Monetary regime choice and optimal credit rationing at the official rate: the case of Russia

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Abstract[2]

Stabilizing monetary policy in a small open economy is constrained by the open economy trilemma. In this paper we investigate whether foreign exchange market interventions and the Central Bank's credit rationing at the official rate (CROR) may soften this 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 non-zero probabilities of losing access to financial market and CROR.

We have found significant credit rationing in the quarterly Russian data of 2001:Q1–2014:Q2. The probability of losing access to financial market and the probability of CROR are estimated as 22% and 66%, respectively. Using Russian data of 2001:Q1–2014:Q2 we demonstrate that CROR provoked forward-looking activity in financial market, which led to more Ruble devaluation in the crises of 2008-2009. It improved poor countercyclical performance of two Russian monetary policy rules, whereas made small effect on welfare. Welfare maximization exercises reveal a trade off between low-inflation and high-welfare solutions and favour of a floating exchange rate regime. We found the optimal value of the probability of CROR in both exchange rate-based and Taylor rule-based models but resulting improvement in welfare is very small.

Keywords: Bayesian estimation; intermediate exchange rate regime; rationing of credit; exchange rate rule; Russia

JEL classification: E52; E58; F41

1. Introduction

During the global financial crises most emerging markets economies (EMEs) were griped in a vice. On the one hand their currencies were devalued after negative external shocks: capital outflow, commodity price fall, and increased world financial market volatility. Countries with significant currency mismatch and big exchange rate path-through might suffer from such devaluation and monetary authorities looked for tight monetary policy measures. On the other hand, economic recession, local financial markets crunch, banking sector problems demanded for loose monetary policy. Difficulty of this type follows from open economy trilemma constraint (Obstfeld, Shambaugh, & Taylor, 2005) and is widely discussed in seminal paper devoted to twin crises of Kaminsky & Reinhart (1999). In such a situation traditional interest rate manipulations is not enough and Central Bank should use all available monetary policy measures which could help resolving such problems bundle. In this paper we analyze

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two additional instruments in monetary toolkit: foreign exchange market interventions (FX interventions) and credit rationing (CR).

FX intervention was widely recognized as useful and to certain extent independent monetary instrument long before the global financial crisis (Calvo & Reinhart, 2002, BIS, 2005). During the global financial crisis this instrument was intensively used by monetary authorities in many countries to avoid excessive currency depreciation and it is now considered as conventional monetary tool (Domanski, Kohlscheen & Moreno, 2016). Several papers were devoted to DSGE modeling of two independent monetary policy instruments framework: Escude (2013), Benesh et al. (2015), Ghosh, Ostry & Chamon (2015), Shulgin (2014, 2015) demonstrated that, first, this instrument was really used by many Central Banks in regular manner and, second, systematic using of FX intervention is helpful for welfare optimization. In this paper we use estimated DSGE model to address the question of optimal parameter in the exchange rate rule which is responsible for exchange rate regime choice. It helps us to answer the question whether we need systematic and predictable FX interventions for better macroeconomic performance.

CR is not drawing much attention of economists because developed countries did not use it explicitly during and after the global financial crisis. But this monetary measure does deserve rapt attention because, first, some EMEs used it explicitly for improving monetary performance (we will discuss Russian case), second, stepwise quantitative easing (QE) may also be thought as CR of specific nature[3]. To distinguish CR as monetary measure from CR in traditional meaning we introduce the term 'credit rationing at the official rate' (CROR) which means a situation where private demand for loans exceed supply at the set by monetary authority official (policy) interest rate. We will use the same term for reverse situation: private supply of assets exceeds demand at the prevailing official rate. CROR is assumed to be performed by Central Bank (CB) because it clears the loans market after it sets official (policy) interest rate and have an ability to introduce some obstacles for borrowers. In their seminal paper Jaffee & Stiglitz (1990), J&S hereinafter, have presented examples of using CR in US monetary policy. As far as I know the CROR assumption has never been introduced in DSGE framework but many properties of theoretical models with CR are widely discussed earlier and should be mentioned here.

Stiglitz & Weiss (1981) demonstrated that informational asymmetries like adverse selection and moral hazard effect may lead to optimal credit rationing in loan market equilibrium. Demand for loans exceeds supply because the expected bank's return increases non-monotonously with increasing interest rate and banks prefer CR to higher interest rate. Resolving information asymmetries problem, for example by loan collateral (Besanko & Takor, 1987) could possibly decrease the importance of CR. The last effect makes CR pro-cyclical mechanism because the volume of collateral is decreasing in a crisis and it limits private agents' ability to consume and invest in a period of low real income.

J&S although did not propose the theoretical model for analyzing macroeconomic impact of CR on the economy, but pointed out several important macroeconomic effects of CR. J&S note that response of real expenditure on CR will be with lag and have multiplier effect. They also assume that '… anticipation of future CR

[3] Here we will not deep in the question of modelling QE as a special case of CROR, but we may think about QE as a stepwise money supply adjustment in a situation when demand for money exceeds money supply at zero policy interest rate.

may have current effect even when there is no CR at present and, hence, impact of CR can not be assessed just in the period in which there is direct evidence for its presence'. Stiglitz & Weiss (1981) also pointed out that CR may also be '…viewed as temporary disequilibrium phenomena… that is the economy has incurred an exogenous shock and for reasons not fully explained, there is some stickiness in the price of capital (interest rate) so that there is a transitional period during which rationing of credit occurs…'. So CR actively interacts with real part of the economy, creates both forward-looking behavior and lagged real variables response and is better analyzed in general equilibrium framework.

J&S also associate CR with borrowing constraint on household's decision about consumption. This idea is traced back to simple Keynesian theory in which consumption expenditures are determined by current income rather than permanent income. Many empirical papers confirm existence of liquidity constrained households (Campbell & Mankiw, 1990, 1991, Attanasio & Weber, 2010). Many authors introduce this assumption in theoretical models and use several terms for labeling constrained households: Rule-of-Thumb consumers, spenders (Mankiw, 2005), Non-Ricardian consumers; Bilbiie (2008) analyzes limited asset market participation (LAMP), whereas Alvarez, Lucas & Weber (2001) consider segmented money market. The idea of liquidity constrained households existence allows us to distinguish among different types of CR: first, we assume that some households may lose access to financial market (be liquidity constrained) in present or in the future and this type of CR is not caused by monetary policy; second, we assume that monetary authorities may limit access to financing at the official rate and this type of CR (labeled as 'CROR') is controlled by CB. Note that for organizing CROR in normal time monetary authorities should make deliberate constraints on borrowing, whereas in a crises time an ability of commercial banks to borrow decreases as loan collateral decreases and CB should decide whether to weaken borrowing conditions or to limit banks access to financing though collateral decrease. To illustrate how it may work in practice we consider the Russian case[4].

