DSGE Model of the Russian Economy: Economic Impact of Oil Price

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Abstract: In the paper the DSGE model proposed on the base of the theory of adaptive expectations. The aim of this work is to describe the possibility of using DSGE models for forecasting the Russian economy. This paper examines how the methodology of dynamic stochastic general equilibrium models can be applied to predict the yields of government bonds in 2018-2020, the proposed modification of the Taylor rule and the components of the prediction rate of the Russian ruble, characteristic of resource economies, where there is a close relationship between the exchange rate and oil price. It proposed the forecast of main macroeconomic indicators in the period 2017-2020 years (economic growth, inflation, oil price, exchange rate, Bank of Russia key rate and effective yields of government bonds). The practical significance of this work lies in the structuring of existing knowledge on the applicability of DSGE models of the Russian economy. The article also outlines the macroeconomic trends and modeling the conditions of an unstable economic situation in Russia. The parameters of monetary policy are also significant for determining the government bond yields. In addition, this article sheds light on forecasting the term structure of interest rates based on macroeconomic indicators.

1. Introduction

Research on the role of oil price in the Russian economy has emphasized the importance of the market channel in RUBUSD fluctuations. In this paper, we develop a dynamic stochastic general equilibrium (DSGE) model to quantify the importance of the endogenous interaction between oil market, inflation and the bank capital position for the transmission of macroeconomic shocks. The model is estimated using Russian data over the period 2008Q1–2017Q4 from Thomson Reuters Datastream.

Dynamic stochastic general equilibrium (DSGE) model that is based on Neo-Keynesian economic theory. Traditionally, they are a modern means of analyzing the impact of monetary and fiscal policies. DSGE models can also be used to predict inflation, GDP, and interest rates. In addition, within the DSGE-models, it is possible to compare the effectiveness of the implementation of the economic policy of the authorities. Since the early nineties of the twenty-first century, they have been used by most Central banks, including the European Central Bank, the US Federal Reserve, the Bank of England, the Bank of Canada, the Bank of Russia and others.

The explanation of the key features of the time structure of interest rates is a problem for standard models. Macroeconomic models [1]-[10] have difficulties in rationalizing the average duration of the expectation hypothesis. At the same time, empirical data indicate a close relationship between bond yields and macroeconomic indicators [18], [19].
In addition, we prove the relationship between the slope of the curve zero-coupon bond yield and forecasts of economic growth [15]-[20].

2. Literature review
This research paper covers the gap in the finance literature on monetary DSGE models with credit market frictions and is related to several recent studies [5], [6]. Many researchers [13], [27], [35], [36] show that term structure of interest rates in a DSGE model with recursive preferences can depend on oil price.

[38] – [41] develop models with financial frictions, in which the real and financial sectors are linked through the spillover effect of financial markets.[37] assume that changes in the volatility of five central European stock markets arise from an exogenous stochastic loan default rate. Most closely related to our framework is a series of DSGE models that allow for an endogenous interaction between financial asset market pricing on the one hand and macroeconomic indicators on the other. In particular,[4] integrate new parameters into a DSGE model to investigate the potential of cyclical bank capital regulation for macroeconomic stabilization. [9] develop the financial parameter proposed in [11], [12] by considering financial contracts. In a similar framework, [34] discusses the effects of macro indicators for the propagation of technology and monetary shocks. [7], [8] develop the impact of money and wage contracts in an optimizing model of the business cycle, and discuss the cost channel of monetary transmission, capital depreciation, and bank riskiness shocks.

First, while [22]-[26] calibrate their models to the U.S. economy, we estimate a model with endogenous interactions between oil price and national currency rate. Second, we discuss the effects of the interaction between bond yield and inflation by explicitly considering a number of macroeconomic shocks.

3. Methods
The monetary policy transmission mechanism [31] describes a channel connecting changes in lending conditions and macroeconomic variables. The article proposes a mechanism based on the dynamic stochastic general equilibrium model (DSGE) for forecasting the time structure of OFZ rates, based on their conditions of monetary policy dynamics and macroeconomic variables.

