



## AN ESTIMATED BAYESIAN DSGE MODEL FOR KAZAKHSTAN



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### ABSTRACT

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A small scale open economy model is estimated for Kazakhstan via Bayesian methods. The model explicitly takes into account the dependence of the economy on commodity exports and also accounts for risk premium shocks in the foreign exchange market. The main contribution of the research is that it is the first DSGE model in literature estimated via Bayesian methods for Kazakhstan. The results of the model are used to determine the historical contribution of structural shocks to endogenous variables, forecast error variance decomposition of observed macroeconomic variables and impulse responses of important endogenous variables to various shocks. It has been found that the output gap turned significantly negative during the Great Recession and the negative oil price shock. The effect of contractionary monetary policy is found to be negative on output gap, but it negligibly affects the inflation rate in the economy. Risk premium shocks are found to account for almost 60% of forecast error variance decomposition of nominal exchange rate of tenge over all horizons.

**Contribution/ Originality:** This research contributes to the literature by estimating a version of Bayesian DSGE model for Kazakhstan and explicitly modelling key characteristics of the economy. The historical decompositions of output gap and inflation rate gap are calculated to detect the fundamental sources of fluctuations in the economy.

## 1. INTRODUCTION

New Keynesian models have been widely employed at central banks, financial and research institutions around the world due their theoretically cohesive structure and ability to fit macroeconomic data. Currently, all central banks have their own versions of dynamic stochastic general equilibrium (DSGE) models for analyzing policy decisions and recovering the fundamental sources of business cycles in a local economy. The development of Bayesian methods due to the improvement in computational power have allowed economists to obtain more reliable results by incorporating external information available about structural parameters of the model. Almost all institutions specializing in macroeconomics have adopted Bayesian techniques to come up with their workhorse DSGE model following the seminal work by [Smets and Wouters \(2007\)](#). In this paper, I estimate a baseline small-open economy model for Kazakhstan via Bayesian methods to use it for analyzing impulse responses of endogenous variables to fundamental shocks, historical decompositions of output gap and inflation rate gap, and forecast error

variance decomposition of observable macroeconomic variables. Most of the modern estimated DSGE models for developed economies are closed economy versions of New Keynesian models as in [Christiano \*et al.\* \(2005\)](#), [Smets and Wouters \(2003\)](#) and [Smets and Wouters \(2007\)](#). The open economy versions of DSGE models have become more widespread starting from the works by [Gali and Monacelli \(2005\)](#) and [Monacelli \(2005\)](#). However, the Great Recession of 2007-09 brought abrupt criticisms of DSGE models by [Krugman \(2009\)](#), [Romer \(2016\)](#) and [Stiglitz \(2018\)](#) for the failure of the models to predict the financial crisis. Despite the inability of the models to capture a large downturn in economic activity, economists have continued to build DSGE models further by incorporating financial frictions and banking sector to account for missing pieces of the models during the financial crisis ([Bernanke \*et al.\*, 1999](#)); ([Ravn and Sterk, 2016](#)); ([Curdia and Woodford, 2010](#)); ([Luk and Vines, 2011](#)). [Linde \(2018\)](#) and [Blanchard \(2018\)](#) maintain that the core structure of DSGE models have the right microeconomic foundations and should be modified further to address past failures and policy issues of interest. Recently, [Christiano \*et al.\* \(2018\)](#) gave a neat response to the set of criticisms on DSGE models by referring to the existing literature and outlining the importance of using these models in policy analysis. Hence, the DSGE models are still useful in policy analysis as long as they are modified to take into account key characteristics of the economy and systematically address failures of the models to take into account unforeseen events.

A vast majority of the literature on DSGE models have been devoted to the study of developed economies. There exist a plenty of studies that have built DSGE models with novel transmission mechanisms of shocks and various frictions that have been tested and employed for developed countries. However, macroeconomic models, including DSGE models, on emerging countries like Kazakhstan tend to be rare in the literature. [Abilov \*et al.\* \(2019\)](#) built a macroeconometric model in the spirit of Cowles Commission models for Kazakhstan for simulation and forecasting purposes. [Algozhina \(2016\)](#) builds a fully-specified DSGE model for Kazakhstan to analyze monetary and fiscal policies under two alternative exchange rate regimes accounting for the dependence of the economy on natural resources. Although the model in [Algozhina \(2016\)](#) takes into account all specific characteristics of the Kazakhstani economy, the size of the model makes the interpretation of conclusions complicated. Most of the parameters in the model were calibrated by either using macro data or borrowing the coefficients from the literature on similar economies. Instead I build a more simplified version of a DSGE model for tractability without losing key characteristics of the economy. Then I estimate the model with Bayesian methods that would allow us to incorporate prior information into the model and fit the model to aggregate macroeconomic time series. The structure of the DSGE model is similar to [Nimark \(2009\)](#) since Kazakhstan is an economy heavily dependent on exports of primary products. The estimation of the model via Bayesian methods and the interpretation of results follow the methodology outlined in [An and Schorfheide \(2007\)](#) and [Rudolf and Zurlinden \(2014\)](#).

Section 2 introduces the structure of the general equilibrium model: optimization problems of agents, frictions, shocks and other key characteristics of the economy. In Section 3, I present the state space form of the model solution and the Bayesian estimation procedure along with priors for the parameters. Section 4 introduces measurement equations from the state space system and the data used in the estimation. Then the results of the model are discussed in Section 5 in which posterior estimates of the parameters are presented as well as historical decompositions of output gap and inflation rate gap. Forecast error variance decompositions of observed variables such as output growth, annual inflation rate and nominal exchange rate are presented in the same section. Section 6 analyzes the impulse response functions of endogenous variables to monetary policy shock, risk premium shock, technology shock and shocks to exports. Finally, concluding remarks are made based on the properties and useful insights of the model.

## 2. MODEL

The model is a small open economy version of New Keynesian DSGE models that consists of households, domestic producers, retail importers, the central bank and the foreign economy. There are some features of the

model that are introduced to fit better the structure of the Kazakhstani economy. Hence, I introduce real shocks to the demand of exports and nominal shocks to the income from exports. In addition, the economy is small relative to the rest of the world and is assumed to have no effect on them whatsoever.

### 2.1. Households

The economy is populated by a continuum of households  $i \in (0,1)$ . I assume that there is a single representative agent in the model, meaning that all households face the same utility optimization problem. That is, households maximize expected lifetime utility given by Equation 1.

$$E \sum_{k=0}^{\infty} \beta^k U(C_{t+k}(i), N_{t+k}(i)) \quad (1)$$

Where  $\beta$  is a time preference parameter (or subjective discount rate);  $C_t(i)$  is consumption whereas  $N_t(i)$  is hours of work of household  $i$ . The exact form of the utility function is given by Equation 2.

$$U(C_{t+k}(i), N_{t+k}(i)) = \exp(\varepsilon_t^c) \frac{(C_t(i) - \eta C_t)^{1-\gamma}}{1-\gamma} - \frac{N_t(i)^{1+\varphi}}{1+\varphi} \quad (2)$$

Meaning that the utility of households depends on their own consumption, aggregate consumption and hours of work. The feature of the utility function of households depending negatively on aggregate consumption is known as an external habit formation or "catching up with the Joneses" (Abel, 1990). It captures the tendency of households to take into account the consumption of other households when making decisions on their own consumption.  $\eta$  is a habit persistence parameter indicating the strength of habit persistence in consumption ( $\eta \in (0,1)$ ). The other two parameters of the utility function,  $\gamma$  and  $\varphi$ , are intertemporal elasticity of substitution and Frisch elasticity of labor supply respectively. There is also a preference shock to consumption denoted by  $\varepsilon_t^c$  which is a white noise process  $\varepsilon_t^c \sim N(0, \sigma_c^2)$ . This shock has been added to reflect exogenous shifts in the consumption of households. Since households have the same utility function, the marginal rates of substitution are equal across households in equilibrium meaning that  $C_t(i) = C_t(j) = C_t$  for  $i \neq j$ .

The openness of the economy implies that households can allocate their consumption over domestically produced goods and imported goods. Domestic goods are differentiated and produced by monopolistically competitive firms whereas retailers sell imported goods in the economy. As a result, the consumption bundle of households consists of domestic and imported goods, and these goods are combined via constant elasticity of substitution aggregate index which are given by Equation 3-5.

$$C_t \equiv \left[ (1-\alpha)^{\frac{1}{\kappa}} C_t^d{}^{\frac{\kappa-1}{\kappa}} + \alpha^{\frac{1}{\kappa}} C_t^m{}^{\frac{\kappa-1}{\kappa}} \right]^{\frac{\kappa}{\kappa-1}} \quad (3)$$

$$C_t^d \equiv \left[ \int C_t(i)^{\frac{\nu-1}{\nu}} di \right]^{\frac{\nu}{\nu-1}} \quad (4)$$

$$C_t^m \equiv \left[ \int C_t^m(j)^{\frac{\nu-1}{\nu}} dj \right]^{\frac{\nu}{\nu-1}} \quad (5)$$

Where  $\alpha$  is the fraction of imported goods in the consumption bundle of households.  $\nu$  is the elasticity of substitution across differentiated products which is assumed to be the same for domestic and imported goods. The expression for aggregate price index is given by Equation 6.

$$P_t \equiv \left[ (1-\alpha)P_t^d^{1-\kappa} + \alpha P_t^m^{1-\kappa} \right]^{\frac{1}{1-\kappa}} \quad (6)$$

Using the solution of the expenditure minimization problem of households and the aggregate consumption index it can be shown that the domestic demand for imported goods takes the form in Equation 7.

$$C_t^m = C_t \exp(\tau_t)^{-\kappa} \quad (7)$$

$\tau_t$  reflects the price of imports relative to aggregate domestic prices which is defined by Equation 8.

$$\tau_t = \log\left(\frac{P_t^m}{P_t}\right) \quad (8)$$

This means that the domestic demand for imported goods depends negatively on the relative price of imports. Households maximize their expected lifetime utility given by Equation 1 and functional form in Equation 2 subject to the budget constraint given by Equation 9.

$$\begin{aligned} B_t + B_t^* + C_t - \frac{\psi}{2} B_{t-1}^{*2} &= Y_t + (\exp(\nu_t^{px}) - 1)X_t \\ + R_t \frac{P_{t-1}}{P_t} B_{t-1} + R_t^* \frac{S_t P_{t-1}}{S_{t-1} P_t} B_{t-1}^* & \end{aligned} \quad (9)$$

Households receive income from the domestic production  $Y_t$  and exports  $X_t$ . They also receive interest income from their holdings of domestic and foreign bonds carried over from the previous period ( $B_t$  and  $B_t^*$ ). Households spend their income on consumption and the purchase of domestic and foreign bonds. In addition, there is a cost paid by households if they are net borrowers from the rest of the world and it is given by the term  $\frac{\psi}{2} B_{t-1}^{*2}$ . A net zero supply of domestic bonds is assumed and the flow budget constraint is rewritten in the form of Equation 10.

$$B_t^* = R_t^* \frac{S_t P_{t-1}}{S_{t-1} P_t} B_{t-1}^* - \frac{\psi}{2} B_{t-1}^{*2} + \exp(\nu_t^{px})X_t - C_t^m \quad (10)$$

As a result, households maximize their expected lifetime utility Equation 1 with respect to consumption, leisure and assets (domestic and foreign bonds) subject to the flow budget constraint Equation 9. Hence, the optimality conditions of households consist of the intertemporal Euler equation, intratemporal labor supply equation and uncovered interest parity condition are given by Equation 11-13.

