematic deviations from UIP can be explained to a large extent by exchange rate management. The simulated model-consistent series closely matches a two-quarter moving average of actual FX interventions by the NBU (Figure 6). The correlation is 69% and even jumps to 86% on the 2015–2020:Q1 horizon. The simulated effect of interventions is quoted as the percentage influence on the nominal exchange rate, while the actual interventions are in terms of the percentage of annual GDP, as there is a need to control for the changing size of the economy. The correlation with actual interventions without the moving average is lower, which is evidence in favor of their influence lasting for two quarters.

Figure 6. Model-simulated interventions in comparison to actually observed series



Source: National Bank of Ukraine, own estimates

Note: a negative model-estimated effect of interventions means that the nominal exchange rate was strengthened; negative actual interventions mean that foreign currency was sold by the NBU on the market.

Simulated interventions correctly reflect periods of FX sales and purchases by the NBU. The variable is mostly positive until 2008 and since 2016, which is consistent with accumulating international reserves. It is mostly negative in between, when the fixed exchange rate was supported with FX sales. The variable's troughs coincide with actual peaks in FX interventions.

As simulated interventions display the amount of influence on the exchange rate, it is possible to measure effectiveness of actual ones. I run an ordinary least squares (OLS) regression of the former on the latter and allow lagged effects. I also control for a change in the monetary policy regime with a dummy. Respective results are shown in Table 4.

Table 4. Model-simulated interventions regressed on actually observed series

Dependent variable: model-simulated interventions

Variable	Coefficient
actual FX interventions	2.96***
actual FX interventions (-1)	2.80***
dummy200614*actual FX interventions	-1.51
dummy200614*actual FX interventions (-1)	-2.24***
dummy200614	0.50
constant	-1.51*
R-squared	0.62
Observations	56

Note: model-simulated interventions are in % of nominal exchange rate; actual FX interventions are in % of annual GDP; dummy200614 equals one in 2006–2014; * means significant at the 10% confidence level, ** 5%, *** 1%

If the NBU in 2015–2020:Q1 sells an additional one percent of GDP worth of dollars on the FX market, the nominal exchange rate appreciates by 5.76% over the course of two quarters. This is the sum of the first two coefficients. It means that 0.17% of GDP is required to nudge the exchange rate by one percent in the desired direction. In 2019 terms, this amounts to USD 273 million. As the third and the forth coefficients are negative, the value for 2006–2014 is higher and stands at 0.5% of GDP. In 2013 terms, this equated to USD 949 million.

The regression results reveal the stronger impact of interventions in 2015–2020:Q1, that is under IT with floating exchange rate. I do not investigate the reasons for this finding, however, the lower carry trade and higher institutional credibility might play an important role. If the NBU does not guarantee any specific level of the exchange rate, it becomes easier to live up to the promise.

8. Conclusions

Many central banks target inflation using interest rates as a main policy instrument. Some of them, especially in emerging market economies, additionally use FX interventions with a view to stabilizing the nominal exchange rate. All of them require proper analytical frameworks for policy analysis.

In this paper I propose a UIP modification to a semi-structural New Keynesian model, which accounts for FX interventions and is relevant for IT regimes with various degrees of exchange rate management. The model is tailored to the case of Ukraine.

The model properties show that moderate management helps stabilize both the nominal exchange rate and inflation. Stronger management is always able to reduce exchange rate volatility. However, at some point, it starts leading to more a volatile inflation and policy interest rate. This emphasizes the need for the floating exchange rate as for an important economic stabilization mechanism.

The model-implied volatility of the output gap demonstrates virtually no reaction to changing degrees of exchange rate management. Low financial depth and foreign currency-invoiced trade make aggregate demand inelastic to real monetary conditions. This weakens monetary policy transmission.

Model simulations demonstrate that sterilized FX interventions under IT influence the nominal exchange rate more effectively than non-sterilized ones under the fixed exchange rate regime. First, heavy interventions may induce carry trade, which reduces their effectiveness. Second, interventions are not able to defend an exchange rate level forever in the case of changed fundamentals. Instead, they should only address temporary shocks. Finally, the effectiveness of FX interventions increases with better monetary policy credibility.