CR may be thought as special type of financial market imperfection; hence this paper is related with wide literature devoted to introducing financial frictions in DSGE models. 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) or collateral constraints (Kiyotaki and Moore, 1995). All these papers assume that financial frictions originate from the

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[4] During the global financial crisis Russian 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.

interaction between private lenders and private borrowers while Central Banks should just take that feature into account in optimizing monetary policy design. Another important distinction of CR modelling used in this paper is that constrained in current period households realize that such constraint is not forever and may disappear in the future. It may amplify households' forward-looking activity based on predictable future response of exchange rate and interest rate on shocks and probability of losing access to financial market in the future. We will demonstrate that such behaviour may serve as countercyclical mechanism for the economy with weak interest rate rule and managed exchange rate.

The main findings of the paper are as follows. A Bayesian estimation demonstrates that the introduction of liquidity constrained households and CROR into the DSGE model is justified by Russian quarterly data of 2001:Q1–2014:Q2. The probability of losing access to financial market and the probability of CROR are estimated as 22% and 66%, respectively. Simulation of the model on Russian data of 2001:Q1–2014:Q2 demonstrates that CROR provoked forward-looking activity in financial market, which led to more Ruble devaluation in the crises of 2008-2009. It improved poor countercyclical performance of two Russian monetary policy rules, whereas made small effect on welfare. Simulating a DSGE model with different values of coefficients in the Taylor rule, the exchange rate adjustment rule, and the CROR parameter allows 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 CROR 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, official interest rate, international reserves, risk premium, and commodity price. Section 4 presents the results of model simulations and welfare optimization exercises. Section 5 concludes.

2. The Model

To deal with different aspects of monetary policy in a small open oil-exporting economy we build medium-scale multi-sector DSGE model with nominal wage and price rigidities, real capital adjustment costs, financial market imperfections and two independent monetary policy instruments.

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, make liquidity constrained decisions on their consumption and manage different types of firms. Multi-sector structure of the model[5] allows comprehensive description of monetary transmission channel, which is crucial for the purposes of the paper. Standard approach in the literature devoted to investigation of monetary policy in a small open

[5] The prototype model for production part of the model is described in Dib (2008)

economy assumes two types of intermediate goods: home produced and imported goods. But in our case we have cogent arguments for introducing richer market structure. First, we assume that commodity goods are produced in the commodity sector (X). Commodity price is exogenously determined outside of the economy and creates unique terms of trade shock which plays significant role in commodity exporters' business-cycle (Chen & Rogoff, 2003, Céspedes & Velasco, 2012). Second, home produced goods are subdivided into tradable (manufactured M) and non-tradable (N) sectors. This subdivision is standard and important in a case of two independent monetary policy instruments, because the two sectors have unique reaction on official interest rate and exchange rate adjustment shocks and hence, results of welfare optimization procedures are sensitive to the presence of non-tradable goods in the model[6]. Third, the model is estimated by Bayesian method and has strong econometric interpretation which usually assumes including enough model blocks for reflecting as many business-cycle properties as possible. We also traditionally assume that final (Z) goods and services are created with CES technologies from manufactured, non-tradable and imported (F) goods in perfectly competitive market. Households choose their consumption path subject to liquidity constraints of two types which are modelled a la Calvo. Households also make different traditional restricted optimization routines: set prices in monopolistic competitive markets subject to nominal rigidity assumptions of Calvo-Yun model and choose investments subject to capital adjustment costs.

The government decides on its spending and does not issue debt, maintaining zero budget deficits. In presence of nominal and real rigidities and different types of shocks, Central Bank tries to maximize welfare by choosing appropriate coefficients in two independent monetary policy rules: Taylor-type rule and exchange rate adjustment rule. It also chooses the degree (intensity) of credit rationing at the official rate. Central Bank performs discretionary monetary policy which is associated with monetary policy shocks[7].

2.1 Households

2.1.1 Utility and budget constraint

Household j utility function is:

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

where β 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 η_t in the model are expected to have zero mean and not expected to be iid processes.

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[6] Appendix D clarifies the role of non-tradable sector in the model. Most important results of the paper are recalculated for the model version, which almost ignores non-tradable sector existence. We may see that the share of non-tradable sector influences both estimated coefficients and results of optimization exercises and hence the available information about the non-tradable sector share in home produced goods had better not to be ignored.

[7] We reveal such shocks in the data but do not analyze optimal discretionary policy

Instantaneous utility is:

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

where $C_t(j)$ is 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 σ_C is the relative risk aversion coefficient or the inverse of the elasticity of the intertemporal substitution of consumption; parameter σ_H is the inverse of the Frisch wage elasticity of labor supply.

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

$$1 + i_t^*(j) = (1 + i_t^*)(1 + rp_t(j)), \tag{3}$$

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):

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

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; τ 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 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 $T_t(j)$, sends net transfers

$S_t NT_t(j)$ abroad, and purchases domestic and foreign denominated securities $B_t(j)$ and $B_t^*(j)$ respectively. Household budget constraint summarizes all its incomes and purchases:

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

2.1.2 Financial decisions in presence of CR

As in many DSGE models constructed for developing economies (for example, Sosunov and Zamulin, (2007) for Russia) we assume that some households have no ability to make an intertemporal optimization of their consumption path. It could be potentially useful in explaining the high correlation between consumption and current income variables in the data. I also assume some limitation on getting financing in home currency at the official rate. It helps explaining that the interest rate of marginal financing may be in the range between the official rate $i_{ref,t}$ and the rate which is based on foreign interest rate, expected devaluation and the risk premium.