$$U_C(C_t) = \beta E_t R_t \frac{P_t U_C(C_{t+1})}{P_{t+1}} \quad (11)$$

$$\frac{W_t}{P_t} = N_t^\phi (C_t + C_{t-1}^{-\eta})^{-\gamma} \quad (12)$$

$$R_t = \exp(\nu_t^r) E_t \left[ \frac{R_t}{\psi B_{t-1}^*} \frac{S_t}{S_{t+1}} \right] \quad (13)$$

where  $\nu_t^r$  is the risk premium of the domestic currency and it follows AR(1) process with the white noise shock  $\varepsilon_t^r$  as shown in Equation 14-15.

$$\nu_t^r = \rho_r \nu_{t-1}^r + \varepsilon_t^r \quad (14)$$

$$\varepsilon_t^r \sim N(0, \sigma_r^2) \quad (15)$$

## 2.2. Firms

The model has two types of firms in the economy: domestic producers and retail importers. Both firms use labor input as a single factor of production to produce goods which are either consumed domestically or exported abroad. Retailers sell imported goods in the domestic market. Both types of firms operate in the monopolistically competitive market. The production function of domestic firms is given by Equation 16.

$$Y_t(j) = \exp(a_t) N_t(j) \quad (16)$$

where  $a_t$  represents the technology of firms and  $N_t(j)$  is the amount of labor used in production by firm  $j$ . It is assumed that technology follows an AR(1) process specified by Equation 17-18 with productivity shocks denoted by  $\varepsilon_t^a$ .

$$a_t = \rho_a a_{t-1} + \varepsilon_t^a \quad (17)$$

$$\varepsilon_t^a \sim N(0, \sigma_a^2) \quad (18)$$

Since all firms operate in monopolistic competition, they have market power whereby they are able to set prices for their differentiated products. Prices are assumed to be rigid in the sense that fractions of  $\theta^d$  and  $\theta^m$  of domestic producers and retailers cannot reset their prices in each period (Calvo, 1983). In addition, it is assumed that the fraction  $\omega$  of firms, which do not reset prices in a given period, link their prices to the inflation rate in the previous period. Hence, there is inflation indexation in the economy. As a result, the equations for the Phillips are given by Equation 19-20.

$$\pi_t^d = \mu_f^d E_t \pi_{t+1}^d + \mu_b^d \pi_{t-1}^d + \lambda^d mc_t^d + \varepsilon_t^\pi \quad (19)$$

$$\pi_t^m = \mu_f^m E_t \pi_{t+1}^m + \mu_b^m \pi_{t-1}^m + \lambda^m mc_t^m + \varepsilon_t^\pi \quad (20)$$

$\pi_t^d$  and  $\pi_t^m$  are inflation rates of domestically produced and imported goods respectively.  $mc_t^d$  and  $mc_t^m$  are marginal costs of domestic producers and retailers whereas  $\varepsilon_t^\pi$  is a Gaussian white noise representing an inflation

shock. Marginal costs of domestic firms are given by the ratio of real wage to productivity of labor whereas marginal costs of retailers is defined by Equation 21.

$$mc_t^m = \log\left(\frac{S_t P_t^*}{P_t}\right) \quad (21)$$

The parameters in the equations for the Phillips curve are functions of the structural parameters of the model as in Galí and Gertler (1999) and given by Equations 22-25.

$$\mu_f^s \equiv \frac{\beta\theta^s}{\theta^s + \omega(1-\theta^s(1-\beta))} \quad (22)$$

$$\mu_f^s \equiv \frac{\beta\theta^s}{\theta^s + \omega(1-\theta^s(1-\beta))} \quad (23)$$

$$\mu_b^s \equiv \frac{\omega}{\theta^s + \omega(1-\theta^s(1-\beta))} \quad (24)$$

$$\lambda^s \equiv \frac{(1-\omega)(1-\theta^s)(1-\beta\theta^s)}{\theta^s + \omega(1-\theta^s(1-\beta))} \quad (25)$$

for  $s \in \{d, m\}$ . So, the aggregate inflation rate in the economy is the weighted-average of price inflation of domestic and imported goods as shown by Equation 26.

$$\pi_t = (1-\alpha)\pi_t^d + \alpha\pi_t^m \quad (26)$$

### 2.3. Exports

A special treatment is given to exports due to the dependence of the Kazakhstani economy on primary exports. The share of exports in GDP was at 36.8% in 2018. In addition, historical shocks to the prices of primary products led to the volatility in exports outlining the dependence of the economy not only on the volume of exports but also on the income received from exports. Therefore, two equations are specified on exports side of the model: exports volume and exports income given by Equation 27-28,

$$X_t = \exp(u_t^x) \left(\frac{P_t^d}{P_t^*}\right)^{\kappa_x} Y_t^* \quad (27)$$

$$Y_t^x = \exp(u_t^{p^x}) X_t \quad (28)$$

where the demand for exports,  $X_t$ , negatively depends on the relative prices of domestic and foreign goods but positively depends on foreign output.  $u_t^x$  and  $u_t^{p^x}$  are export demand shocks (real) and shocks to the prices of

exports (nominal). Hence,  $Y_t^x$  represents the income from exports whereas  $V_t^{px}$  reflects fluctuations in the prices of primary products that are exogenous in the model. It is assumed that both shocks are AR(1) processes with white shocks, and these are given by Equation 29-32.

$$U_t^x = \rho_x U_{t-1}^x + \varepsilon_t^x \quad (29)$$

$$\varepsilon_t^x \sim N(0, \sigma_x^2) \quad (30)$$

$$U_t^{px} = \rho_{px} U_{t-1}^{px} + \varepsilon_t^{px} \quad (31)$$

$$\varepsilon_t^{px} \sim N(0, \sigma_{px}^2) \quad (32)$$

Resource-dependent economies tend to be affected by both of these shocks, but their fundamental sources are clearly different. The first one could be driven by the discovery of oil rigs, sanctions and trade barriers whereas the second shock is apparently driven by the world prices of export goods of the economy. Hence, business cycle fluctuations due to these shocks should be distinguished.

#### 2.4. Central Bank

The Taylor rule is introduced into the model to describe the conduct of monetary policy of the central bank. A systematic part of the monetary policy is determined by the weighted average of lagged interest rate and lagged values of output gap and inflation rate.  $\varepsilon_t^{IR}$  is a surprise monetary policy shock that is a white noise process with zero mean and variance  $\sigma_{IR}^2$ . The Taylor rule is given by Equation 33.

$$i_t = \rho_{IR} i_{t-1} + (1 - \rho_{IR})(\phi_y y_{t-1} + \phi_\pi \pi_{t-1} + \phi_s \Delta s_t) + \varepsilon_t^{IR} \quad (33)$$

#### 2.5. Foreign Economy

Finally, the model's general equilibrium is closed by specifying equations for foreign economy variables. In this case, the Russian economy is assumed to be the foreign economy with output gap, inflation rate and interest rate variables following VAR(1) process given by Equation 34-35.

$$\mathbf{W}_t = A\mathbf{W}_{t-1} + \varepsilon_t^* \quad (34)$$

$$\varepsilon_t^* \sim N(\mathbf{0}, \Sigma^*) \quad (35)$$

where  $\mathbf{W}_t$  is a vector containing output gap, inflation rate and interest rate variables in Russia whereas  $\varepsilon_t^*$  is assumed to be a vector of structural shocks in the Russian economy. It is assumed that only the shocks to output gap in Russia have an impact on the Kazakhstani economy. Finally, optimality conditions, resource constraints and other equations are log-linearized around the steady state to solve the model in terms of state variables and exogenous shock processes. The Uhlig's toolkit is used to solve the log-linearized rational expectations model in the form of Equations 36-37.

$$\mathbf{x}_t = D\mathbf{x}_{t-1} + G\varepsilon_t \quad (36)$$

$$\mathbf{y}_t = H\mathbf{x}_{t-1} + Q\boldsymbol{\varepsilon}_t \quad (37)$$

$\mathbf{x}_t$  is a vector of endogenous state variables whereas  $\mathbf{y}_t$  is a vector of control variables of the model.  $\boldsymbol{\varepsilon}_t$  is a vector of 8 structural shocks in the model: consumption preference shock, risk premium shock, productivity shock, domestic inflation shock, export income shock, export volume shock, monetary policy shock and foreign output shock. Historical contributions of each of these shocks to output gap and inflation rate shall be given in later sections.

### 3. ESTIMATION

The rational expectations solution of the model given by Equation 36 and Equation 37 are estimated via Bayesian methods. The main advantage of Bayesian approach is that it allows to use external information on parameters as priors in the estimation. These priors might be beliefs of a researcher or the knowledge from other studies in the literature. As a result, our knowledge on priors are updated via Bayes' probability that states.

$$P(\boldsymbol{\theta} | \mathbf{Y}^T) = \frac{P(\mathbf{Y}^T | \boldsymbol{\theta})P(\boldsymbol{\theta})}{P(\mathbf{Y})} \quad (38)$$

Where  $\boldsymbol{\theta}$  is a vector of model parameters whereas  $\mathbf{Y}^T$  represents the data observed over the entire sample.

The purpose of Bayesian estimation is to obtain the posterior distribution of parameters,  $P(\boldsymbol{\theta} | \mathbf{Y}^T)$ , given the likelihood function  $P(\mathbf{Y}^T | \boldsymbol{\theta})$  and the priors of parameters  $P(\boldsymbol{\theta})$ . The denominator of Equation 38 can be ignored for the purposes of Bayesian estimation since there is no  $\boldsymbol{\theta}$  appearing in this term. Hence, the posterior density is proportional to the product of the likelihood and prior as shown by Equation 39.

$$P(\boldsymbol{\theta} | \mathbf{Y}^T) \propto P(\mathbf{Y}^T | \boldsymbol{\theta})P(\boldsymbol{\theta}) \quad (39)$$

In order to conduct Bayesian estimation there is a need to convert the solution of the model given by Equation 36 and Equation 37 into state space representation of the following form:

$$\mathbf{Z}_t = \Psi_0 + \Psi_1 \mathbf{s}_t + \nu_t \quad (40)$$

$$\mathbf{s}_t = \Phi_1(\boldsymbol{\theta})\mathbf{s}_t + \Phi_\varepsilon(\boldsymbol{\theta})\boldsymbol{\varepsilon}_t \quad (41)$$

where Equation 40-41 form the state space system in which the former is called the state equation and the latter is the measurement equation.  $\mathbf{Z}_t$  represents the vector of observable variables whereas  $\mathbf{s}_t$  is the vector of state variables from the model. If some variables in  $\mathbf{Z}_t$  appear in growth rates, there is a need to adjust the vector of state variables accordingly, so that the mapping from the state variables to the observable variables is consistent. Hence, the state vector  $\mathbf{s}_t$  is augmented by the lagged values of some state variables using a suitably chosen matrix  $M$ . Hence, the new state vector is given by Equation 42.

$$\boldsymbol{\zeta}_t = (\mathbf{s}_t', \mathbf{s}_{t-1}' M')' \quad (42)$$



Hence, the state space system consistent with the model state variables and growth rate of observable variables is given by

$$\zeta_t = \Phi_1'(\theta)\zeta_{t-1} + \Phi_\varepsilon'(\theta)\varepsilon_t \quad (43)$$

$$\mathbf{Z}_t = \Psi_0' + \Psi_1'\zeta_t + \mathbf{e}_t \quad (44)$$

where  $\varepsilon_t$  is a vector structural shocks of the model and  $\mathbf{e}_t$  is a vector of measurement errors. The state space system given by Equation 43 and Equation 44 is used in the Kalman filter to calculate the likelihood of the model.