Among possible directions for further research is extending the model with the stock of international reserves. Central banks may target a certain level of reserves and have preferences about their accumulation or spending. Moreover, higher reserves can improve investor sentiments.

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Appendix 1: Parametrization of the model

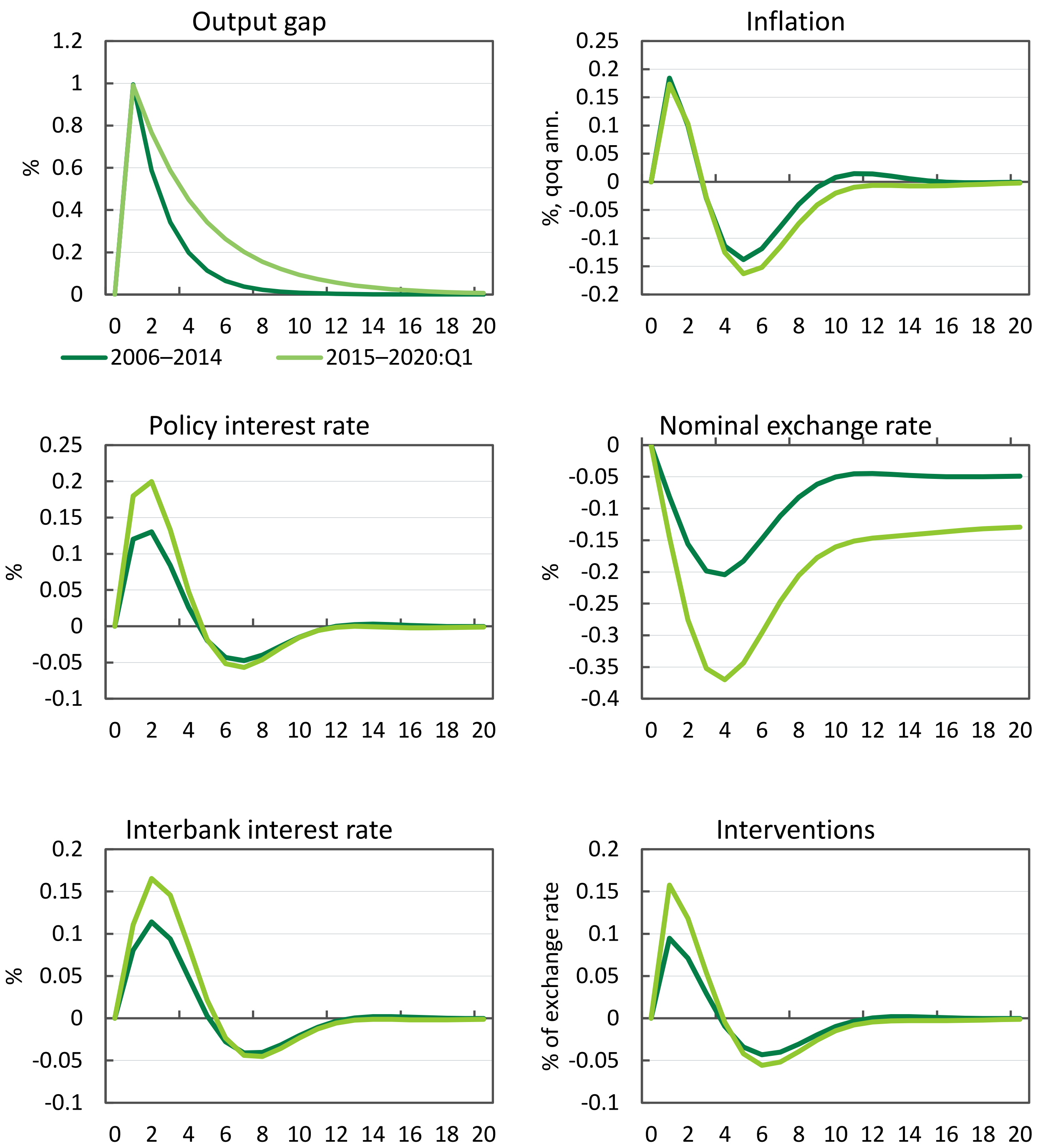
Table 5. Parametrization of the model

Parameter	Value		Interpretation
	2006–2014	2015–2020:Q1	
Open economy IS curve			
α_1	0.60	0.79	Business-cycle inertia
β_1	0.04	0.05	Influence of real monetary conditions
γ_1	0.38	0.40	Weight on interest rate channel
δ_1	0.57	0.45	Sensitivity to foreign output
θ_1	0.08	0.09	Sensitivity to commodity terms of trade
μ_1	0.25	0.06	Sensitivity to sovereign risk premium
σ_1^ε	0.33	0.20	Standard deviation (Std.) of demand shocks
Phillips curve with rational expectations			
α_2	0.41	0.44	Inflation persistence
β_2	0.36	0.39	Influence of real marginal costs
γ_2	0.42	0.41	Weight of internal producers
σ_2^ε	0.87	1.24	Std. of supply shocks
Taylor-type policy reaction function			
α_3	0.79	0.70	Monetary policy persistence
β_3	1.00	1.00	Reaction to inflation deviations
γ_3	0.39	0.39	Reaction to output gap
σ_3^ε	0.70	0.94	Std. of monetary policy shocks
Hybrid uncovered interest parity & Interventions			
