A macroeconometric model for Russia

Bolatbayeva, Aizhan; Tolepbergen, Alisher; Abilov, Nurdaulet

Veröffentlichungsversion / Published Version
Zeitschriftenartikel / journal article

PUBLISHED BY
VOPROSY
EKONOMIKI
N. P.

Russian Journal of Economics 6 (2020) 114–143
DOI 10.32609/j.ruje.6.47009
Publication date: 30 June 2020

Russian
Journal of
Economics

www.rujec.org

A macroeconometric model for Russia

Aizhan Bolatbayeva*, Alisher Tolepbergen, Nurdaulet Abilov

NAC Analytica, Nur-Sultan, Kazakhstan

Abstract

The paper outlines a structural macroeconometric model for the economy of Russia. The aim of the research is to analyze how the domestic economy functions, generate forecasts for important macroeconomic indicators and evaluate the responses of main endogenous variables to various shocks. The model is estimated based on quarterly data starting from 2001 to 2019. The majority of the equations are specified in error correction form due to the non-stationarity of variables. Stochastic simulation is used to solve the model for ex-post and ex-ante analysis. We compare forecasts of the model with forecasts generated by the VAR model. The results indicate that the present model outperforms the VAR model in terms of forecasting GDP growth, inflation rate and unemployment rate. We also evaluate the responses of main macroeconomic variables to VAT rate and world trade shocks via stochastic simulation. Finally, we generate ex-ante forecasts for the Russian economy under the baseline assumptions.

Keywords: macroeconometric model, Cowles Commission approach, structural macroeconomic model, macroeconomic model for Russia, forecasting.
JEL classification: B22, E17, E27.

1. Introduction

In pursuit of accurate macroeconomic forecasting and effective policy analysis, structural macroeconomic models have advanced significantly with the use of more sophisticated computational techniques. The literature contains a variety of structural macroeconometric models for different countries. The common objective of these works is to construct a model which can explain fluctuations in major macroeconomic variables and be used for the purpose of policy analysis. This paper presents a structural macroeconometric model for the economy of Russia. The model has been constructed for the following essential objectives. First, the model gives better insight into the structural relationships between different

* Corresponding author, E-mail address: aizhan.bolatbayeva@nu.edu.kz

macroeconomic variables underpinning the Russian economy. Second, it allows to determine the economic implications of policy changes. Investigating the responses of endogenous variables to various shocks is an additional advantage of a structural macroeconometric model. Third, the model can generate forecasts for main macroeconomic indicators.

Most equations are estimated in error-correction form based on quarterly data starting from 2001 to 2019. Other equations are estimated using Tobit regression and the ARIMA model via the maximum likelihood estimation (MLE) technique. The estimated equations are in line with economic theory and satisfy standard statistical properties by the robustness checks on the residuals. The model is solved for ex-post and ex-ante analysis using a stochastic simulation technique. To demonstrate the properties of the model for using it as a tool for exogenous shock analysis, we conduct two additional simulation exercises. First, we investigate the responses of endogenous variables to an increase in the value added tax (VAT) rate by two percentage points. This issue stands at the top of the agenda at the time of writing this paper since the VAT rate has been raised from 18% to 20% starting from January 1, 2019. Second, we analyze the effect of a negative world trade shock on the Russian economy. In particular, we assume a contraction of the world trade by 5% and show associated changes in real GDP growth, inflation rate, unemployment rate and other relevant macroeconomic variables. Assessing the impact of a world trade shock is relevant because the Russian economy has mostly been dependent on exports of oil and other raw materials. In addition, the macroeconometric model is a useful tool for generating ex-ante forecasts with various assumptions on exogenous variables, and the stochastic simulation technique allows us to construct confidence bands around median forecasts.

The structure of the paper is as follows. Section 2 presents a review of relevant research on macroeconometric modeling and also discusses various versions of macroeconometric models for Russia. In Section 3, we present the data description in detail and discuss the main barriers encountered in the data structuring process. Section 4 presents the main characteristics and structure of the model, including the specification of the equations. The ex-post simulation of the model is discussed in Section 5. Section 6 presents the results of the model under VAT rate and world trade shocks. Section 7 outlines ex-ante forecasts generated for some endogenous variables, and Section 8 provides concluding remarks.

2. Literature review

Tinbergen (1939) was one of the first economists to construct a fully-specified macroeconometric model. His textbook, Business Cycles in the United States, 1919–1932, describes a 48 equations model of the US economy that explains business cycles. The model uses macroeconomic concepts to explain accurately cyclical fluctuations for testing the theories of business cycles and evaluating public policies. The model consists of four blocks: demand for goods and services, supply or price equations for food and services, demand and supply in the money and capital markets, and income formation. The majority of equations are linear in parameters with regression coefficients treated as constant over time. He also studies the model under various scenarios, namely in the presence of stock market boom and hoarding. The last part of his study tests the effects of different policies on the business cycles and briefly discusses the validity of some business cycle theories from the point of view of statistical analysis.

Fair (1984) gives a detailed discussion of macroeconometric model building for the US economy. His methodology allows to determine which model best approximates the structure of the economy. He also emphasizes four primary sources of forecast uncertainty in the model: error terms, coefficient estimates, exogenous variable forecasts and possible misspecification of the model. The model consists of 30 stochastic equations that are estimated via either two-stage least squares (TSLS) or ordinary least squares (OLS). Statistical tests on regression coefficients show that they have expected signs and are significant in line with economic theory. The estimation results of the US model show that the choice of estimator does not make a significant difference. Fair (1984) also analyzes two versions of the US model with the first model containing rational expectations only in the bond market and the other accounting for rational expectations both in the bond and stock markets. He first modifies the US model to be consistent with rational expectations assumption, then examines the sensitivity of the policy properties of the model to this assumption in the bond and stock markets.

One of the models that the Federal Reserve Board used for forecasting and macroeconomic analysis of fiscal and monetary policies was the FRB/US model. A detailed description of the model and its equations is presented in Brayton and Tinsley (1996). The FRB/US is a large-scale structural macroeconometric model of the US economy, which contains around 50 stochastic equations and 250 identities. The model consists of four types of equations: arbitrage equilibria, equilibrium planning, dynamic adjustment, and forecasting. They also discuss different approaches to introducing expectations in the model. One approach is VAR expectations which assumes only limited knowledge about the joint dynamics of the variables. The second approach is full-model expectations that implies expectations to be consistent with the forecasts of the model.

Dreger and Marcellino (2007) build an aggregate macroeconometric model for the Euro economy useful for both forecasting and policy analysis. They use instrumental variables (IV) estimation technique to avoid inconsistent estimates of coefficients which occur due to the presence of endogenous right-hand side variables. One-step forecasts of endogenous variables from static simulations are used as instruments in IV estimation. Thus, the problem of endogeneity is handled appropriately, and estimates of coefficients are consistent. In comparison to the previous version, where Dreger (2003) relies on the two-step procedure suggested by Engle and Granger (1987), this paper employs one step-procedure suggested by Stock and Watson (1993). The paper also compares the forecasting performance of the model to ARIMA and VAR models. For most variables prediction errors of the structural model are smaller than errors of alternative models. Several scenario analyses are simulated within the model, namely, a temporary slowdown in the GDP growth of the US economy, an interest rate shock and sudden currency appreciation.

There also exists literature on macroeconometric modeling for emerging countries including the Russian economy. Abilov et al. (2019) and Weyerstrass et al. (2018) construct macroeconometric models for Kazakhstan and Slovenia respectively. They assess the forecasting performance of the model and generate ex-ante and ex-post forecasts. Aivazian et al. (2017) present a two-part methodology for constructing a disaggregated macroeconomic model of the Russian economy for the period 1990–2010. They conclude that the Russian economy can be theoretically described based on a structural disaggregated model, which in turn can be used for macroeconometric modeling. Benedictow et al. (2010) gives a good treatment of a macroeconometric model of the Russian economy, aimed at evaluating the impact of changes in the oil price and economic policy variables. Two alternative scenarios with different oil prices are discussed in the paper. Although the results show substantial output growth in the absence of an increase in the oil price, simulation exercises reveal that the Russian economy is sensitive to large oil price fluctuations. Demeshev and Malakhovskaya (2015) discuss the forecasting performance of Bayesian vector autoregressions (BVARs) based on the Russian economy data. In particular, they compare the forecast accuracy of BVAR with other VARs and random walk with drift models for important macroeconomic variables. The authors find that for many variables BVARs are superior to the other models in terms of forecasting performance. Nevertheless, in some cases, a small-dimensional BVAR shows better forecasting results than its high-dimensional counterpart does. Modern factor models have also become a useful tool in policy analysis and real-time forecasting. Borzykh (2016) uses the combination of factor models and time-varying parameter VAR to assess the effectiveness of bank lending channel of monetary policy in Russia. Porshakov et al. (2015) exploit nowcasting techniques based on factor models to generate short-term forecasts in real time based on mixed frequency data on the Russian economy.

Structural macroeconometric models have been also developed by various Russian scientific organizations and government agencies. The Central Economics and Mathematics Institute of the Russian Academy of Sciences (CEMI RAS) constructed a structural econometric model for the Russian economy. The model is built as a system of six simultaneous equations based on quarterly data starting from the fourth quarter of 1994. Short term forecasts can be generated for several endogenous variables. One can independently formulate scenarios and obtain forecasts for this model on the official website of CEMI RAS.[1] The Institute of Economic Forecasting of the Russian Academy of Sciences (IEF RAS) built a quarterly macroeconomic model known as the QUMMIR model for the Russian economy. Approximately 460 variables and 200 regression equations are used in the model. Short and medium-term forecasts can be generated online within the framework of various scenarios.[2] IEF RAS publishes quarterly forecasts of macroeconomic indicators for Russia based on the QUMMIR model.

3. Data description

The section describes the data used in the model in detail. The model is estimated based on quarterly data without seasonal adjustments. The data spans the period from 2001 to 2019 (76 observations) for the majority of variables. The primary source of national accounts and labor market data is the Federal

1 www.cemi.rssi.ru
2 www.ecfor.ru

State Statistics Service of the Russian Federation (hereinafter—the Federal State Statistics Service). The government revenues and expenditures data are retrieved from the database of the Federal Treasury of the Russian Federation. Other data is gathered from the Bank of Russia, Bloomberg and the International Monetary Fund databases.

A number of adjustments have been made to the raw data from the national accounts. The Federal State Statistics Service publishes quarterly data on expenditure components of GDP, and on the domestic output calculated by the production side.[3] In theory, GDP figures calculated by the expenditure and production sides must be equal, but in practice, they do not coincide and the difference is usually attributed to a statistical discrepancy. Some adjustments have also been made to GDP and its expenditure components at constant prices. During the period between 2001 and 2019, the Federal State Statistics Service changed the base year for the calculation of GDP and expenditure components of GDP at constant prices four times. In this model, the base period is taken to be the first quarter of 2010. The equations below explain the way GDP and expenditure components have been calculated at 2010 prices:[4]

$$D_{i,t} = \frac{P_{i,t} Q_{i,t}}{P_k Q_{i,t}} 100, \tag{1}$$

$$A_{i,t} = \frac{D_{i,t}}{D_{i,2010}} 100, \tag{2}$$

$$X_{i,t} = \frac{P_{i,t} Q_{i,t}}{A_{i,t}} 100, \tag{3}$$

where i refers to GDP and expenditure components of GDP; $D_{i,t}$ is the price deflator; k refers to the base years of 2003, 2008, 2011 and 2016 from the national accounts; $A_{i,t}$ is the adjusted price ratio; $P_{i,t}$ is the price variable; $Q_{i,t}$ is the quantity variable. Equation 2 demonstrates the way price deflators calculated in Equation (1) are used to find the price ratios. Equation 3 converts nominal values of GDP and expenditure components of GDP to 2010 prices. As a result, we find GDP and expenditure components of GDP at 2010 prices and refer to them as being the real GDP and real expenditure components of GDP.