A random-walk Metropolis-Hastings algorithm from the family of Markov Chain Monte Carlo (MCMC) methods is used to derive the numerical posterior densities of the structural parameters of the model. The joint posterior of structural parameters is approximated by Equation 39.

#### 4. DATA

Quarterly data is used in the estimation of the model over the period from 2002:Q1 to 2018:Q4. The data on output, consumption, exports, inflation rate, nominal exchange rate and foreign economy variables are used in the measurement equation. The official macroeconomic data on Kazakhstan tend to be noisy and subject to measurement errors. Hence, the data on output, consumption and exports used in this model are taken from the adjusted dataset of NAC Analytica<sup>1</sup>. Inflation rate and nominal exchange rate are taken from the website of the National Bank of the Republic of Kazakhstan. The data on output, inflation rate and interest rate in Russia are obtained from the Russian Federal State Statistics Service and the Central Bank of Russia. The time series observable variables are shown in Appendix Figure 8. Most of the variables in the dataset are deseasonalized using Census X-13<sup>2</sup>. The data on output and inflation rate are used in annual growth rates in the measurement equation whereas exports, imports and nominal exchange rate are specified in quarterly growth rates. Output gap and inflation rate for Russia are detrended via Hodrick-Prescott filter before using it in the measurement equations whereas interest rates are specified in annual terms. The measurement equations of the model are given by Equation 45.

$$\begin{aligned} c_t^{Data} &= \bar{y}_c + c_t - c_{t-1} + e_t^c \\ \pi_t^{Data} &= \bar{\pi} + 4\pi_t + e_t^\pi \\ s_t^{Data} &= \bar{s} + s_t - s_{t-1} + e_t^s \\ y_t^{Data} &= \bar{y}_y + 4(y_t - y_{t-1} + a_t) + e_t^y \\ i_t^{Data} &= 4(\bar{i} + i_t) + e_t^i \\ x_t^{Data} &= \bar{y}_x + x_t - x_{t-1} + e_t^x \\ c_t^{m,Data} &= \bar{y}_m + c_t^m - c_{t-1}^m + e_t^m \\ y_t^{*,Data} &= y_t^* + e_t^{y*} \\ \pi_t^{*,Data} &= \pi_t^* + e_t^{\pi*} \\ i_t^{*,Data} &= 4(\bar{i}^* + i_t^*) + e_t^{i*} \end{aligned} \quad (45)$$

<sup>1</sup> NAC Analytica is a non-commercial research organization in Kazakhstan. Since the data on output and expenditure components of GDP are subject to large measurement errors and other inaccuracies, they use the official data from the Statistics Committee and adjust it for the purposes of obtaining more reliable and consistent dataset (see Abilov, Tolepbergen and Weyerstrass, (2019)).

<sup>2</sup> Census X-13 is the model of the FRB for deseasonalization.

Measurement errors are added into the observation equations to account for inaccuracies in the data as well as in the detrending technique. As the state space system is fully specified the log-likelihood of the model can be calculated for the draws of parameters from the multivariate normal proposal density. Since the final goal of Bayesian estimation is to obtain posteriors, I specify priors of the parameters to get the posterior distribution in Equation 39.

#### 4.1. Calibration of Parameters and Priors

Most of the structural parameters of the model are estimated and other parameters have been calibrated using empirical data. The calibrated structural parameters are subjective discount rate,  $\beta$ ; the share of imports in the consumption bundle of households,  $\alpha$ , and the debt cost coefficient,  $\psi$ . The subjective discount rate is set to a common value of 0.99 whereas the share of imports in consumption is 0.35 in line with the mean value of the imports to GDP ratio in Kazakhstan over 2001 and 2018. The debt cost coefficient is set to 0.01 which is the value of the prior mean of the coefficient in Nimark (2009). In addition, there are steady state values of the observed variables in the measurement equations that are set to their sample means from the data.

The values of calibrated structural parameters, steady states of observed variables and distributions of measurement errors are given in Table 1. Means of measurement errors are set to 0 whereas variances are assumed to be equal to 0.05 to fit the observed data.

**Table-1.** Calibrated parameters, steady state values and distribution of measurement errors.

Structural parameter	Parameter notation	Parameter values
Subjective discount factor	$\beta$	0.990
Share of imports in the consumption basket	$\alpha$	0.300
Debt cost coefficient	$\psi$	0.010
Steady state consumption growth	$\gamma_c$	0.020
Steady state inflation rate	$\bar{\pi}$	0.080
Steady state nominal exchange rate	$\bar{s}$	0.002
Steady state output growth	$\bar{\gamma}_y$	0.058
Steady state export growth	$\bar{i}$	0.010
Steady state import growth	$\bar{i}$	0.013
Steady state interest rate	$\bar{i}$	0.070
Steady state output gap in Russia	$\bar{y}^*$	0
Steady state inflation rate in Russia	$\bar{\pi}^*$	0
Steady state interest rate in Russia	$\bar{i}^*$	0.090
Measurement error	Distribution	
$e_{c,Data,t}$	$N(0,0.05)$	
$e_{\pi,Data,t}$	$N(0,0.05)$	
$e_{s,Data,t}$	$N(0,0.05)$	
$e_{y,Data,t}$	$N(0,0.05)$	
$e_{i,Data,t}$	$N(0,0.05)$	
$e_{x,Data,t}$	$N(0,0.05)$	
$e_{y,Data,t}^*$	$N(0,0.05)$	

The rest of the parameters are given priors in line with the beliefs and knowledge from the literature. There is not much reliable and good quality literature on the structural parameters of the Kazakhstani economy. Adilkhanova (2019) is one of the few works that estimates structural parameters for Kazakhstan using micro level data. According to this study, the intertemporal elasticity of substitution ( $1/\gamma$ ) is equal to 0.37 that makes  $\gamma$  equal to 2.71. The Frisch elasticity of labor supply ( $\varphi$ ) turns out to be 1.98 and 2.11 depending on whether hours worked or labor units are used in the regression model. Hence, the values of 2.71 and 1.98 are taken as prior means for the parameters of interest ( $\gamma$  and  $\varphi$ ). Other prior distributions and means are set in line with the literature on Bayesian estimation of DSGE models.

Table-2. Prior distributions, means and variances of parameters.

Parameter	Parameter notation	Type	Mean	Std
Habit persistence	$\eta$	Beta	0.5	0.050
Constant relative risk aversion	$\gamma$	Gamma	2.71	0.063
Frisch elasticity of labor supply	$\varphi$	Normal	1.98	0.100
Demand elasticity of consumption	$\kappa$	Normal	1	0.100
Demand elasticity of exports	$\kappa_x$	Normal	1	0.100
Fraction of domestic firms not adjusting prices	$\theta_d$	Beta	0.75	0.040
Fraction of importers not adjusting prices	$\theta_m$	Beta	0.50	0.040
Fraction of firms indexing prices to past inflation	$\omega$	Beta	0.50	0.100
Interest rate persistence in Taylor rule	$\rho_{IR}$	Beta	0.50	0.050
Coefficient of output gap in Taylor rule	$\phi_y$	Normal	0.50	0.065
Coefficient of inflation rate in Taylor rule	$\phi_\pi$	Normal	2.50	0.065
Coefficient of exchange rate in Taylor rule	$\phi_\pi$	Normal	0.42	0.05
Autoregressive coefficient of risk premium shock	$\rho_r$	Beta	0.50	0.100
Autoregressive coefficient of productivity shock	$\rho_a$	Beta	0.50	0.100
Autoregressive coefficient of exports income shock	$\rho_{px}$	Beta	0.50	0.100
Autoregressive coefficient of exports volume shock	$\rho_x$	Beta	0.50	0.100
Std of consumption shock	$\sigma_c$	Inv. Gamma	0.50	0.250
Std of risk premium	$\sigma_r$	Inv. Gamma	0.50	0.250
Std of productivity shock	$\sigma_a$	Inv. Gamma	0.50	0.250
Std of inflation shock	$\sigma_\pi$	Inv. Gamma	0.50	0.250
Std of export income shock	$\sigma_{px}$	Inv. Gamma	0.50	0.250
Std deviation of export volume shock	$\sigma_x$	Inv. Gamma	0.50	0.250
Std of monetary policy shock	$\sigma_{IR}$	Inv. Gamma	0.50	0.250
Std of output shock in Russia	$\sigma_y^*$	Inv. Gamma	0.50	0.250

Table 2 presents assumptions on prior distributions of the structural parameters of the model. The parameters that strictly lie in the interval  $(0,1)$  are assumed to have beta distributions as priors whereas standard deviations of shocks have inverse gamma distributions. Other parameters have either a normal or gamma distribution depending on the beliefs on the shapes of prior distributions.

Finally, the likelihood and priors are combined to run the Metropolis-Hastings algorithm to obtain numerical posteriors of the structural parameters. The algorithm is run 3,000,000 times with 20% of the simulation used as a burnin sample.

## 5. RESULTS

The results from the MCMC draws of structural parameters with the starting 20% of the simulation being discarded as a burnin sample are summarized by the posterior distributions of structural parameters of the model in Figure 1-3. The acceptance rate of the simulation is 0.289 which is in the optimal range of 0.2-0.4 indicated in the literature on Bayesian estimation. Table 3 presents means and standard deviations of posterior distributions of the structural parameters of the model. It shows us that posterior means of structural parameters significantly differ from the prior means except for the coefficient of output gap in Taylor rule. The coincidence of the posterior and the prior can be explained by the actual coefficient of output gap coinciding with the prior mean, because the National Bank of the Republic of Kazakhstan had indeed used the coefficient of output gap in Taylor rule equal to 0.5 in 2017. It is possible that the central bank used this value of the coefficient for the period before and after 2017. Parameters such as habit persistence, Frisch elasticity of labor supply and the fraction of domestic firms not adjusting prices substantially differ from their priors as shown in Figure 1 and 2. It is interesting to notice that the standard deviation of export income shock is large relative to the standard deviation of other shocks, meaning that the shocks to export prices tend to be more volatile. Overall, the posterior distributions are smooth which is a sign of convergence of MCMC simulation.

The dynamics of state variables of the model calculated by Kalman smoother are presented in Figures 9-10 in Appendix. The deviation of consumption from its steady state has been positive for the most period between 2006 and 2018. Consumption exceeded its steady state level by more than 5% before the decrease in oil prices in 2014, but it fell significantly afterwards and reached -5% in 2018. This implies that the welfare of households in the economy has fallen over the last 5 years. Figure 9 shows that the inflation rate of imported goods has been more volatile than the inflation rate of domestic goods. Output gap substantially declined during the Great Recession and the oil price decline in 2015. Consumption and output gap have similar dynamics over the period and the correlation is equal to 0.86. The relative price of imports in terms of domestic goods fell during 2009 and 2015 when the price of primary products was in free fall.

Figure 11 presents structural shocks of the model. Consumption shocks have been volatile than other shocks in the model whereas risk premium shocks have been least volatile but positive. Export volume and monetary policy shocks have been smaller in magnitude than other shocks. It can also be observed that there are large upward and downward spikes in export volume and export income shocks that are relevant in determining domestic economic conditions. These spikes correspond to the periods of instability due to the economic crisis of 2009 and the speculative attack of 2015.