In addition, it is assumed that the factor of endogenous growth of vertical innovations [16], [17] can also be included in the standard Neo-Keynesian DSGE model. This model has several distinctive features.

First, households are sensitive to uncertainty over the long-term prospects of economic growth [2]. Second, the Central Bank sets short-term nominal interest rates based on the Taylor rule. Thirdly, the expected economic growth is associated with business solutions for the production of goods and services. Fourthly, the uncertainty factor of business activity changes over time. When the time series are adjusted in accordance with macroeconomic variables such as consumption, production, investment, unemployment, inflation and wage dynamics. This model quantifies the return to the average, volatility and nominal yield of bonds. Bond yields can be predicted by spreads between forwarding contracts or by a linear combination of forwarding rates.

The following assumptions should be made for successful bond yield modeling. First, the channel of endogenous growth creates long-term risks due to innovative solutions of firms [3]. Second, the presence of nominal linkages helps to assess the relationship between expected economic growth and inflationary expectations. Third, changing the uncertainty of economic growth leads to a time-varying bond risk premium. The Taylor rule and asset price model has ceased to be effective after the transition to quantitative easing and keeping interest rates low for a long time. The modern model of the interrelation of dynamics of endogenous inflation and dynamics of growth of consumption [14] influences decisions of producers of goods and services.

The article contracts with asset price models within the framework of liquidity preference theory [21], which take into account long-term risks arising in the economy. Taking into account the positive results achieved before, it is possible to expand the existing paradigm to study the time structure of interest rates. The dynamic stochastic general equilibrium model, unlike the static models studied in the General Equilibrium Theory, shows the development of the economy based on the preferences of economic agents. For example, households optimize consumption and labor efforts. Firms usually
maximize profits. Technological restrictions on agent decisions may also include the cost of adjusting their stocks, labor relations, or the price of their products. Agents must comply with the exogenous limitations of monetary and fiscal policy and may vary depending on the political process. Currently dominated by two competing scientific schools:

- The school of real business cycles is based on a neoclassical growth model. She studies how real shocks in the economy can cause business cycle fluctuations.
- Neo-Keynesian models suggest conditions of monopoly competition. They cannot react instantly to changes in macroeconomic variables.

The Bank of Russia uses a model of Smets–Wouters to analyze the Russian economy as a whole. Models contain three types of decision-making agents:

- Household;
- Firms;
- Central bank.

The parameters of the equations are estimated using Bayesian statistical methods in such a way that the model roughly describes the dynamics of GDP, consumption, investment, prices, wages, employment, and interest rates in the Russian economy (Fig. 1, 2, 3, 4).

**Figure 1.** GDP Dynamics in the Russian Federation (2008-2017)
GDP (% YOY, Standardized): Russia 
Source Thomson Reuters Data Stream

**Figure 2.** CPI Dynamics in the Russian Federation (2008-2018)
CPI(YOY): Russia 
Source Thomson Reuters Data Stream
To accurately reproduce the behavior of some variables, the model includes different types of frictions and shocks. The following formula is used to model GDP:

\[ y_t = a_1 y_{t-1} - a_2 mci_t + a_3 y^*_t + \varepsilon^y_t \]  

(1)

where \( y_t \) is the gap in the output of goods and services relative to the average level at time \( t \); the monetary policy index is calculated by the formula:

\[ mci_t = a_4 y^*_t + (1 - a_4)(-z_t) \]  

(2)

where \( y^*_t \) – the gap world output relative to the average level at time \( t \); \( \varepsilon^y_t \) – frictions of the demand in time \( t \); \( r_t \) deviation of the real interest rate relative to the equilibrium at time \( t \); \( z_t \) – deviation of the real exchange rate from the equilibrium at time \( t \); \( a_1 \) is the coefficient of inertia of the output gap; \( a_2 \) – coefficient of influence of monetary policy on the output of goods and services; \( a_3 \) – coefficient of influence of demand on the output of goods and services; \( a_4 \) – coefficient of influence of monetary policy on real interest rates.

