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## **MONETARY REGIME CHOICE AND OPTIMAL CREDIT RATIONING AT THE OFFICIAL RATE: THE CASE OF RUSSIA**<sup>2</sup>

Stabilizing monetary policy in a small open economy is constrained by the open economy trilemma. In a crisis this constraint may not allow the Central Bank to cut interest rates because this may cause significant capital flight and the ensuing problems. In this paper we investigate whether the Central Bank's credit rationing at the official rate (CROR) may soften the open economy trilemma constraint and improve the results of monetary policy for different monetary regimes. We construct a DSGE model appropriate for analysing the forward-looking behaviour of households facing a non-zero probability of credit rationing at the official rate. A simulation of estimated on a Russian data model and welfare optimization exercises allow us to contribute to the question of optimal monetary regime choice and to analyse the role of credit rationing for different monetary regimes.

We have found significant credit rationing in the quarterly Russian data of 2001–2014. The share of liquidity constrained (non-Ricardian) households and the probability of CROR are estimated as 22% and 66% respectively. Welfare maximization exercises reveal a trade off between low-inflation and high-welfare solutions and favour of a floating exchange rate regime. Researching CROR gives mixed results. On the one hand we found the optimal value of the probability of CROR in both exchange rate-based and Taylor rule-based models. On the other hand the resulting improvement in welfare is very small.

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## 1. Introduction

Foreign exchange rate dynamics are considered a constraint on monetary policy. The intensity of such constraints varies across monetary regimes from low, for floaters, to high, for fixers. Irrespective of the monetary regime, in a period of negative external shock the Central Bank should choose between a high official interest rate, a national currency devaluation, capital flight, and imposing restrictions on capital flows. All alternatives are painful for the real part of economy and Central Banks may try to find another solution. A possible alternative is credit rationing at the official rate (CROR) which may help the real sector with lower interest rates and prevent significant international reserves fall or/and national currency depreciation as a result of significant capital flight. On the other hand credit rationing could lead to an increase of risk premium and the forward-looking behaviour of agents who would try to get more credit in advance.

In this paper we investigate whether the Central Bank's CROR may soften the open economy trilemma constraint (Obstfeld et al., 2005) and improve results of monetary policy for different monetary regimes. The paper also contributes to the optimal monetary regime choice for Russia which has used elements of credit rationing in monetary policy<sup>3</sup>.

Credit rationing is a financial market imperfection which may be introduced into a model to explain a significant share of real sector volatility and refining of monetary policy transmission and shock propagation mechanisms. Financial frictions make risk premium more pro-cyclical, cause shocks amplification, and increase the persistence of variables. In the papers of Carlstrom and Fuerst (1997), Bernanke, Gertler and Gilchrist (1996), Gertler and Karadi (2009), and Gertler and Kiyotaki (2011) financial frictions arise as a result of restrictions on net worth of the firm. They also may be the result of monitoring costs as in Bernanke and Gertler (1989); collateral constraints Kiyotaki and Moore (1995) and Monacelli (2009); or quantity rationing Waters (2013) and Boissay (2001). All these papers assume that financial frictions originate from the interaction between private lenders and private borrowers while Central Banks should just take that feature into account in optimizing monetary policy design. In this paper we assume that credit rationing, as controlled by authorities, is a financial market imperfection which may help to improve monetary transmission mechanism.

To answer the questions raised above we elaborate the DSGE model to analyse the forward-looking behaviour of households facing a non-zero probability of CROR. In the model we assume that in every period, some of the liquidity constrained households have no ability to make an intertemporal optimization of its consumption path after getting a random signal a la Calvo (1983). We also assume that another random signal gives households access to financing at the official rate. Each household will have, with some probability: (1) no access to financial markets, (2) access to financing at an interest rate driven by foreign interest rates and a pro-cyclical risk premium, (3) access to Central Bank financing. Introducing liquidity constraints into the model allows the model to be customised to give a high correlation between consumption and current income. Introducing CROR provides a reasonable restriction on the independence of two monetary instruments and helps explain the pro-cyclical behaviour of risk premium, interest rates and consumption. In DSGE models the open economy trilemma constraint takes the form of the equation for risk premium as a function of the foreign indebtedness level (Benigno, 2001, Adolfson et al., 2007, Linde et al.,

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<sup>3</sup> For example in the crises of 2008-2009 interbank interest rate was frequently higher than official (refinance) rate. Russian commercial banks faced with a lack of collateral instruments and had no ability to borrow needed volume of liquidity from Central Bank. To resolve the liquidity shortage problem authorities elaborated different facilities (Aleksashenko et al., 2011) and the most important one was uncollateralized lending auctions (ULA) conducted by Bank of Russia (BoR). Interest rate on the ULA was usually higher than interbank rate and demand always exceeded supply in a crises. So the volume of liquidity supplied through the ULA was controlled by BoR and was an important monetary policy instrument. To decrease speculative pressure on foreign exchange market BoR limited volume of liquidity supplied through the ULA. Other way BoR used ULA was the threat to reduce borrowing limits for commercial banks which speculate on foreign exchange market. Facing the probability of not getting financing through the ULA Russian banks behaved in forward-looking manner. Similar situation was in the foreign crediting boom of 2005–2007 when short-term interbank interest rate was far below refinance rate. BoR issued sterilizing facilities and chose the volume of sterilized liquidity due to the needs of its anti-inflationary policy.

2009). Escude (2013) demonstrated that in a model with such a constraint two optimal rules for systematic foreign exchange rate and interest rate policies help to improve household welfare. Shulgin (2015) found the same result for estimated on a Russian data DSGE model with two monetary policy rules: the Taylor rule and the exchange rate adjustment rule. Introducing CROR in the model will change the constraint on the two independent monetary policy instruments and will influence the results of welfare maximization exercises.

The main findings of the paper are as follows. A Bayesian estimation demonstrates that the introduction of liquidity constrained (non-Ricardian) households and CROR into the DSGE model is justified by Russian quarterly data of 2001–2014. The share of liquidity constrained (non-Ricardian) households and the probability of CROR are estimated as 22% and 66%, respectively. Simulating a DSGE model with different values of coefficients in the Taylor rule, the exchange rate adjustment rule, and the credit rationing parameter allow welfare optimization exercises. The results demonstrate a trade off between low-inflation and high-welfare regimes. We have found that a floating regime appears to be the best solution for Russia for all the optimization exercises conducted. A welfare optimization over credit rationing parameter gives a mixed result. We found the optimal value of the probability of CROR in both the exchange rate-based and Taylor rule-based models. On the other hand the resulting improvement in welfare is very small.

The rest of the paper is organized as follows. Section 2 presents the DSGE model for a small open economy with two independent monetary policy instruments and two types of credit rationing. In Section 3 we perform a calibration of the parameters which determine the steady state of the model and a Bayesian estimation of other parameters on the basis of a Russian de-seasoned de-trended series: consumption, output, inflation, exchange rate, refinance rate, international reserves, risk premium, and commodity price. Section 4 presents the results of welfare optimization exercises. Section 5 concludes.

## 2. The Model

A small open economy is inhabited by a continuum of households indexed by  $j \in [0, 1]$ . Households supply labour services in a monopolistically competitive market and make decisions on their consumption. Goods and services are produced by firms all belonging to the corresponding households. Intermediate manufactured (M), non-tradable (N) and imported goods and services are produced in monopolistically competitive markets, while commodity (X), final (Z) and capital goods are produced in perfectly competitive markets. The government decides on its spending  $G_t$  and does not issue debt, maintaining zero budget deficits. The Central Bank manipulates interest and exchange rates simultaneously and performs CROR.

### Households

Household  $j$  utility function is:

$$U_t(j) = E_t \sum_{s=t}^{\infty} \beta^{s-t} \eta_{b,s} \Lambda_s(j), \quad (1)$$

where  $\beta$  is the intertemporal discount factor;  $\eta_{b,t}$  is the intertemporal preference shock which helps to account for unexplained volatility in consumption. All structural shocks  $\eta_t$  in the model are expected to have zero mean and not expected to be iid processes.

Instantaneous utility is:

$$\Lambda_t(j) = \frac{(C_t(j) - hC_{t-1})^{1-\sigma_C}}{1-\sigma_C} - \frac{H_t(j)^{1+\sigma_H}}{1+\sigma_H}, \quad \sigma_C, \sigma_H > 0 \quad (2)$$

where  $C_t(j)$  is the consumption of household  $j$ ;  $hC_{t-1}$  is the external habits in consumption;  $h \in (0, 1)$  is a habits parameter;  $H_t(j) = H_{M,t}(j) + H_{N,t}(j) + H_{X,t}(j)$ , where  $H_{M,t}(j)$ ,  $H_{N,t}(j)$  and  $H_{X,t}(j)$  are hours worked in the manufactured (M), non-tradable (N) and commodity (X) sectors respectively. Parameter  $\sigma_C$  is the relative risk aversion coefficient or the inverse of the elasticity of the intertemporal substitution of consumption; parameter  $\sigma_H$  is the inverse of the Frisch wage elasticity of labour supply.

Households can buy or sell foreign denominated securities  $B_t^*(j)$  on an incomplete international financial market. Cost of funding for households  $j$ :

$$1 + i_t^*(j) = (1 + i_t^*)(1 + rp_t(j)), \quad (3)$$

where foreign risk free interest rate  $i_t^*$  is assumed to be an exogenous constant; risk premium  $rp_t(j)$  depends on the foreign indebtedness level of household  $j$ , as in Adolfson et al. (2007):

$$1 + rp_t(j) = \exp\left(-\tau \frac{S_t B_t^*(j)}{P_t Y_t} + \eta_{rp,t}\right), \quad \tau > 0 \quad (4)$$

where  $S_t$  is the foreign exchange rate;  $B_t^*(j)$  is the volume of private foreign assets of household  $j$ ;  $P_t$  is the price level;  $Y_t$  is the aggregate output level;  $\tau$  is the sensitivity of risk premium to indebtedness level;  $\eta_{rp,t}$  is the risk premium shock.

Households can also buy/issue bonds denominated in the domestic currency  $B_t(j)$  at the official rate  $i_{ref,t}$  set by the Central Bank, which supply/demand domestic currency bonds  $B_t$  to clear the market.

Every household with some probability may lose access to financial markets and the ability to manipulate their bond volume  $B_t^*(j)$  and  $B_t(j)$ . Every household should also take into account the possibility of such events in the future when it can optimize  $B_t(j)$  and  $B_t^*(j)$ .

Households get rental payments  $Q_{i,t}$  on their capital  $K_{i,t}(j)$ ; wages  $W_{i,t}$  for the hours they work  $H_{i,t}(j)$ , where  $i = M, N, X$ ; payments for natural resources used in commodity goods production  $P_{L,t}L_t(j)$ ; profit from monopolistically competitive markets  $D_t(j) = D_{M,t}(j) + D_{N,t}(j) + D_{F,t}(j)$ , and income from previous period securities  $B_{t-1}(j)(1 + i_{t-1}) + S_t B_{t-1}^*(j)(1 + i_{t-1}^*)(1 + rp_{t-1})$ . Household  $j$  consumes goods and services  $C_t(j)$ , invests in the capital of their firms in three intermediate goods sectors  $I_t(j) = I_{M,t}(j) + I_{N,t}(j) + I_{X,t}(j)$ , pays lump-sum taxes  $T_t(j)$  and purchases domestic and foreign denominated securities,  $B_t(j)$  and  $B_t^*(j)$  respectively. Household budget constraints summarize all its incomes and purchases:

$$P_t \cdot (C_t(j) + I_t(j)) + T_t(j) + B_t(j) + S_t B_t^*(j) = \sum_{i=X,M,N} (Q_{i,t} K_{i,t}(j) + W_{i,t} H_{i,t}(j)) + P_{L,t} L_t(j) + D_t(j) + B_{t-1}(j)(1 + i_{t-1}) + S_t B_{t-1}^*(j)(1 + i_{t-1}^*)(1 + rp_{t-1}) \quad (5)$$

## Optimal financing decisions in a face of two types of credit rationing

As in many DSGE models constructed for developing economies (for example, Sosunov and Zamulin, (2007) for Russia) we assume that some of the liquidity constrained households have no ability to make an intertemporal optimization of their consumption path.