γ_4	0.06	0.07	Sensitivity to commodity terms of trade
σ_4^ε	1.01	0.80	Std. of exchange rate shocks
β_5	0.61	0.57	Willingness of the NBU to intervene
Market interest rates			
α_6	0.33	0.39	Interbank deviations persistency
σ_6^ε	1.02	0.33	Std. of interbank shocks
Domestic trends			
–	0.79		Potential GDP growth persistence
–	0.79		Std. of potential GDP growth shocks
–	0.96		REER trend growth persistence
–	0.08		Std. of REER trend growth shocks
–	0.97		Inflation target persistence
–	0.12		Std. of inflation target shocks
Foreign sector			
–	0.68		Sovereign risk premium persistence
–	0.67		Std. of sovereign risk premium shocks
–	0.98		Sovereign risk prem. trend persistence
–	0.05		Std. of sovereign risk prem. trend shocks

–	0.72	Commodity terms of trade gap persistence
–	0.63	Std. of commodity terms of trade gap shocks
–	0.99	Foreign interest rate persistence
–	0.10	Std. of foreign interest rate shocks
–	0.91	Foreign output gap persistence
–	0.17	Std. of foreign output gap shocks
–	0.38	Foreign inflation persistence
–	2.72	Std. of foreign inflation shocks
Calibrated steady state values		
–	4	Potential GDP annual growth rate
–	-2	REER trend annual appreciation rate
–	5	Domestic inflation target
–	4	Sovereign risk premium trend
–	3	Foreign inflation target
–	1	Foreign real neutral interest rate