The following formula is used to simulate inflation:

\[ \pi_t = b_1 \pi_{t+1} + (1 - b_1) \pi_{t-1} + b_2 rmc_t + \varepsilon^\pi_t \]  

(3)

where \( \pi_t \) - inflation; \( \pi_{t+1} \) – inflation expectations; \( rmc_t \) - real marginal costs are calculated by the formula:

\[ rmc_t = b_3 y_t + (1 - b_3) z_t \]  

(4)
where $e_t^i$ – frictions of inflation at time $t$; $b_1$ is the coefficient of inertia of inflation; $b_2$ – coefficient of influence of economic growth on inflation; $b_d$ – the share of domestic goods and services consumption.

Instead of the traditional Taylor rule for interest rate modeling, we use the following formula proposed by the First Deputy Chairman of the Bank of Russia Ksenya Yudaeva:

$$i_t = f_1 i_{t-1} + (1-f_1) i_t + f_2 (\pi_{t+1} - \pi_t^*) + f_3 + f_4 + e_t^i$$

(5)

where $e_t^i$ – is the friction of interest rates at the time $t$; $f_1$ is the inertia degree of the nominal interest rate, $f_2$ is the elasticity of the interest rate of the real exchange rate, $f_3$ is the elasticity of the interest rate of GDP, $f_4$ is the elasticity of the interest rate of the ruble.

The following formula is used to model the exchange rate of the national currency:

$$S_t = e_t S_t^b + (1-e_t) \left( S_{t+1}^b + \frac{i_t^* - i_t + prem_t}{4} \right) + e_t^s$$

(6)

where

$$S_{t+1}^b = S_{t-1} + \left( -\pi_t^* + \pi_t + z_t \right)$$

(7)

where $S_t$ – growth rate of nominal exchange rate of the ruble; $S_{t+1}^b$ – is the expected growth rate of the nominal exchange rate; $i_t^*$ – the average nominal interest rate in the world; $prem_t$ – risk premium; $e_t^s$ – frictions of the ruble exchange rate at time $t$; $-\pi_t^* + \pi_t$ – deviation of domestic inflation from global; $z_t$ – the equilibrium level of the real exchange rate at time $t$; $e_t$ – coefficient of inertia in the exchange rate. After calibration of the specified model, we obtained the optimal values of the model parameters (Table 1).

The complexity of DSGE modeling of the Russian economy is the high volatility of the dynamics of the exchange rate of the Russian ruble and the complexity of its forecasting, which, in fact, is the mathematical derivative of the price of oil. While forecasting oil prices on the basis of mathematical models is a futile exercise: the supply of oil depends on political arrangements and its accuracy, the demand for oil is largely regulated by reserve storages.

| Parameter | Value |
|-----------|-------|
| Impact of monetary conditions on the real economy | -0.2 |
| The significance of interest rate in monetary policy | 0.45 |
| Impact of costs | 0.18 |
| Smoothing inflation expectations | 0.37 |
| Influence of the deviation of expected inflation from the target level | 0.65 |
| Effect of the exchange rate deviation from the stable | 0.35 |
| Smoothing of currency expectations | 0.35 |
| The inertia of interest rates | 0.61 |
| The influence of the deviation of expected inflation from the target level | 0.65 |
| Impact of the deviation of GDP from the steady state | 0.34 |
| Effect of the exchange rate deviation from the stable | 0.35 |
| The flexibility of the foreign exchange market | 0.11 |
| Smoothing of currency expectations | 0.35 |

Source: compiled by the author.