Data on capital stock is not available for Russia. The Perpetual Inventory Method (PIM) is used to obtain a suitable capital stock variable. This approach is based on the idea that today's stock of capital is composed of gross investment in the current period added to the capital stock from the previous period less depreciation. Equation (4) demonstrates the way the capital stock is derived based on the PIM:

$$K_t = I_t + (1 - \delta) K_{t-1}, \tag{4}$$

where K_t is the capital stock at time t; I_t is the gross fixed capital formation in the current period; δ is the depreciation rate in the current period. The application of the PIM approach requires the initial value of the capital stock. Data

[3] Expenditure components of GDP: private consumption, private investment, government consumption, exports and imports.

[4] For simplicity, we refer to the first quarter of 2010 prices simply as 2010 prices.

from the Penn World Table is used to estimate the value of the capital stock in 2001. The capital-output ratio of 2.55 is deduced using the capital stock and the real GDP values from the Penn World Table. Then we use the depreciation rates from the Penn World Table to calculate the capital stock over the sample via the PIM. Since the data on depreciation rates is only available until 2014, we further assume a constant depreciation rate of 4.3% per annum from 2015 onwards.

Since the data on total population and population of working age are available in annual frequency, we convert them into quarterly frequency by assuming an exponential growth within a given year. That is, total population and working-age population grow at a constant rate each quarter in a given year to make the annual growth rate compatible with the actual observed growth rate.

4. The model

We start the model-building by analyzing the properties of variables (see Appendix A) in order to specify regression equations for estimation purposes. Unit root tests are used to check the stationarity of variables. Commonly applied statistical tests such as Augmented Dickey–Fuller (ADF), Phillips–Perron (PP) and Kwiatkowski–Phillips–Schmidt–Shin (KPSS) are used to determine whether a given series has a unit root or not. The test results show that most variables are non-stationary in levels and stationary in year-over-year measures (YoY).[5]

Most of the variables are integrated of order one (I(1)) processes and have a cointegrating relation with a set of other variables. First, we specify long-run equations in logarithmic levels and estimate them via OLS to extract residuals. Second, the residuals are tested for unit root via ADF, PP and KPSS tests. If the tests confirm the stationarity of residuals, then the non-stationary endogenous variables have a cointegrating relation with the set of non-stationary right-hand side variables. Hence, the cointegration relation is included into the regression equation as the long-run relationship between the variables. Appendix E presents the results of the tests for cointegration. They indicate that there indeed exists cointegration between dependent and independent variables in many equations. As a result, most regression equations are specified in error correction form with the inclusion of a long run relation. Other equations have been specified in levels due to the stationary nature of dependent variables. The residual diagnostics have been conducted for all equations, the results of which are presented in Appendix D.

We also use YoY measures of variables as a form of differencing in regression equations. In this way, we address the seasonality present in the data. In addition, dummy variables have been added into most equations to address the problems of structural breaks and shifts. The model uses a backward-looking approach in forming expectations through the inclusion of lagged dependent variables in the equations. Thus, the model possesses the property of adaptive expectations.

The model is composed of the following blocks: supply side, goods market, labor market, financial market, central bank policy rule, prices, and the government sector. The supply block consists of equations for potential output, labor

[5] The unit root test results are presented in Appendix C.

supply, long-run total factor productivity (TFP) and natural unemployment rate. Potential output is determined by the Cobb–Douglas production function which is assumed to exhibit constant returns to scale.

$$Y_t = BA_t K_t^{\alpha} L_t^{1-\alpha}, \tag{5}$$

where A_t stands for TFP and B is any normalizing constant. The shares of capital and labor are fixed at 0.4 and 0.6, respectively. The potential output is calculated using the capital stock, natural level of employment and TFP. We use the non-accelerating inflation rate of unemployment (NAIRU) and the labor force to calculate the natural employment. Therefore, we find the NAIRU by applying the Hodrick–Prescott (HP) filter to the actual unemployment rate. The Solow residual from the estimated production function is also detrended via the HP filter to extract the trend of TFP. Finally, we specify and estimate regression equations for NAIRU, trend TFP and labor force to endogenize these variables in the model. The labor force depends on its own lag and real wages, and both variables enter the regression with a positive sign. NAIRU and trend TFP equations are specified in ARIMA form. The resulting equations for potential output, labor supply, trend TFP and NAIRU form the supply side of the model.

1) Cobb–Douglas production function equation:

$$\log(Gdpr_t) = 6.231 + 0.4\log(Capsr_t) + 0.6\log(Emp_t).$$

2) Potential output equation:

$$\log(Ypot_t) = 6.231 + 0.4\log(Capsr_t) + \\ + 0.6\log(Lforce_t(1 - Hp\_nairu_t)) + \log(Hp\_tfp_t).$$

3) Labor force equation:

$$\log\left(\frac{Lforce_t}{Lforce_{t-4}}\right) = \underset{(0.001)}{-0.002} + \underset{(0.081)}{0.602}\log\left(\frac{Lforce_{t-1}}{Lforce_{t-5}}\right) + \\ + \underset{(0.011)}{0.034}\log\left(\frac{Wageavr_t}{Wageavr_{t-4}}\right) + \underset{(0.003)}{0.014}\,dum1,$$

Adj.R^2 = 0.62, F-stat = 37.21, LM(2) = 1.43.

4) NAIRU trend equation:

$$\Delta^2(Hp\_nairu_t) = \underset{(0.000)}{1.59 \cdot 10^{-7}} + \underset{(0.034)}{1.854}\,\Delta^2(Hp\_nairu_{t-1}) - \\ - \underset{(0.040)}{0.931}\,\Delta^2(Hp\_nairu_{t-2}) + \underset{(0.151)}{0.635}\,SAR(4) + \\ + \underset{(0.108)}{0.669}\,\epsilon_{t-1},$$

Adj.R^2 = 0.99, SIC = –22.80.

5) Trend TFP equation:

$$\Delta^3(Hp\_tfp_t) = \underset{(0.681)}{0.877} + \underset{(0.001)}{2.960}\,\Delta^3(Hp\_tfp_{t-1}) - \underset{(0.001)}{2.926}\,\Delta^3(Hp\_tfp_{t-2}) +$$
$$+ \underset{(0.000)}{0.966}\,\Delta^3(Hp\_tfp_{t-3}) + \underset{(0.111)}{0.673}\,SAR(4),$$

Adj.R^2 = 0.99, SIC = −16.49.

The demand side of the model consists of five real expenditures components of GDP with each being modeled separately: private consumption, private investment, oil exports, non-oil exports, and imports. Government consumption is treated as an exogenous variable in the model. According to the Keynesian consumption function, household consumption is a function of current disposable income. In addition, the permanent income hypothesis implies that economic agents make their consumption decisions taking into account discounted future wealth (see Friedman, 1957). As a result, we use an error correction term which is the long-run relationship between private consumption and disposable income. In addition, the household interest rate is used as a proxy for the wealth effect via discounting factor. The negative sign of the latter implies that the higher interest rate leads to lower wealth, which in turn results in decline in private consumption. We use the nominal interest rate in the equation due to Fair (2018), who establishes that the nominal interest rate provides a better empirical fit than the real interest rate in determining consumption. The equation is also explained by a lagged consumption variable that represents habit formation. The significant positive sign of the coefficient implies persistence in consumption behavior.

6) Private consumption equation:

$$\log\left(\frac{Cr_t}{Cr_{t-4}}\right) = \underset{(0.191)}{0.728} + \underset{(0.070)}{0.506}\log\left(\frac{Cr_{t-1}}{Cr_{t-5}}\right) + \underset{(0.040)}{0.186}\log\left(\frac{Incomer_t}{Incomer_{t-4}}\right) -$$
$$- \underset{(0.206)}{0.474}\,Hsr_{t-2} - \underset{(0.066)}{0.245}\log(Cr_{t-4}) + \underset{(0.050)}{0.157}\log(Incomer_{t-4}) -$$
$$- \underset{(0.019)}{0.061}\,dum2,$$

Adj.R^2 = 0.93, F-stat = 123.35, LM(2) = 3.75.

Private investment in the model depends on the lagged value of itself, demand for domestic goods and services, and long-term interest rate. The lagged value of the dependent variable represents investment adjustment costs which enter the right-hand side of the equation with a positive sign as well as the demand for domestic goods variable. The positive response of the latter can be explained by the fact that firms tend to add more capacity when the demand for their goods rises. The interest rate has a significant negative impact on investment since firms tend to cut on investment when the opportunity cost of capital rises.

7) Investment equation:

$$\log\left(\frac{Invr_t}{Invr_{t-4}}\right) = \underset{(0.004)}{-0.005} + \underset{(0.071)}{0.237}\log\left(\frac{Invr_{t-1}}{Invr_{t-5}}\right) + \underset{(0.109)}{1.082}\log\left(\frac{Demandr_t}{Demandr_{t-4}}\right) -$$

$$- \underset{(0.113)}{0.201}(Midgovb_{t-4} - Infl_{t-4}) - \underset{(0.031)}{0.087}\, dum3,$$

Adj.R^2 = 0.91, F-stat = 144.88, LM(2) = 1.85.

The link between the country's economy and the rest of the world is established via the equations for oil exports, non-oil exports, and imports. Due to the important role of crude oil exports in determining domestic economic conditions in Russia, we disaggregate it into oil and non-oil exports. Moreover, the disaggregation allows for estimation of the equations for these variables based on different sets of explanatory variables. The oil exports depend on the lagged dependent variable, world trade index and oil price where the world trade index is a proxy for the amount of international trade. All these variables have a positive impact on oil exports as expected.

8) Oil exports equation:

$$\log\left(\frac{Exoilr_t}{Exoilr_{t-4}}\right) = \underset{(0.417)}{1.934} + \underset{(0.031)}{0.253}\log\left(\frac{Oilpusd_t}{Oilpusd_{t-4}}\right) +$$

$$+ \underset{(0.155)}{0.319}\log\left(\frac{Wtrade_t}{Wtrade_{t-4}}\right) - \underset{(0.077)}{0.331}\log(Exoilr_{t-4}) +$$

$$+ \underset{(0.031)}{0.072}\log(Oilpusd_{t-4}) + \underset{(0.010)}{0.262}\, dum4,$$

Adj.R^2 = 0.79, F-stat = 48.27, LM(2) = 0.17.

The non-oil exports equation is determined by the lagged value of itself, the world trade index and the real exchange rate. The latter affects non-oil exports in line with the mainstream view whereas the world trade has a positive influence on the dependent variable as expected. Both explanatory variables have statistically significant coefficients.