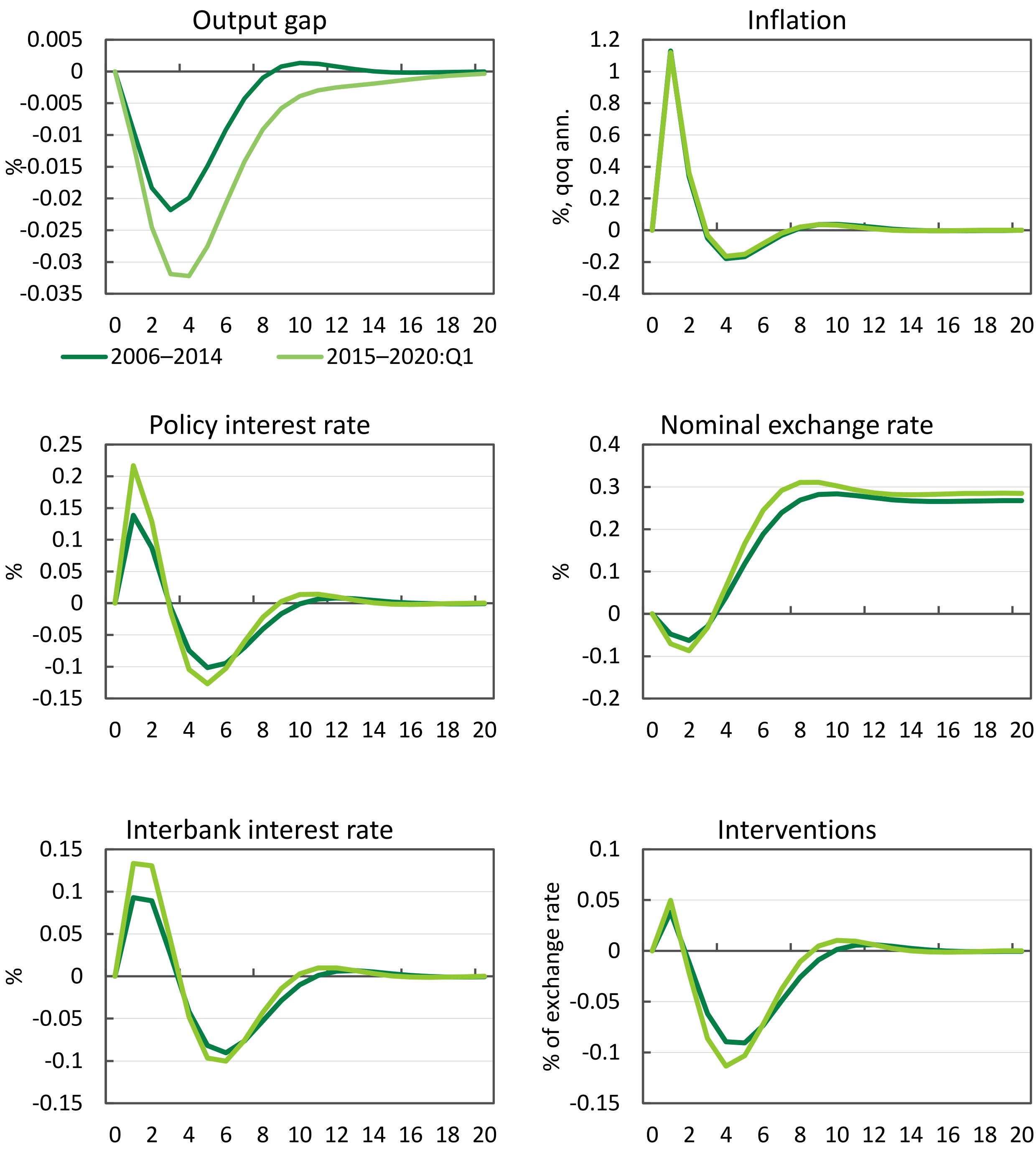
Appendix 2: Impulse response functions

Figure 7. Impulse response functions to the demand shock ($\varepsilon_{1,t}$)