Let us assume that every household in every period gets two random signals about their ability to borrow/invest money in different financial market segments. The first signal reveals whether household  $j$  has the ability to optimize its consumption path using any financial market instrument. If it gets such signal (with the probability  $1 - \theta_A$ ) it may adjust some of its financial instruments:  $B_t$  and/or  $B_t^*$ . With probability  $\theta_A$  household  $j$  has to consume its current income and has no ability to smooth its consumption path. We label the last group ‘liquidity constrained (non-Ricardian)’ households.

The second signal reveals whether household  $j$  has access to financing at the official (refinance) rate  $i_{ref,t}$ . If it gets such signal (with probability  $1 - \theta_B$ ) it may adjust both  $B_t$  and  $B_t^*$ . With probability  $\theta_B$  household  $j$  has no ability to adjust  $B_t$  and may adjust only its foreign assets volume  $B_t^*$ .

## Euler equation in the presence of liquidity constrained households

To derive the Euler equation for the consumption path we use a calculus variation approach. Assume that household  $j$  has the ability to adjust its financial assets/debts during the period  $t$  and thinks about the effect of marginal consumption  $dC_t(j)$ . With probability  $1 - \theta_A$  it will have the ability to consume its marginal savings  $dC_{t+1}^o(j) = -\frac{P_t}{P_{t+1}}(1 + i_t)dC_t(j)$ , where superscripts  $^n$  and  $^o$  denote non-optimizing and optimizing households respectively. Household  $j$  will have no ability to smooth consumption during the period  $t+1$  with probability  $\theta_A$  and has to consume only additional interest payments on marginal savings  $dC_{t+1}^n(j) = -\frac{P_t}{P_{t+1}}i_t dC_t(j)$ . The same logic may be applied to the period  $t+2$ : with probability  $\theta_A(1 - \theta_A)$  it will consume  $dC_{t+2}^o(j) = -\frac{P_t}{P_{t+2}}(1 + i_{t+1})dC_t(j)$ . With probability  $\theta_A^2$ , it will consume interest payments  $dC_{t+2}^n(j) = -\frac{P_t}{P_{t+2}}i_{t+1}dC_t(j)$ . Recurring in this way we find the expected utility of marginal consumption which should optimally be zero:

$$\Lambda_{C,t}^o \eta_{b,t} - \beta E_t \left\{ (1 - \theta_A) \sum_{k=1}^{\infty} (\beta \theta_A)^{k-1} \Lambda_{C,t+k}^o \eta_{b,t+k} \frac{P_t}{P_{t+k}} (1 + i_{t+k-1}) + \theta_A \sum_{k=1}^{\infty} (\beta \theta_A)^{k-1} \Lambda_{C,t+k}^n \eta_{b,t+k} \frac{P_t}{P_{t+k}} i_{t+k-1} \right\} = 0, \quad (6)$$

where the marginal utilities of consumption for optimizing and non-optimizing households are:

$$\Lambda_{C,t}^{o,n} = (C_t^{o,n} - hC_t)^{-\sigma_c}, \quad (7)$$

where  $C_t^o$  and  $C_t^n$  are the consumption levels for the two households types.

Rearranging (6) gives:

$$\Lambda_{C,t}^o \eta_{b,t} = \beta P_t ((1 - \theta_A) E_t J_{t+1}^o + \theta_A E_t J_{t+1}^n), \quad (8)$$

where

$$J_t^o = \Lambda_{C,t}^o \eta_{b,t} \frac{(1+i_{t-1})}{P_t} + \beta \theta_A E_t J_{t+1}^o \text{ and} \quad (9)$$

$$J_t^n = \Lambda_{C,t}^n \eta_{b,t} \frac{i_{t-1}}{P_t} + \beta \theta_A E_t J_{t+1}^n. \quad (10)$$

Aggregating consumption gives:

$$C_t = (1 - \theta_A) C_t^o + \theta_A C_t^n. \quad (11)$$

Non-optimizing households consume their current income:

$$C_t^n = \frac{(P_{X,t} Y_{X,t}^{ex} + P_{M,t} Y_{M,t}^{ex})(1 - \alpha_{WD}) + P_{M,t} Y_{M,t}^d + P_{N,t} Y_{N,t} + S_t IR_{t-1}^* i_{t-1}^* + S_t B_{t-1}^* (i_{t-1}^* + r p_{t-1} (1 + i_{t-1}^*)) + B_{t-1} i_{t-1}}{P_t} - I_t - G_t, \quad (12)$$

where  $\alpha_{WD}$  is the share of exports withdrawn from exporters income and will be explained below;  $G_t$  is the government spending level;  $Y_{M,N,X,t}$  is the output in manufactured (M), non-tradable (N) and commodity (X) sectors respectively;  $P_{M,N,X,t}$  is the price level in manufactured (M), non-tradable (N) and commodity (X) sectors respectively.

Equations (8)–(12) describe an incomplete smoothing of consumption and help explain the high correlation between consumption and current income variables.

### Credit rationing at the official rate

We assume that in every period, with probability  $1 - \theta_B$ , household  $j$  may have the ability to adjust its domestic asset volume to the optimal level  $B_t = B_t^o$ . With probability  $\theta_B$  the household leaves it unchanged  $B_t = B_{t-1}$ .

Foreign and domestic assets are substitutes for achieving the optimal level of financing  $Fin_t$  which household  $j$  demands in period  $t$ . Changes in financing depend on the difference between current consumption and current income. For the households which received the signal to adjust their financing level (with probability  $1 - \theta_A$ ) such difference is:

$$\Delta Fin_t^o = P_t (C_t^o + I_t + G_t) - \left\{ (P_{X,t} Y_{X,t}^{ex} + P_{M,t} Y_{M,t}^{ex})(1 - \alpha_{WD}) + P_{M,t} Y_{M,t}^d + P_{N,t} Y_{N,t} + S_t IR_{t-1}^* i_{t-1}^* + S_t B_{t-1}^* (i_{t-1}^* + r p_{t-1} (1 + i_{t-1}^*)) + B_{t-1} i_{t-1} \right\}. \quad (13)$$

We use superscript  $^o$  to refer the optimal levels of variables for households which have the ability to adjust both  $B_t$  and  $B_t^*$  in period  $t$ .

For households not having the ability to smooth their consumption path in period  $t$  (with probability  $\theta_A$ )  $\Delta Fin_t^n = 0$ .

We use superscript  $^{opt}$  to refer the levels of foreign and domestic assets for the case when a household may adjust its level of  $B_t$  in every period. In that case marginal financing costs equal the official rate  $i_{ref,t}$  and the levels of foreign and domestic assets satisfy:

$$1 + i_{ref,t} = (1 + i_t^*) \frac{E_t S_{t+1}}{S_t} \exp\left(-\tau \frac{S_t B_t^{*opt}}{P_t Y_t} + \varepsilon_{rp,t}\right), \quad (14)$$

$$B_t^{opt} = Fin_t - S_t B_t^{*opt} \quad (15)$$

where (14) is the uncovered interest parity condition; and (15) is the demand for domestic financing at the official rate  $i_{ref,t}$ .

If household  $j$  has no ability to adjust  $B_t(j)$  it has to use the only available instrument  $B_t^*(j)$  to achieve its needed level of financing  $Fin_t$ . In that case  $B_t(j) \neq B_t^{opt}$ ,  $B_t^*(j) \neq B_t^{*opt}$  and household  $j$  will bear the losses of deviation from the optimum. The loss function for household  $j$ , which cannot adjust  $B_t(j)$  is:

$$\Phi_t = \int_{B_t^*}^{B_t^{*opt}} S_t (B_t^{*opt} - B_t^*(j)) (1 + i_t(j)) dB_t^*(j) - S_t (B_t^{*opt} - B_t^*(j)) (1 + i_{ref,t}), \quad (16)$$

where  $i_t(j)$  is expressed in terms of the domestic currency interest rate of foreign financing:

$$1 + i_t(j) = (1 + i_t^*) \frac{E_t S_{t+1}}{S_t} \exp\left(-\tau \frac{S_t B_t^*(j)}{P_t Y_t} + \varepsilon_{rp,t}\right). \quad (17)$$

To calculate the loss function we find the Taylor series expansion of (17) around  $B_t^{*opt}$

$$1 + i_t(j) = (1 + i_{ref,t}) \left[1 + \tau \frac{S_t}{P_t Y_t} (B_t^{*opt} - B_t^*(j))\right]. \quad (18)$$

Then the loss function is:

$$\Phi_t = 0.5\tau \frac{S_t}{P_t Y_t} (1 + i_{ref,t}) S_t (B_t^{*opt} - B_t^*(j))^2. \quad (19)$$

If the level of domestic and foreign assets in period  $t+k$  is still to be set in period  $t$  we have

$$B_{t+k} \Big|_{B_t^{*o}} = B_t^0 \quad B_{t+k}^* \Big|_{B_t^{*o}} = B_t^{*o} - \sum_{l=1}^k \frac{\Delta Fin_{t+l}}{S_{t+l}} \quad (20)$$

Households choose  $B_t^{*o}$  to minimize:

$$\min_{B_t^{*o}} E_t \sum_{k=0}^{\infty} (\beta \theta_B)^k \eta_{b,t+k} \Lambda_{C,t+k} \frac{S_{t+k}}{P_{t+k}} 0.5\tau \frac{S_{t+k}}{P_{t+k} Y_{t+k}} (1 + i_{ref,t}) (B_{t+k}^{*opt} - B_t^{*o} + \sum_{l=1}^k \frac{\Delta Fin_{t+l}}{S_{t+l}})^2, \quad (21)$$

where  $\Delta Fin_t = (1 - \theta_A)\Delta Fin_t^o$  is an aggregated financing change;  $\Lambda_{C,t} = (C_t - hC_t)^{-\sigma_C}$  is the marginal utility of aggregated consumption.

The first order condition for (21) is:

$$B_t^{*o} = \frac{J_{B,t} + T_{B,t}}{N_{B,t}} + \eta_{B,t}, \quad (22)$$

where  $\eta_{B,t}$  is the optimal foreign asset shock;

$$N_{B,t} = \eta_{b,t} \Lambda_{C,t} \frac{S_t^2}{P_t^2 Y_t} (1 + i_{ref,t}) + \beta \theta_B E_t N_{B,t+1}, \quad (23)$$

$$J_{B,t} = \eta_{b,t} \Lambda_{C,t} \frac{S_t^2}{P_t^2 Y_t} (1 + i_{ref,t}) B_t^{*opt} + \beta \theta_B E_t J_{B,t+1}, \quad (24)$$

$$T_{B,t} = \beta \theta_B E_t M_{B,t+1}, \quad (25)$$

where:

$$M_{B,t} = N_{B,t} \frac{\Delta Fin_t}{S_t} + \beta \theta_B E_t M_{B,t+1}. \quad (26)$$

Equations (22)–(26) describe the incomplete adjustment of interest rate  $i_t$  to the official rate  $i_{ref,t}$ . It helps explain the increase of the interest rate of marginal financing in a crisis: the interest rate is the average of the official rate  $i_{ref,t}$  and is based on the expected devaluation rate as in the equation (17).

The rest of the model follows Dib (2008) and is presented in Appendix A.

## The Central Bank

The Central Bank issues money  $M_t$  and its own securities  $B_t$  backed by international reserves:

$$M_t + B_t = IR_t, \quad (27)$$

where  $IR_t = S_t IR_t^*$  are the domestic currency international reserves;  $IR_t^*$  are the foreign currency international reserves.

If  $B_t > 0$  we assume that the Central Bank issues securities bought by households. In the opposite case  $B_t < 0$  households issue securities bought by the Central Bank, which issues money backed by the securities. The Central Bank profit consists of interest on foreign and domestic assets and is fully transferred to the government:

$$D_{CB,t} = S_t IR_{t-1}^* i_{t-1}^* - B_{t-1} i_{t-1} \quad (28)$$

As in Escudé (2013), the Central Bank uses the two monetary policy instruments independently. It means that we have two independent monetary policy rules in the model.