Table-3. Prior means, posterior means and variances of parameters.

Parameter	Parameter notations	Prior mean	Posterior mean	Posterior standard deviation
Habit persistence	$\eta$	2	1.875	0.101
Constant relative risk aversion	$\gamma$	2.71	2.490	0.249
Frisch elasticity of labor supply	$\varphi$	1.98	2.370	0.224
Demand elasticity of consumption	$\kappa$	1	1.059	0.091
Demand elasticity of exports	$\kappa_x$	1	0.736	0.096
Fraction of domestic firms not adjusting prices	$\theta_d$	0.75	0.679	0.044
Fraction of importers not adjusting prices	$\theta_m$	0.5	0.524	0.038
Fraction of firms indexing prices prices to past inflation	$\omega$	0.5	0.289	0.078
Interest rate persistence	$\rho_{IR}$	0.5	0.558	0.047
Coefficient of output gap in Taylor rule	$\phi_y$	0.5	0.438	0.063
Coefficient of inflation rate	$\phi_\pi$	2.5	2.497	0.062
Coefficient of exchange rate in Taylor rule	$\phi_\pi$	0.42	0.453	0.049
Autoregressive coefficient of risk premium shock	$\rho_r$	0.5	0.353	0.073
Autoregressive coefficient of productivity shock	$\rho_a$	0.5	0.384	0.086
Autoregressive coefficient of export income shock	$\rho_{px}$	0.5	0.465	0.0961
Autoregressive coefficient of export volume shock	$\rho_x$	0.5	0.465	0.099
Std of consumption shock	$\sigma_c$	0.5	0.031	0.004
Std of risk premium	$\sigma_r$	0.5	0.043	0.006
Std of productivity shock	$\sigma_a$	0.5	0.031	0.004
Std of inflation shock	$\sigma_\pi$	0.5	0.026	0.004
Std of export income shock	$\sigma_{px}$	0.5	0.21	0.069
Std deviation of exports volume shock	$\sigma_x$	0.5	0.060	0.009
Std of monetary policy shock	$\sigma_{IR}$	0.5	0.028	0.004
Std of output shock in Russia	$\sigma_y^*$	0.5	0.032	0.004

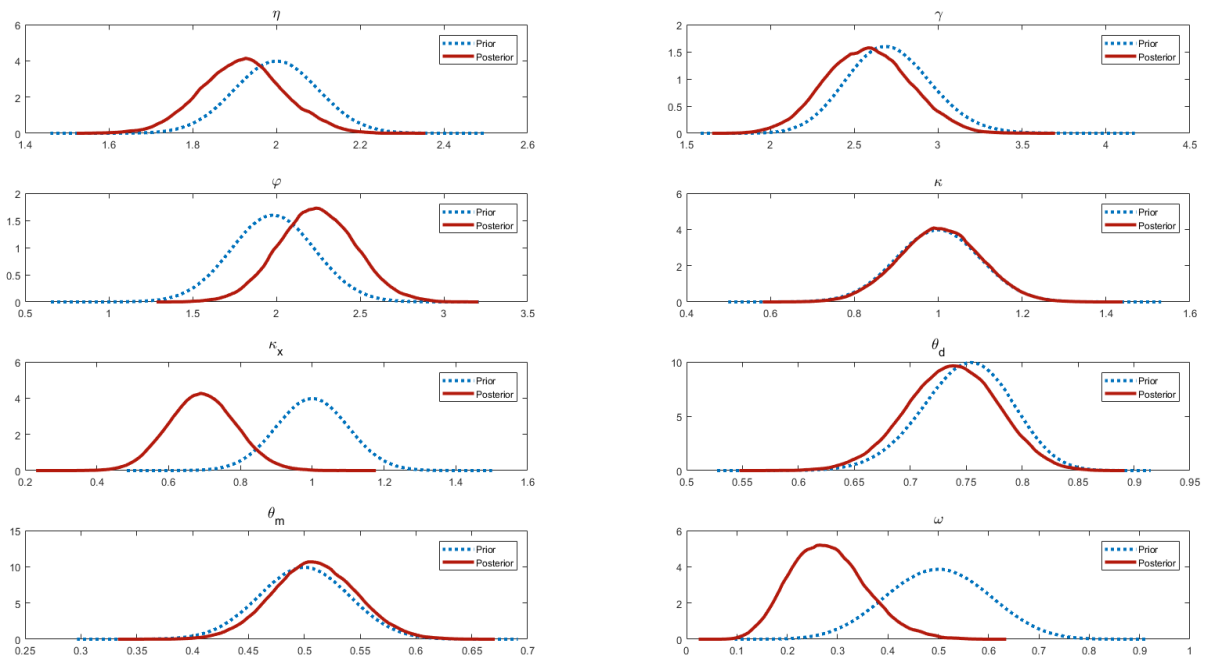


Figure-1. Posterior and prior distributions of parameters.

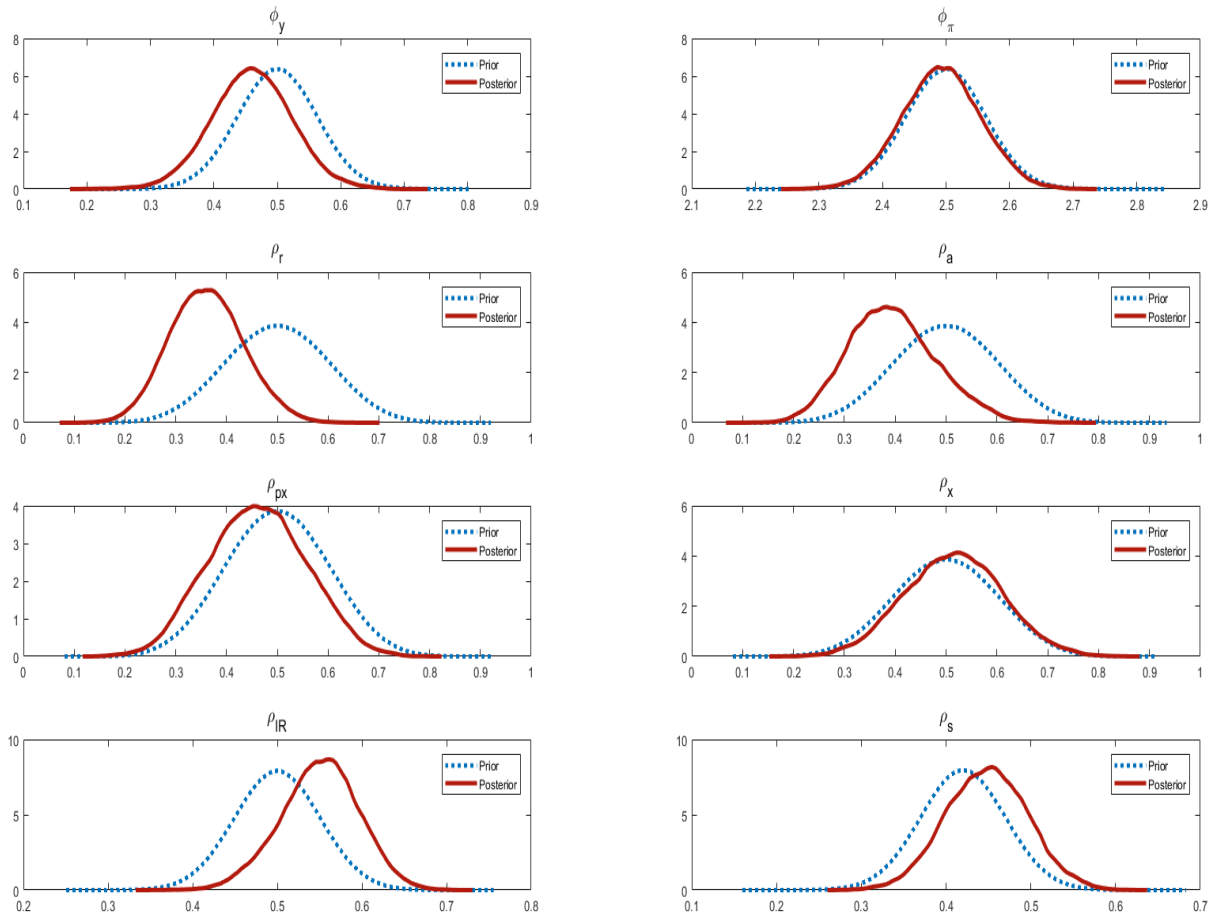


Figure-2. Posterior and prior distributions of parameters.

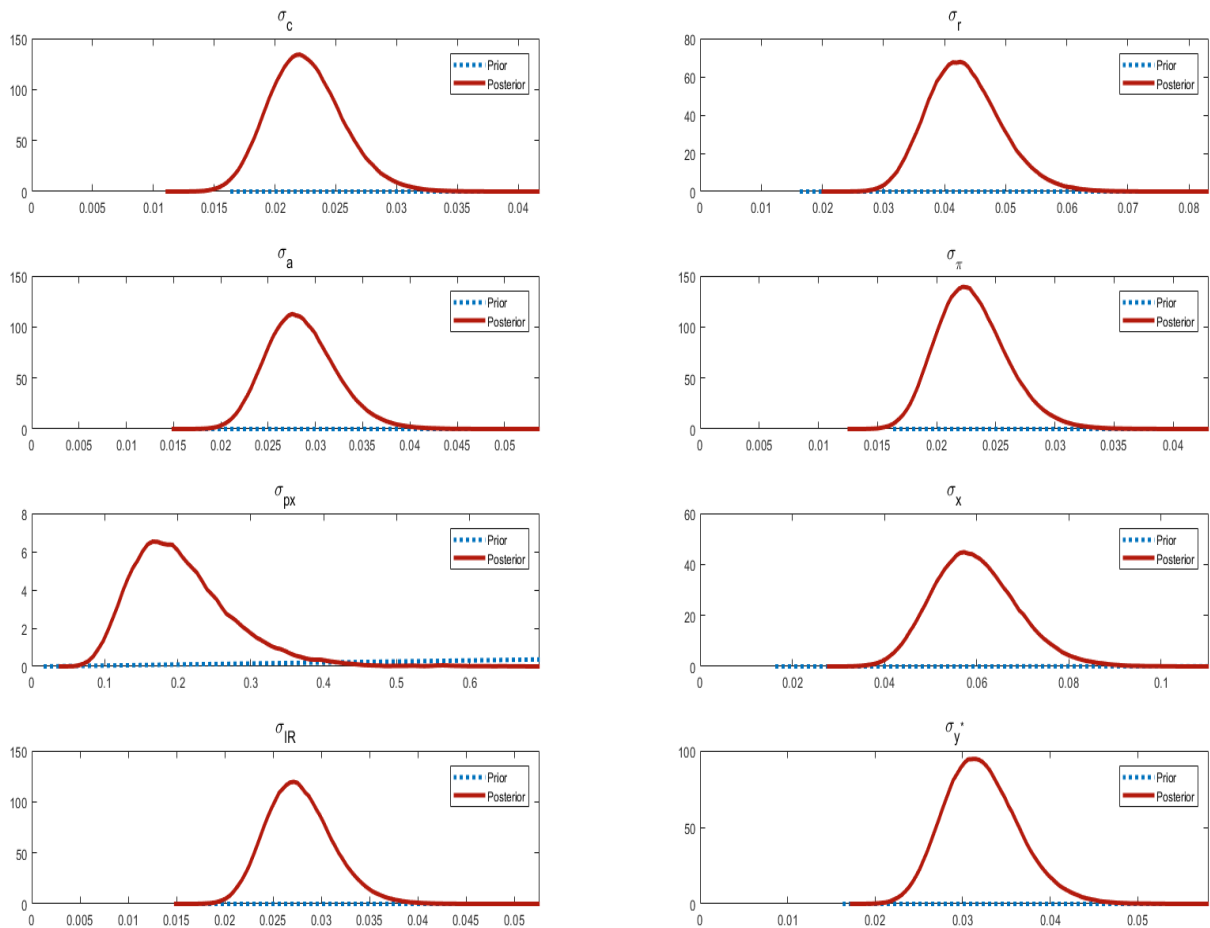


Figure-3. Posterior and prior distributions of parameters.