4. Results
The price of bonds with n-period to maturity is expressed by the formula:

\[ P_t^{(n)} = E_t \left[ M_{t+1}^s P_{t+1}^{(n-1)s} \right] \]  \hfill (8)

where \( E_t \) is the yield on bond ownership during the period \([t; t+1]\), \( P_t^{(n)} \) is the bond price at the time \( t \), \( P_{t+1}^{(n-1)s} \) is the bond price at the time \( t+1 \), \( M_{t+1}^s \) is maturity at the time \( t+1 \)

\( M_{t+1}^s \) has a conditionally normal distribution, the formula takes the form of:

\[ P_t^{(n)} = E_t \left[ \sum_{j=1}^{n} m_{t+j}^s \right] + \frac{1}{2} \text{var}_t \left[ \sum_{j=1}^{n} m_{t+j}^s \right] \]  \hfill (9)

where \( \text{var}_t \) – variance at time \( t \), \( n \) is the number of periods payments of the coupons.  

Then the yield of the bond to maturity \( (y_t^{(n)}) \) can be found by the formula:

\[ y_t^{(n)} = -\frac{1}{n} E_t \left[ \sum_{j=1}^{n} m_{t+j}^s \right] - \frac{1}{2n} \text{var}_t \left[ \sum_{j=1}^{n} m_{t+j}^s \right] \]  \hfill (10)

The low frequency of economic growth and inflation, as well as the negative relationship between expected economic growth and inflationary expectations, have important implications for the temporary structure of rates. In the study period significantly increased correlation between the key rate of the Bank of Russia and interest rates on the bond market (Figure 5 and 6). In 2016 there is an alignment of the cordless yield curve. It acquires a positive slope inherent in a “healthy” economy. At the same time, the negative relationship between economic growth and inflationary expectations suggests that long-term bonds have lower yields when long-term growth is expected to be low. That is the zero-coupon yield curve of government bonds, acquires a negative slope [32]. To understand the negative long-term relationship between growth and inflation, it needs to consider a positive shock. A prolonged increase in productivity lowers real marginal costs over a long period of time and leads to lower inflation. The model of endogenous growth of consumption and inflation has been described in previous research in detail [28].  

The slope of the nominal bond yield curve is a strong predictor of economic growth and inflation over a given business cycle. The growth channel plays an important role in explaining the average temporary spread while increasing the maturity of the bond. In addition to generating long-term growth risks, endogenous growth is also important for assessing the negative long-term relationship between inflation expectations and economic growth [29, 30]. The above model allows us to make a forecast of economic indicators.
**Figure 6:** Effective Yield of Russian Government Bonds in 2008-2018
Source Thomson Reuters Data Stream

| Parameter                        | 2017  | 2018  | 2019  | 2020  |
|----------------------------------|-------|-------|-------|-------|
| Growth rate of real GDP, %       | 1.02  | 0.64  | 0.46  | 1.14  |
| Inflation expectations, %        | 4.20  | 3.54  | 5.31  | 6.27  |
| Average exchange rate of RUBUSD, rubles | 57.02 | 62.36 | 70.78 | 75.55 |
| Average effective yield of OFZ 20Y, % | 7.42  | 7.02  | 7.89  | 8.55  |

Source: compiled by the author.

Current trends in the strengthening of USD may presumably go until 2019-2020, based on the revealed in recent years, the long macroeconomic cycles characteristic of the world economy after the signing of the Bretton woods agreement [33]. Therefore, we believe that the proposed forecast values are fair and it has a maximum deviation error of + / -5% (Table 2).

5. **Conclusion**

Thus, we adopt the DSGE model widely used in developed economies for the Russian one. The relationship between the parameters of monetary policy and the yield of the government bond market is studied. In addition, this article sheds light on the prediction of the yields of OFZ bonds on the base of macroeconomic indicators using a General stochastic equilibrium model of endogenous growth. As a result, a medium-term forecast of Russian macroeconomics is obtained: the current political and economic situation is maintained.

6. **References**

[1] Agénor, P.-R., Bratsiotis, G.J., Pfajfar, D. (2014), Credit frictions, collateral, and the cyclical behavior of the finance premium. Macroecon. Dyn. 18 (05), 985–997.