The exchange rate adjustment rule is based on international reserve dynamics<sup>4</sup>:

$$\frac{S_t - \bar{S}}{\bar{S}} = -k_{IR} \frac{IR_t^* - \bar{IR}^*}{\bar{IR}^*} + \eta_{S,t}, \quad k_{IR} > 0 \quad (29)$$

where  $k_{IR}$  is the coefficient of the exchange rate flexibility or the absolute value of the elasticity of the exchange rate with respect to international reserves; a stationary level of any endogenous variable  $X_t$  is denoted by  $\bar{X}$ ;  $\eta_{S,t}$  are the discretionary exchange rate policy shocks.

The exchange rate augmented Taylor rule allows the Central Bank to stabilize the fluctuations of real variables, inflation and exchange rate:

$$i_t = \bar{i} + k_Y \frac{Y_t - \bar{Y}}{\bar{Y}} + k_\pi \pi_t + k_S \frac{S_t - \bar{S}}{\bar{S}} + \varepsilon_{PR,t}, \quad (30)$$

where  $k_Y, k_\pi, k_S > 0$  are Taylor rule coefficients;  $\varepsilon_{PR,t}$  is the discretionary component of the interest rate dynamics following AR(1) process:

$$\varepsilon_{PR,t} = \rho_{PR} \varepsilon_{PR,t-1} + \eta_{PR,t}, \quad \rho_{PR} \in (0, 1) \quad (31)$$

where  $\eta_{PR,t}$  is the official rate shock;  $\rho_{PR}$  is the persistence parameter of the official rate dynamics.

The Central Bank uses CROR by making the probability of getting credit at the official rate less than one. This presumably helps correct the open economy trilemma constraint for better monetary policy performance. To show this we estimate the model and make welfare optimization exercises.

### 3. The Bayesian estimation

The model parameterization combines the calibration of the parameters which determine the steady state of the model and the Bayesian estimation of the parameters which determine the model dynamics and can be seen in de-trended data.

We calibrate the model on the basis of Russian macro-statistics. In Tab. A1 we demonstrate the empirical ratios needed for the steady state calculation. Other calibrated parameters are presented in Tab. A2.

The Bayesian estimation is based on eight de-seasoned and Hodrick-Prescott de-trended Russian series of consumption  $C_t$ , output (real GDP)  $Y_t$ , CPI inflation  $\pi_t$ , commodity price index  $P_{X,t}$ , exchange rate (nominal effective exchange rate)  $S_t$ , international reserves  $IR_t^*$ , the official rate (refinance rate)  $i_{ref,t}$ , risk premium (CDS spread)  $rp_t$ . The time sample is Q1:2001–Q2:2014 (54 quarters). To fit eight observable variables we use eight structural shocks: intertemporal preferences shock  $\eta_{b,t}$ , risk premium shock  $\eta_{rp,t}$ , markup shock  $\eta_{\mu,t}$ , commodity price shock  $\eta_{PX,t}$ , total factor productivity shock  $\eta_{A,t}$ , exchange rate policy shock  $\eta_{S,t}$ , official rate shock  $\eta_{PR,t}$ , optimal foreign assets shock  $\eta_{B,t}$ .

<sup>4</sup> Rule (29) is an approximation in terms of deviations from steady state of historical exchange rate adjustment rule used by BoR in 2009-2014 (see [The Bank of Russia FX policy](#))

## Priors

We use both informative and non-informative prior distributions for the estimated parameters. We use a Gamma-distribution for setting priors for the utility function parameters  $\sigma_C$ ,  $\sigma_H$  and capital adjustment costs  $\phi_K$  and Beta-distributions for the habit parameter  $h$ , the Calvo-pricing parameter  $\theta$ , the share of liquidity constrained (non-Ricardian) households  $\theta_A$ , the probability of CROR  $\theta_B$ . Other parameters have non-informative uniformly distributed priors. Tab. A1 presents all prior distributions.

The means of prior distributions for utility function parameters are set at  $E(\sigma_C)=2$  and  $E(\sigma_H)=1$  as in Dib (2008). Prior means for the habit parameter  $h$  and the Calvo-pricing parameter  $\theta$  are 0.5 and 0.75, respectively. We need non-flat priors for the four referenced parameters to alleviate the problem of likelihood function flatness. We set a relatively high standard deviation of their prior distributions (weak priors) reflecting a shortage of prior information about these parameters.

We set the prior mean at  $E(\theta_A)=0.4$  and the standard deviation at  $\sigma(\theta_A)=0.1$  for the share of liquidity constrained (non-Ricardian) households. The usual practice is to set the prior mean for  $\theta_A$  at 0.5, but in the model we have two types of credit rationing and the contribution of the liquidity constraint is less than in a model with only a liquidity constraint.

Vernikov (2009) calculated the share of state-influenced banks in total banking assets as 45.4% (in 2007). 53 state-influenced banks had better financing during the crises of 2008–2009 and their share in total assets is possible proxy for estimation of credit rationing parameter. Aleksashenko et al. (2011) found that from September 2008 til arch 2009 about 60% of foreign exchange market interventions were sterilized by the Bank of Russia and The Ministry of Finance. Unsterilized part of foreign exchange market interventions gives us more prior information about  $\theta_B$ . We set the mean of the prior distribution of  $\theta_B$  at 0.546.

In the Bayesian estimation we do not use information about the Russian labour market, so we fix the Calvo-parameter for wages at  $\theta_w=0.75$  (the average period for wage adjustment is 1 year) for stable results of the posterior density function maximization. The parameters of the autoregressive process for commodity prices  $P_{X,t}$ , are estimated separately from other parameters and fixed in Bayesian procedures at  $\sigma(\eta_{PX})=0.119$   $\rho_{PX}=0.713$ . We also fix the coefficient in the Taylor rule  $k_y=0$  as we have prior information that it is non-negative and the likelihood function is decreasing in  $k_y$  for any  $k_y \geq 0$ .

## Estimation results

First we estimate the Baseline model (M1) which includes both liquidity constraints (LC) and CROR blocks. To reveal the contribution of the LC and CROR blocks, and to check robustness we estimate three modifications of M1: a model which includes only the LC block (M2); the model which includes only the CROR block (M3); and the model which includes neither (M4).

The results of the posterior density function maximization for the four models M1–M4 are presented in Tab. A3<sup>5</sup>. We have received correctly interpreted estimates for all parameters in models M1–M4. Modes for household preference parameters in M1 are  $\sigma_C=1.96$  and  $\sigma_H=2.39$ . The value of intertemporal elasticity substitution is  $\frac{1}{\sigma_C}=0.51$  and it significantly deviates from the calculation of that parameter on micro-data in Khvostova et al. (2014) ( $\frac{1}{\sigma_C} \cong 5$ ). A possible explanation is that Khvostova et al. (2014) did not take into account alternative ways of explaining

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<sup>5</sup> Model computation was performed in Dynare (Adjemian et al., 2011)

the high correlation between consumption and current income. The mode for Calvo-pricing parameter is relatively high ( $\theta = 0.91$ ) and corresponds to 2 years and 9 months of the average duration period for price adjustment. The habit parameter is estimated at  $h = 0.71$  in M1. The mode for the sensitivity of risk premium to indebtedness level is estimated as  $\tau = 0.0278$ .

The modes for the coefficients in the Taylor rule are  $k_\pi = 0.0425$  and  $k_S = 0.0185$  with a persistence parameter  $\rho_{PR} = 0.64$  for M1. We call this result the ‘weak Taylor rule’ because the low official rate reaction to inflation and to the output gap does not contribute to the stabilization of the real part of the economy. The mode of the exchange rate flexibility coefficient is estimated as  $k_S = 0.296$  for M1. We call this result the ‘strong exchange rate rule’ because both the exchange rate and international reserves make about equal contribution in the balance of payment adjustment.

The share of liquidity constrained (non-Ricardian) households is estimated at a relatively low level ( $\theta_A = 0.218$ ). To check this result we performed an estimation of the model without the forward-looking behaviour of households (model with the LC and CROR blocks and the usual Euler equation). The result was the same as in M1:  $\theta_A = 0.225$ . The probability of CROR is estimated at a relatively high level:  $\theta_B = 0.664$ .

Tab. 1 presents the calculation of most important correlations for models M1–M4 in comparison with historical data.

**Table 1.** Correlations of historical and simulated series

	Historical data	Simulated data M1 LC+RCOR	Simulated data M2 Only LC	Simulated data M3 Only RCOR	Simulated data M4 None
<b>Correlations with <math>P_{x,t}</math></b>					
GDP	0.77	0.72	0.68	0.57	0.52
Consumption	0.65	0.70	0.65	0.15	0.16
International Reserves	0.73	0.38	0.42	0.48	0.49
Exchange rate	-0.61	-0.38	-0.51	-0.51	-0.58
Inflation	0.00	0.10	0.07	-0.02	-0.03
Risk premium	-0.02	-0.36	-0.36	-0.35	-0.36
Official rate	-0.08	-0.19	-0.30	-0.32	-0.40
<b>Correlations with <math>C_t</math></b>					
GDP	0.87	0.68	0.62	0.18	0.19
International Reserves	0.81	0.57	0.53	0.49	0.43
Exchange rate	-0.62	-0.53	-0.63	-0.51	-0.50
Inflation	0.09	0.03	-0.01	0.06	0.05
Risk premium	0.18	-0.48	-0.52	-0.42	-0.45
Official rate	0.22	-0.30	-0.42	-0.32	-0.35
Laplace approximation of natural logarithm of marginal density function		1007.68	1000.83	1005.54	1001.40
Prior probability that the model Mj is true		25%	25%	25%	25%
Posterior probability that the model Mj is true		<b>89.2%</b>	<b>0.1%</b>	<b>10.5%</b>	<b>0.2%</b>

Models M3 and M4, without liquidity constrained households, are unable to explain the high historical correlation between consumption, and output and oil prices, while they better explain the

correlations between the exchange rate and international reserves, and oil prices than models M1 and M2. The correlations calculated for M1 demonstrate a tradeoff between explaining the high correlations between consumption, and output and oil prices, and explaining the high correlations between the exchange rate and international reserves, and oil prices.

If we assume that the data are described by one of four models M1–M4 we can calculate posterior probabilities that the model  $M_j$  is true. Tab. 1 demonstrates that M1 with both the LC and CROR blocks strongly dominates other alternative models: 89.2% vs. 10.8% for M2–M4 together.

We can see impulse-response functions (IRF) for six endogenous variables, four shocks, and four models in Figs. A1–A4. IRF of consumption on all shocks in models M3 and M4 are much more smoothed than for M1 and M2. This fact agrees with the low correlation between consumption and the current income variables for models M3 and M4 (see Tab. 1). IRF of the exchange rate and international reserves for M1 are more persistent than for other models and this fact agrees with the lower mode of the exchange rate flexibility coefficient for M1 (see Tab. A3). The reaction of foreign assets to shocks for M1 is the most smoothed among all models.

All tests made for adequacy of the four model favour M1, so we use it in the welfare analysis.

#### 4. Welfare analysis and the optimal monetary regime

We maximize unconditional welfare over the coefficients in the Taylor rule  $k_\pi$ ,  $k_Y$ ,  $k_S$ , exchange rate flexibility coefficient  $k_{IR}$ , and the probability of CROR  $\theta_B$ . To get a reasonable and interpretable solution we impose limitations on the optimized coefficients. The optimized parameters in the monetary policy rules should be non-negative for the non-increasing procyclicality of the corresponding variables  $k_\pi \geq 0$ ,  $k_Y \geq 0$ ,  $k_S \geq 0$ ,  $k_{IR} \geq 0$  (the pro-cyclicality constraint). The probability of CROR should be within its natural limits  $\theta_B \in [0,1]$  (the natural constraint). In some welfare optimization exercises the coefficient  $k_\pi$  should correspond to the inflation targeting framework  $k_\pi \geq 1.1$  (the institutional constraint). All coefficients should lead to a unique and stable solution of the model, that is, the number of stable roots  $N(\lambda \leq 1)$  should be equal to the number of predetermined variables  $N^{pred}$  in the model (the stability constraint).