### 5.1. Historical Decomposition

The historical decompositions of output gap and inflation rate gap are presented in Figures 12 and 13 in Appendix. The dynamics of output gap is interesting in its own right since it clearly depicts the periods of distress in the economy. The output gap was positive before the Great Recession reaching a peak of 3.7%, then it turned negative in the third quarter of 2008 (-1.1%) and reached its trough at -6.5% in the first quarter of 2009. As it is shown in the figure the consumption shock, inflation shock and export price shock contributed to the decline in output gap during the Great Recession. The trough of the economy in 2009 was reached mainly due to negative inflation shocks (aggregate supply shock). The Kazakhstani economy recovered only by the third quarter of 2010 when the output gap turned positive. The main drivers of recovery were expanding foreign output in Russia, loose domestic monetary policy and increasing volume of exports.

The output gap reached 8.3% in the second quarter of 2014, when the oil price peaked at above 140 US dollars per barrel. It is also apparent from the figure that the positive output gap was mainly driven by positive export income shocks due to the rising prices of oil and other primary products. However, the output gap started falling again in 2014 due to the sanctions on Russia and declining oil prices. There was also a speculative attack on the domestic currency in 2014–2015 that led to a higher interest rate in the economy. As a result, there were both risk-premium and monetary policy shocks that made actual output fall below its potential level reaching the lowest level of -3.2% in the fourth quarter of 2016. The output gap recovery has not taken place and it stands at -2.6% in 2018. Exports volume and productivity shocks have contributed negatively to the output gap which was not offset by the positive contribution of inflation and risk premium shocks. Overall, consumption and exports income shocks have been volatile throughout the period and contributed a lot to the changes in output gap in Kazakhstan throughout 2005–2018.

Figure 13 presents the historical decomposition of inflation rate gap. The inflation rate gap has been very stable with only two outbursts in 2008 and 2016. Actual inflation rate exceeded its steady state by 1.7 percentage points in 2008 when the inflation rate skyrocketed up to 20% due to the positive inflation and risk-premium shocks. However, fundamental sources of a large and positive inflation rate gap changed in 2016: consumption, risk-premium, monetary policy and export income shocks contributed to the inflation rate rising above its steady state. As the central bank adopted an inflation targeting regime the inflation rate has settled at its steady state after 2016. The main drivers of inflation rate tend to be consumption, inflation and exports income shocks over the period between 2005 and 2018.

### 5.2. Forecast Error Variance Decomposition

The fraction of the variance of observable variables explained by the structural shocks of the model is presented in Appendix. The forecast error variance decomposition of output gap is presented in Figure 14 which shows us that 43% of variation in GDP growth is due to productivity shocks. Consumption and risk-premium shocks account for another 30% of variation in GDP growth with each shock contributing equally. Monetary policy and export-income shocks contribute around 8% each to the variation in output growth. Figure 15 shows us the forecast error variance decomposition of annual inflation rate, which is almost entirely driven by inflation shocks. Consumption and export volume shocks together account for 20% of variation in inflation rate with each structural shock contributing equally. The most interesting finding concerns the forecast error variance decomposition of monthly changes in the nominal exchange rate of tenge vis a vis Russian ruble. Figure 16 shows us that risk-premium shocks account for almost 60% of the variance of nominal exchange rate whereas monetary policy contributes around 27%. As a result, other structural shocks do not determine much of the variation in the nominal exchange rate. Risk-premium shocks have played a major role in the Kazakhstani economy since there were four major devaluations in the last 10 years that had been preceded by a bulk of uncertainty over the exchange rate. Hence, it makes sense that the forecast error variance decomposition gives us the result which had been frequently observed over the past decade in Kazakhstan.

## 6. POLICY AND SHOCK ANALYSES

One of the main goals of DSGE models has been their use in policy analysis using impulse responses of endogenous variables to structural shocks. Impulse responses of main endogenous variables to structural shocks of the economy are analyzed to explain the underlying transmission mechanisms of shocks and their overall effect on the variables. Figure 4 presents the impulse responses of the variables to a productivity shock in the economy. The figure shows that the productivity shock affects output gap positively and the effect disappears slowly over 20 quarters whereas inflation rate is affected negatively. The interest rate falls upon impact during 4 quarters, then it rises due to the impact of positive output gap outweighing the effect of low inflation rate and strong domestic currency in the Taylor rule. Employment falls during the first 2 quarters, then it rises in line with the real wage in the economy. Consumption of households rises whereas exports fall after the productivity shock and the effects persist for 20 quarters (5 years).

Figure 5 shows the effect of a contractionary monetary policy shock on the endogenous variables. The output gap responds negatively to one standard deviation shock to the central bank interest rate. The effect of monetary policy on output gap becomes negligible after 14 quarters (3.5 years). The inflation rate also responds negatively when the shock arises, but the effect becomes positive and very negligible after 2 quarters implying the ineffectiveness of monetary policy in combating inflation. The exchange rate appreciates and exports fall upon the impact of the monetary policy shock. However, the response of exports becomes positive in the first quarter since the fall in inflation rate leads to a stronger demand for exports. Consumption and employment fall for 12 quarters after the shock to start rising afterwards.



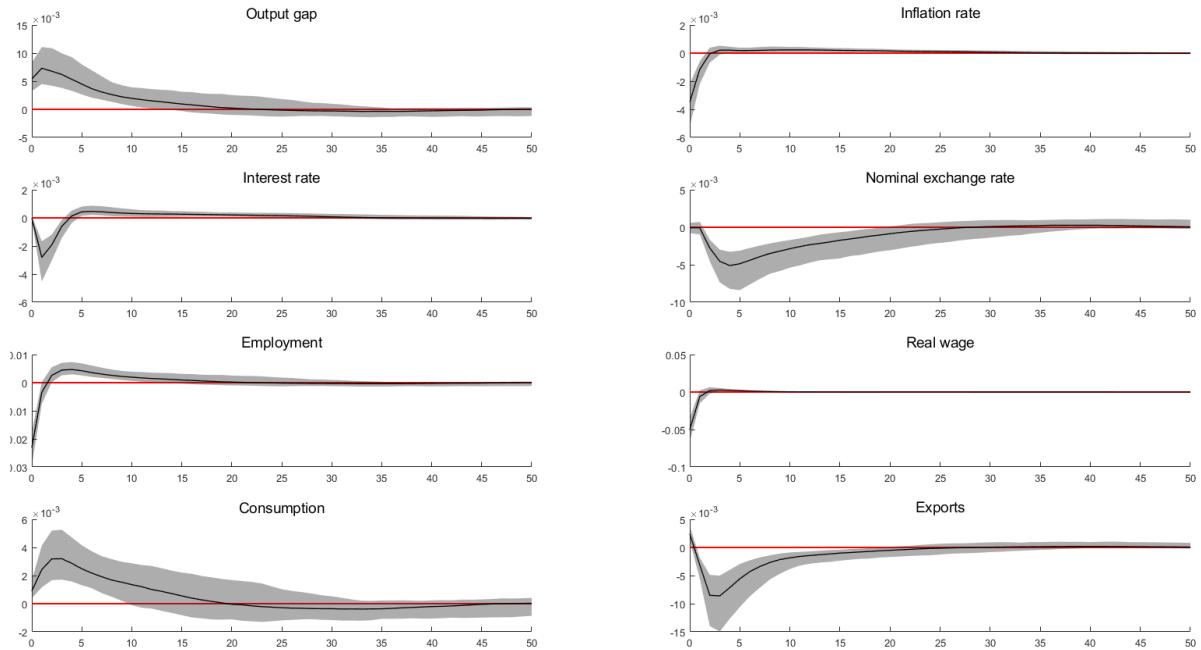


Figure-4. Impulse responses to productivity shock.

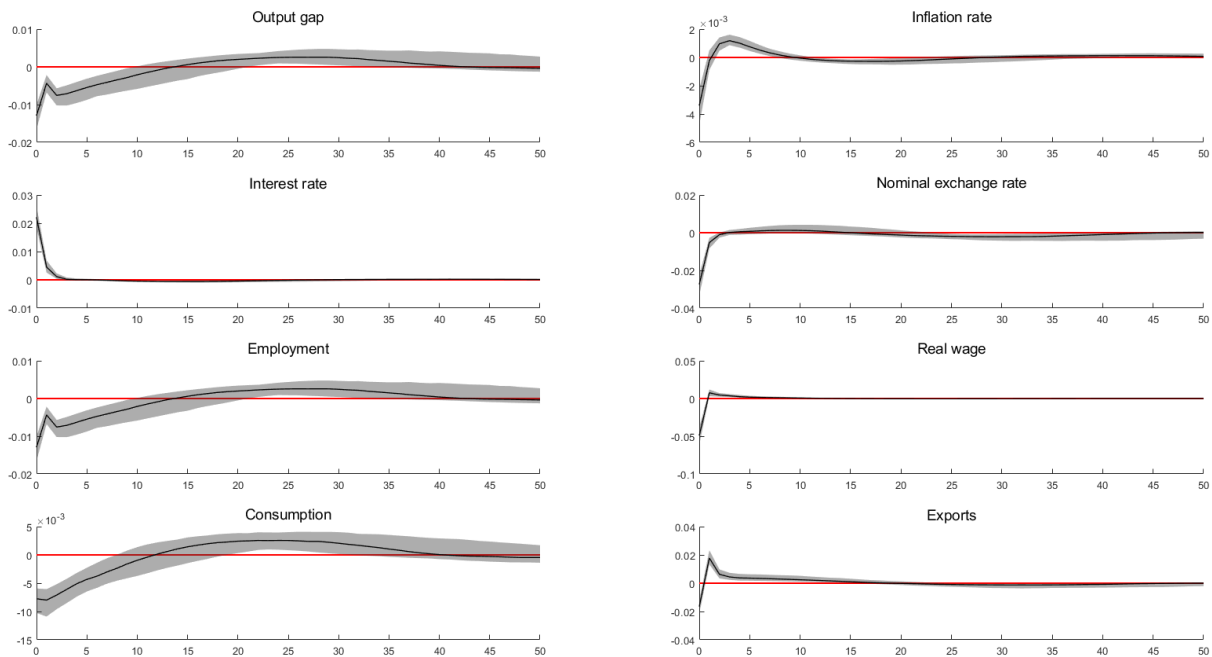


Figure-5. Impulse responses to monetary policy shock.