[2] Albertazzi, U., Gambacorta, L. (2009), Bank profitability and the business cycle. J. Financ. Stabil. 5 (4), 393–409.

[3] Aliaga-Daz, R., Olivero, M.P. (2010), Is there a financial accelerator in US banking? Evidence from the cyclicality of banks’ price-cost margins. Econ. Lett. 108 (2), 167–171.

[4] Angeloni, I., Faia, E. (2013), Capital regulation and monetary policy with fragile banks. J. Monet. Econ. 60 (3), 311–324.

[5] Bansal, R., D. Kiku, A. Yaron (2012), An empirical evaluation of the long-run risks model for asset prices. Critical Finance Review 1(1), 183-221.

[6] Bansal, R., I. Shaliastovich (2013), A long-run risks explanation of predictability puzzles in bond and currency markets. Review of Financial Studies 26(1), 1-33.

[7] Barth, M.J.I., Ramey, V.A. (2002), The cost channel of monetary transmission. In: NBER Macroeconomics Annual 2001, Volume 16. National Bureau of Economic Research, Inc, pp. 199–256.
8

[8] Benassy, J.-P. (1995), Money and wage contracts in an optimizing model of the business cycle. J. Monet. Econ. 35 (2), 303–315.
[9] Benes, J., Kumhof, M. (2015), Risky bank lending and countercyclical capital buffers. J. Econ. Dyn. Control 58 (C), 58–80.
[10] Beeler, J., Y. Campbell. (2012), The long-run risks model and aggregate asset prices: an empirical assessment. Critical Finance Review 1(1), 141-182.
[11] Bernanke, B., Lown, C.S. (1991), The credit crunch. Brookings Pap. Econ. Act.22 (2), 205–248.
[12] Bernanke, B.S., Gertler, M., Gilchrist, S. (1999), The financial accelerator in a quantitative business cycle framework. In: Taylor, J.B., Woodford, M. (Eds.), Handbook of Macroeconomics: Vol. I. Elsevier Science B.V., pp. 1341–1392.
[13] Binsbergen, J., J. Fernandez-Villaverde, R. Kojien, J. Rubio-Ramirez. (2012), The term structure of interest rates in a dsge model with recursive preferences. Journal of Monetary Economics 59(7), 634-648.
[14] Bloom, N., M. Floetotto, N. Jaimovich, I. Saporta-Eksten, S. J. Terry. (2012), Really uncertain business cycles. Unpublished working paper. Stanford University.
[15] Berrospide, J.M., Edge, R.M. (2010), The Effects of Bank Capital on Lending: What do We Know, and What does it Mean?. Finance and Economics Discussion Series 44. Federal Reserve Board.
[16] Bikker, J.A., Hu, H. (2002), Cyclical patterns in profits, provisioning and lending of banks and procyclical of the new Basel capital requirements. BNL Q. Rev. 55 (221), 143–175.
[17] Bolt, W., de Haan, L., Hoeberichts, M., van Oordt, M.R., Swank, J. (2012), Bank profitability during recessions. J. Bank. Finance 36 (9), 2552–2564.
[18] Borio, C., Zhu, H. (2012), Capital regulation, risk-taking and monetary policy: a missing link in the transmission mechanism? J. Financ. Stabil. 8 (4), 236–251.
[19] Brooks, S.P., Gelman, A. (1998), General methods for monitoring convergence of iterative solutions. J. Comput. Graph. Stat. 7 (4), 434–455.
[20] Buch, C.M., Eickmeier, S., Prieto, E. (2014), In search for yield? Survey-based evidence on bank risk taking. J. Econ. Dyn. Control 43, 12–30.
[21] Carlstrom, C.T., Fuerst, T.S. (1997), Agency costs, net worth, and business fluctuations: a computable general equilibrium analysis. Am. Econ. Rev. 87 (5), 893–910.
[22] Cecchetti, S.G., Li, L. (2008), Do capital adequacy requirements matter for monetary policy? Econ. Inq. 46 (4), 643–659.
[23] Cho, J.-O., Cooley, T.F. (1995), The business cycle with nominal contracts. Econ. Theory 6 (1), 13–33.
[24] Croce, M., H. Kung, T. Nguyen, L. Schmid. (2012), Fiscal policies and asset prices. Review of Financial Studies.
[25] Croce, M., T. Nyugen, L. Schmid. (2012), Fiscal policies and the distribution of consumption risk. Unpublished working paper. Duke University 25(9), 2635-2672.
[26] Haan, W. (1995), The term structure of interest rates in real and monetary economies. Journal of Economic Dynamics and Control 19(5-7), 909-940.
[27] Mikhaylov A.Y. (2012), Ocenka ehffektivnosti funkcionirovaniya investicionnyh fondov v Rossii [Assessment of efficiency of functioning of investment funds in Russia]. Vestnik Instituta Ekonomiki RAN = Bulletin of the Institute of Economics (RAS), no. 5, pp. 121–129.
[28] Mikhaylov A.Y. (2013), Effektivnost ispol'zovaniya aktivov investitsionnyh fondov na osnove GIPS [Efficiency of use of assets of investment funds on the basis of GIPS]. Ekonomika i predprinimatelstvo = Economics and entrepreneurship, no. 4, pp. 372–375.
[29] Mikhaylov A. Y. (2014), Faktory razvitiya ekonomiki Rossii v 2015 godu [Factors of development of the Russian economy in 2015]. Voprosy regulirovaniya ekonomiki = Questions of economic regulation, no. 4, pp. 62-69.
[30] Mikhaylov A.Y. (2018), Pricing In Oil Market And Using Probit Model For Analysis Of Stock Market Effects = International Journal of Energy Economics and Policy, 2, pp. 69–73.
[31] Taylor, J. (1993), Discretion versus policy rules in practice. Carnegie-Rochester Conference Series on Public Policy (39), 195-214.
[32] Mikosch, T. and Starica, C. (2004), Non-stationarities in financial time series, the long range dependence, and the IGARCH effects. Review of Economics and Statistics, 86, pp. 378-390.