The second order Taylor series expansion of the utility function around steady state gives:

$$\Lambda_t = \frac{((1-h) \cdot \bar{C})^{1-\sigma_C}}{1-\sigma_C} - \frac{\bar{H}^{1+\sigma_H}}{1+\sigma_H} + (1-h)^{-\sigma_C} \bar{C}^{1-\sigma_C} \tilde{C}_t - \bar{H}^{1+\sigma_H} \tilde{H}_t - \frac{\sigma_C(1-h)^{-(1+\sigma_C)} \bar{C}^{1-\sigma_C}}{2} \tilde{C}_t^2 - \frac{\sigma_H \bar{H}^{1+\sigma_H}}{2} \tilde{H}_t^2, \quad (32)$$

where the variable with tilde denotes the logarithmic deviation of the variable from its steady state value.

We make the decomposition of the unconditional expectation of utility on the level effect and stabilization (variance) effect as in Ambler et al. (2004) and Dib (2008). Ambler et al. (2004) argue that we should use both effects in optimization, while Shulgin (2015) have demonstrated that the calculation of the level effect in a similar DSGE model is unstable for a small sample of historical data. We base the welfare optimization on the stabilization (variance) effect only, and for convenience express the results of the expected utility calculations in terms of compensative variation (CV) of deterministic consumption.

The main optimization criterion in terms of CV of the deterministic consumption  $\mu_v$  is determined by:

$$1 + \mu_v = \left( 1 - \frac{\sigma_c}{2} \cdot \frac{1 - \sigma_c}{(1-h)^2} \cdot E\tilde{C}_t^2 - \frac{\sigma_H}{2} \cdot \frac{1 - \sigma_c}{(1-h)^{1-\sigma_c}} \cdot \frac{\bar{H}^{1+\sigma_H}}{\bar{C}^{1-\sigma_c}} \cdot E\tilde{H}_t^2 \right)^{\frac{1}{1-\sigma_c}}, \quad (33)$$

We cannot rely merely on the criteria (33), so we also take into account the second unconditional moments of inflation  $E\pi_t^2$  and the foreign exchange rate  $ES_t^2$ . Both variances characterize price stability which may not be captured by the main criterion.

We first solve constrained optimization problem:

$$\begin{aligned} & \max_{k_\pi, k_Y, k_S, k_{IR}, \theta_B} \mu_v \\ & s.t. \ k_\pi \geq 1.1 \\ & \quad k_Y \geq 0 \\ & \quad k_S \geq 0 \\ & \quad k_{IR} \geq 0 \\ & \quad \theta_B \in [0, 1] \\ & \quad N(\lambda \leq 1) = N^{pred} \end{aligned} \quad (34)$$

and results are shown in Tab. 2.

**Table 2.** Results of welfare optimization in inflation targeting regime.

Parameter	Model with optimal parameters for inflation targeting regime			
	Baseline M1 model	E1. No additional restrictions on $k_S$	E2. Low $k_S$	E3. Moderate $k_S$
$k_\pi$	0.043	<b>7.077</b>	<b>7.423</b>	<b>7.957</b>
$k_Y$	0	<b>1.156</b>	<b>1.339</b>	<b>1.630</b>
$k_S$	0.019	0	0.02	0.05
$k_{IR}$	0.296	$\infty$	$\infty$	$\infty$
$\theta_B$	0.664	0	0	0
$\mu_v$	-0.1014	-0.0875	-0.0882	-0.0892
Main criterion improvement in comparison with Baseline M1 model	–	1.39%	1.32%	1.22%
$EC_t^2$	$1.25 \cdot 10^{-3}$	$1.38 \cdot 10^{-3}$	$1.38 \cdot 10^{-3}$	$1.39 \cdot 10^{-3}$
$EH_t^2$	$4.03 \cdot 10^{-2}$	$3.27 \cdot 10^{-2}$	$3.30 \cdot 10^{-2}$	$3.35 \cdot 10^{-2}$
$E\pi_t^2$	$5.93 \cdot 10^{-5}$	$6.16 \cdot 10^{-5}$	$6.15 \cdot 10^{-5}$	$6.13 \cdot 10^{-5}$
$ES_t^2$	0.0035	2.8118	0.0664	0.0321

The solution to problem (34) characterizes the optimal rules in an inflation targeting regime and demonstrates the ability to improve unconditional welfare. In an inflation targeting regime there can be a significant improvement in terms of the CV of deterministic consumption. We make three exercises ‘E1–E3’. E1 assumes that coefficient  $k_S$  has only the pro-cyclicality constraint

$k_S \geq 0$  which appears to be binding. Internal optima for the coefficients are marked in bold in all tables. In E1–E3 we found internal optima for the Taylor rule coefficients  $k_\pi$  and  $k_Y$ . The problem of solution E1 is large exchange rate volatility which is a result of the close to random walk dynamics of  $S_t$ . To eliminate this we can set the coefficient in the Taylor rule to  $k_S > 0$  and to repeat the maximization. Columns E2 and E3 in Tab. 2 demonstrate optimization result for  $k_S = 0.02$  and  $k_S = 0.05$  respectively. In the column E3 we see appropriate exchange rate volatility and significant improvement of the main criterion. The results of welfare optimization favour of a floating exchange regime ( $k_{IR} \rightarrow \infty$ ) and no CROR ( $\theta_B = 0$ ). These results are broadly in line with the empirical and theoretical literature on inflation targeting.

The second optimization exercise is devoted to the optimization over the probability of CROR  $\theta_B$  for the model with historical (estimated) coefficients in two monetary policy rules:

$$\begin{aligned}
& \max_{\theta_B} \mu_v \\
& s.t. k_\pi = 0.0425 \\
& k_Y = 0 \\
& k_S = 0.0185 \\
& k_{IR} = 0.2962 \\
& \theta_B \in [0,1] \\
& N(\lambda \leq 1) = N^{pred}
\end{aligned} \tag{35}$$

The results are presented in Tab. 3.

**Table 3.** Results of welfare optimization over probability of rationing credit at official rate  $\theta_B$  for the model with historical (estimated) coefficients in two monetary policy rules.

Parameter	Historical data and the Baseline M1 model	Model with optimal probability of rationing credit at official rate and historical (estimated) coefficients	Model with zero probability of rationing credit at official rate and historical (estimated) coefficients
$k_\pi$	0.043	0.043	0.043
$k_Y$	0	0	0
$k_S$	0.019	0.019	0.019
$k_{IR}$	0.296	0.296	0.296
$\theta_B$	0.664	<b>0.151</b>	0
$\mu_v$	-0.1014	-0.0998	-0.0999
Improvement in comparison with Baseline M1 model	–	0.16%	0.15%
$EC_t^2$	$1.25 \cdot 10^{-3}$	$1.41 \cdot 10^{-3}$	$1.45 \cdot 10^{-3}$
$EH_t^2$	$4.03 \cdot 10^{-2}$	$3.87 \cdot 10^{-2}$	$3.86 \cdot 10^{-2}$
$E\pi_t^2$	$5.93 \cdot 10^{-5}$	$5.80 \cdot 10^{-5}$	$5.79 \cdot 10^{-5}$
$ES_t^2$	0.00353	0.00302	0.00294

The most interesting result presented in Tab. 3 is the existence of an internal optimum for the probability of CROR  $\theta_B = 0.151$ . To analyse this result we added in the last column of Tab. 3 the criteria for the model with historical (estimated) coefficients in two rules and no CROR  $\theta_B = 0$ . We can see that the model with optimal  $\theta_B$  leads to a small improvement compared to M1 in terms of the main criterion and that improvement almost disappears if we compare it to  $\theta_B = 0$ .

To comprehend the results of the two maximization exercises above, we simulate the model for different monetary regimes: Classic Taylor rule (CTR), Fixed exchange rate (FER), Fixed official rate (FOR), Optimal Taylor rule (OTR). The results are presented in Tab. 4.

**Table 4.** Results of the model simulation for different monetary regimes.

Parameter	Baseline model	Model E3: Optimal inflation targeting	Classic Taylor rule	Classic Taylor rule with optimal $\theta_B$	Fixed exchange rate	Fixed official rate	Optimal Taylor rule
Abbreviation	M1	OIT	CTR		FER	FOR	OTR
$k_\pi$	0.043	<b>7.957</b>	1.5	1.5	0	0	0
$k_Y$	0	<b>1.630</b>	0.125	0.125	0	0	<b>0.292</b>
$k_S$	0.019	0.05	0.01	0.01	0	$10^{-5}$	$10^{-5}$
$k_{IR}$	0.296	$\infty$	$\infty$	$\infty$	0	$\infty$	$\infty$
$\theta_B$	0.664	0	0	<b>0.215</b>	0	0	0
$\mu_v$	-0.1014	-0.0892	-0.0987	-0.0986	-0.1041	-0.0832	-0.0774
Main criterion improvement in comparison with Baseline M1 model	–	1.22%	0.27%	0.28%	-0.27%	1.82%	2.39%
$EC_t^2$	$1.25 \cdot 10^{-3}$	$1.39 \cdot 10^{-3}$	$1.96 \cdot 10^{-3}$	$1.91 \cdot 10^{-3}$	$1.19 \cdot 10^{-3}$	$1.05 \cdot 10^{-3}$	$0.58 \cdot 10^{-3}$
$EH_t^2$	$4.03 \cdot 10^{-2}$	$3.35 \cdot 10^{-2}$	$3.54 \cdot 10^{-2}$	$3.56 \cdot 10^{-2}$	$4.20 \cdot 10^{-2}$	$3.22 \cdot 10^{-2}$	$3.17 \cdot 10^{-2}$
$E\pi_t^2$	$5.93 \cdot 10^{-5}$	$6.13 \cdot 10^{-5}$	$6.95 \cdot 10^{-5}$	$6.97 \cdot 10^{-5}$	$6.00 \cdot 10^{-5}$	$6.36 \cdot 10^{-5}$	$9.24 \cdot 10^{-5}$
$ES_t^2$	0.0035	0.0321	0.0315	0.0313	0	0.0151	0.1139

We have included in Tab. 4 only regimes with appropriate exchange rate volatility<sup>6</sup>.

The best value for the main criterion among the different regimes (+2.39%) is achieved in OTR, where the official rate reacts only to the output gap and does not react to inflation. Additional criteria for OTR are quite poor: much higher inflation and exchange rate volatility. FOR is a more balanced regime. It has a good improvement in terms of the main criterion (+1.82%) and low exchange rate volatility. Optimal inflation targeting (OIT) has a moderate improvement in terms of the main criterion (+1.22%) but lower inflation in comparison with OTR and FOR.

CTR demonstrates surprisingly poor performance. CTR gives higher volatilities of consumption, working hours, inflation and exchange rate in comparison with OIT and FOR. The main explanation is that the stabilizing effect of the official rate on inflation in the model starts with  $k_\pi > 1.1$ . So Taylor rule-based models with moderate coefficients have worse performance than

<sup>6</sup> For example not included in the table Taylor rule-based regime without reaction of official rate on foreign exchange rate ( $k_S = 0$ ) leads to near-unit-root behavior and huge volatility of exchange rate.

FOR. The stabilizing effect on inflation enough to improve on FOR in terms of  $E\pi_t^2$  corresponds to  $k_\pi > 3.2$ .

FER has moderate inflation and a zero exchange rate volatility but a poor value for the main criterion ( $-0.27\%$ ). M1 outperforms FER in both welfare and inflation stability. Both M1 and FER have significant drawbacks in comparison with the other regimes: they are prone to exchange rate crises. In making all welfare calculations we did not take that into account.

To make an additional check for the optimal probability of the CROR inference we performed optimization exercises for all the referenced regimes. The main finding is that the correction of the transmission mechanism made by changing  $\theta_B$  may lead to an improvement of monetary policy performance in different monetary policy regimes (see Tabs. 3, 4). This improvement is very small ( $+0.01\%$  in terms of the main criterion) and hence the optimal monetary regime should not include CROR.

## 5. Conclusion

This paper investigates whether CROR performed by a Central Bank may soften the open economy trilemma constraint and improve results of monetary policy for different monetary regimes and contributes to the optimal monetary regime choice for Russia.

To answer the questions raised we elaborated a DSGE model analysed the forward-looking behaviour of households facing a non-zero probability of CROR. Introducing liquidity constraints into the model allows customizing the model to give a high correlation between consumption and current income. Introducing CROR into the model provides a reasonable restriction on the independence of the two monetary instruments and helps explain the pro-cyclical behaviour of risk premium, interest rates and consumption.