Let us assume that every household in every period gets two random independent of each other 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 its financial instruments: B_t and B_t^*. With probability θ_A household *j* loses access to financial market and has to consume its current income. We label the last group 'temporarily liquidity constrained' 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 θ_B household *j* has no ability to adjust B_t and may adjust only its foreign assets volume B_t^*.

2.1.2.1 First signal: financial market participation

The equation, which describes the solution of the utility function (1) maximization problem subject to budget constraint in the presence of liquidity constrained households (determined by the first signal), is derived in the Appendix A and takes the form[8]:

$$\Lambda_{C,t}^o \eta_{b,t}=\beta P_t((1-\theta_A)E_t J_{t+1}^o+\theta_A E_t J_{t+1}^n), \quad (6)$$

where the marginal utility of consumption for optimizing household is:

$$\Lambda_{C,t}^o=\left(C_t^o-hC_t\right)^{-\sigma_C}, \quad (7)$$

where C_t^o is the consumption level for the optimizing in current period households.

[8] Here and after we omit households' index *j* and firms' index *k* except the Calvo pricing model where we need it to derive aggregated behavior.

Having no ability to use financial instruments in current period households consume their current income:

$$C_t^n = \frac{P_{X,t}Y_{X,t}^{ex} + P_{M,t}Y_{M,t} + P_{N,t}Y_{N,t} + S_t IR_{t-1}^* i_{t-1}^* + S_t B_{t-1}^* (i_{t-1}^* + rp_{t-1}(1+i_{t-1}^*)) + B_{t-1} i_{t-1}}{P_t} - \tag{8}$$
$$- I_t - T_t - S_t NT_t$$

where $Y_{M,N,X,t}$ 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.

In the first order condition (6) the variables J_t^o and J_t^n are forward-looking auxiliary variables which describe an incomplete smoothing of consumption:

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

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

Aggregating consumption gives

$$C_t = (1-\theta_A) C_t^o + \theta_A C_t^n \tag{11}$$

2.1.2.2 Second signal: financing at the official rate

When household gets the ability to optimize the level of home assets B_t it solves the problem of optimal financial resources allocation subject to possibility of losing the excess to financial markets in the future. The first order condition for the problem of choosing optimal private foreign assets B_t^{*o} (determined by the second signal) is derived in Appendix A and takes the form:

$$B_t^{*o} = \frac{J_{B,t} + T_{B,t}}{N_{B,t}} + \eta_{B,t} , \tag{12}$$

where $\eta_{B,t}$ is the optimal foreign assets shock; auxiliary variables which describe the incomplete adjustment of interest rate i_t to the official rate $i_{ref,t}$ are:

$$N_{B,t} = \eta_{b,t} \Lambda_{C,t} \frac{S_t^2}{P_t^2 Y_t} (1 + i_{ref,t}) + \beta\theta_B E_t N_{B,t+1} , \tag{13}$$

$$J_{B,t} = \eta_{b,t} \Lambda_{C,t} \frac{S_t^2}{P_t^2 Y_t} (1 + i_{ref,t}) B_t^{*opt} + \beta\theta_B E_t J_{B,t+1} , \tag{14}$$

where B_t^{*opt} is the level of foreign assets for the case when a household may adjust its level of B_t in every period without constraints (see Appendix A).

$$T_{B,t} = \beta\theta_B E_t M_{B,t+1}, \tag{15}$$

where $M_{B,t} = N_{B,t}\dfrac{\Delta Fin_t}{S_t} + \beta\theta_B E_t M_{B,t+1}$, (16)

where ΔFin_t is the change in optimal households financing (see Appendix A).

Taking into account two types of constraint we introduce in the model, the aggregate levels of foreign and home assets held by households are:

$$B_t^* = B_{t-1}^* + (1-\theta_A)(1-\theta_B)(B_t^{*o} - B_{t-1}^*) - \theta_B \frac{\Delta Fin_t}{S_t} \tag{17}$$

$$B_t = B_{t-1} - (1-\theta_A)(1-\theta_B)S_t(B_t^{*o} - B_{t-1}^*) - (1-\theta_B)\Delta Fin_t \tag{18}$$

2.1.3 Investments and labor supply

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

$$K_{i,t} = (1-\delta)K_{i,t-1} + I_{i,t-1} - \Phi_{i,t}, \tag{19}$$

where $\Phi_{i,t} = \dfrac{\phi_K}{2}\left(\dfrac{K_{i,t}}{K_{i,t-1}} - 1\right)^2 K_{i,t-1}$ 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

$$\beta \cdot E_t\left\{\frac{\eta_{b,t+1}\Lambda_{C,t+1}}{\eta_{b,t}\Lambda_{C,t}}\left(\frac{Q_{t+1}}{P_{t+1}} + (1-\delta) + \phi_K\left(\frac{K_{i,t+2}}{K_{i,t+1}} - 1\right)\frac{K_{i,t+2}}{K_{i,t+1}} - \frac{\phi_K}{2}\left(\frac{K_{i,t+2}}{K_{i,t+1}} - 1\right)^2\right)\right\} = \\ = 1 + \phi_K\left(\frac{K_{i,t+1}}{K_{i,t}} - 1\right), \tag{20}$$

where $\Lambda_{C,t} = (C_t - hC_{t-1})^{-\sigma_C}$ is the marginal utility of consumption; $\pi_{t+1} \equiv \dfrac{P_{t+1}}{P_t} - 1$ 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:

$$H_{i,t} = \left(\int_0^1 H_{i,t}(j)^{\frac{\varphi_H - 1}{\varphi_H}} dj\right)^{\frac{\varphi_H}{\varphi_H - 1}}, \tag{21}$$

where $\varphi_H > 1$ is the constant elasticity of substitution among different types of labour.