A positive risk premium shock implies that the return required on domestic bonds rises relative to the interest rate on foreign bonds. As a result, the exchange rate depreciates to compensate for the interest rate differential as shown in Figure 6. Hence, output gap and inflation rate rise upon impact due to the currency depreciation. There are also accompanying increases in employment and exports at the time of the shock. However, the central bank reacts to exchange rate depreciation by raising the domestic interest rate at the same time. The interest rate is raised further by the central bank due to the higher inflation rate. The high domestic interest rate reduces the output gap and lowers the inflation rate in the following quarters. The effect of risk-premium shock on consumption is more persistent. Consumption of households falls at the time of the shock due to the currency depreciation which lowers the consumption of imported goods. The fall in consumption is exacerbated by the increase in domestic interest rate which significantly reduces the consumption for more than 10 quarters.

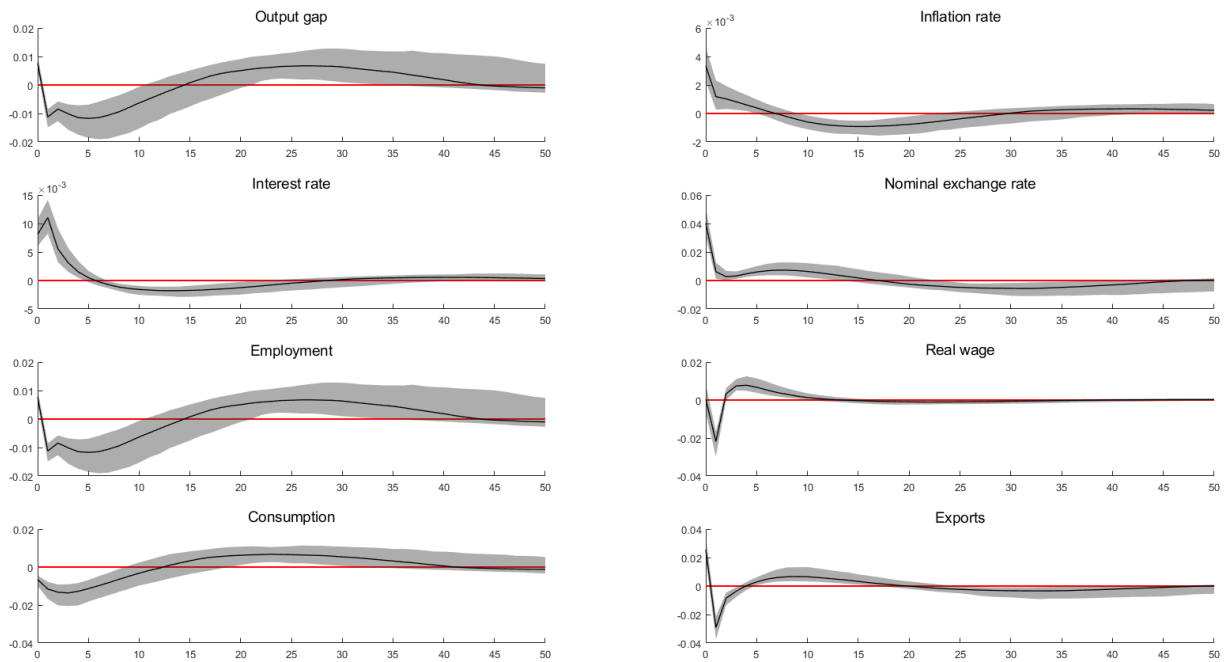


Figure-6. Impulse responses to risk premium shock.

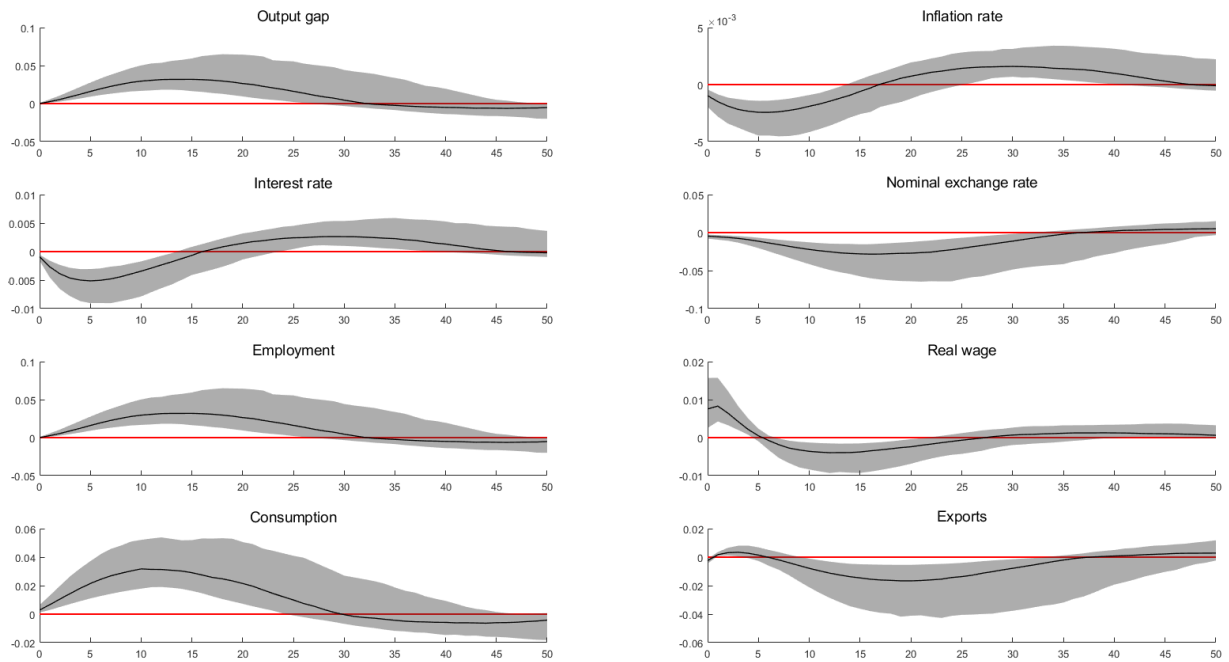


Figure-7. Impulse responses to export price shock.

The effect of exports income shock is shown in Figure 7. A positive exports income shock can also be interpreted as favourable increases in the prices of primary products in the world markets that increase the value of exports. As a result, the output gap, employment and consumption rise significantly over 5 years after the positive exports income shock. However, the inflation rate falls and nominal exchange rate appreciates, since the higher income from exports makes the domestic currency relatively strong. The interest rate is lowered by the central bank in response to lower inflation rate and exchange rate appreciation. Exports rise over 5 quarters due to the relative attractiveness of exporting goods abroad, but the effect on exports turns negative, because the domestic currency strengthens sufficiently enough to offset the positive impact of exports income shock. Employment rises over 20 quarters whereas real wages rise for 5 quarters and start falling negligibly afterwards.

## 7. CONCLUSION

Bayesian analysis has become a workhorse tool in estimating macroeconomic models due its attractive nature of handling large-dimensionality problem of models and the possibility of estimating models even if the time series available is rather short. In this paper, the main contribution to the literature is that this is the first DSGE model for Kazakhstan estimated via Bayesian methods. The model is a small scale version of a family of open economy DSGE models and it captures frictions and shocks relevant for the economy. More specifically, a high degree of export dependence of the economy is taken into account by including export volume and export income shocks. In addition, risk premium shocks have also been given a relevant place in the model due to a series of devaluations that occurred in the economy over the past decade.

The posterior distributions obtained from the simulation via Metropolis-Hastings algorithm exhibit good properties in terms of convergence of the parameters. Most of the posterior distributions have smooth densities and differ from their prior distributions. The state space form of rational expectations solution of the model are used to determine unobservable state variables of the model and assess the contribution of structural shocks. The findings indicate that the estimated output gap has been negative during the Great Recession and oil price declines. It has also been shown that most of the variation in output gap has been due to the consumption and export income shocks. Inflation rate gap has been stable at its steady for the most period with infrequent outbursts in 2008 and 2015. The model allowed us to determine the fundamental sources of two upward spikes in the inflation rate gap, which in the first case was due to pure inflationary shocks, whereas in the second case it was due to consumption, risk premium and export income shocks. It has also been found that productivity shocks account for almost half of the forecast error variance decomposition in observed GDP growth whereas pure inflationary shocks account for 80% of the variance decomposition in inflation rate. The most interesting finding that justifies the effort of including risk premium into the model is that almost 60% of variation in nominal exchange rate comes from risk premium shocks. In addition, the model is used for analyzing the responses of endogenous variables to monetary policy and other relevant shocks. A contractionary monetary policy leads to a decrease in output gap, exchange rate appreciation and a negligible impact on inflation rate. Hence, it is deduced that the monetary policy is rather ineffective in lowering inflation by raising interest rates. Both productivity and export income shocks lead to an expansion of output gap and a decrease in inflation rate, but the effect of export income shock on the economy is more persistent. The effect of risk premium shock is similar to the events that have been observed in 2015, when there was a speculative attack on the currency. The impulse responses of the model shows us that the exchange rate depreciates significantly whereas output decreases and inflation rate rises. The consumption of households decline in response to a higher interest rate and lower purchasing power of domestic currency. Hence, the model precisely predicts the direction of responses of endogenous variables during the speculative attack on the domestic currency in 2015. Overall, the model gives sound results on the fundamental sources of fluctuations in the economy and the transmission mechanisms of structural shocks.

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**Competing Interests:** The authors declare that they have no competing interests.

**Acknowledgement:** All authors contributed equally to the conception and design of the study.

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APPENDIX

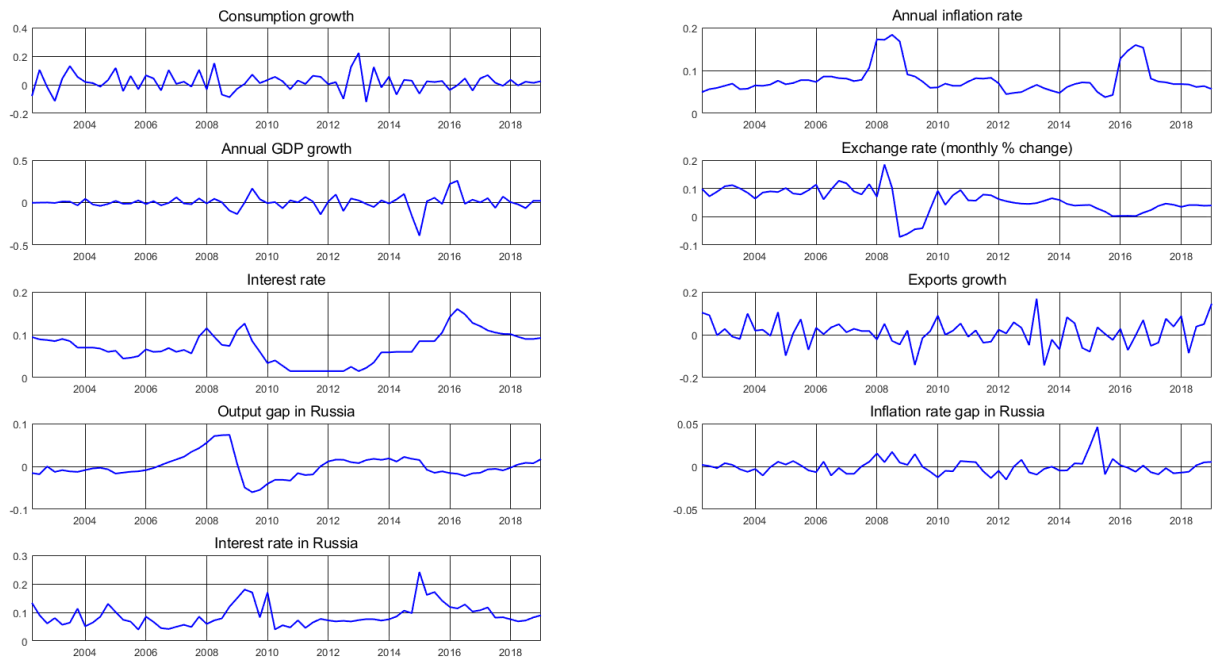


Figure-8. Observable variables of the model.