The Bayesian estimation of the model on Russian quarterly data from 2001–2014 empirically confirms the idea of including liquidity constraint and CROR blocks in the model. To demonstrate this we estimated four alternative models and, assuming that the data are described by the one of four models, we found that the posterior probability of the hypothesis ‘the baseline model is true’ is 89.2%. Posterior modes for the share of liquidity constrained (non-Ricardian) households and the probability of CROR were estimated at 22% and 66% respectively.

We simulated a DSGE model with different values for the coefficients in the Taylor rule, the exchange rate adjustment rule and the probability of CROR. To make welfare maximization exercises we decompose the unconditional expectation of utility for the level effect and stabilization (variance) effect. The results of the welfare optimization exercises and the calculations for different monetary regimes made on the basis of the estimated DSGE model demonstrate the trade-off between low-inflation and high-welfare regimes. We found the local optimum with relatively high Taylor rule coefficients and relatively low inflation volatility (OIT). The other local optimum (OTR) has better welfare criterion but much higher inflation and exchange rate volatilities. Between the two local optima we found an intermediate solution in terms of welfare and inflation with no reaction of the official rate to inflation and output gap (FER). CTR demonstrates a surprisingly poor performance.

We found that a floating regime appears to be the best exchange rate regime for Russia in all optimization exercises. This is in contrast with the results of Shulgin (2015) which, on the basis of a similar DSGE model without financial imperfections, demonstrated the need for exchange rate smoothing for better monetary policy performance.

Welfare optimization over the credit rationing parameter gives a mixed result. We found the optimal value for the probability of CROR for the model with a historical (estimated) coefficient as 15%. The same exercise for the model with the Classic Taylor rule gives the optimal value as 20%. However the resulting improvement in welfare was very small and we also did not find an internal optimum for that parameter for other regimes. We therefore infer that the optimal monetary regime should not include credit rationing at the official rate. Abandoning that controversial element from



Russian monetary policy practice could bring Russia welfare a gain of 0.15% in terms of deterministic consumption.

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## Appendix A. Model

### Investments and labour supply

The capital dynamics of the intermediate good sectors  $i = X, M, N$  are given by:

$$K_{i,t} = (1 - \delta)K_{i,t-1} + I_{i,t-1} - \Phi_{i,t}, \quad (\text{A1})$$

where  $\Phi_{i,t} = \frac{\phi_K}{2} \left( \frac{K_{i,t}}{K_{i,t-1}} - 1 \right)^2 K_{i,t-1}$  is the adjustment cost function and  $\phi_K > 0$  is the coefficient of adjustment costs.

First order condition for capital stock in sectors  $i = X, M, N$  is

$$\beta \cdot E_t \left\{ \frac{\eta_{b,t+1} \Lambda_{C,t+1}}{\eta_{b,t} \Lambda_{C,t}} \left( \frac{Q_{t+1}}{P_{t+1}} + (1 - \delta) + \phi_K \left( \frac{K_{i,t+2}}{K_{i,t+1}} - 1 \right) \frac{K_{i,t+2}}{K_{i,t+1}} - \frac{\phi_K}{2} \left( \frac{K_{i,t+2}}{K_{i,t+1}} - 1 \right)^2 \right) \right\} =$$

$$= 1 + \phi_K \left( \frac{K_{i,t+1}}{K_{i,t}} - 1 \right), \quad (\text{A2})$$

where  $\Lambda_{C,t} = (C_t - hC_{t-1})^{-\sigma_C}$  is the marginal utility of consumption;  $\pi_{t+1} \equiv \frac{P_{t+1}}{P_t} - 1$  is the inflation rate definition and;  $Q_t$  is the capital good price.

In each sector  $i = X, M, N$  households supply their labour to a recruiting agency, which uses next aggregation technology:

$$H_{i,t} = \left( \int_0^1 H_{i,t}(j)^{\frac{\varphi_H - 1}{\varphi_H}} dj \right)^{\frac{\varphi_H}{\varphi_H - 1}}, \quad (\text{A3})$$

where  $\varphi_H > 1$  is the constant elasticity of substitution among different types of labour. Demand for each labour type  $j$  is

$$H_{i,t}(j) = \left( \frac{W_{i,t}(j)}{W_{i,t}} \right)^{-\varphi_H} H_{i,t}, \quad (\text{A4})$$

where  $W_{i,t} = \left( \int_0^1 W_{i,t}(j)^{1-\varphi_H} dj \right)^{\frac{1}{1-\varphi_H}}$  is the aggregated wage in each sector.

Household  $j$  chooses the optimal wage according to the Calvo (1983) model with indexation as in Yun (1996). It gets a random signal to adjust the wage from previous level  $W_{i,t-1}(j)$  to the optimal level  $W_{i,t}(j) = W_{i,t}^o(j)$  with probability  $(1 - \theta_W)$ . If household  $j$  does not get such signal it indexes wage on previous inflation  $\pi_{t-1}$ :  $W_{i,t}(j) = W_{i,t-1}(j)(1 + \pi_{t-1})^{\chi_W}$ , where  $\chi_W \in (0, 1)$  is the degree of wage indexation.

Aggregation of all households' decisions gives:

$$\left(\frac{W_{i,t}}{P_t}\right)^{1-\varphi_H} = \theta_W \cdot \left(\frac{(1+\pi_{t-1})^{\zeta_W} W_{i,t-1}}{1+\pi_t} \frac{W_{i,t-1}}{P_{t-1}}\right)^{1-\varphi_H} + (1-\theta_W) \left(\frac{W_{i,t}^o}{P_t}\right)^{1-\varphi_H} \quad i = X, M, N \quad (\text{A5})$$

Maximizing the expected discounted value of the utility function (1) subject to labour demand equations (34) gives three optimal conditions:

$$\frac{W_{i,t+1}^o(j)}{P_t} = \frac{\varphi_H}{(\varphi_H - 1)} \frac{J_{W,i,t}}{N_{W,i,t}}, \quad i = X, M, N \quad (\text{A6})$$

$$J_{W,i,t} = \eta_{b,t} H_{i,t} \left(\frac{W_{i,t}}{P_t}\right)^{\varphi_H} (-\Lambda_{H,t}) + \theta_W \beta E_t \left\{ \left(\frac{(1+\pi_{t+1})}{(1+\pi_t)^{\zeta_W}}\right)^{\varphi_H} J_{W,i,t+1} \right\} \text{ and} \quad (\text{A7})$$

$$N_{W,i,t} = \eta_{b,t} H_{i,t} \left(\frac{W_{i,t}}{P_t}\right)^{\varphi_H} \Lambda_{C,t} + \theta_W \beta E_t \left\{ \left(\frac{(1+\pi_{t+1})}{(1+\pi_t)^{\zeta_W}}\right)^{\varphi_H - 1} N_{W,i,t+1} \right\}, \quad (\text{A8})$$

where  $\Lambda_{H,t} = -H_t^{\sigma_H}$  is the marginal utility of labour,  $J_{W,i,t}$  and  $N_{W,i,t}$  are auxiliary forward looking variables describing labour supply process.

## Commodity goods production

Commodity goods (X-sector) are produced from aggregated capital  $K_{X,t} = \int_0^1 K_{X,t}(j) dj$ , aggregated worked hours  $H_{X,t} = \int_0^1 H_{X,t}(j) dj$  and natural resource  $L_t$ . The production function of commodities is:

$$Y_{X,t} = \left(K_{X,t}^{\alpha_X} H_{X,t}^{1-\alpha_X}\right)^{1-\zeta_X} L_t^{\zeta_X}, \quad \alpha_X, \zeta_X \in (0, 1) \quad (\text{A9})$$

where  $\zeta_X$ ,  $\alpha_X(1-\zeta_X)$  and  $(1-\alpha_X)(1-\zeta_X)$  are the shares of natural resource owner income, capital owner income and worker income in the total commodity sector income respectively<sup>7</sup>.

Natural resource supply is absolutely inelastic:  $L_t = \bar{L}$ , while demand for the country's commodity export is absolutely elastic because of the small open economy assumption. The domestic commodity price is  $P_{X,t} = S_t P_{X,t}^*$ , where the world commodity price  $P_{X,t}^*$  follows AR(1) process:

$$P_{X,t}^* = \left(P_{X,t-1}^*\right)^{\rho_{PX}} \left(\bar{P}_X^*\right)^{1-\rho_{PX}} \exp(\eta_{PX,t}), \quad (\text{A10})$$

where  $\eta_{PX,t}$  is the commodity price shock.

First order conditions for commodity producer are:

<sup>7</sup> Natural resources owners' income determines pure rent flow generated by X-sector. Sosunov and Zamulin (2007) assumed in their model that whole income of commodity sector is a pure rent flow.

$$K_{X,t} Q_{X,t} = \alpha_X (1 - \zeta_X) P_{X,t} Y_{X,t}, \quad (\text{A11})$$

$$H_{X,t} W_{X,t} = (1 - \alpha_X)(1 - \zeta_X) P_{X,t} Y_{X,t} \text{ and} \quad (\text{A12})$$

$$L_t P_{L,t} = \zeta_X P_{X,t} Y_{X,t}. \quad (\text{A13})$$

Equations (A11)–(A13) define the demand functions for resources used in the X-sector production function. The perfect competition assumption implies zero profit in the X-sector  $D_{X,t} = 0$ .

The produced commodity goods  $Y_{X,t}$  are exported  $Y_{X,t}^{ex}$  at world commodity price  $P_{X,t}^*$  and used as intermediate goods in the production of manufactured  $Y_{X,t}^M$  and non-tradable  $Y_{X,t}^N$  goods.

$$Y_{X,t} = Y_{X,t}^M + Y_{X,t}^N + Y_{X,t}^{ex} \quad (\text{A14})$$

### Manufactured and non-tradable goods production

The production of manufactured (M-sector) and non-tradable (N-sector) goods is similar in most aspects. In both sectors we have a continuum of monopolistically competitive firms indexed by  $k \in [0, 1]$ , which produce differentiated goods. The production function for producer  $k$  in each sector  $z = M, N$  is:

$$Y_{z,t}(k) = A_t (K_{z,t}(k))^{\alpha_z} (H_{z,t}(k))^{1 - \alpha_z - \zeta_z} (Y_{z,t}^z(k))^{\zeta_z}, \quad \alpha_z, \zeta_z, 1 - \alpha_z - \zeta_z \in (0, 1) \quad (\text{A15})$$

where  $K_{z,t}(k) = \int_0^1 K_{z,t}(jk) dj$  and  $H_{z,t}(k) = \int_0^1 H_{z,t}(jk) dj$  are aggregated capital and worked hours, respectively, used by producer  $k$ ;  $A_t$  is the total factor productivity following AR(1) process:

$$A_t = \bar{A} \exp(\eta_{A,t}). \quad (\text{A16})$$

Aggregation technology in both sectors sector is:

$$Y_{z,t} = \left( \int_0^1 (Y_{z,t}(k))^{\frac{\varphi-1}{\varphi}} dk \right)^{\frac{\varphi}{\varphi-1}}, \quad \varphi > 1 \quad (\text{A17})$$

where  $\varphi$  is the elasticity of substitution among differentiated goods.

Demand function for producer  $k$  is:

$$Y_{z,t}(k) = \left( \frac{P_{z,t}(k)}{P_{z,t}} \right)^{-\varphi} Y_{z,t}, \quad z = M, N \quad (\text{A18})$$

where  $P_{z,t} = \left( \int_0^1 (P_{z,t}(k))^{1-\varphi} dk \right)^{\frac{1}{1-\varphi}}$  is the aggregated price index in sector  $z = M, N$ .