9) Non-oil exports equation:

$$\log\left(\frac{Exotherr_t}{Exotherr_{t-4}}\right) = \underset{(0.009)}{0.022} + \underset{(0.115)}{0.281}\log\left(\frac{Exotherr_{t-1}}{Exotherr_{t-5}}\right) -$$

$$- \underset{(0.057)}{0.146}\log\left(\frac{Reer_{t-1}}{Reer_{t-5}}\right) + \underset{(0.097)}{0.219}\log\left(\frac{Wtrade_t}{Wtrade_{t-4}}\right) -$$

$$- \underset{(0.009)}{0.151}\, dum5 + \underset{(0.013)}{0.108}\, dum6,$$

Adj.R^2 = 0.42, F-stat = 9.59, LM(2) = 7.50.

Imports of goods and services also form an important part of international linkage of the Russian economy with the rest of the world. The lagged value of imports is added into the imports equation to allow for smooth adjustment. The equation is estimated in error correction form, in which the cointegrating relation exists between imports, domestic output, and real exchange rate. The estimated coefficients of domestic output and real exchange rate are positive and statistically significant in line with economic theory.

10) Imports equation:

$$\log\left(\frac{Impr_t}{Impr_{t-4}}\right) = \underset{(0.846)}{-5.849} + \underset{(0.049)}{0.285}\log\left(\frac{Impr_{t-1}}{Impr_{t-5}}\right) + \underset{(0.204)}{2.144}\log\left(\frac{Gdpr_t}{Gdpr_{t-4}}\right) +$$

$$+ \underset{(0.061)}{0.441}\log\left(\frac{Reer_{t-1}}{Reer_{t-5}}\right) - \underset{(0.067)}{0.455}\log(Impr_{t-4}) +$$

$$+ \underset{(0.119)}{0.802}(Gdpr_{t-4}) + \underset{(0.073)}{0.418}\log(Reer_{t-4}),$$

Adj.R^2 = 0.95, F-stat = 194.64, LM(2) = 0.25.

The labor market of the economy is based on a theoretical framework of the bargaining model, in which firms and unions negotiate over wages and employment. Thus, we estimate equations for average nominal wage and labor demand. The average nominal wage is influenced by the lagged value of itself, labor productivity, unemployment rate and inflation rate. The positive and significant coefficient of the lagged dependent variable implies the existence of persistence. Unemployment rate has a negative impact on average nominal wage, whereas the labor productivity affects it positively. The cointegrating relation has been imposed in the estimated equation between the average nominal wage and price level, the restriction being one to one movement of the nominal wage with the price level in the long run.

11) Nominal wage equation:

$$\log\left(\frac{Wageav_t}{Wageav_{t-4}}\right) = \underset{(0.007)}{0.033} - \underset{(0.051)}{0.706}\log\left(\frac{Wageav_{t-1}}{Wageav_{t-5}}\right) + \underset{(0.088)}{0.255}\log\left(\frac{Prod_t}{Prod_{t-4}}\right) -$$

$$- \underset{(0.317)}{0.735}(Unemprate_t - Unemprate_{t-4}) -$$

$$- \underset{(0.012)}{0.039}ECM_{t-4} - \underset{(0.012)}{0.046}dum7 - \underset{(0.017)}{0.049}dum8,$$

$$ECM_t = \log(Wageav_t) - \underset{(0.034)}{5.190} - \log(Cpi_t),$$

Adj.R^2 = 0.95, F-stat = 225.20, LM(2) = 0.12.

The other part of the labor market, the employment equation, is estimated in the form of Tobit regression. We define the dependent variable as the ratio of employment to labor force. Hence, the MLE technique is exploited to estimate the regression model with the censored dependent variable with censoring being at 0 and 0.99. The dependent variable is determined by the lagged value of itself, growth in production and real wage. All coefficients have expected signs and are statistically significant.

12) Employment equation:

$$\log\left(\frac{Emp_t}{Lforce_{t-4}}\right) = \underset{(0.050)}{-0.052} + \underset{(0.053)}{1.055}\log\left(\frac{Emp_{t-4}}{Lforce_{t-4}}\right) + \underset{(0.016)}{0.168}\log\left(\frac{Gdpr_t}{Gdpr_{t-4}}\right) - \underset{(0.009)}{0.046}\log\left(\frac{Wageav_{t-3}}{Wageav_{t-7}}\right) + \underset{(0.003)}{0.013}\,dum9 - \underset{(0.005)}{0.014}\,dum10,$$

SIC = –7.52.

Aggregate price levels are also included into the model by specifying and estimating regression equations for them. The annual rate of inflation has been modeled as depending on lagged inflation, output growth and nominal exchange rate. We assume adaptive expectations in the model which explains the reason the lagged inflation appears on the right-hand side of the equation. The nominal exchange rate is included as a regressor since imported goods are a substantial part of the consumer basket in Russia. The GDP deflator equation is defined in terms of lagged dependent variable, local CPI and consumer price level in the US. The price level in the US affects the GDP deflator in Russia due to the managed floating exchange rate regime against US dollar that prevailed in Russia until 2014. We also construct equations for other price deflators, including private consumption deflator, government consumption deflator, exports and imports deflators.

13) CPI equation:

$$\log\left(\frac{Cpi_t}{Cpi_{t-4}}\right) = \underset{(0.120)}{0.003} + \underset{(0.040)}{0.853}\log\left(\frac{Cpi_{t-1}}{Cpi_{t-5}}\right) + \underset{(0.009)}{0.045}\log\left(\frac{Rubusd_t}{Rubusd_{t-4}}\right) + \underset{(0.050)}{0.186}\log\left(\frac{Gdpr_{t-1}}{Gdpr_{t-5}}\right) + \underset{(0.005)}{0.036}\,dum11,$$

Adj.R^2 = 0.92, F-stat = 194.97, LM(2) = 10.21.

14) GDP deflator equation:

$$\log\left(\frac{Gdpdef_t}{Gdpdef_{t-4}}\right) = \underset{(0.084)}{-0.086} + \underset{(0.070)}{0.466}\log\left(\frac{Gdpdef_{t-1}}{Gdpdef_{t-5}}\right) + \underset{(0.123)}{0.302}\log\left(\frac{Cpi_t}{Cpi_{t-4}}\right) + \underset{(0.302)}{1.697}\log\left(\frac{Uscpi_t}{Uscpi_{t-4}}\right) - \underset{(0.046)}{0.120}\log(Gdpdef_{t-4}) + \underset{(0.061)}{0.138}\log(Cpi_{t-4}) + \underset{(0.015)}{0.066}\,dum12,$$

Adj.R^2 = 0.86, F-stat = 67.30, LM(2) = 4.30.

15) Private consumption deflator equation:

$$\log\left(\frac{Cdef_t}{Cdef_{t-4}}\right) = \underset{(0.050)}{0.056} + \underset{(0.140)}{0.348}\log\left(\frac{Cdef_{t-1}}{Cdef_{t-5}}\right) + \underset{(0.112)}{0.308}\log\left(\frac{Gdpdef_t}{Gdpdef_{t-4}}\right) + \\ + \underset{(0.154)}{0.438}\log\left(\frac{Cpi_{t-1}}{Cpi_{t-5}}\right) - \underset{(0.058)}{0.137}\log(Cdef_{t-4}) + \\ + \underset{(0.053)}{0.123}\log(Gdpdef_{t-4}),$$

Adj.R^2 = 0.81, F-stat = 57.09, LM(2) = 6.51.

16) Government consumption deflator equation:

$$\log\left(\frac{Gdef_t}{Gdef_{t-4}}\right) = \underset{(0.049)}{-0.041} + \underset{(0.057)}{0.646}\log\left(\frac{Gdef_{t-1}}{Gdef_{t-5}}\right) + \underset{(0.046)}{0.295}\log\left(\frac{Gdpdef_t}{Gdpdef_{t-4}}\right) - \\ - \underset{(0.039)}{0.111}\log(Gdef_{t-4}) + \underset{(0.047)}{0.120}(Gdpdef_{t-4}) + \underset{(0.017)}{0.043}\,dum13,$$

Adj.R^2 = 0.95, F-stat = 227.30, LM(2) = 0.14.

17) Export deflator equation:

$$\log\left(\frac{Expdef_t}{Expdef_{t-4}}\right) = \underset{(0.153)}{0.330} + \underset{(0.070)}{0.299}\log\left(\frac{Expdef_{t-1}}{Expdef_{t-5}}\right) + \\ + \underset{(0.185)}{1.217}\log\left(\frac{Gdpdef_t}{Gdpdef_{t-4}}\right) - \underset{(0.098)}{0.531}\log(Expdef_{t-4}) + \\ + \underset{(0.075)}{0.453}\log(Gdpdef_{t-4}),$$

Adj.R^2 = 0.81, F-stat = 71.52, LM(2) = 2.70.

18) Import deflator equation:

$$\log\left(\frac{Impdef_t}{Impdef_{t-4}}\right) = \underset{(0.006)}{0.030} + \underset{(0.067)}{0.129}\log\left(\frac{Impdef_{t-1}}{Impdef_{t-5}}\right) + \underset{(0.048)}{0.602}\log\left(\frac{Rubusd_t}{Rubusd_{t-4}}\right),$$

Adj.R^2 = 0.86, F-stat = 205.48, LM(2) = 4.45.

Financial markets of the model consist of equations for real exchange rate, medium-term government bond yield and household saving rate. On the foreign exchange market, the real effective exchange rate (REER) is explained by changes in the domestic price level (inflation rate), nominal exchange rates and policy interest rate differential. In this case, a rise of the real exchange rate means a real appreciation of the domestic currency. Since the REER index is determined as the weighted average of bilateral exchange rates of Russian ruble against other major currencies, we include nominal exchange rates of euro and US dollar against the ruble as explanatory variables on the right-hand side. The equation for the medium-term government bond yield represents the bonds market. The equation is specified in levels due to the stationary nature of the dependent variable. The medium-term government bond yield depends on its own lagged value and the central bank policy rate. Similarly, the household saving rate equation is determined in levels and consists of the lagged dependent variable and the central bank policy rate.

19) Real exchange rate equation:

$$\log\left(\frac{Reer_t}{Reer_{t-4}}\right) = \underset{(0.012)}{-0.020} + \underset{(0.152)}{0.713}\log\left(\frac{Cpi_t}{Cpi_{t-4}}\right) - \underset{(0.035)}{0.216}\log\left(\frac{Rubusd_t}{Rubusd_{t-4}}\right) -$$

$$- \underset{(0.061)}{0.659}\log\left(\frac{Rubeur_t}{Rubeur_{t-4}}\right) + \underset{(0.124)}{0.228}\log(Cbpr_t - Fedr_t) -$$

$$- \underset{(0.016)}{0.105}\, dum14,$$

Adj.R^2 = 0.94, F-stat = 190.57, LM(2) = 8.60.

20) Medium-term government bond yield equation:

$$Midgovb_t = \underset{(0.006)}{0.011} + \underset{(0.072)}{0.746}\, Midgovb_{t-1} + 0.1\, Cbpr_t,$$

Adj.R^2 = 0.64, F-stat = 117.14, LM(2) = 7.66.

21) Household saving rate equation:

$$Hsr_t = \underset{(0.003)}{0.012} + \underset{(0.069)}{0.718}\, Hsr_{t-1} + \underset{(0.041)}{0.092}\, Cbpr_t + \underset{(0.009)}{0.033}\, dum15,$$

Adj.R^2 = 0.90, F-stat = 203.89, LM(2) = 1.90.