[33] Newey, W.K. and West, K.D. (1994), Automatic lag selection in covariance matrix estimation. Review of Economic Studies, 61, pp. 631-654.

[34] Sanso, A., Arago, V. and Carrión-i-Silvestre, J. (2004), Testing for changes in the unconditional variance of financial time series. Revista de Economía Financiera, 4, pp. 32-53.

[35] Wachter, J. (2006), A consumption-based model of the term structure of interest rates. Journal of Financial Economics 79(2), 365-399.

[36] Walid, C., Chaker, A., Masood, O. and Fry, J. (2011), Stock market volatility and exchange rates in emerging countries: Markov-state switching approach. Emerging Markets Review, 12, pp. 272-292.

[37] Wang, P. and Moore, T. (2009), Sudden changes in volatility: The case of five central European stock markets. Journal of International Financial Markets, Institutions and Money, 19, pp. 33-46.

[38] Woodford, M. (2003), Interest and Prices: Foundations of a Theory of Monetary Policy. Princeton University Press, New Jersey.

[39] Wright, J. H. (2011), Term premia and inflation uncertainty: Empirical evidence from an international panel dataset. The American Economic Review 101(4), 1514-1534.

[40] Zhao, H. (2010), Dynamic relationship between exchange rate and stock price: Evidence from China. Research in International Business and Finance, 24, pp. 103-112.

[41] Zivkov, D., Njegic, J. and Milenkovic, I. (2015), Bidirectional Volatility Spillover Effect between the Exchange Rate and Stocks in the Presence of Structural Breaks in Selected Eastern European Economies. Finance a uver-Czech Journal of Economics and Finance, 65, no. 6.