Demand for each labour type *j* is

$$H_{i,t}(j) = \left(\frac{W_{i,t}(j)}{W_{i,t}} \right)^{-\varphi_H} H_{i,t}, \tag{22}$$

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 π_{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:

$$\left(\frac{W_{i,t}}{P_t} \right)^{1-\varphi_H} = \theta_W \cdot \left(\frac{(1+\pi_{t-1})^{\chi_W}}{1+\pi_t} \frac{W_{i,t-1}}{P_{t-1}} \right)^{1-\varphi_H} + (1-\theta_W) \left(\frac{W_{i,t}^{o}}{P_t} \right)^{1-\varphi_H} \quad i = X, M, N \tag{23}$$

Maximizing the expected discounted value of the utility function (1) subject to labour demand equations (22) gives three optimal conditions:

$$\frac{W_{i,t+l}^{o}(j)}{P_t} = \frac{\varphi_H}{(\varphi_H - 1)} \frac{J_{W,i,t}}{N_{W,i,t}} \qquad i = X, M, N \tag{24}$$

$$J_{W,i,t} = \eta_{b,t} H_{i,t} \left(\frac{W_{i,t}}{P_t} \right)^{\varphi_H} (-\Lambda_{H,t}) + \theta_W \beta E_t \left\{ \left(\frac{(1+\pi_{t+1})}{(1+\pi_t)^{\chi_W}} \right)^{\varphi_H} J_{W,i,t+1} \right\} \tag{25}$$

$$N_{W,i,t} = \eta_{b,t} H_{i,t} \left(\frac{W_{i,t}}{P_t} \right)^{\varphi_H} \Lambda_{C,t} + \theta_W \beta E_t \left\{ \left(\frac{(1+\pi_{t+1})}{(1+\pi_t)^{\chi_W}} \right)^{\varphi_H - 1} N_{W,i,t+1} \right\}, \tag{26}$$

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.

2.2 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 recourse L_t. The production function of commodities is:

$$Y_{X,t} = \left(K_{X,t}^{\alpha_X} H_{X,t}^{1-\alpha_X}\right)^{1-\varsigma_X} L_t^{\varsigma_X}, \qquad \alpha_X, \varsigma_X \in (0,1) \tag{27}$$

where ς_X, $\alpha_X(1-\varsigma_X)$ and $(1-\alpha_X)(1-\varsigma_X)$ are the shares of natural resource owner income, capital owner income and worker income in the total commodity sector income respectively[9].

Natural resource supply is absolutely inelastic: $L_t = \overline{L}$, 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:

$$P_{X,t}^* = \left(P_{X,t-1}^*\right)^{\rho_{PX}} \left(\overline{P}_X^*\right)^{1-\rho_{PX}} \exp(\eta_{PX,t}), \tag{28}$$

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

First order conditions for commodity producer are

$$K_{X,t} Q_{X,t} = \alpha_X (1-\varsigma_X) P_{X,t} Y_{X,t} \tag{29}$$

$$H_{X,t} W_{X,t} = (1-\alpha_X)(1-\varsigma_X) P_{X,t} Y_{X,t} \tag{30}$$

$$L_t P_{L,t} = \varsigma_X P_{X,t} Y_{X,t} \tag{31}$$

Equations (29)–(31) 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.

$$Y_{X,t} = Y_{X,t}^M + Y_{X,t}^N + Y_{X,t}^{ex} \tag{32}$$

2.3 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:

$$Y_{z,t}(k) = A_t \left(K_{z,t}(k)\right)^{\alpha_z} \left(H_{z,t}(k)\right)^{1-\alpha_z-\varsigma_z} \left(Y_{X,t}^z(k)\right)^{\varsigma_z}, \quad \alpha_z, \varsigma_z, 1-\alpha_z-\varsigma_z \in (0,1) \tag{33}$$

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[9] Natural recourses 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.

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:

$$A_t=\overline{A}\exp(\eta_{A,t}) \qquad (34)$$

Aggregation technology in both sectors sector is

$$Y_{z,t}=\left(\int_0^1 \left(Y_{z,t}(k)\right)^{\frac{\varphi-1}{\varphi}}dk\right)^{\frac{\varphi}{\varphi-1}}, \qquad \varphi>1 \qquad (35)$$

where φ is the elasticity of substitution among differentiated goods.
Demand function for producer *k* is

$$Y_{z,t}(k)=\left(\frac{P_{z,t}(k)}{P_{z,t}}\right)^{-\varphi}Y_{z,t}, \qquad z=M,N \qquad (36)$$

where $P_{z,t}=\left(\int_0^1 \left(P_{z,t}(k)\right)^{1-\varphi}dk\right)^{\frac{1}{1-\varphi}}$ 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 $P^o_{z,t}(k)$ with probability $1-\theta$. If firm *k* does not get such signal it indexes the previous period price on the previous rate of inflation π_{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

$$\left(\frac{P_{z,t}}{P_t}\right)^{1-\varphi}=\theta\left(\frac{(1+\pi_{t-1})^{\chi}}{1+\pi_t}\frac{P_{z,t-1}}{P_{t-1}}\right)^{1-\varphi}+(1-\theta)\left(\frac{P^o_{z,t}}{P_t}\right)^{1-\varphi} \qquad z=M,N \qquad (37)$$

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

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

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

$$Q_{z,t}K_{z,t}(k)=\alpha_z P_t Y_{z,t}(k)\xi_{z,t}(k), \qquad z=M,N \tag{38}$$

$$W_{z,t}H_{z,t}(k)=(1-\alpha_z-\varsigma_z)P_t Y_{z,t}(k)\xi_{z,t}(k), \tag{39}$$

$$P_{X,t}Y^{z}_{X,t}(k)=\varsigma_z P_t Y_{z,t}(k)\xi_{z,t}(k), \tag{40}$$

$$\frac{P^o_{z,t}}{P_t}=\frac{\varphi}{\varphi-1}\frac{J_{z,t}}{N_{z,t}}\exp(\eta_{\mu,t}), \tag{41}$$

$$J_{z,t}=\eta_{b,t}\Lambda_{C,t}Y_{z,t}\left(\frac{P_{z,t}}{P_t}\right)^{\varphi}\xi_{z,t}+\beta\theta E_t\left\{\left(\frac{(1+\pi_{t+1})}{(1+\pi_t)^{\chi}}\right)^{\varphi}J_{z,t+1}\right\} \text{ and} \tag{42}$$

$$N_{z,t}=\eta_{b,t}\Lambda_{C,t}Y_{z,t}\left(\frac{P_{z,t}}{P_t}\right)^{\varphi}+\beta\theta E_t\left\{\left(\frac{(1+\pi_{t+1})}{(1+\pi_t)^{\chi}}\right)^{\varphi-1}N_{z,t+1}\right\}, \tag{43}$$

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 mark-up shock which explains the inflation volatility.