The central bank policy rate equation has been included in the model as a relevant monetary policy instrument. The Bank of Russia has been conducting monetary policy under the inflation targeting regime since the end of 2014. The inflation rate enters the equation as its deviation from the target level, which is currently set at 4%. Data on inflation targets for the period 2001–2013 was taken from “Guidelines for the Single State Monetary Policy” annually published by the Bank of Russia. Since the equation is constructed in the spirit of Taylor rule, we also include output gap on the right-hand side. Due to the export dependent nature of the economy, the real effective exchange rate has been added on the right-hand side as an important indicator in determining the conduct of monetary policy.

22) Central bank policy rate equation:

$$Cbpr_t = \underset{(0.003)}{0.004} + \underset{(0.024)}{0.936}\, Cbpr_{t-1} + \underset{(0.126)}{0.149}\left(\log\left(\frac{Cpi_t}{Cpi_{t-1}}\right) - \frac{Inflt_t}{4}\right) +$$

$$+ \underset{(0.017)}{0.051}\, Ygap_t - \underset{(0.052)}{0.109}\log\left(\frac{Reer_t}{Reer_{t-1}}\right) - \underset{(0.003)}{0.032}\, dum16,$$

R^2 = 0.97, F-stat = 382.64, LM(2) = 0.43.

The model also contains regression equations for relevant government revenue components such as personal income taxes, corporate income taxes, VAT, excises, and other taxes. All equations on the government side of the model are estimated in error correction form. The personal income tax equation is estimated as depending on the lagged value of itself and nominal wages paid to employees. Revenues from corporate income taxes are explained by the nominal GDP multiplied by the corporate income tax rate. Value added tax revenues are associated with total consumption expenditures multiplied by the VAT rate. Excise tax revenues are determined by the lagged dependent variable in the short run and the cointegrating relation with private consumption of households in the long run. Finally, other tax revenues are determined by the nominal GDP in the economy.

23) Personal income taxes equation:

$$\log\left(\frac{Inctaxpers_t}{Inctaxpers_{t-4}}\right) = \underset{(0.365)}{-1.030} + \underset{(0.073)}{0.337}\log\left(\frac{Inctaxpers_{t-1}}{Inctaxpers_{t-5}}\right) + \underset{(0.115)}{0.985}\log\left(\frac{Emp_t \cdot Wageav_t}{Emp_{t-4} \cdot Wageav_{t-4}}\right) - \underset{(0.038)}{0.072}\log(Inctaxpers_{t-4}) + \underset{(0.038)}{0.093}\log(3 \cdot Emp_{t-4} \cdot Wageav_{t-4}),$$

Adj.$R^2 = 0.93$, F-stat = 225.43, LM(2) = 0.57.

24) Corporate income taxes equation:

$$\log\left(\frac{Inctaxcorp_t}{Inctaxcorp_{t-4}}\right) = \underset{(0.273)}{-0.440} + \underset{(0.155)}{1.616}\log\left(\frac{Gdpn_t \cdot Corprate_t}{Gdpn_{t-4} \cdot Corprate_{t-4}}\right) - \underset{(0.088)}{0.491}\log(Inctaxcorp_{t-4}) + \underset{(0.087)}{0.434}\log(Gdpn_{t-4} \cdot Corprate_{t-4}),$$

Adj.$R^2 = 0.68$, F-stat = 47.63, LM(2) = 3.96.

25) VAT equation:

$$\log\left(\frac{Vat_t}{Vat_{t-4}}\right) = \underset{(0.275)}{0.044} + \underset{(0.140)}{0.400}\log\left(\frac{Vat_{t-1}}{Vat_{t-5}}\right) + \underset{(0.436)}{0.820}\log\left(\frac{Vatrate_t \cdot Tcn_t}{Vatrate_{t-4} \cdot Tcn_{t-4}}\right) - \underset{(0.153)}{0.780}\log(Vat_{t-4}) + \underset{(0.131)}{0.680}\log(Vatrate_{t-4} \cdot Tcn_{t-4}) - \underset{(0.057)}{0.379}\,dum17,$$

Adj.$R^2 = 0.63$, F-stat = 21.85, LM(2) = 7.52.

26) Excise tax equation:

$$\log\left(\frac{Excises_t}{Excises_{t-4}}\right) = \underset{(0.192)}{-0.327} + \underset{(0.080)}{0.606}\log\left(\frac{Excises_{t-1}}{Excises_{t-5}}\right) -$$

$$- \underset{(0.052)}{0.142}\log(Excises_{t-4}) + \underset{(0.045)}{0.124}\log(Cn_{t-4}) -$$

$$- \underset{(0.129)}{0.481}\,dum18 + \underset{(0.130)}{0.460}\,dum19 - \underset{(0.129)}{0.337}\,dum20,$$

Adj.R^2 = 0.66, F-stat = 20.76, LM(2) = 4.71.

27) Other tax equation:

$$\log\left(\frac{Othertax_t}{Othertax_{t-4}}\right) = \underset{(0.418)}{-1.922} + \underset{(0.078)}{0.484}\log\left(\frac{Othertax_{t-1}}{Othertax_{t-5}}\right) +$$

$$+ \underset{(0.222)}{0.520}\log\left(\frac{Gdpn_t}{Gdpn_{t-4}}\right) - \underset{(0.097)}{0.552}\log(Othertax_{t-4}) +$$

$$+ \underset{(0.112)}{0.631}\log(Gdpn_{t-4}) - \underset{(0.133)}{0.501}\,dum21,$$

Adj.R^2 = 0.66, F-stat = 25.08, LM(2) = 1.15.

We have estimated all the relevant equations, and then identities are introduced to complete the model. The identities of the model are given in Appendix B.

5. Simulation

Once the model specification has been completed, the model is solved for ex-post and ex-ante simulation. Stochastic simulation is used to provide a measure of uncertainty in the results. In comparison with a deterministic solution where error terms are set to their expected value, which is zero, stochastic simulation requires the error terms to be drawn randomly from the estimated residuals (see Fair, 2018). Drawing errors in this way is known as bootstrapping. Thus, the model simulation was run 1,000 times to obtain confidence intervals for all endogenous variables over the simulation horizon.

The ability of the model to repeat the dynamics of actual endogenous variables is assessed based on ex-post simulation for the period 2004–2019. Fig. F1 to Fig. F6 in Appendix F show the median values of the ex-post simulation for the following macroeconomic variables: real GDP growth, potential output growth, inflation rate, unemployment rate, real wage growth and real exchange rate. Solid lines show actual observations and dashed lines represent median values of baseline stochastic simulations. The simulation exercise reveals reasonable accuracy of the model in tracking the actual dynamics of the relevant endogenous variables.

The ex-post simulation of the model is evaluated by forecast evaluation measures. In particular, we compare ex-post forecasts obtained by the structural macroeconometric model with ex-post forecasts generated by the VAR(2) model. We resort to commonly used forecast evaluation measures such as mean absolute

Table 1
Forecast evaluation measures.

	Variable	Macroeconometric model	VAR(2) model
MAPE	Real GDP growth	**52.949**	137.339
	Unemployment rate	**5.596**	34.699
	Inflation rate	**28.591**	59.754
Theil's U2	Real GDP growth	**0.155**	0.821
	Unemployment rate	0.684	**0.428**
	Inflation rate	**0.598**	1.338
RMSE	Real GDP growth	**0.013**	0.014
	Unemployment rate	**0.003**	0.021
	Inflation rate	**0.020**	0.034
MAE	Real GDP growth	**0.010**	0.012
	Unemployment rate	**0.003**	0.015
	Inflation rate	**0.016**	0.030

Note: Bold shows smaller values which indicate a better fit.
Source: Authors' calculations.

percentage error (MAPE), Theil's inequality coefficient U2, root mean squared error (RMSE) and mean absolute error (MAE) to compare the performance of the two models. Table 1 presents the forecast evaluation measures for some chosen macroeconomic variables. The results indicate that the structural macroeconometric model gives a better fit for GDP growth, inflation rate and unemployment rate.

6. Shock analysis

An additional advantage of the present model is its ability to evaluate the impact of various shocks on the economy. In this section, we present the results of two additional simulation exercises which are carried out to analyze the responses of main economic indicators to various shocks. First, the impact of an increase in the VAT rate is investigated. Second, the effect of a contraction in the world trade by 5% is considered. The influences of these shocks on GDP growth and inflation rate of the Russian economy are presented in Appendix F Figs. F7–F10. Notably, the figures show the difference between the endogenous variables under the baseline and alternative scenarios.

In 2018, the Russian government introduced amendments to the tax code with the key change being an increase in the VAT rate from 18% to 20%. Therefore, we find it reasonable to analyze the effect of the fiscal policy on important macroeconomic indicators. The increase in the VAT rate translates into the slowdown in real disposable income, which in turn affects private consumption of households in a negative manner. Hence, the GDP growth of the Russian economy falls under the alternative scenario. The maximum deviation from the baseline scenario is 0.11 percentage points. According to the model simulation under the alternative scenario, the impact of the VAT rate shock on inflation seems to be insignificant, even though the effect persists for five years as shown in Appendix F Fig. F8. Based on these results, the model indicates that the VAT rate increase in January 2019 will not create a significant upward inflation pressure in the economy.

The world trade shock produces an intense and persistent effect on economic growth since the Russian economy is heavily dependent on commodity exports. Real GDP quickly returns to its baseline level (see Appendix F Fig. F9). The most significant deviation from the baseline was found in oil exports (see Appendix F Fig. F11). The variable falls by 1.6 percentage points in the year when the shock arises followed by an immediate increase in the next year. In comparison, non-oil exports show a lower deviation from the baseline and the effect of the shock disappears rapidly as illustrated in Appendix F Fig. F12. The response of inflation to the shock appears to be more persistent, but the maximum deviation from the baseline is only 0.15 percentage points.

7. Ex-ante forecasts and scenarios

Since the model performance is reasonably good in ex-post simulation we use it for ex-ante forecasting in this section. Assumptions on the future paths of exogenous variables are made within the model, including the assumptions on oil prices, nominal exchange rates, foreign price levels, US federal funds rate, population growth and world trade.

Table 2 presents ex-ante forecasts for key macroeconomic variables, including real GDP growth, potential output growth, inflation rate, and unemployment rate. The results are the median values obtained from stochastic simulation. The forecast horizon covers the period from 2020 to 2023 under the scenario of oil prices remaining at 30 dollars per barrel from the second quarter of 2020.

According to ex-ante simulation results, the real GDP is expected to decline by 0.5% in 2020. The Russian economy will likely face the negative growth due to the contraction in world trade and declining oil prices caused by the pandemic of coronavirus. We assume that the world trade contracts by 11% in 2020 and recovers with an increase of 8.4% in 2021 based on the *World economic outlook* projections prepared by the International Monetary Fund (IMF, 2020). The inflation rate is forecast to remain below its target level in 2020, while the unemployment rate is anticipated to rise to 5%. The economic situation is expected to improve in the following periods. The real GDP growth reaches 2.9% in 2021 and stays positive until the end of the forecast horizon. The potential output growth and the unemployment rate are forecast to slow down by 2023, while the inflation rate is rising.