We assume Calvo-Yun pricing with indexation on the previous rate of inflation. Firm  $k$  gets a random signal to adjust its price to the optimal level  $P_{z,t}^o(k)$  with probability  $1 - \theta$ . If firm  $k$  does not get such signal it indexes the previous period price on the previous rate of inflation  $\pi_{t-1}$ :  $P_{z,t}(k) = P_{z,t-1}(k)(1 + \pi_{t-1})^\chi$ , where  $\chi \in (0, 1)$  is the degree of price indexation. The aggregate real price level in both sectors is

$$\left(\frac{P_{z,t}}{P_t}\right)^{1-\varphi} = \theta \left(\frac{(1 + \pi_{t-1})^\chi P_{z,t-1}}{1 + \pi_t} \frac{P_{z,t-1}}{P_{t-1}}\right)^{1-\varphi} + (1 - \theta) \left(\frac{P_{z,t}^o}{P_t}\right)^{1-\varphi}. \quad z = M, N \quad (\text{A19})$$

Profit of monopolistic competitor  $k$  in both sectors in period  $t+l$ , subject to price  $P_{z,t}^o(k)$ , is set in period  $t$  and is indexed until the period  $t+l$ :

$$D_{z,t+l}(k) \Big|_{P_{z,t}^o} = \left(\frac{P_{t+l-1}}{P_{t-1}}\right)^\chi P_{z,t}^o(k) \left(\frac{\left(\frac{P_{t+l-1}}{P_{t-1}}\right)^\chi P_{z,t}^o(k)}{P_{z,t+l}}\right)^{-\varphi} Y_{z,t+l} - Q_{z,t+l} K_{z,t+l}(k) - W_{z,t+l} H_{z,t+l}(k) - P_{X,t+l} Y_{X,t+l}^z(k).$$

First order conditions for the problem  $\max_{K_{z,t}(k), H_{z,t}(k), Y_{z,t}^z(k), P_{z,t}^o(k)} E_t \sum_{l=0}^{\infty} \left( (\beta\theta)^l \eta_{b,t+l} \Lambda_{C,t+l} \frac{D_{z,t+l}(k) \Big|_{P_{z,t}^o}}{P_{t+l}} \right)$  are:

$$Q_{z,t} K_{z,t}(k) = \alpha_z P Y_{z,t}(k) \xi_{z,t}(k), \quad z = M, N \quad (\text{A20})$$

$$W_{z,t} H_{z,t}(k) = (1 - \alpha_z - \varsigma_z) P Y_{z,t}(k) \xi_{z,t}(k), \quad (\text{A21})$$

$$P_{X,t} Y_{X,t}^z(k) = \varsigma_z P Y_{z,t}(k) \xi_{z,t}(k), \quad (\text{A22})$$

$$\frac{P_{z,t}^o}{P_t} = \frac{\varphi}{\varphi - 1} \frac{J_{z,t}}{N_{z,t}} \exp(\eta_{\mu,t}), \quad (\text{A23})$$

$$J_{z,t} = \eta_{b,t} \Lambda_{C,t} Y_{z,t} \left(\frac{P_{z,t}}{P_t}\right)^\varphi \xi_{z,t} + \beta \theta E_t \left\{ \left(\frac{(1 + \pi_{t+1})}{(1 + \pi_t)^\chi}\right)^\varphi J_{z,t+1} \right\} \text{ and} \quad (\text{A24})$$

$$N_{z,t} = \eta_{b,t} \Lambda_{C,t} Y_{z,t} \left(\frac{P_{z,t}}{P_t}\right)^\varphi + \beta \theta E_t \left\{ \left(\frac{(1 + \pi_{t+1})}{(1 + \pi_t)^\chi}\right)^{\varphi-1} N_{z,t+1} \right\}, \quad (\text{A25})$$

where  $\xi_{z,t}(k) \equiv \frac{MC_{z,t}(k)}{P_t}$  is the real marginal cost for the firm  $k$  in sector  $z = M, N$ ;  $J_{z,i,t}$  and  $N_{z,i,t}$  are auxiliary forward looking variables describing the pricing in sectors  $z = M, N$ ; and  $\eta_{\mu,t}$  is the markup shock which explains the inflation volatility.

The produced manufactured goods  $Y_{M,t}$  are exported  $Y_{M,t}^{ex}$  and used as intermediate input in the final goods production function  $Y_{M,t}^d$ :

$$Y_{M,t} = Y_{M,t}^{ex} + Y_{M,t}^d \quad (\text{A26})$$

Zero transaction costs and the producer currency pricing principle imply  $P_{M,t}^*(k) = \frac{P_{M,t}(k)}{S_t}$ .

Demand for exported goods is:

$$Y_{M,t}^{ex} = \left( \frac{P_{M,t}/S_t}{P_t^*} \right)^{-\nu} w_{ex} Y_t^*, \quad \nu > 0 \quad (\text{A27})$$

where  $w_{ex}$  is the share of world demand for domestic manufactured goods,  $\nu$  is the elasticity of substitution among domestic and foreign goods in the world market;  $Y_t^*$  is an exogenous world demand evolving according to the AR(1) process:

$$Y_t^* = (Y_{t-1}^*)^{\rho_{Y^*}} (\bar{Y}^*)^{1-\rho_{Y^*}} \exp(\eta_{Y^*,t}), \quad \rho_{Y^*} \in (0, 1) \quad (\text{A28})$$

where  $\eta_{Y^*,t}$  is the foreign demand shock.

We assume infinite transaction costs of exporting non-tradable goods so the whole volume of produced goods  $Y_{N,t}$  is sold domestically to the final goods producer. Demand functions for domestically consumed intermediate goods  $Y_{M,t}^d$  and  $Y_{N,t}$  follow from the optimization of the final goods production.

### Imported goods production

The continuum of importing firms (F-sector) indexed by  $k \in [0, 1]$  acquire homogeneous goods from abroad at price  $P_t^*$  and produce a unit of differentiated good from a unit of homogeneous good with zero costs. Importer  $k$  is the monopolistic competitor choosing price  $P_{F,t}(k)$  to maximize the expected utility of a household.

Demand for importer  $k$  is:

$$Y_{F,t}(k) = \left( \frac{P_{F,t}(k)}{P_{F,t}} \right)^{-\varphi} Y_{F,t}, \quad (\text{A29})$$

where  $Y_{F,t} = \left( \int_0^1 (Y_{F,t}(k))^{\frac{\varphi-1}{\varphi}} dk \right)^{\frac{\varphi}{\varphi-1}}$  and  $P_{F,t} = \left( \int_0^1 (P_{F,t}(k))^{1-\varphi} dk \right)^{\frac{1}{1-\varphi}}$  are the aggregated output

and the aggregated price level in F-sector, respectively.

As in other sectors with monopolistic competition we assume Calvo-Yun pricing with indexation on the previous rate of inflation. Parameter  $1-\theta \in (0, 1)$  is the probability of getting signal of price adjustment while  $\chi \in (0, 1)$  is the degree of price indexation. The aggregated real price level in F-sector is:

$$\left(\frac{P_{F,t}}{P_t}\right)^{1-\varphi} = \theta \left(\frac{(1+\pi_{t-1})^\zeta \cdot P_{F,t-1}}{1+\pi_t} \cdot \frac{P_{F,t-1}}{P_{t-1}}\right)^{1-\varphi} + (1-\theta) \left(\frac{P_{F,t}^o}{P_t}\right)^{1-\varphi} \quad (\text{A30})$$

Profit of importer  $k$  in period  $t+l$  subject to price  $P_{F,t}^o(k)$  is set in period  $t$  and is just indexed until the period  $t+l$ :

$$D_{F,t+l}(k)|_{P_{F,t}^o} = \left( \left( \frac{P_{t+l-1}}{P_{t-1}} \right)^{\chi_F} P_{F,t}^o(k) - S_{t+l} P_{t+l}^* \right) \left( \frac{P_{F,t}^o(k) \left( \frac{P_{t+l-1}}{P_{t-1}} \right)^{\chi_F}}{P_{F,t+l}} \right)^{-\varphi} Y_{F,t+l} \quad (\text{A31})$$

The first order conditions for the optimization problem of importer  $k$   $\max_{P_{F,t}^o(k)} E_t \sum_{l=0}^{\infty} \left( (\beta \theta_F)^l \eta_{b,t+l} \Lambda_{C,t+l} \frac{D_{F,t+l}(k)|_{P_{F,t}^o}}{P_{t+l}} \right)$  are:

$$\frac{P_{F,t}^o}{P_t} = \frac{\varphi}{\varphi-1} \frac{J_{F,t}}{N_{F,t}} \exp(\eta_{\mu,t}), \quad (\text{A32})$$

$$J_{F,t} = \eta_{b,t} \Lambda_{C,t} Y_{F,t} \left( \frac{P_{F,t}}{P_t} \right)^\varphi R_t + \beta \theta E_t \left\{ \left( \frac{(1+\pi_{t+1})}{(1+\pi_t)^\zeta} \right)^\varphi J_{F,t+1} \right\} \text{ and} \quad (\text{A33})$$

$$N_{F,t} = \eta_{b,t} \Lambda_{C,t} Y_{F,t} \left( \frac{P_{F,t}}{P_t} \right)^\varphi + \beta \theta E_t \left\{ \left( \frac{(1+\pi_{t+1})}{(1+\pi_t)^\zeta} \right)^{\varphi-1} N_{F,t+1} \right\}, \quad (\text{A34})$$

where  $R_t \equiv \frac{S_t \cdot P_t^*}{P_t}$  is the real foreign exchange rate and;  $J_{F,t}$  and  $N_{F,t}$  are auxiliary forward looking variables describing the pricing in F-sector.

## Final goods production

The final goods  $Z_t$  are produced from intermediate non-tradable goods  $Y_{N,t}$ , manufactured goods  $Y_{M,t}^d$  and imported goods  $Y_{F,t}$  in a perfectly competitive market with the CES production function:

$$Z_t = \left( (\gamma_M)^\frac{1}{\kappa} (Y_{M,t}^d)^\frac{\kappa-1}{\kappa} + (\gamma_N)^\frac{1}{\kappa} (Y_{N,t})^\frac{\kappa-1}{\kappa} + (1-\gamma_M-\gamma_N)^\frac{1}{\kappa} (Y_{F,t})^\frac{\kappa-1}{\kappa} \right)^\frac{\kappa}{\kappa-1}, \quad (\text{A35})$$

where  $\kappa > 0$  is the elasticity of the substitution of inputs in the production function; parameters  $\gamma_M, \gamma_N, (1-\gamma_M-\gamma_N) \in (0, 1)$  assign the shares of sectors  $M, N$  and  $F$  in domestic consumption, respectively.



First order conditions for representative firm in Z-sector define demands for inputs:

$$Y_{M,t}^d = \left( \frac{P_{M,t}}{P_t} \right)^{-\kappa} \gamma_M Z_t \quad (\text{A36})$$

$$Y_{N,t} = \left( \frac{P_{N,t}}{P_t} \right)^{-\kappa} \gamma_N Z_t \text{ and} \quad (\text{A37})$$

$$Y_{F,t} = \left( \frac{P_{F,t}}{P_t} \right)^{-\kappa} (1 - \gamma_M - \gamma_N) Z_t, \quad (\text{A38})$$

where  $P_t = \left( \gamma_M (P_{M,t})^{1-\kappa} + \gamma_N (P_{N,t})^{1-\kappa} + (1 - \gamma_M - \gamma_N) (P_{F,t})^{1-\kappa} \right)^{\frac{1}{1-\kappa}}$  is the consumer price index.

The demand for final goods consists of private consumption  $C_t$ , government spending  $G_t$  and investments  $I_t$ :

$$Z_t = C_t + I_t + G_t, \quad (\text{A39})$$

where  $I_t = I_{M,t} + I_{N,t} + I_{X,t}$  is the investment aggregate.

## Government

The government in the model does not issue bonds and has a zero budget deficit:

$$P_t \cdot G_t = T_t + D_{CB,t}, \quad (\text{A40})$$

where  $T_t = \int_0^1 T_t(j) dj$  is the aggregate lump-sum taxes;  $D_{CB,t}$  is the Central Bank profit.