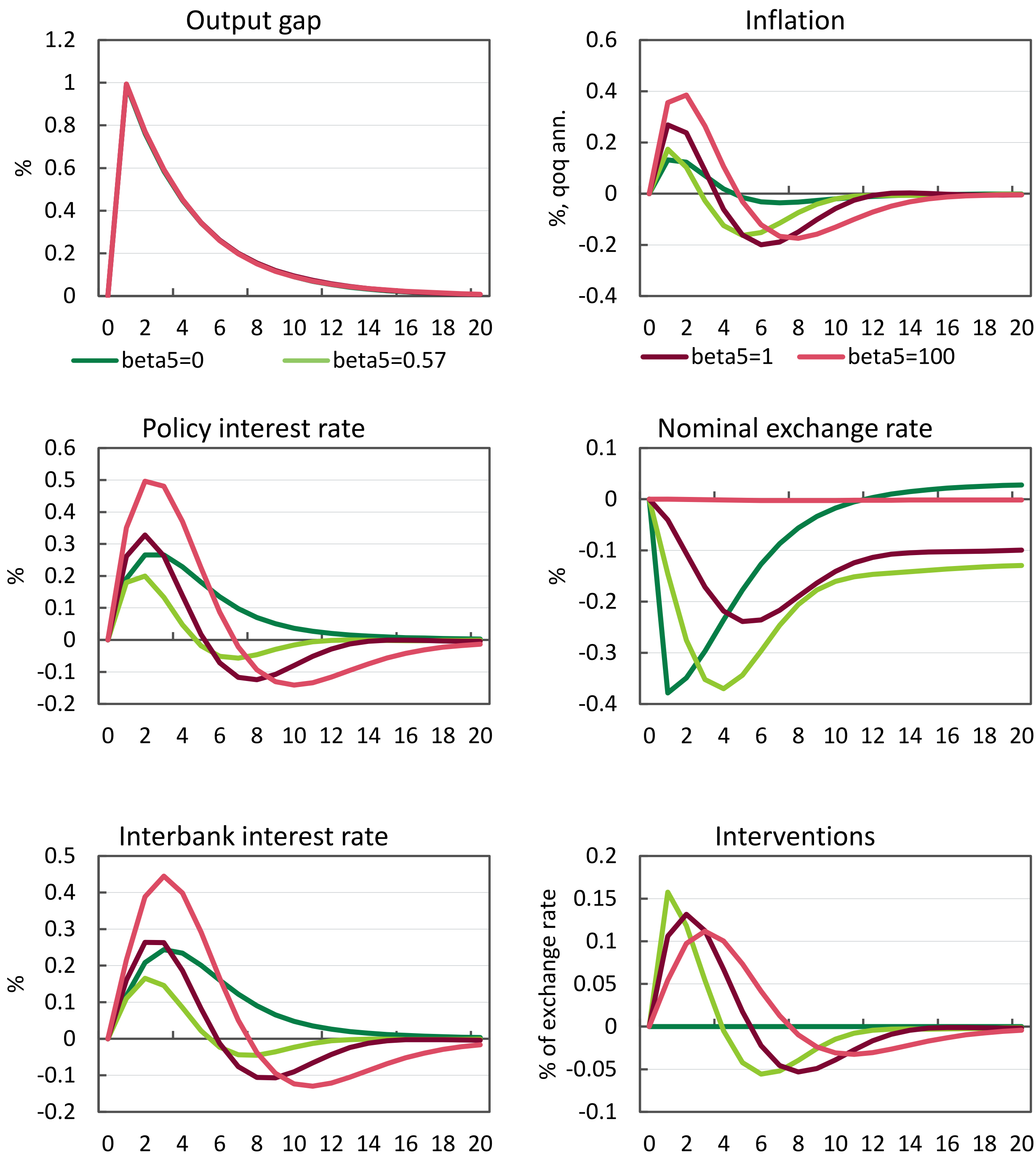
Source: own calculation

Figure 8. Impulse response functions to the supply shock ($\varepsilon_{2,t}$)