Equations (38) – (40) describe optimal demands for production factors: capital, labor and commodity goods, respectively. Equations (41) – (43) determine staggered Calvo-Yun pricing.

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

$$Y_{M,t}=Y^{ex}_{M,t}+Y^{d}_{M,t} \tag{44}$$

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:

$$Y^{ex}_{M,t}=\left(\frac{P_{M,t}/S_t}{P^{*}_t}\right)^{-\upsilon}w_{ex}Y^{*}_t \qquad \upsilon>0 \tag{45}$$

where w_{ex} is the share of world demand for domestic manufactured goods, υ 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:

$$Y_t^* = \left(Y_{t-1}^*\right)^{\rho_{Y*}} \left(\overline{Y}^*\right)^{1-\rho_{Y*}} \exp(\eta_{Y*,t}), \qquad \rho_{Y*} \in (0,1) \tag{46}$$

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.

2.4 Imported goods

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:

$$Y_{F,t}(k) = \left(\frac{P_{F,t}(k)}{P_{F,t}}\right)^{-\varphi} Y_{F,t}, \tag{47}$$

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

$$\left(\frac{P_{F,t}}{P_t}\right)^{1-\varphi} = \theta\left(\frac{(1+\pi_{t-1})^{\chi}}{1+\pi_t}\cdot\frac{P_{F,t-1}}{P_{t-1}}\right)^{1-\varphi} + (1-\theta)\left(\frac{P_{F,t}^o}{P_t}\right)^{1-\varphi} \tag{48}$$

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 $t+l$:

$$D_{F,t+l}(k)\Big|_{P_{F,t}^o} = \left(\left(\frac{P_{t+l-1}}{P_{t-1}}\right)^{\chi_F} P_{F,t}^o(k) - S_{t+l}P_{t+l}^*\right)\left(\frac{P_{F,t}^o(k)\left(P_{t+l-1}/P_{t-1}\right)^{\chi_F}}{P_{F,t+l}}\right)^{-\varphi} Y_{F,t+l} \tag{49}$$

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

$$\frac{P_{F,t}^o}{P_t} = \frac{\varphi}{\varphi - 1} \frac{J_{F,t}}{N_{F,t}} \exp(\eta_{\mu,t}) \tag{50}$$

$$J_{F,t} = \eta_{b,t} \Lambda_{C,t} Y_{F,t} \left({P_{F,t}}/{P_t} \right)^{\varphi} R_t + \beta\theta E_t \left\{ \left(\frac{(1+\pi_{t+1})}{(1+\pi_t)^{\chi}} \right)^{\varphi} J_{F,t+1} \right\} \tag{51}$$

$$N_{F,t} = \eta_{b,t} \Lambda_{C,t} Y_{F,t} \left({P_{F,t}}/{P_t} \right)^{\varphi} + \beta\theta E_t \left\{ \left(\frac{(1+\pi_{t+1})}{(1+\pi_t)^{\chi}} \right)^{\varphi-1} N_{F,t+1} \right\}, \tag{52}$$

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

2.5 *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:

$$Z_t = \left((\gamma_M)^{\frac{1}{\kappa}} \left(Y_{M,t}^d \right)^{\frac{\kappa-1}{\kappa}} + (\gamma_N)^{\frac{1}{\kappa}} \left(Y_{N,t} \right)^{\frac{\kappa-1}{\kappa}} + (1 - \gamma_M - \gamma_N)^{\frac{1}{\kappa}} \left(Y_{F,t} \right)^{\frac{\kappa-1}{\kappa}} \right)^{\frac{\kappa}{\kappa-1}}, \tag{53}$$

where $\kappa > 0$ is the elasticity of the substitution of inputs in the production function; parameters γ_M, γ_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:

$$Y_{M,t}^d = \left(\frac{P_{M,t}}{P_t} \right)^{-\kappa} \gamma_M Z_t \tag{54}$$

$$Y_{N,t} = \left(\frac{P_{N,t}}{P_t} \right)^{-\kappa} \gamma_N Z_t \tag{55}$$

$$Y_{F,t} = \left(\frac{P_{F,t}}{P_t} \right)^{-\kappa} (1 - \gamma_M - \gamma_N) Z_t , \tag{56}$$

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:

$$Z_t = C_t + I_t + G_t , \tag{57}$$

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

2.6 *Government*

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

$$P_t \cdot G_t = T_t + D_{CB,t} , \tag{58}$$

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:

$$G_t = \overline{G} , \tag{59}$$

2.7 *The Central Bank*

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

$$M_t + B_t = IR_t , \tag{60}$$

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:

$$D_{CB,t} = S_t IR_{t-1}^* i_{t-1}^* - B_{t-1} i_{t-1} \tag{61}$$

As in Escudé (2013), Benes et al. (2015), Ghosh et al. (2015), Shulgin (2014) 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 reserves dynamics[10]:

$$\frac{S_t - \overline{S}}{\overline{S}} = -k_{IR} \frac{IR_t^* - \overline{IR^*}}{\overline{IR^*}} + \eta_{S,t}, \qquad k_{IR} > 0 \tag{62}$$

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 $\overline{X}$; $\eta_{S,t}$ 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:

$$i_t = \overline{i} + k_Y \frac{Y_t - \overline{Y}}{\overline{Y}} + k_\pi \pi_t + k_S \frac{S_t - \overline{S}}{\overline{S}} + \varepsilon_{PR,t}, \tag{63}$$

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:

$$\varepsilon_{PR,t} = \rho_{PR}\varepsilon_{PR,t-1} + \eta_{PR,t}, \qquad \rho_{PR} \in (0,1) \tag{64}$$

where $\eta_{PR,t}$ is the official rate shock; ρ_{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.

2.8 General equilibrium

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

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

Nominal GDP definition in the model is

$$P_t^{def} Y_t = P_{M,t}Y_{M,t} + P_{N,t}Y_{N,t} + P_{X,t}Y_{X,t}^{ex}, \tag{65}$$

where P_t^{def} is the GDP deflator.