Fig. F13 to Fig. F16 in Appendix F present fan charts for ex-ante forecasts of real GDP growth, potential output growth, inflation rate and unemployment rate under the scenario of oil price 30 dollars per barrel. The fan charts illustrate a range of possible outcomes with corresponding confidence bands.

Table 2
Ex-ante forecasts under the scenario of oil price 30 dollars per barrel (%).

	Real GDP growth	Potential output growth	Inflation rate	Unemployment rate
2020	–0.5	2.0	3.2	5.0
2021	2.9	1.9	4.5	4.8
2022	2.1	1.6	5.0	4.7
2023	1.6	1.2	4.9	4.5

Source: Authors' calculations.

The grey bands reflect uncertainty over the evolution of the above-mentioned variables in the future. The lightest band reflects the 95% confidence interval, while the darkest band — 60%. The median forecast is shown by the solid line for the forecast horizon.

8. Conclusion

The paper builds the structural macroeconometric model for the Russian economy. The model is composed of the following blocks: supply side, goods market, labor market, financial market, central bank policy rule, prices, and the government sector. The majority of the equations are estimated in error-correction form based on quarterly data spanning from 2001 to 2019. Thus, the equations capture the short run dynamics and long-run relationships between the variables. Stochastic simulation is used for both ex-post and ex-ante simulation. The method provides a measure of uncertainty in the results by drawing the error terms randomly from estimated residuals.

The performance of the model in ex-post simulation for 2004–2019 reveals good accuracy in tracking the actual dynamics of relevant endogenous variables. The ex-post simulation of the model is also assessed by the forecast evaluation measures. In particular, ex-post forecasts obtained for the structural macroeconometric model are compared with forecasts generated by the VAR model for GDP growth, inflation rate and unemployment rate. The results indicate that the structural macroeconometric model gives a better fit for all variables than the VAR model does. In order to illustrate the impact of various shocks on main macroeconomic variables in the model, we investigate the way the economy reacts to the increase in the VAT rate from 18% to 20%, and the drop in the world trade index by 5%. The responses of the endogenous variables to the shocks are in line with the mainstream view in the literature. The model is also used to generate ex-ante forecasts from 2020 to 2023 for important macroeconomic indicators. The results indicate that the real GDP is expected to drop by 0.5% in 2020 due to a decline in economic activity caused by the pandemic. Overall, the model demonstrates good performance in repeating the actual behavior of endogenous macroeconomic variables and conducting exogenous shock analysis.

References

Abilov, N., Tolepbergen, A., & Weyerstrass, K. (2019). A macroeconometric model for Kazakhstan. *NAC Analytica Working Paper.* Available at SSRN: https://dx.doi.org/10.2139/ssrn.3495353

Aivazian, S., Bereznyatsky, A., & Brodsky, B. (2017). Macroeconomic modeling for Russia. *Applied Econometrics*, *47*, 5–27.

Benedictow, A., Fjærtoft, D., & Løfsnæs, O. (2010). Oil dependence of the Russian economy: An econometric analysis. *Statistics Norway Discussion Papers*, No. 617.

Borzykh, O. (2016). Bank lending channel in Russia: A TVP-FAVAR approach. *Applied Econometrics, 43*, 96–117.

Brayton, F., & Tinsley, P. (1996). A guide to FRB/US: A macroeconomic model of the United States. *Finance and Economics Discussion Series,* No. 1996-42. New York: Federal Reserve Board.

Brayton, F., Laubach, T., & Reifschneide, D. (2014). A guide to FRB/US: A macroeconomic model of the United States. *IWH Discussion Papers*, No. 42.

Demeshev, B., & Malakhovskaya, O. (2015). Forecasting Russian macroeconomic indicators with BVAR. *HSE Working papers*, No. 105.
Dougherty, C. (2011). *Introduction to econometrics*. Oxford: Oxford University Press.
Dreger, C. (2003). A macroeconometric model for the Euro economy. *IWH Discussion Papers*, No. 181.
Dreger, C., & Marcellino, M. (2007). A macroeconometric model for the Euro economy. *Journal of Policy Modeling*, *29* (1), 1–13. https://doi.org/10.1016/j.jpolmod.2006.01.007
Engle, R., & Granger, C. (1987). Cointegration and error correction: Representation, estimation and testing. *Econometrica*, *55* (2), 251–276. https://doi.org/10.2307/1913236
Fair, R. (1984). *Specification, estimation, and analysis of macroeconomic models*. Cambridge, MA: Harvard University Press.
Fair, R. (1994). *Testing macroeconometric models*. Cambridge, MA: Harvard University Press.
Fair, R. (2018). *Macroeconometric modeling: 2018*. Unpublished manuscript, https://fairmodel.econ.yale.edu/mmm2/mm2018.pdf
Feenstra, R., Inklaar, R., & Timmer, M. (2015). The next generation of the Penn World Table. *American Economic Review*, *105* (10), 3150–3182. https://doi.org/10.1257/aer.20130954
Ferson, W., & Constantinides, G. (1991). Habit persistence and durability in aggregate consumption: Empirical tests. *Journal of Financial Economics*, *29* (2), 199–240. https://doi.org/10.1016/0304-405X(91)90002-2
Friedman, M. (1957). *A theory of the consumption function*. Princeton, NJ: Princeton University Press.
IMF (2020). *World economic outlook. Chapter 1: The great lockdown*. Washington, DC: International Monetary Fund.
Porshakov, A., Deryugina, E., Ponomarenko, A., & Sinyakov, A. (2015). Nowcasting and short-term forecasting of Russian GDP with a dynamic factor model. *Bank of Russia Working Paper Series,* No. 2.
Stock, J., & Watson, M. (1993). A simple estimator of cointegrating vectors in higher order integrated systems. *Econometrica*, *61* (4), 783–820. https://doi.org/10.2307/2951763
Taylor, J. (1993). Discretion versus policy rules. *Carnegie-Rochester Conference Series on Public Policy*, *39*, 195–214. https://doi.org/10.1016/0167-2231(93)90009-L
Tinbergen, J. (1939). *Business cycle in the United States, 1919–1932*. Geneva: League of Nations.
Weyerstrass, K., Neck, R., Blueschke, D., Majcen, B., Srakar, A., & Verbic, M. (2018). Slopol10: A macroeconometric model for Slovenia. *Economic and Business Review*, *20* (2), 269–302.

Appendix A

Table A1
List of variables.

Variables	Definitions	Units of measurement	Source
Endogenous			
Capsr	Capital stock, real	Billion RUB10 [a)]	Own
Cdef	Private consumption deflator	Index	Own
Cn	Private consumption, nominal	Billion RUB	STAT [b)]
Cr	Private consumption, real	Billion RUB10	Own
Cpi	Consumer price index, 2010 = 100	Index	STAT
Demandr	Final demand, real	Billion RUB10	Own
Emp	Number of employees	Million	STAT
Excises	Excises revenues	Billion RUB10	FT [c)]
Exoilr	Exports of oil, real	Billion RUB10	Own
Exotherr	Exports of other, real	Billion RUB10	Own
Expdef	Exports deflator	Index	Own
Gdef	Government consumption deflator	Index	Own

(continued on next page)

Table A1 (continued)

Variables	Definitions	Units of measurement	Source
Gdpdef	GDP deflator	Index	Own
Gdpn	GDP by expenditure, nominal	Billion RUB	STAT
Gdpr	GDP by expenditure, real	Billion RUB10	Own
Gr	Government consumption, real	Billion RUB10	Own
Hp_nairu	NAIRU	Percentage	Own
Hp_tfp	TFP	Level	Own
Impdef	Imports deflator	Index	Own
Impr	Imports of goods and services, real	Billion RUB10	Own
Incomen	Disposable income of private households, nominal	Billion RUB10	Own
Incomer	Disposable income of private households, real	Billion RUB10	Own
Inctaxcorp	Corporate income tax revenues	Billion RUB10	FT
Inctaxpers	Personal income tax revenues	Billion RUB10	FT
Infl	Inflation rate	Percentage	Own
Invr	Gross fixed capital formation, real	Billion RUB10	Own
Lforce	Labor force	Million	STAT
Midgovb	Midterm government bond rate	Percentage	CBRF [d)]
Cbpr	Policy interest rate of the Central Bank	Percentage	CBRF
Othertax	Other tax revenues	Billion RUB	FT
Prod	Labor productivity	1000 RUB10 per employee	Own
Reer	Real effective exchange rate index	Index	CBRF
Unemp	Unemployment	Million	STAT
Unemprate	Unemployment rate	Percentage	Own
VAT	VAT revenues	Billion RUB	FT
Wageav	Average gross wage per employee, nominal	RUB	STAT
Wageavr	Average gross wage per employee, real	RUB10	Own
Ygap	Output gap	Billion RUB10	Own
Ypot	Potential output	Billion RUB10	Own
Exogenous			
Cpic	CPI in China	Index	Bloomberg
Uscpi	CPI in the USA	Index	Bloomberg
Depr	Capital stock depreciation rate	Percentage	Own
Fedr	Federal funds rate	Percentage	Bloomberg
Gn	Government consumption	Billion RUB	STAT
Corprate	Corporate income tax rate	Percentage	Own
Inventr	Change in inventory, real	Billion RUB10	Own
Inflt	Target inflation rate	Percentage	CBRF
Rubeur	Nominal exchange rate RUB/EUR	RUB	CBRF
Rubusd	Nominal exchange rate RUB/USD	RUB	CBRF
Oilpusd	Oil price, Brent	USD/Barrel	Bloomberg
Wapop	Working age population, 15 to 72 years	Thousands	STAT
Socpol	Social policy	Billion RUB	FT
Vatrate	VAT rate	Percentage	FT
Wtrade	World trade index, 2010=100	Index	Bloomberg

[a)] Billion RUB10 — at constant 2010 prices.
[b)] STAT — The Federal State Statistics Service.
[c)] FT — The Federal Treasury.
[d)] CBRF — The Central Bank of the Russian Federation.

Appendix B. Identities

$$Capsr_t = Capsr_{t-1}(1 - Depr_t) + Invr_t. \tag{B.1}$$

$$Ygap_t = \frac{Gdpr_t - Ypot_t}{Ypot_t}. \tag{B.2}$$

$$Gdpr_t = Cr_t + Gr_t + Invr_t + Exoilr_t + Exotherr_t - Impr_t + Inventr_t. \tag{B.3}$$

$$Demandr_t = Cr_t + Gr_t + Invr_t + Exoilr_t + Exotherr_t + Inventr_t. \tag{B.4}$$

$$Gdpn_t = Gdpr_t \frac{Gdpdef_t}{100\%}. \tag{B.5}$$

$$Cn_t = Cr_t \frac{Cdef_t}{100\%}. \tag{B.6}$$

$$Gr_t = \frac{Gn_t}{Gdef_t} 100\%. \tag{B.7}$$

$$Tcn_t = Cn_t + Gn_t. \tag{B.8}$$

$$Prod_t = \frac{Gdpr_t}{Emp_t}. \tag{B.9}$$

$$Wageavr_t = \frac{Wageav_t}{Cpi_t} 100\%. \tag{B.10}$$

$$Incomen_t = Gdpn_t + Socpol_t - Inctaxpers_t - Inctaxcorp_t - Vat_t - Excises_t - Othertax_t. \tag{B.11}$$

$$Incomer_t = \frac{Incomen_t}{Cpi_t} 100\%. \tag{B.12}$$

$$Infl_t = \frac{Cpi_t}{Cpi_{t-4}} - 1. \tag{B.13}$$

$$Unemp_t = Lforce_t - Emp_t. \tag{B.14}$$

$$Unemprate_t = \frac{Unempt_t}{Lforce_t}. \tag{B.15}$$

$$Util_t = \frac{Gdpr_t}{Ypot_t} 100\%. \tag{B.16}$$

Appendix C

Table C1
Unit root test results of variables in levels.