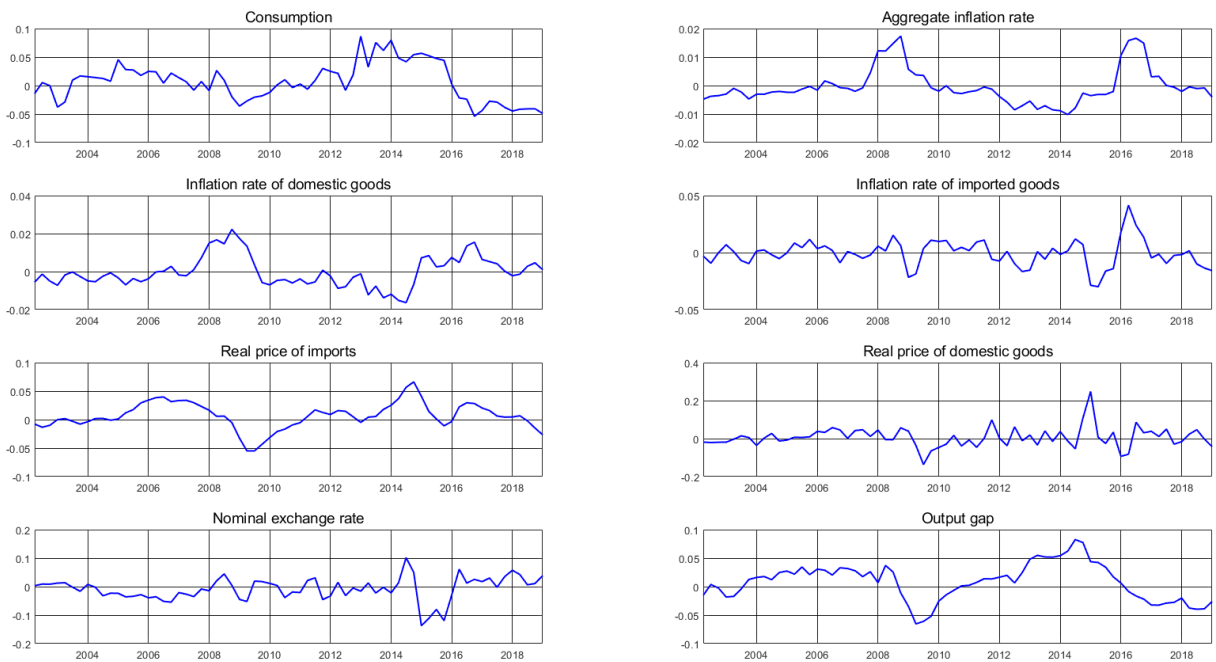


Figure-9. State variables of the model.

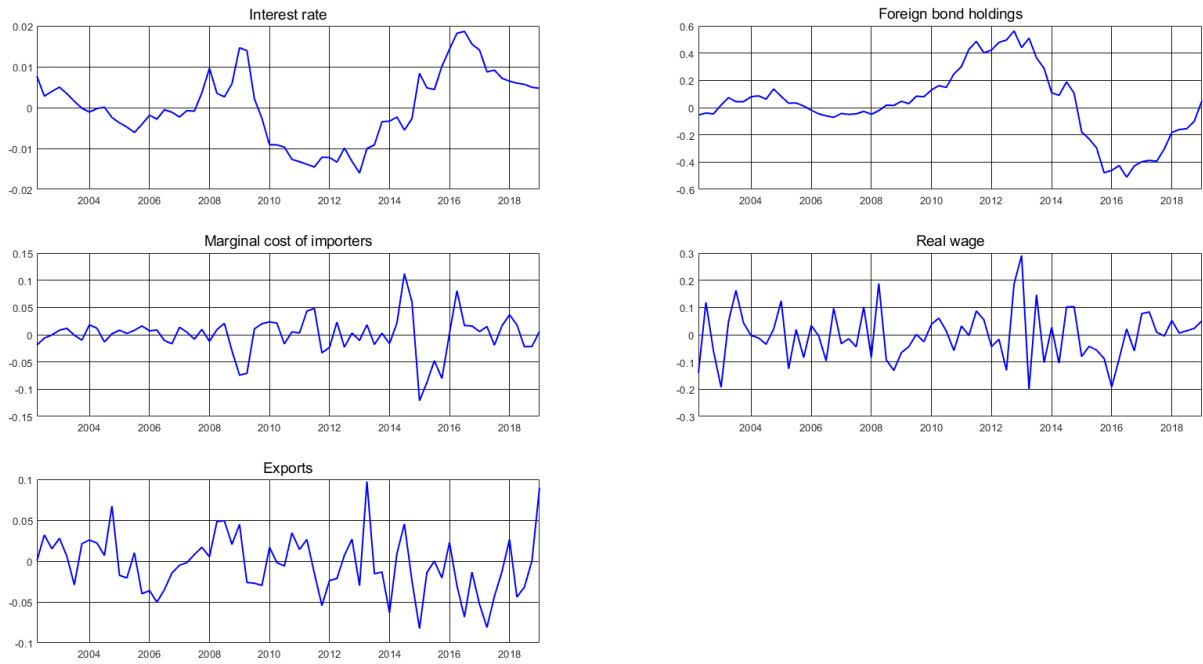


Figure-10. State variables of the model.

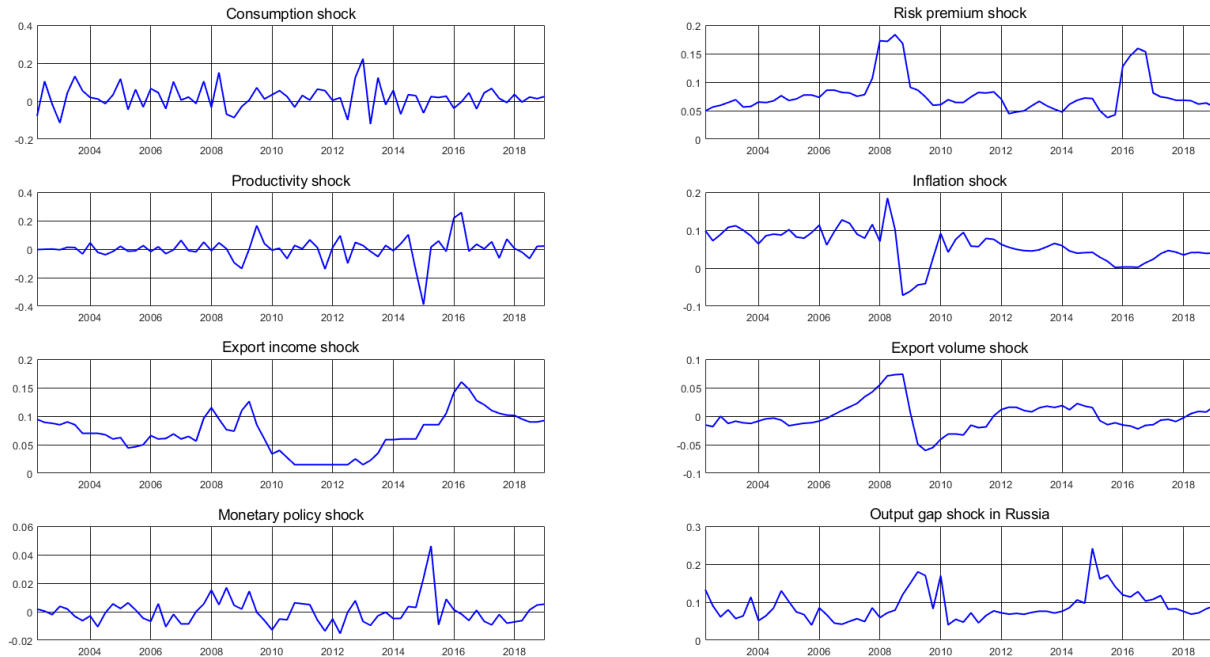


Figure-11. Structural shocks of the model.

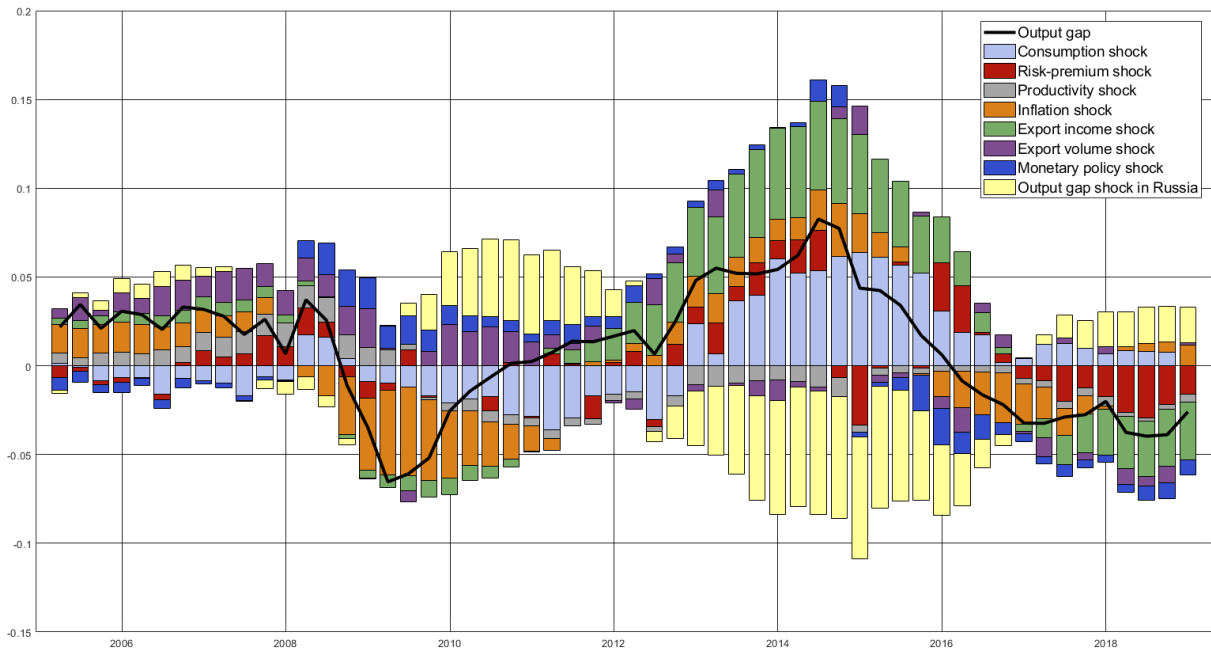


Figure-12. Historical decomposition of output gap.