[10] The rule (62) is an approximation in terms of deviations from steady state of the historical exchange rate adjustment rule used by BoR in 2009-2014 (Shulgin, 2015).

Real GDP is calculated on the base of stationary prices:

$$Y_t = \overline{P}_M Y_{M,t} + \overline{P}_N Y_{N,t} + \overline{P}_X Y_{X,t}^{ex}, \tag{66}$$

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

Balance of payments equation in the model is:

$$P_{X,t}^* \cdot Y_{X,t}^{ex} + \frac{P_{M,t}}{S_t} \cdot Y_{M,t}^{ex} - P_t^* \cdot Y_{F,t} - NT_t + B_{t-1}^* \cdot (1+i_{t-1}^*) \cdot (1+rp_{t-1}) - B_t^* = IR_t^* - IR_{t-1}^* \cdot (1+i_{t-1}^*), \tag{67}$$

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 revealed from de-trended data.

We calibrate the model on the basis of Russian macro-statistics. In Tab. A1 we can find 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 Hoddrick-Prescott de-trended Russian series of consumption C_t, output (real GDP) Y_t, CPI inflation π_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 2001:Q1–2014:Q2 (54 quarters). We start from 2001 because Russian macroeconomic dynamics was mainly determined by the crisis of 1998 before that year[11]. The end of the sample corresponds to the period of high exchange rate volatility which eventually prompted Bank of Russia to hasten the transition to free floating regime in the end of 2014. 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 $\eta_{B,t}$.

3.1 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 σ_C, σ_H and capital adjustment costs ϕ_K and Beta-distributions for the habit parameter h, the Calvo-pricing parameter θ, the share of temporarily liquidity

[11] We can not include this crisis in the sample because, first, introduced in the model monetary policy rules could not be used for that period, second, the crisis of 1998 is mainly associated with sovereign debt crisis, whereas the role of debt dynamics is mainly ignored in the model.

constrained households θ_A, the probability of CROR θ_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 θ 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 temporarily liquidity constrained households. The usual practice is to set the prior mean for θ_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 till March 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 θ_B. We set the mean of the prior distribution of θ_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 $\sigma(\eta_{PX})=0.119$ $\rho_{PX}=0.713$. I also fix the coefficient in the Taylor rule $k_Y=0$ and indexation parameters for intermediate goods prices $\chi=0$ and wages $\chi_W=0$ as we have prior information that they are non-negative and the likelihood function is decreasing with respect to these parameters in nonnegative zone.

3.2 *Estimation results*

To calculate likelihood function for the model I use Kalman filter, realized in Dynare (Adjemian et al., 2011). Marco Ratto's 'newrat' algorithm (see Adjemian et al., 2011) is used for maximization of posterior function. Quantitative analysis of the estimated model is based on posterior *modes*.

First I 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 I 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. 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, Larin, and Novak (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 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 temporarily liquidity constrained 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. A4 presents the calculation of most important correlations for models M1–M4 in comparison with historical data.

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 Mj is true. Tab. A4 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. A4). 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 models favour M1, so we use it in the welfare analysis.

4. Welfare analysis and the optimal monetary regime

First, we discuss the results of the model simulation on Russian data assuming no CROR. Then we make welfare maximization exercises to reveal the most appropriate monetary regime for the economy, configured by estimated on Russian data shocks.

4.1 Role of credit rationing at official rate in Russian macroeconomic dynamics

For better understanding the role of CROR in explaining Russian data and in stabilizing monetary policy, we simulate estimated model assuming no CROR ($\theta_B = 0$) on the base of historical shocks revealed in a process of Baseline model estimation. It allows us finding of the CROR contribution to macroeconomic dynamics. Results of this exercise are shown on Fig. 5-8.

Fig. 5 demonstrates moderately countercyclical contribution of CROR to Russian consumption C_t and output Y_t before and after the global financial crises (GFC) and strongly countercyclical contribution during the GFC. At the same time the contribution of CROR to hours worked H_t and utility Λ_t (Fig. A6) appeared to be weakly procyclical. For understanding that result we should note that the contribution of CROR to exchange rate S_t and international reserves IR_t has positive correlation with observable cyclical components of these variables during the GFC (Fig. A7). CROR made the main contribution in the dynamics of exchange rate and international reserves during the GFC. The same picture could be found in the dynamics of home B_t and foreign B_t^* assets (Fig. A8).

Capital market imperfections were the source of overshooting and further gradual adjustment in net foreign assets B_t^* dynamics and led to more international reserves losses compared with no CROR case. As a result we get more significant Ruble devaluation comparing with no CROR case which improved weak demand for home produced goods and made countercyclical contribution to consumption and GDP dynamics. At the same time the increase in hours worked H_t appeared to be not significant compared to its fluctuations in response to other structural shocks. Resulting effect on the utility in period of the GFC was small and ambiguous.

We may conclude that relying on weak Taylor rule together with limited exchange rate adjustment, the Bank of Russia could create very limited countercyclical impulse for the Russian economy. Expectations about the possibility to lose the access to financial markets and financing at the official rate in the future provoked forward-looking behavior based on predictability of gradual exchange rate adjustment. This behavior led to deeper Ruble devaluation in comparison with Baseline model, and generated positive countercyclical effect on home demand during the GFC. This result contradicts to financial accelerator of Bernanke et al. (1999) where financial market frictions make procyclical effect on the economy. Such a contradiction is conceivably related to the dubious monetary regime and, particularly the role of the exchange rate rule (62) the Bank of Russia used during the GFC. This rule weakens automatic stabilizer effect of exchange rate in response to structural shocks and restricts ability of monetary authorities to use countercyclical interest rate rule. Financial market imperfections generate forward-looking behavior which amplifies automatic stabilizer effect of exchange rate. This unusual effect on the one hand, favor CROR, on the other hand it is hardly imagine that based on frictions and created by speculative behavior mechanism would be the first best solution of the monetary regime choice problem.