Variable (level)	ADF (*c*)	ADF (*c,t*)	PP (*c*)	KPSS
Capsr	–0.751	–2.168	0.697	1.188+++
Cbpr	–2.573	–2.481	–2.572	0.785+++
Cdef	0.339	–2.318	0.488	1.180+++
Cn	0.199	–2.949	1.242	1.187+++
Cpi	0.632	–2.241	0.801	1.178+++
Cpic	0.455	$–4.157^{***}$	1.019	1.186+++
Cr	–1.800	–2.384	–1.480	1.068+++
Demandr	–2.094	–1.774	$–2.730^{*}$	1.014+++
Emp	–1.668	–2.359	–2.348	1.084+++
Excises	–0.492	$–3.535^{**}$	–0.994	1.072+++
Exoilr	$–2.687^{*}$	–2.830	$–2.616^{*}$	0.662++
Exotherr	–1.171	–2.520	–2.040	1.134+++
Expdef	–0.592	$–3.688^{**}$	–0.317	1.165+++
Fedr	$–2.736^{*}$	$–3.432^{*}$	–2.218	0.330
Gdef	0.505	$–3.287^{*}$	1.385	1.188+++
Gdpdef	0.287	–2.974	0.420	1.184+++
Gdpn	0.592	–2.903	1.054	1.186+++
Gdpr	–2.255	–1.802	$–3.102^{**}$	1.071+++
Gn	0.944	–2.885	1.853	1.188+++
Gr	–2.001	–2.525	–2.201	0.97+++
Hsr	$–4.078^{***}$	$–3.959^{**}$	$–3.782^{***}$	0.524++
Impdef	–0.130	–2.114	–0.148	1.055+++
Impr	–1.969	–2.070	–2.238	0.82+++
Incomen	–0.410	–2.346	0.269	1.207+++
Incomer	–2.209	–1.580	–2.085	1.086+++
Inctaxcorp	–0.278	$–4.322^{***}$	–1.188	1.029+++
Inctaxpers	0.862	–2.737	–0.172	1.19+++
Infl	–2.276	$–3.354^{*}$	–2.283	0.692++
Inflt	–1.446	–2.117	– 1.443	0.844+++
Inventr	–2.264	$–3.967^{**}$	$–7.326^{***}$	1.037+++
Invr	–2.052	–1.989	$–6.810^{***}$	1.225+++
Lforce	–2.529	–1.103	–2.533	0.959+++
Midgovb	$–2.959^{**}$	–2.877	$–3.013^{**}$	0.127
Oilpusd	–2.291	–2.193	–2.207	0.415+
Othertax	2.457	0.566	2.698	1.128+++
Prod	–2.433	–1.980	$–3.642^{***}$	1.048+++
Reer	–2.129	–1.895	–2.099	0.396+
Rubeur	–0.728	–2.156	–0.728	1.019+++
Rubusd	–0.351	–1.725	–0.372	0.861+++
Socpol	–0.043	$–6.928^{***}$	–0.13	1.185+++
Tcn	0.372	–3.026	1.603	1.188+++
Unemp	–1.623	$–4.398^{***}$	–2.129	0.97+++
Unemprate	–1.506	$–4.466^{***}$	–1.986	1.016+++
Uscpi	–0.462	–2.180	–0.460	1.179+++
Util	$–3.295^{**}$	$–3.305^{*}$	$–11.364^{***}$	0.194
Vat	–1.171	$–4.435^{***}$	–1.171	1.129+++
Vatrate	–1.782	–1.062	–1.840	0.368+
Wageav	1.740	–1.500	1.971	1.19+++
Wageavr	–1.253	–2.483	–1.376	1.09+++
Wtrade	–1.522	$–3.569^{**}$	–1.012	1.119+++
Ygap	$–3.295^{**}$	$–3.305^{*}$	$–11.364^{***}$	0.194
Ypot	–2.258	–2.926	$–5.362^{***}$	1.098+++

Note: The null hypothesis is rejected at 10% (+), 5% (++), 1% (+++); $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Table C2
Unit root test results of variables in year over year measure.

Variable (YoY)	ADF (*c*)	ADF (*c,t*)	PP (*c*)	PP(*c,t*)
Capsr	–2.460	–2.238	–1.943	–1.533
Cbpr	–2.961**	–2.978	–3.615***	–3.872**
Cdef	–2.996**	–3.007	–3.219**	–3.259*
Cn	–2.514	–2.542	–2.675*	–2.736
Cpi	–2.917**	–2.873	–2.552	–2.528
Cpic	–2.256	–2.232	–3.124**	–3.170*
Cr	–2.099	–3.478**	–2.523	–2.741
Demandr	–4.062***	–4.310***	–2.861*	–3.002
Emp	–3.035**	–3.987**	–3.253**	–3.384*
Excises	–1.438	–0.930	–5.174***	–5.130***
Exoilr	–3.567***	–3.769**	–3.567***	–3.769**
Exotherr	–3.06**	–3.073	–6.898***	–6.949***
Expdef	–5.156***	–5.103***	–3.535***	–3.457*
Fedr	–2.961**	–2.810	–2.788*	–2.645
Gdef	–2.434	–2.515	–2.759*	–2.924
Gdpdef	–3.609***	–3.557**	–3.018**	–2.919
Gdpn	–3.931***	–4.002**	–2.962**	–2.945
Gdpr	–3.673***	–4.032**	–2.747*	–2.589
Gn	–2.357	–2.635	–2.357	–2.635
Gr	–1.846	–1.718	–2.804*	–2.866
Hsr	–3.672***	–3.593**	–3.641***	–3.540**
Impdef	–3.024**	–3.010	–3.281**	–3.294*
Impr	–3.775***	–3.857**	–2.918**	–2.965
Incomen	–3.816***	–3.768**	–3.862***	–3.810**
Incomer	–3.496**	–3.899**	–3.475**	–3.937**
Inctaxcorp	–4.805***	–4.799***	–4.865***	–4.862***
Inctaxpers	–3.308**	–3.613**	–3.242**	–3.596**
Infl	–2.925**	–2.915	–3.386**	–3.366*
Inflt	–3.085**	–3.188**	–3.227**	–3.257**
Inventr	–3.566***	–3.525**	–3.786***	–3.750**
Invr	–3.274**	–3.460*	–3.340**	–3.54**
Lforce	–3.26**	–3.995**	–3.363**	–3.995**
Midgovb	–3.126**	–3.110	–3.455**	–3.436*
Oilpusd	–4.52***	–4.596***	–3.843***	–3.893**
Othertax	–2.757*	–3.755**	–2.702*	–3.775**
Prod	–3.575***	–3.974**	–2.902*	–3.162
Reer	–4.356***	–4.731***	–3.568***	–3.601**
Rubeur	–3.064**	–3.003	–3.331**	–3.280*
Rubusd	–2.560	–2.564	–3.015**	–3.050
Socpol	–5.966***	–5.905***	–6.562***	–6.506***
Tcn	–2.386	–2.458	–2.564	–2.677
Unemp	–4.147***	–4.134***	–3.38**	–3.362*
Unemprate	–4.198***	–4.171***	–3.414**	–3.380*
Uscpi	–2.326	–2.359	–3.945***	–3.955**
Util	–4.543***	–4.505***	–2.862*	–2.831
Vat	–2.884*	–2.925	–2.968**	–2.975
Vatrate	–1.836	–2.630	–2.194	–2.883
Wageav	–1.764	–3.646**	–2.100	–2.899
Wageavr	–2.789*	–2.768	–2.566	–2.580
Wtrade	–5.944***	–5.987***	–3.116**	–3.185*
Ygap	–4.543***	–4.505***	–2.862*	–2.831
Ypot	–1.136	–0.938	–1.206	–1.290

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Appendix D

Table D1
Normality, heteroskedasticity and autocorrelation tests.

Equation	JB	LM	BPG	ARCH
Average nominal wage equation	0.673	0.118	6.31	0.081
Central bank policy rate equation	40.102***	0.426	92.439***	0.163
Consumption deflator equation	56.773***	6.511**	20.566***	0.389
Corporate income taxes equation	0.004	3.957	1.073	1.165
CPI equation	13.932***	10.212***	3.297	0.025
Employment equation	0.479	–	–	–
Excise tax equation	4.259	4.706*	13.541**	1.553
Export deflator equation	1.677	2.698	2.793	1.294
GDP deflator equation	1.013	4.295	4.386	0.016
Government spending deflator equation	1.349	0.137	9.896*	0.006
Household saving rate equation	55.132***	1.905	19.568***	0.068
Imports deflator equation	0.290	4.447	0.316	3.366*
Imports equation	5.560*	0.247	12.156*	0.295
Investment equation	0.173	1.851	3.351	1.865
Labor force equation	0.580	–	–	–
NAIRU equation	28.172***	7.656**	29.695***	0.178
Medium–term government bond yield equation	22.636***	–	–	–
Non–oil exports equation	0.321	7.497**	4.229	0.504
Oil exports equation	1.135	0.175	14.302**	0.809
Other tax equation	99.664***	1.153	15.343***	0.208
Personal income tax equation	9.510***	0.567	8.073*	0.372
Private consumption equation	0.743	3.752	9.799	1.697
Real exchange rate equation	5.803*	8.596**	12.216**	4.285**
Real GDP equation	4.224	–	–	–
TFP trend equation	19.266***	–	–	–
VAT equation	13.781***	7.523**	1.508	0.361

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Appendix E

Table E1
Unit root tests of residuals from long-run equation (test for cointegration).

Equation	ADF	PP	KPSS
Average nominal wage equation	–2.904*	–3.942***	0.261
Consumption deflator equation	–2.976**	–2.946**	0.161
Corporate income taxes equation	–2.424	–4.495***	0.149
Excise tax equation	–1.703	–2.219	0.281
Export deflator equation	–4.791***	–4.927***	0.045
Government spending deflator equation	–2.496	–3.560***	0.227
Imports equation	–3.671***	–6.626***	0.057
Non–oil exports equation	–3.443**	–8.622***	0.101
Oil exports equation	–2.155	–4.825***	0.406+
Other taxes equation	–4.964***	–4.964***	0.182
Personal income taxes equation	–1.767	–8.409***	0.408+
Private consumption equation	–6.795***	–6.798***	0.177
VAT equation	–5.305***	–5.305***	0.055

Note: The null hypothesis is rejected at 10% (+); *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Appendix F

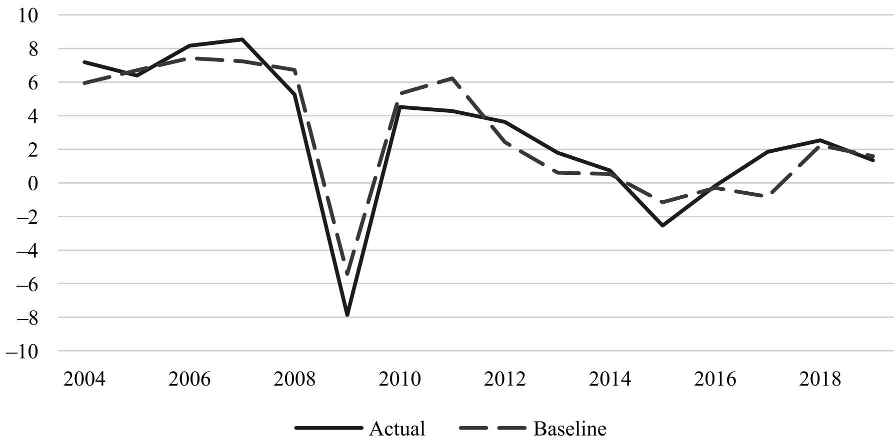

Fig. F1. Real GDP growth rate (%).