Government spending  $G_t$  equals its steady state value:

$$G_t = \bar{G}, \quad (\text{A41})$$

## General equilibrium

We analyze a symmetric equilibrium with identical decisions of households and firms:

$$\begin{aligned} C_t(j) = C_t, H_{i,t}(j) = H_{i,t}, W_{i,t}^o(j) = W_{i,t}^o, K_{z,t}(jk) = K_{z,t}(k), B_t^*(j) = B_t^*, B_t(j) = B_t, \\ Y_{z,t}(k) = Y_{z,t}, Y_{F,t}(k) = Y_{F,t}, Y_{X,t}^z(k) = Y_{X,t}^z, P_{z,t}^o(k) = P_{z,t}^o, P_{F,t}^o(k) = P_{F,t}^o, K_{z,t}(k) = K_{z,t} \quad \text{for all} \\ j \in [0,1] \quad k \in [0,1] \quad i = X, M, N \quad z = M, N. \end{aligned}$$

Nominal GDP definition in the model is:

$$P_t^{def} Y_t = P_{M,t} Y_{M,t} + P_{N,t} Y_{N,t} + P_{X,t} Y_{X,t}^{ex}, \quad (\text{A42})$$

where  $P_t^{def}$  is the GDP deflator.

Real GDP is calculated on the basis of stationary prices:

$$Y_t = \bar{P}_M Y_{M,t} + \bar{P}_N Y_{N,t} + \bar{P}_X Y_{X,t}^{ex}, \quad (\text{A43})$$

where  $\bar{P}_M$ ,  $\bar{P}_N$  and  $\bar{P}_X$  are stationary levels of prices in the manufactured, non-tradable and commodity sectors, respectively.

Balance of payments equation in the model is:

$$\left[ P_{X,t}^* \cdot Y_{X,t}^{ex} + \frac{P_{M,t}}{S_t} \cdot Y_{M,t}^{ex} \right] (1 - \alpha_{WD}) - P_t^* \cdot Y_{F,t} + B_{t-1}^* \cdot (1 + i_{t-1}^*) \cdot (1 + rp_{t-1}) - B_t^* = IR_t^* - IR_{t-1}^* \cdot (1 + i_{t-1}^*), \quad (\text{A44})$$

where  $\alpha_{WD}$  is the share of exports withdrawn from exporter income which helps to account for all outflows from foreign exchange markets other than import, foreign assets and international reserve purchases. In the data the main component of withdrawals is a suspicious transaction with capital, so it is natural to model withdrawals as a share of exports, which is the main source of foreign capital inflow.

## Appendix B. Estimation

### Calibrated values

**Table A1.** Empirical ratios used to calculate the steady state of the model

Ratio	Equation in the model	Value
Government spending to GDP ratio	$\Gamma_G \equiv \frac{\overline{PG}}{\overline{P}^{def} \overline{Y}}$	$\Gamma_G = 0.189$
Export to GDP ratio	$\Gamma_{EX} \equiv \frac{\overline{Y}_X^{ex} \overline{P}_X + \overline{Y}_M^{ex} \overline{P}_M}{\overline{P}^{def} \overline{Y}}$	$\Gamma_{EX} = 0.325$
Share of commodity export in total export	$\Gamma_{XEX} \equiv \frac{\overline{Y}_X^{ex} \overline{P}_X}{\overline{Y}_X^{ex} \overline{P}_X + \overline{Y}_M^{ex} \overline{P}_M}$	$\Gamma_{XEX} = 0.563$
Manufactured to non-tradable output ratio	$\Gamma_{MN} \equiv \frac{\overline{Y}_M \overline{P}_M}{\overline{Y}_N \overline{P}_N}$	$\Gamma_{MN} = 0.333$
Withdrawn share of export	$\Gamma_{WD} \equiv \alpha_{WD}$	$\Gamma_{WD} = 0.174$
Interests on international reserves and foreign assets to export ratio	$\Gamma_{i^*/EX} \equiv \frac{\overline{B}^* (\overline{i}^* + (1 + \overline{i}^*) \overline{rp}) + \overline{IR}^* \overline{i}^*}{\overline{Y}_X^{ex} \overline{P}_X + \overline{Y}_M^{ex} \overline{P}_M}$	$\Gamma_{i^*/EX} = -0.0697$
International reserves to export ratio	$\Gamma_{IR^*/EX} \equiv \frac{\overline{IR}^*}{\overline{Y}_X^{ex} \overline{P}_X + \overline{Y}_M^{ex} \overline{P}_M}$	$\Gamma_{IR^*/EX} = 3.193$
Foreign assets to export ratio	$\Gamma_{B^*/EX} \equiv \frac{\overline{B}^*}{\overline{Y}_X^{ex} \overline{P}_X + \overline{Y}_M^{ex} \overline{P}_M}$	$\Gamma_{B^*/EX} = -2.741$

The ratios  $\Gamma_G$ ,  $\Gamma_{EX}$  and  $\Gamma_{MN}$  are calculated on the basis of Rosstat statistics of Russian GDP and value added by different sectors at constant 2008 prices. The ratios  $\Gamma_{XEX}$ ,  $\Gamma_{i^*/EX}$  are calculated on the basis of Russian balance of payments. The ratios  $\Gamma_{IR^*/EX}$  and  $\Gamma_{B^*/EX}$  are calculated on the basis of the Russian international investments position. To calculate the ratio  $\Gamma_{WD}$  we total error and omission items, private and government transfers, wage transfers, government debt operations and suspicious capital transactions in the balance of payments.

**Table A2.** Calibrated constants

Parameter	Value	Sources and comments
Share of capital income in total income of M-sector.	$\alpha_M = 0.45$	Semko (2013)
Share of capital income in total income of N-sector.	$\alpha_N = 0.55$	Semko (2013)
Share of capital income in income of X-sector, leaved after natural recourse owners income is paid off	$\alpha_X = 0.46$	Semko (2013)
Share of intermediate X-sector goods income in total income of M-sector	$\zeta_M = 0.14$	Polbin (2013)
Share of intermediate X-sector goods income in total income of M-sector	$\zeta_N = 0.095$	Polbin (2013)
Share of natural recourses owners income in total income of X-sector	$\zeta_X = 0.2$	Dib (2008), Semko (2013)

Elasticity of substitution among differentiated goods in M, N and F-sectors	$\varphi = 5$	It corresponds to 25% monopolistic markup
Elasticity of substitution among differentiated labour types in M, N and X-sectors	$\varphi_H = 6$	It corresponds to 20% monopolistic markup
Depreciation rate	$\delta = 0.025$	
Elasticity of substitution among intermediate goods of M,N and F-sectors in domestic final good production function	$\kappa = 0.66$	Like in Sosunov, Zamulin (2007), Semko (2013) we assume complementary factors in the final good production function
Elasticity of substitution among intermediate goods of M-sector and foreign produced goods in foreign final good production function	$\nu = 0.66$	Like in Dib (2008) we assume $\nu = \kappa$

To find the steady state values of the risk premium  $\overline{rp}$ , domestic and foreign interest rates  $\bar{i}$  and  $\bar{i}^*$  and to calculate intertemporal discount factor  $\beta$  we resolve next system:

$$\begin{cases} 1 + \bar{i} = \frac{1}{\beta} \\ (1 + \bar{i}^*)(1 + \overline{rp}) = \frac{1}{\beta} \\ \Gamma_{i^*/EX} = \Gamma_{B^*/EX} (\bar{i}^* + \overline{rp}(1 + \bar{i}^*)) + \Gamma_{IR^*/EX} \bar{i}^* \\ \overline{rp} = \exp(-\tau \Gamma_{EX} \Gamma_{B^*/EX}) \end{cases}, \quad (A45)$$

where the sensitivity of the risk premium to the indebtedness level  $\tau$  is estimated.

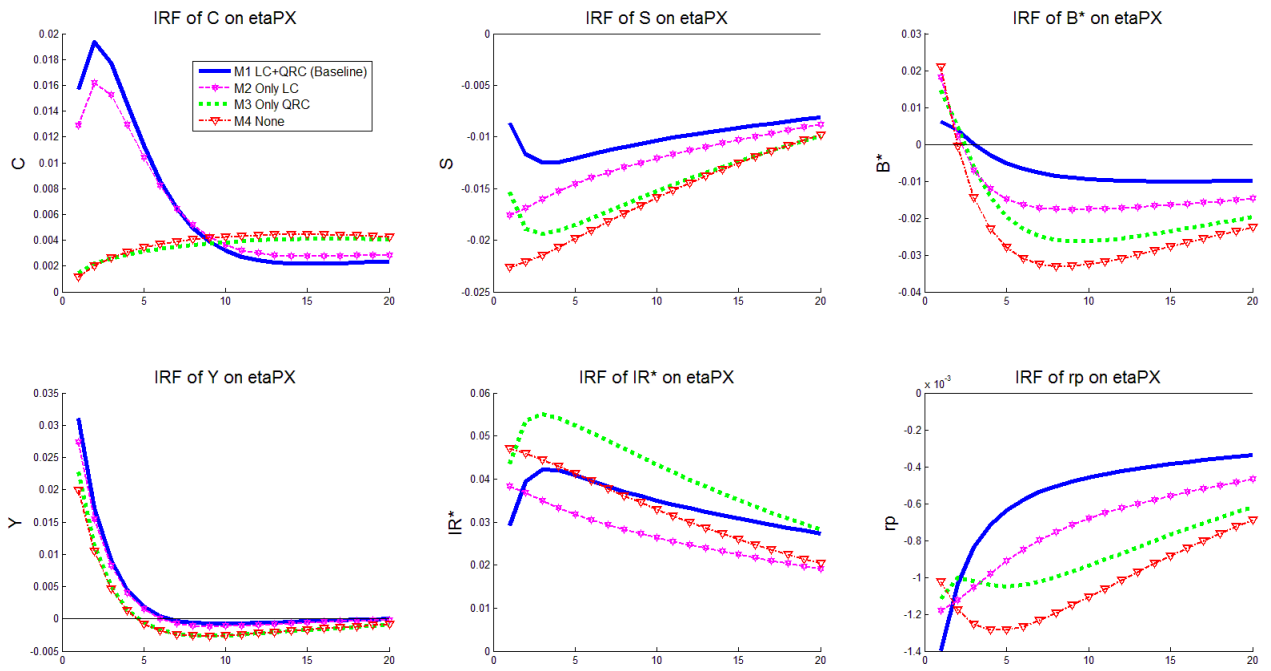
We normalize the following steady state values for the real and nominal parts of domestic and foreign economies:

$$\bar{A} = 1, \bar{Y}^* = 1, \bar{P} = 1, \bar{P}^* = 1, \bar{P}_X^* = 1 \quad (A46)$$

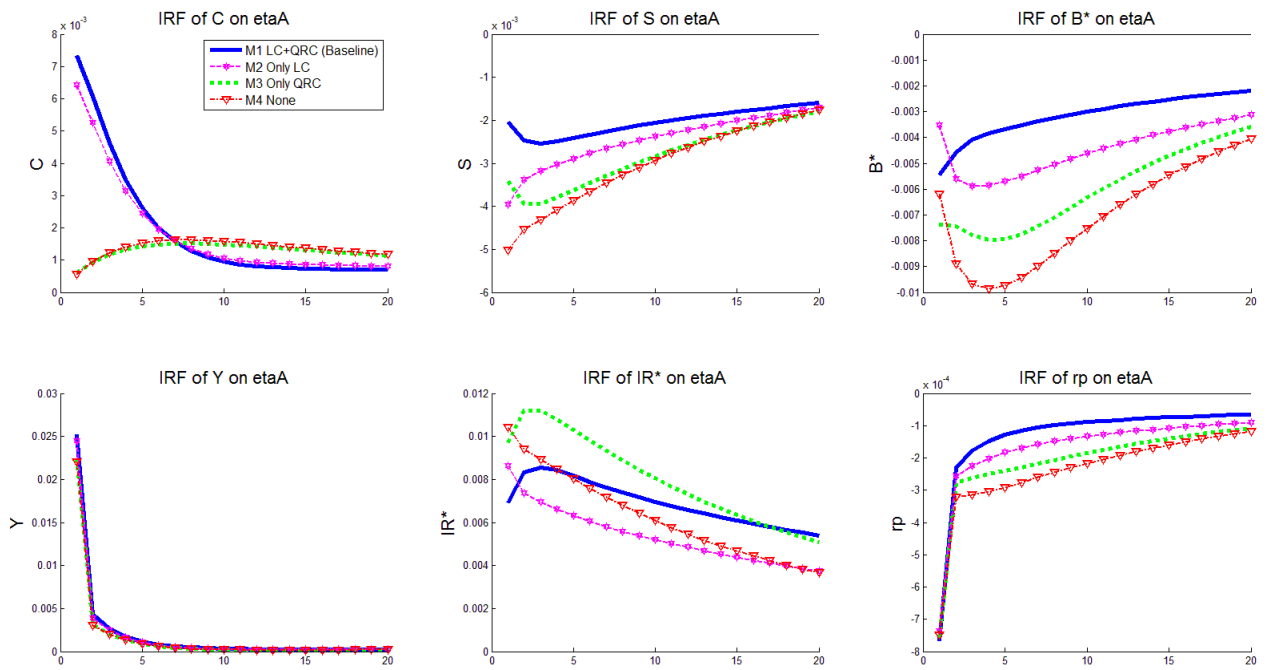
Parameters  $w_{ex}$ ,  $\gamma_M$  and  $\gamma_N$  are not supplied exogenously but calculated together with the steady state values of all endogenous variables.