4.2 Optimal regime choice

For choosing the most appropriate monetary regime we maximize unconditional welfare over the coefficients in the Taylor rule k_π, k_Y, k_S exchange rate flexibility coefficient k_{IR}, and the probability of CROR θ_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 pro-cyclicality 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_π 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:

$$\begin{aligned}\Lambda_t = &\frac{((1-h)\cdot \overline{C})^{1-\sigma_C}}{1-\sigma_C} - \frac{\overline{H}^{1+\sigma_H}}{1+\sigma_H} + (1-h)^{-\sigma_C}\overline{C}^{1-\sigma_C}\widetilde{C}_t - \overline{H}^{1+\sigma_H}\widetilde{H}_t - \\ &- \frac{\sigma_C(1-h)^{-(1+\sigma_C)}\overline{C}^{1-\sigma_C}}{2}\widetilde{C}_t^2 - \frac{\sigma_H \overline{H}^{1+\sigma_H}}{2}\widetilde{H}_t^2\end{aligned}, \qquad (68)$$

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, Dib, and Rebei (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 μ_v is determined by:

$$1+\mu_v = \left(1 - \frac{\sigma_C}{2}\cdot\frac{1-\sigma_C}{(1-h)^2}\cdot E\widetilde{C}_t^2 - \frac{\sigma_H}{2}\cdot\frac{1-\sigma_C}{(1-h)^{1-\sigma_C}}\cdot\frac{\overline{H}^{1+\sigma_H}}{\overline{C}^{1-\sigma_C}}\cdot E\widetilde{H}_t^2\right)^{\frac{1}{1-\sigma_C}}, \qquad (69)$$

We cannot rely merely on the criteria (69), 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.

4.2.1 *Optimal inflation targeting rule*

We first solve constrained optimization problem:

$$\begin{aligned}
&\max_{k_\pi, k_Y, k_S, k_{IR}, \theta_B} \mu_v \\
&s.t.\, k_\pi \geq 1.1 \\
&k_Y \geq 0 \\
&k_S \geq 0 \\
&k_{IR} \geq 0 \\
&\theta_B \in [0.1] \\
&N(\lambda \leq 1) = N^{pred}
\end{aligned} \tag{70}$$

and results are shown in Tab. A5.

The solution to problem (70) characterizes the optimal rules in an inflation targeting regime and demonstrates the ability to improve unconditional welfare. In 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_π 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. A5 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 rate regime ($k_{IR} \to \infty$) and no CROR ($\theta_B = 0$). These results are broadly in line with the empirical and theoretical literature on inflation targeting.

4.2.2 *Optimal credit rationing at the official rate*

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

$$\max_{\theta_B} \mu_v$$
$$s.t.\ k_\pi = 0.0425$$
$$k_Y = 0$$
$$k_S = 0.0185 \quad (71)$$
$$k_{IR} = 0.2962$$
$$\theta_B \in [0.1]$$
$$N(\lambda \le 1) = N^{pred}$$

The results are presented in Tab. A6.

The most interesting result presented in Tab. A6 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. A6 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 θ_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 $\theta_B = 0$. As we assumed before possible advantages of CROR are related with peculiar monetary policy regime the BoR used during the GFC and disappear when we analyze optimal inflation targeting framework. We also should note that Central Bank has no full control over credit rationing process in a period of financial crises. Many financial organizations are in trouble during the financial crises, for instance, they may have asymmetric information problem, collateral constraints problem, financial market fragmentation problem. In such a situation they can not get financing neither from other financial market participants nor from Central Bank, because they can not meet the requirements for getting financing by conventional monetary tools. Financial market frictions make significant contribution to CROR during financial crises and the main task of the Central Bank is to mitigate such problem by different unconventional monetary policy tools.

4.2.3 Different monetary regimes: simulation on Russian data

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), and Optimal Taylor rule (OTR). The results are presented in Tab. A7.

We have included in Tab. A7 only regimes with appropriate exchange rate volatility[12].

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.

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[12] 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.

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 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 artificial introduction of financial frictions may give very small improvement (+0.01% in terms of the main criterion) of monetary policy performance only in two regimes with poor performance: historical regime with limited exchange rate adjustment and Classical Taylor rule (see Tabs. A6 and A7). We have found several Pareto-efficient monetary policy regimes: optimal inflation targeting, optimal Taylor rule, fixed official rate and all of them should not include CROR.

5. Conclusion

This paper investigates whether credit rationing at the official rate performed by a Central Bank may soften the open economy trilemma constraint and improve results of monetary policy for different monetary regimes. It also 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:Q1 – 2014:Q2 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 temporarily liquidity constrained households and the probability of CROR were estimated at 22% and 66% respectively.

We made two types of exercises devoted to optimal monetary policy regime choice. First we simulated the model for identifying the CROR contribution to Russian macroeconomic dynamics on the base of historical shocks revealed in a process of Baseline model estimation. Analysis of such contribution during the global financial crisis clarifies the channel through which the CROR influenced economy. The underlying mechanism is related with forward-looking behavior of agents understanding non-zero probability of loosing access to financing at the official rate in the future. It amplifies the automatic stabilizer effect of exchange rate fluctuation and creates countercyclical dynamics in GDP and consumption. At the same time the resulting effect of the CROR on welfare is small and ambiguous.

Second, 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 (optimal inflation targeting regime). The other local optimum for optimal Taylor rule regime 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 (fixed official rate regime). Regime with classical Taylor rule 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. Optimal inflation targeting regime adapting will bring much more significant gain of 1.22% in terms of consumption and more stable inflation.

6. Literature

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Appendix A. Euler equations in the presence of financial market constraints

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 $dC^o_{t+1}(j) = -\frac{P_t}{P_{t+1}}(1+i_t)dC_t(j)$, 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 θ_A and has to consume only additional interest payments on marginal savings $dC^n_{t+1}(j) = -\frac{P_t}{P_{t+1}} i_t dC_t(j)$. The same logics may be apply to the period *t+2*: with probability $\theta_A(1-\theta_A)$ it will consume $dC^o_{t+2}(j) = -\frac{P_t}{P_{t+2}}(1+i_{t+1})dC_t(j)$. With probability $\theta_A{}^2$ it will consume interest payments $dC^n_{t+2}(j) = -\frac{P_t}{P_{t+2}} i_{t+1} dC_t(j)$. Recurring in this way we may find the expected utility of marginal consumption which should optimally be zero:

$$\Lambda^o_{C,t}\eta_{b,t} - \beta E_t \left\{ \begin{aligned} &(1-\theta_A)\sum_{k=1}^{\infty}(\beta\theta_A)^{k-1}\Lambda^o_{C,t+k}\eta_{b,t+k}\frac{P_t}{P_{t+k}}(1+i_{t+k-1}) + \\ &+\theta_A\sum_{k=1}^{\infty}(\beta\theta_A)^{k-1}\Lambda^n_{C,t+k}\eta_{b,t+k}\frac{P_t}{P_{t+k}} i_{t+k-1} \end{aligned} \right\} = 0 \qquad \text{(A1)}$$