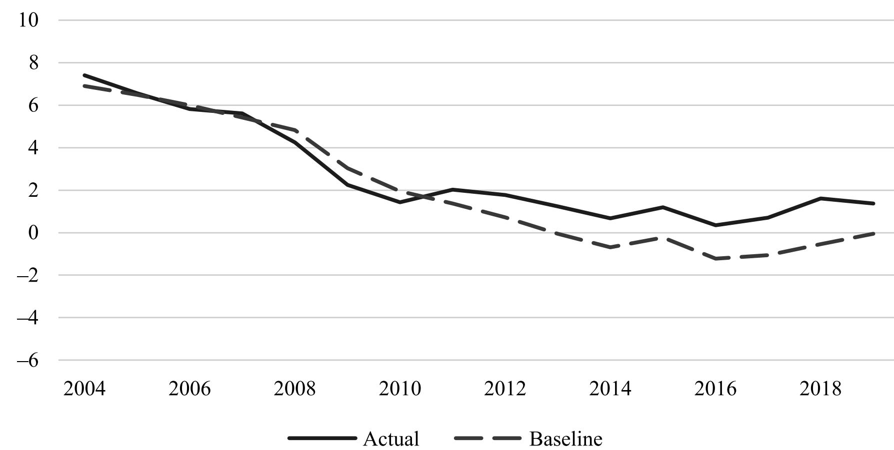

Fig. F2. Potential output growth (%).

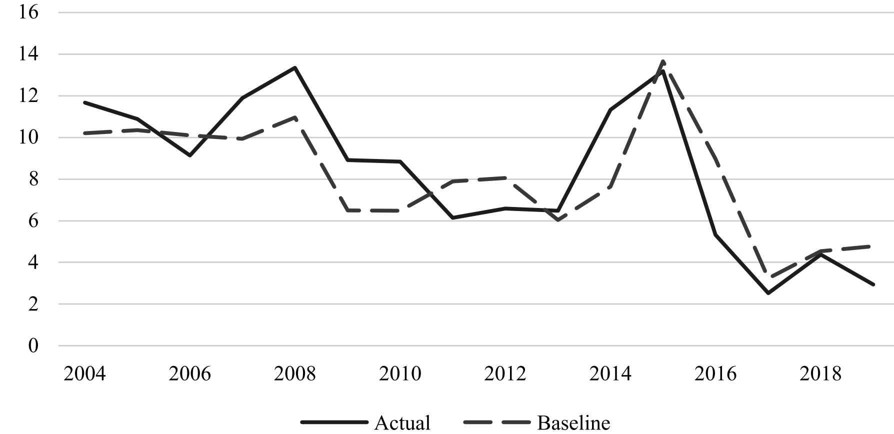

Fig. F3. Inflation rate (%).

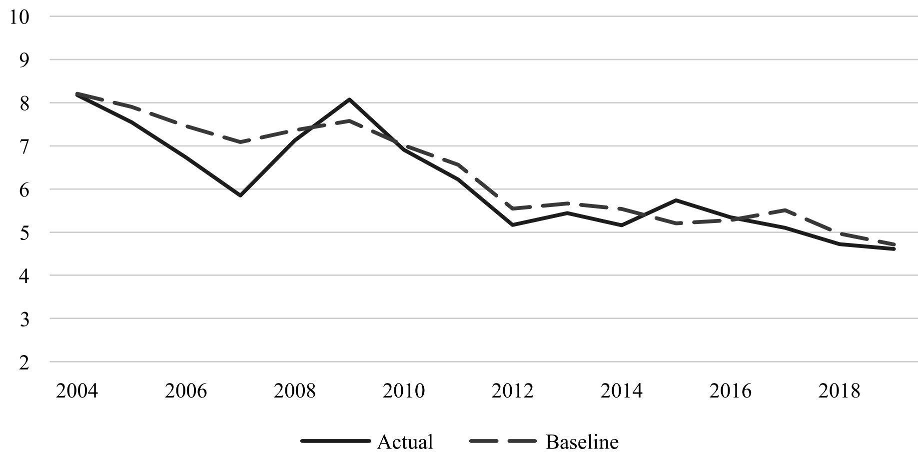

Fig. F4. Unemployment rate (%).

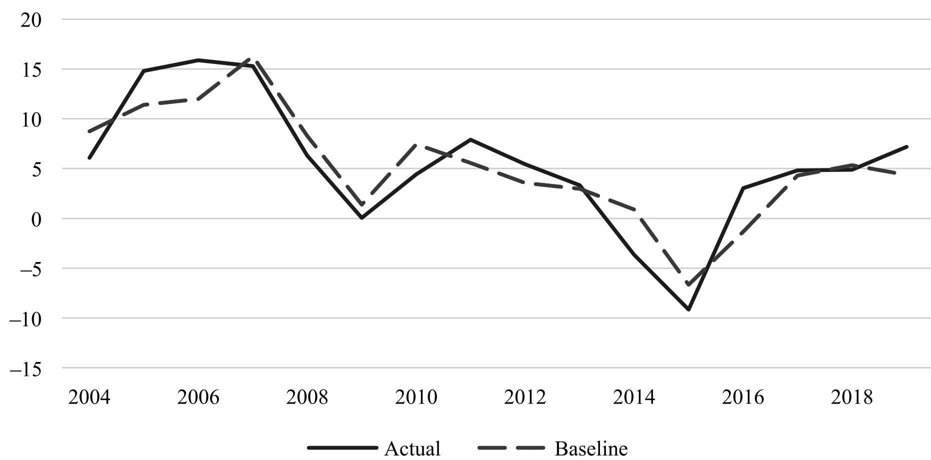

Fig. F5. Real wage growth rate (%).

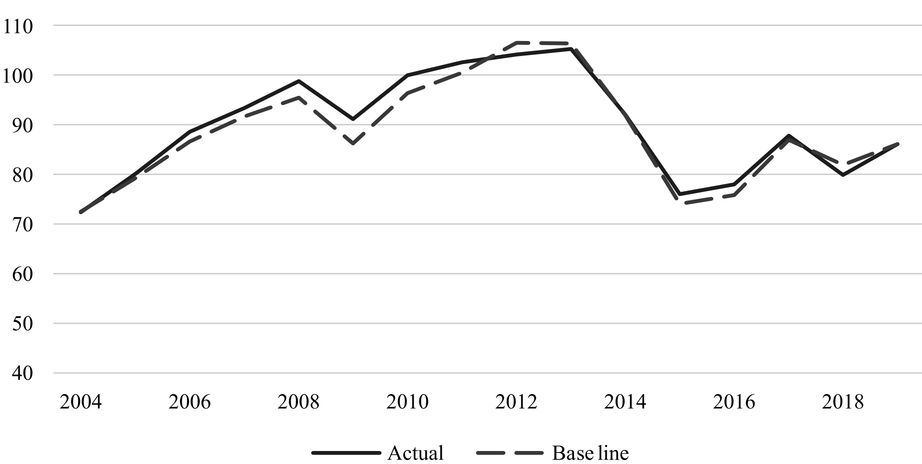

Fig. F6. Real effective exchange rate (the weighted average of the ruble against the basket of all currencies).

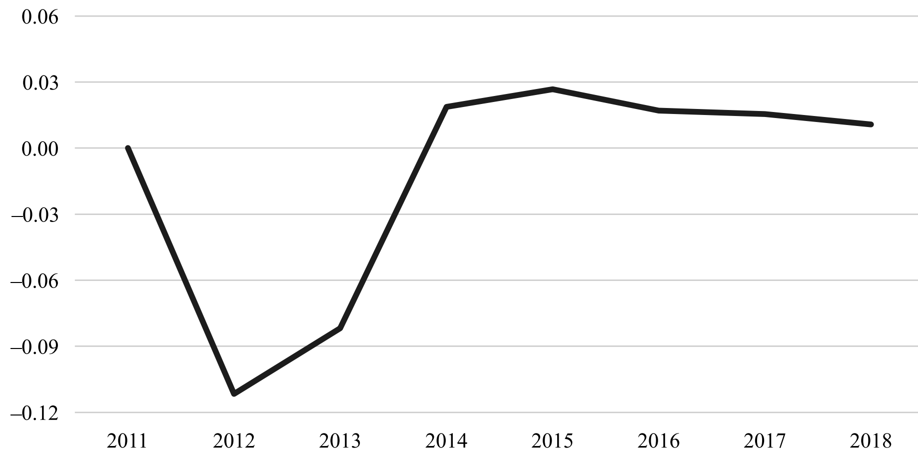

Fig. F7. Real GDP growth response to the VAT rate shock.

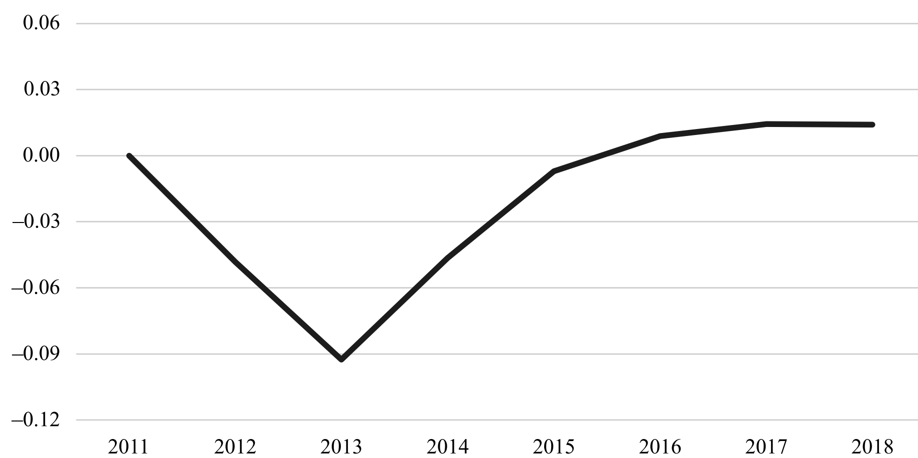

Fig. F8. Inflation rate response to the VAT rate shock.