**Table A3.** Results of Bayesian estimation of four models.

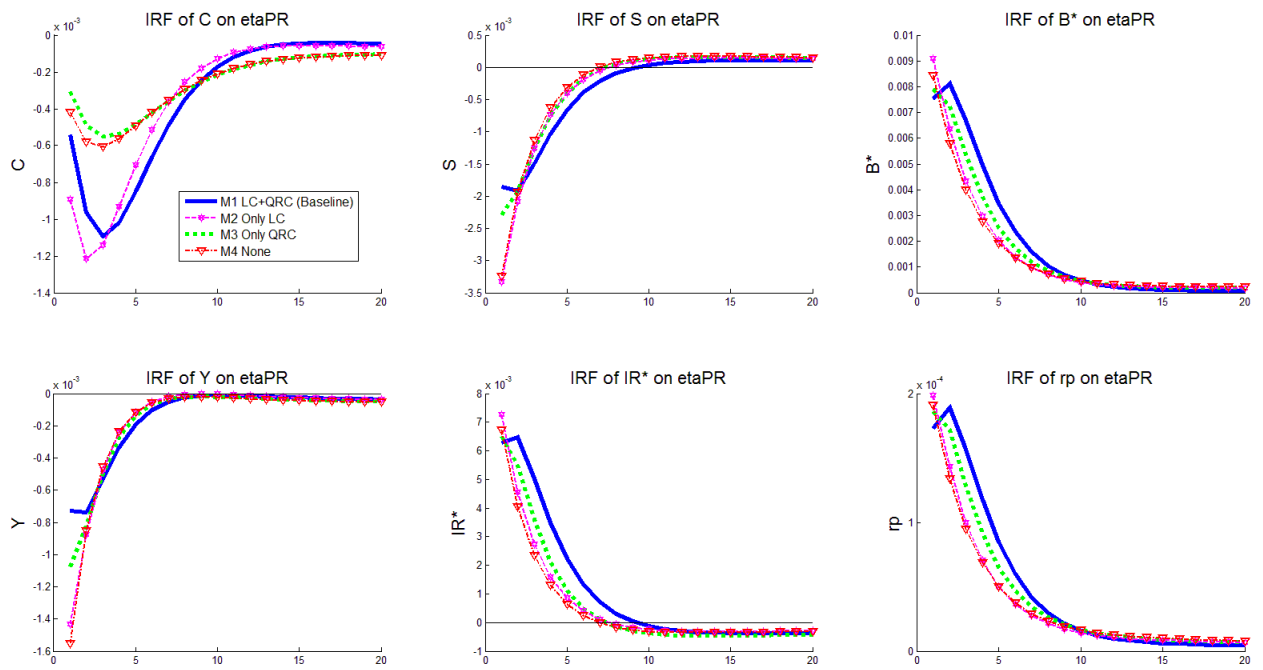
<b>Parameter</b>		<b>Prior</b>	<b>M1</b>	<b>M2</b>	<b>M3</b>	<b>M4</b>
			<b>LC+CROR</b>	<b>LC</b>	<b>CROR</b>	<b>None</b>
			<b>(Baseline)</b>			
	Name	Type	Mode	Mode	Mode	Mode
		(mean,std.dev)	(std.dev.)	(std.dev.)	(std.dev.)	(std.dev.)
$\sigma(\eta_{A,t})$	Standard deviation of total productivity shock	Uniform	<b>0.1085</b> (0.0170)	<b>0.1119</b> (0.0166)	<b>0.1223</b> (0.0180)	<b>0.1233</b> (0.0179)
$\sigma(\eta_{b,t})$	Standard deviation of intertemporal preferences shock	Uniform	<b>0.0927</b> (0.0241)	<b>0.0910</b> (0.0226)	<b>0.1757</b> (0.0511)	<b>0.1607</b> (0.0467)
$\sigma(\eta_{S,t})$	Standard deviation of exchange rate policy shock	Uniform	<b>0.0403</b> (0.0054)	<b>0.0558</b> (0.0105)	<b>0.0448</b> (0.0071)	<b>0.0584</b> (0.0117)
$\sigma(\eta_{PR,t})$	Standard deviation of official rate shock	Uniform	<b>0.0016</b> (0.0002)	<b>0.0016</b> (0.0002)	<b>0.0016</b> (0.0002)	<b>0.0016</b> (0.0002)
$\sigma(\eta_{\mu,t})$	Standard deviation of markup shock	Uniform	<b>0.0839</b> (0.0135)	<b>0.0825</b> (0.0130)	<b>0.0697</b> (0.0112)	<b>0.0695</b> (0.0110)
$\sigma(\eta_{rp,t})$	Standard deviation of risk premium shock	Uniform	<b>0.0044</b> (0.0005)	<b>0.0044</b> (0.0004)	<b>0.0046</b> (0.0005)	<b>0.0045</b> (0.0005)
$\sigma(\eta_{B,t})$	Standard deviation of optimal foreign assets shock	Uniform	<b>4.0971</b> (0.9348)	<b>9.3969</b> (2.3661)	<b>4.1784</b> (1.0344)	<b>9.3812</b> (2.3943)
$\rho_{PR}$	Persistence parameter of official rate dynamics	Uniform	<b>0.6375</b> (0.0927)	<b>0.6396</b> (0.0923)	<b>0.6305</b> (0.0909)	<b>0.6326</b> (0.0908)
$\sigma_C$	Relative risk aversion coefficient	$\Gamma(2.0,1.0)$	<b>1.9623</b> (0.5138)	<b>2.0362</b> (0.4973)	<b>2.4854</b> (0.6931)	<b>2.4651</b> (0.6718)
$\sigma_H$	Inverse of Frisch wage elasticity of labor supply	$\Gamma(1.0,0.5)$	<b>2.3920</b> (0.8659)	<b>2.1725</b> (0.7687)	<b>1.7704</b> (0.6676)	<b>1.7764</b> (0.6570)
$h$	Habits parameter	$B(0.5,0.1)$	<b>0.7127</b> (0.0538)	<b>0.6968</b> (0.0544)	<b>0.7717</b> (0.0518)	<b>0.7536</b> (0.0540)
$\theta$	Calvo parameter for prices	$B(0.75,0.05)$	<b>0.9105</b> (0.0138)	<b>0.9093</b> (0.0136)	<b>0.8955</b> (0.0158)	<b>0.8952</b> (0.0154)
$\theta_A$	Share of liquidity constrained (non-Ricardian) households	$B(0.4,0.1)$	<b>0.2184</b> (0.0389)	<b>0.1953</b> (0.0367)		
$\theta_B$	Probability of rationing credit at official rate	$B(0.546,0.05)$	<b>0.6637</b> (0.0496)		<b>0.6302</b> (0.0574)	
$\phi_K$	Capital adjustment cost parameter	$\Gamma(10,10)$	<b>75.89</b> (21.37)	<b>72.82</b> (20.56)	<b>31.74</b> (12.34)	<b>30.54</b> (11.69)
$\tau$	Sensitivity of risk premium to indebtedness level	Uniform	<b>0.0278</b> (0.0015)	<b>0.0277</b> (0.0014)	<b>0.0282</b> (0.0016)	<b>0.0281</b> (0.0015)
$k_{IR}$	Coefficient of exchange rate flexibility	Uniform	<b>0.2962</b> (0.0519)	<b>0.4588</b> (0.0798)	<b>0.3521</b> (0.0613)	<b>0.4820</b> (0.0886)
$k_\pi$	Taylor rule coefficient (reaction on inflation)	Uniform	<b>0.0425</b> (0.0315)	<b>0.0435</b> (0.0315)	<b>0.0437</b> (0.0308)	<b>0.0439</b> (0.0310)
$k_S$	Taylor rule coefficient (reaction on exchange rate)	Uniform	<b>0.0185</b> (0.0074)	<b>0.0208</b> (0.0074)	<b>0.0193</b> (0.0074)	<b>0.0214</b> (0.0073)
Laplace approximation of natural logarithm of marginal density function			<b>1007.68</b>	<b>1000.83</b>	<b>1005.54</b>	<b>1001.40</b>



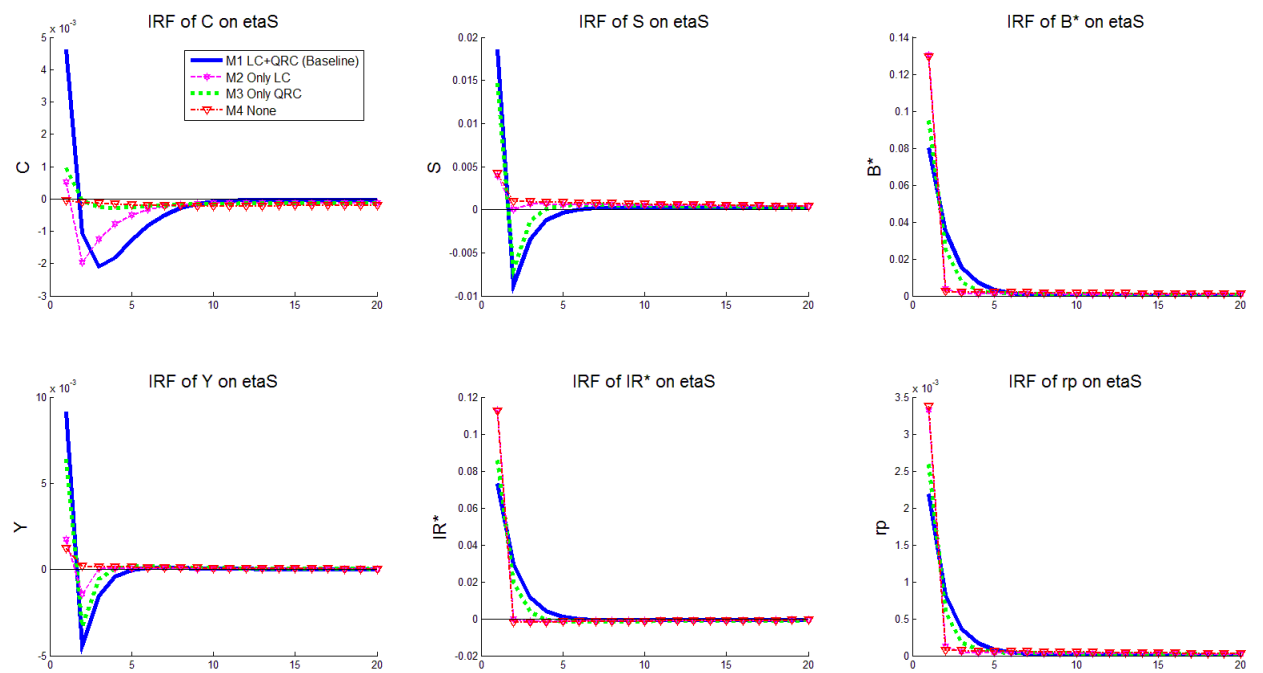
**Fig. A1. Impulse response function on 1 std. dev. oil price shock  $\eta_{PX,t}$**



**Fig. A2. Impulse response function on the 1 std. dev. total factor productivity shock  $\eta_{A,t}$**



**Fig. A3. Impulse response function on the 1 std. dev. official rate shock  $\eta_{PR,t}$**



**Fig. A4. Impulse response function on the 1 std. dev. exchange rate policy shock  $\eta_{S,t}$**

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