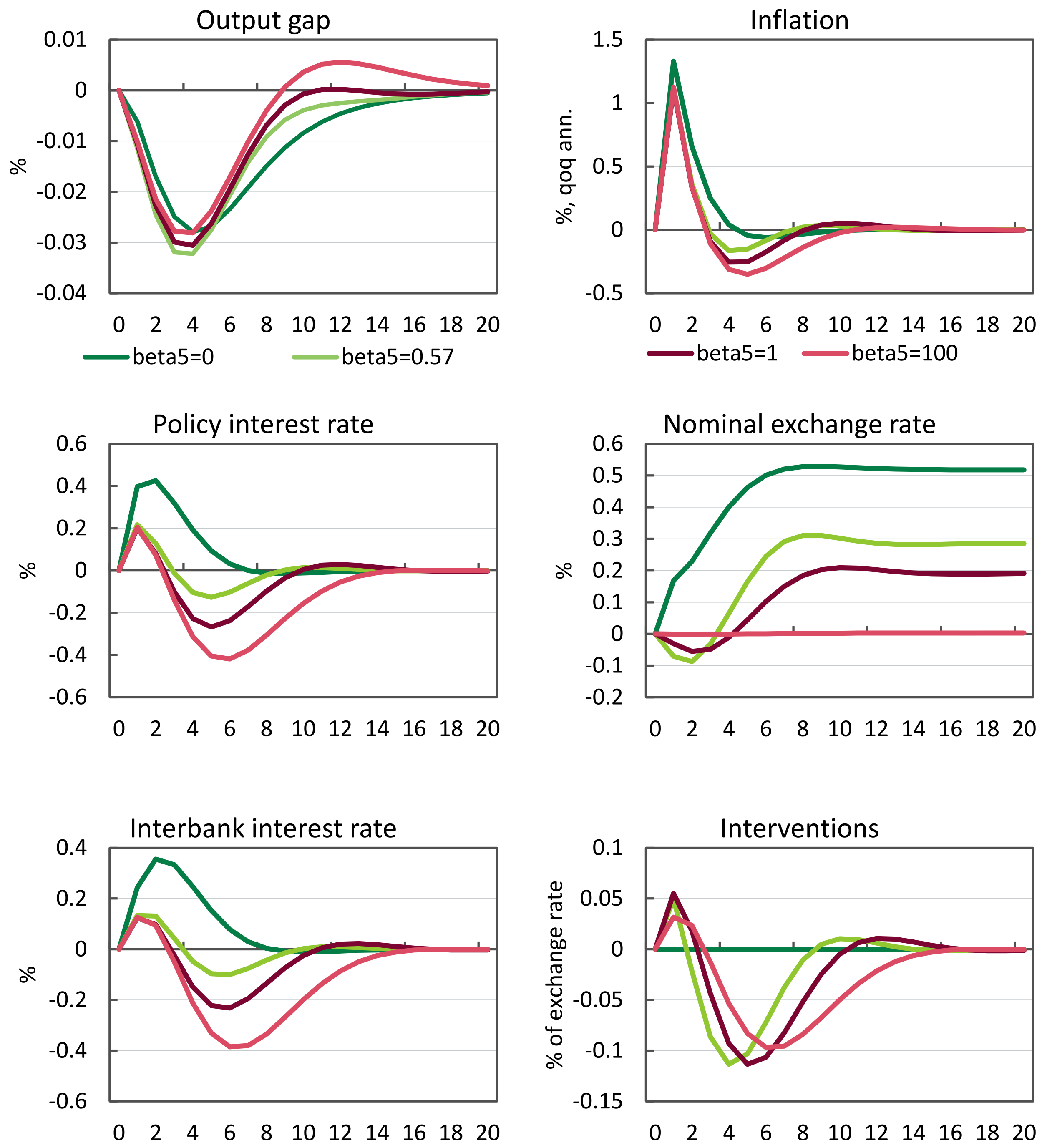
Source: own calculation

Figure 9. Impulse response functions to the demand shock ($\varepsilon_{1,t}$): varying β_5



Source: own calculation

Figure 10. Impulse response functions to the supply shock ($\varepsilon_{2,t}$): varying β_5



Source: own calculation

Appendix 3: Raw data

Table 6. Raw data

Variable	**Raw Units**	**Note**	**Model transformations**	**Source**
Real GDP	UAH millions in 2010 prices	Gross Domestic Product of Ukraine at constant prices	ln*100	*State Statistic Service of Ukraine, SSSU*
Headline CPI	Index	Consumer Price Index (CPI)	–Seasonal adjustment –ln*100 –Quarterly average	*SSSU*
Inflation target	%, y-o-y	Official target of the NBU		*NBU*
NBU's key policy rate	%, p.a.	–Reference rate until 2015 –14-days deposit certificates and (since 2019) also 14-days refinance	Quarterly average	*NBU*
Interbank rate	%, p.a.	Interbank overnight interest rates excluding overdrafts	Quarterly average	*NBU*
Commodity terms of trade	Index	Weighted average of prices of exported and imported commodities	ln*100	*Thomson Reuters*
Real effective exchange rate	Index	Weighted average of nominal exchange rates with trading partners adjusted by respective consumer price indices	ln*100	*NBU*
UAH/USD exchange rate	UAH	Official nominal exchange rate UAH per USD	ln*100	*NBU*

Foreign interest rate	%, p.a.	One-month LIBOR	–	*Thomson Reuters*
World output gap	Index	Weighted average of real GDP of main trading partners	–ln*100 –HP filter to estimate trend	*National statistical offices, NBU calculations*
Risk premium	p.p.	Spread between yields to maturity of Ukrainian Eurobonds and 10Y US Treasuries	–	*cbonds.com*
Foreign exchange interventions	USD million	Net interventions by the NBU on the foreign exchange market	–	*NBU*