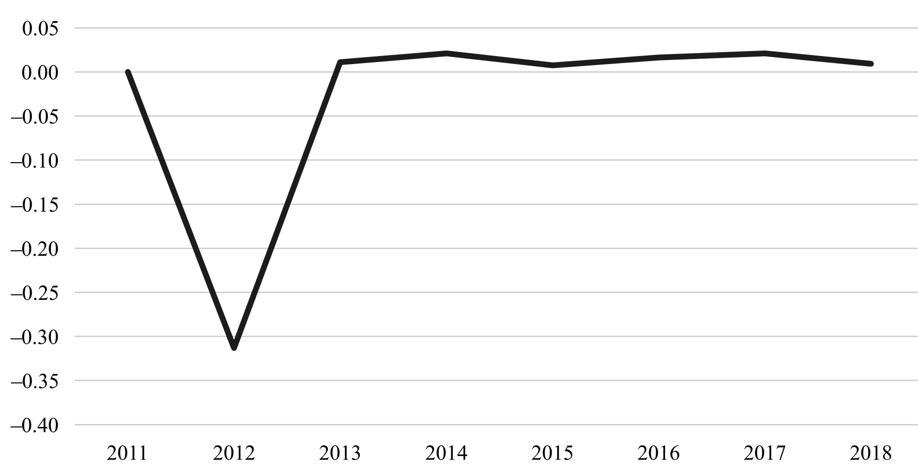

Fig. F9. Real GDP growth response to the world trade shock.

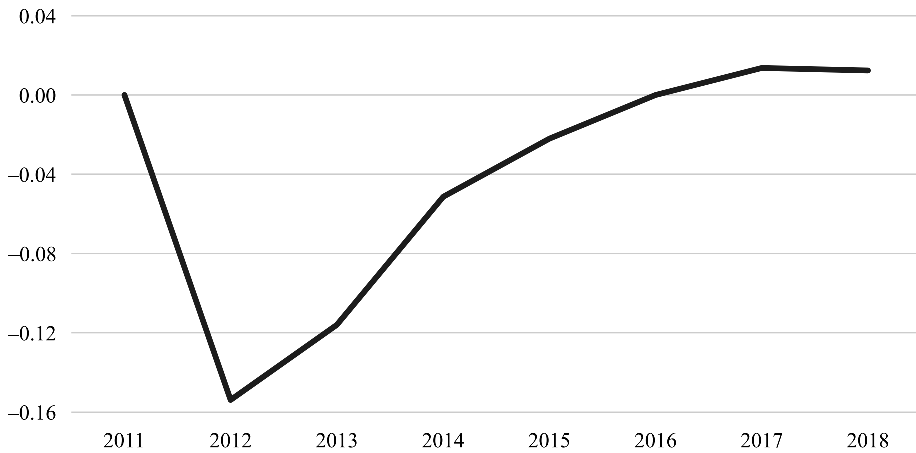

Fig. F10. Inflation rate response to the world trade shock.

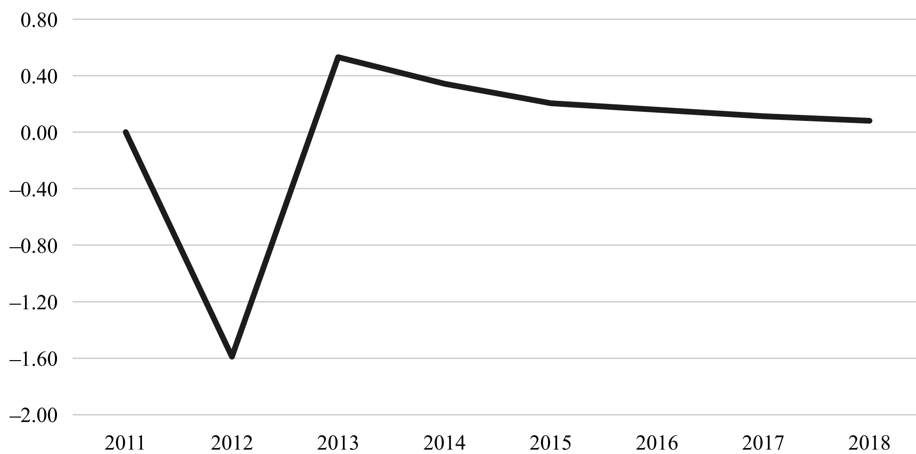

Fig. F11. Oil exports response to the world trade shock.

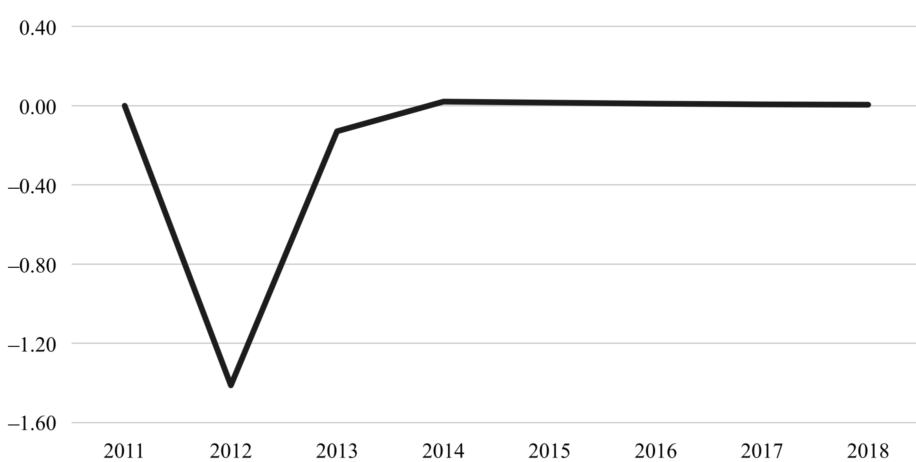

Fig. F12. Non-oil exports response to the world trade shock.

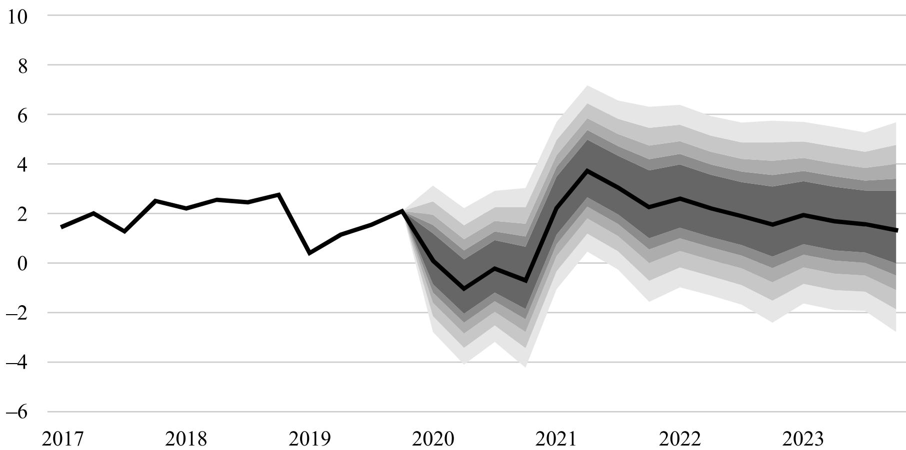

Fig. F13. Real GDP growth rate forecast (%).

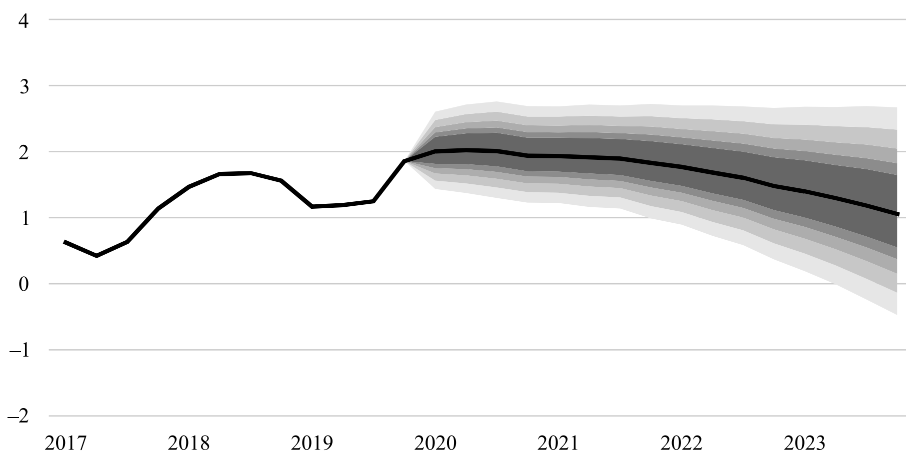

Fig. F14. Potential output growth forecast (%).

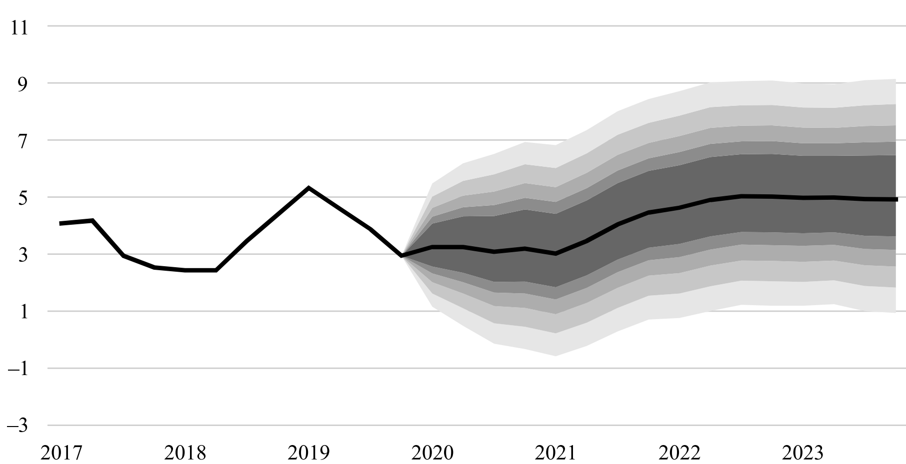

Fig. F15. Inflation rate forecast (%).

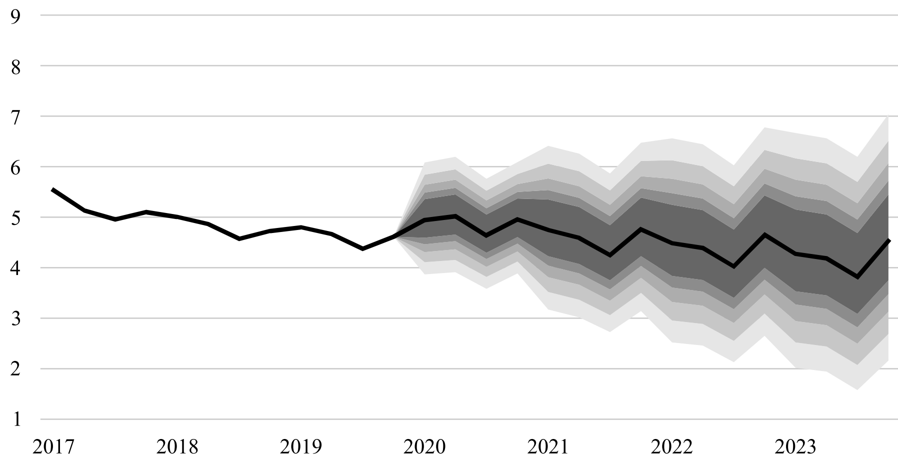

Fig. F16. Unemployment rate forecast (%).