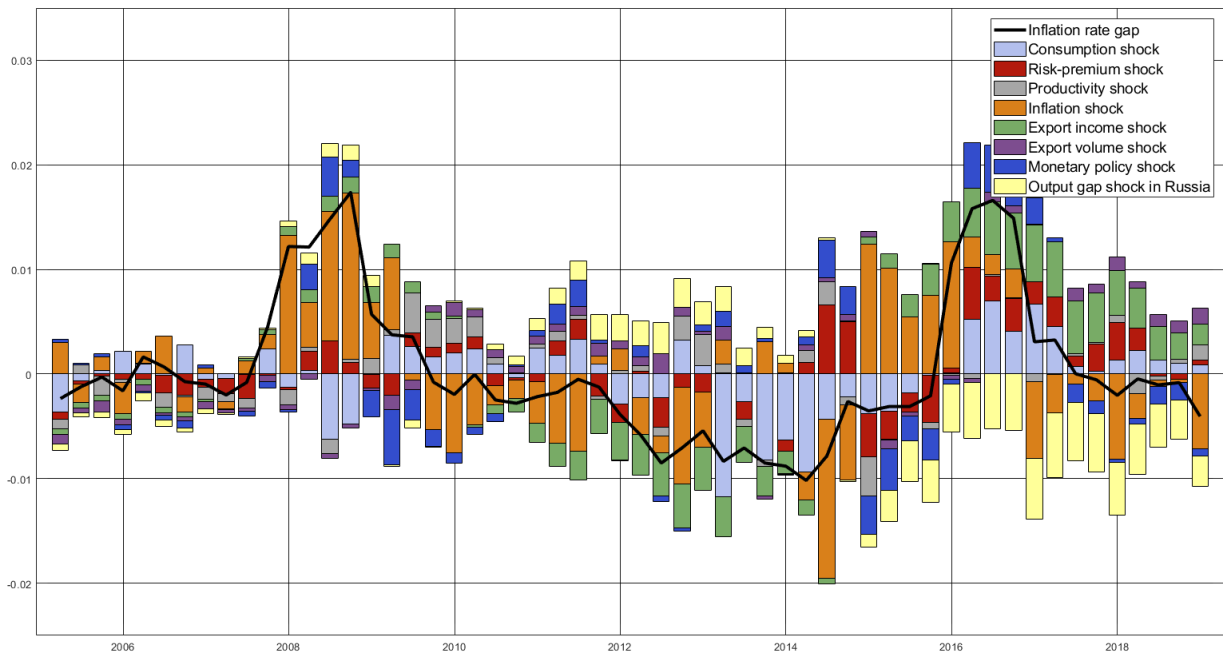


Figure-13. Historical decomposition of inflation rate gap.

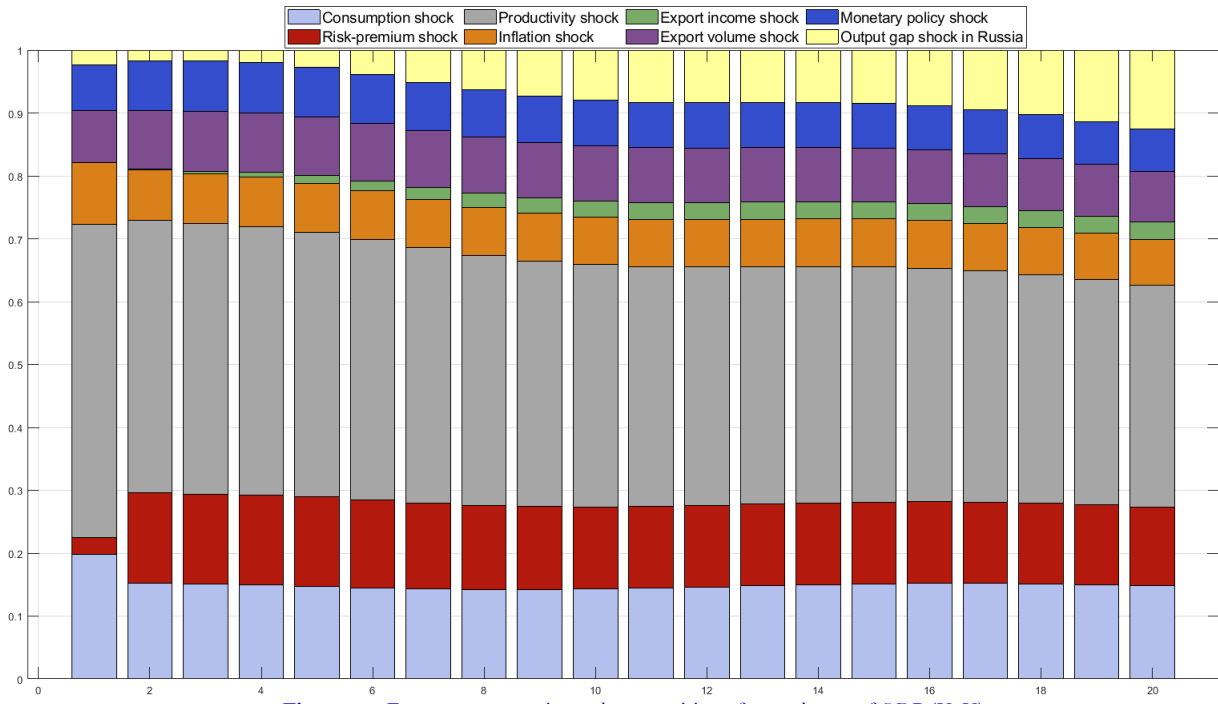


Figure-14. Forecast error variance decomposition of growth rate of GDP (YoY).

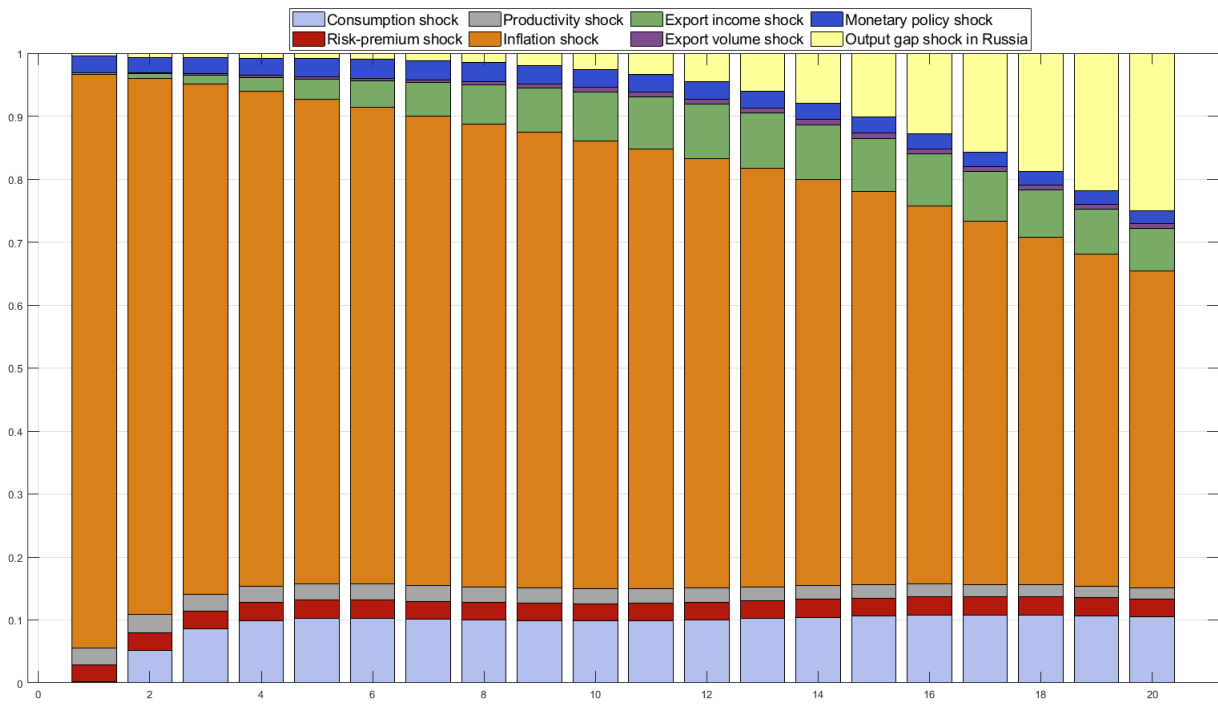


Figure-15. Forecast error variance decomposition of inflation rate.



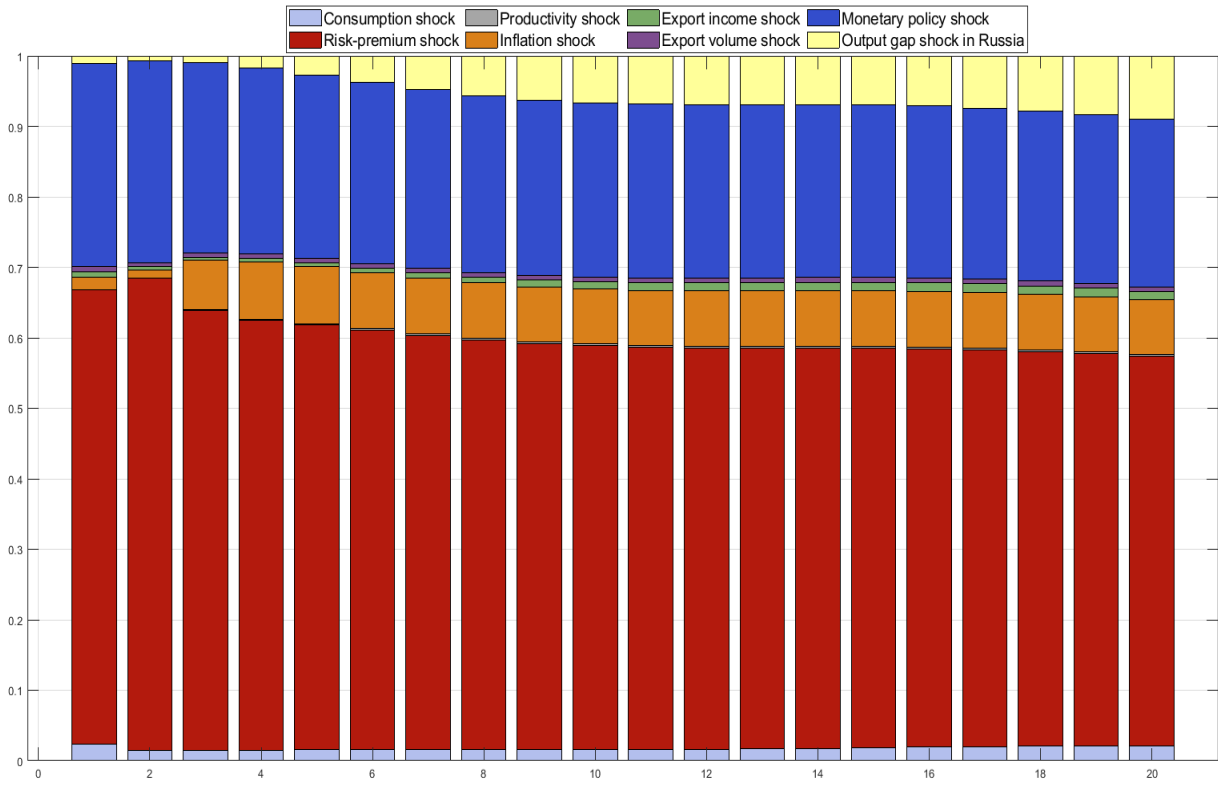


Figure-16. Forecast error variance decomposition of nominal exchange rate.

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