Rearranging (A1) gives equation (6):

$$\Lambda^o_{C,t}\eta_{b,t} = \beta P_t((1-\theta_A)E_t J^o_{t+1} + \theta_A E_t J^n_{t+1}), \qquad (6)$$

Credit rationing at the official rate

We assume that every period with probability $1-\theta_B$ household j may have the ability to adjust its domestic assets volume to optimal level $B_t = B^o_t$. With probability θ_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:

$$\Delta Fin_t^o = P_t(C_t^o + I_t + G_t) - \left\{ \begin{array}{l} (P_{X,t}Y_{X,t}^{ex} + P_{M,t}Y_{M,t}^{ex})(1-\alpha_{WD}) + P_{M,t}Y_{M,t}^d + P_{N,t}Y_{N,t} + S_t IR_{t-1}^* i_{t-1}^* + \\ + S_t B_{t-1}^*(i_{t-1}^* + rp_{t-1}(1+i_{t-1}^*)) + B_{t-1}i_{t-1} \end{array} \right\} \quad \text{(A2)}$$

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 θ_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:

$$1 + i_{ref,t} = (1 + i_t^*)\frac{E_t S_{t+1}}{S_t}\exp(-\tau\frac{S_t B_t^{*opt}}{P_t Y_t} + \varepsilon_{rp,t}), \quad \text{(A3)}$$

$$B_t^{opt} = Fin_t - S_t B_t^{*opt} \quad \text{(A4)}$$

where (A3) is the uncovered interest parity condition; and (A4) 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:

$$\Phi_t = \int_{B_t^*}^{B_t^{*opt}} S_t(B_t^{*opt} - B_t^*(j))(1 + i_t(j))dB_t^*(j) - S_t(B_t^{*opt} - B_t^*(j))(1 + i_{ref,t}), \quad \text{(A5)}$$

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

$$1 + i_t(j) = (1 + i_t^*)\frac{E_t S_{t+1}}{S_t}\exp(-\tau\frac{S_t B_t^*(j)}{P_t Y_t} + \varepsilon_{rp,t}) \quad \text{(A6)}$$

To calculate the loss function we find the Taylor series expansion of (A6) around B_t^{*opt}

$$1 + i_t(j) = (1 + i_{ref,t})[1 + \tau\frac{S_t}{P_t Y_t}(B_t^{*opt} - B_t^*(j))] \quad \text{(A7)}$$

Then the loss function is

$$\Phi_t = 0.5\tau\frac{S_t}{P_t Y_t}(1 + i_{ref,t})S_t(B_t^{*opt} - B_t^*(j))^2 \quad \text{(A8)}$$

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

$$B_{t+k}\big|_{B_t^{*o}} = B_t^0 \qquad\qquad B_{t+k}^*\big|_{B_t^{*o}} = B_t^{*o} - \sum_{l=1}^{k} \frac{\Delta Fin_{t+l}}{S_{t+l}} \tag{A9}$$

Households choose B_t^{*o} to minimize

$$\min_{B_t^{*o}} E_t \sum_{k=0}^{\infty} (\beta\theta_B)^k \eta_{b,t+k} \Lambda_{C,t+k} \frac{S_{t+k}}{P_{t+k}} 0.5\tau \frac{S_{t+k}}{P_{t+k} Y_{t+k}} (1+i_{ref,t})(B_{t+k}^{*opt} - B_t^{*o} + \sum_{l=1}^{k} \frac{\Delta Fin_{t+l}}{S_{t+l}})^2 , \tag{A10}$$

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 (A10) gives:

$$B_t^{*o} = \frac{J_{B,t} + T_{B,t}}{N_{B,t}} + \eta_{B,t} , \tag{12}$$

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	$\Gamma_G \equiv \frac{\overline{P}\,\overline{G}}{\overline{P}^{def}\overline{Y}}$	$\Gamma_G = 0.189$
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	$\Gamma_{MN} \equiv \frac{\overline{Y}_M\overline{P}_M}{\overline{Y}_N\overline{P}_N}$	$\Gamma_{MN} = 0.333$
Net transfers to export ratio	$\Gamma_{NT} \equiv \frac{\overline{NT}}{\overline{Y}_X^{ex}\overline{P}_X + \overline{Y}_M^{ex}\overline{P}_M}$	$\Gamma_{NT} = 0.174$
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 Γ_G, Γ_{EX} and Γ_{MN} are calculated on the basis of Rosstat statistics of Russian GDP and value added by different sectors at constant 2008 prices. The ratios Γ_{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 Γ_{NT} 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	$\varsigma_M = 0.14$	Polbin (2013)
Share of intermediate X-sector goods income in total income of M-sector	$\varsigma_N = 0.095$	Polbin (2013)
Share of natural recourses owners income in total income of X-sector	$\varsigma_X = 0.2$	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 labor 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	$\upsilon = 0.66$	Like in Dib (2008) we assume $\upsilon = \kappa$

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 β we resolve next system:

$$\begin{cases} 1+\bar{i} = \dfrac{1}{\beta} \\ (1+\bar{i}^*)(1+\overline{rp}) = \dfrac{1}{\beta} \\ \Gamma_{i^*/EX} = \Gamma_{B^*/EX}(\bar{i}^* + \overline{rp}(1+\bar{i}^*)) + \Gamma_{IR^*/EX}\bar{i}^* \\ \overline{rp} = \exp(-\tau\,\Gamma_{EX}\Gamma_{B^*/EX}) \end{cases}, \quad \text{(A11)}$$

where the sensitivity of the risk premium to the indebtedness level τ is estimated.

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

$$\bar{A} = 1,\ \bar{Y}^* = 1,\ \bar{P} = 1,\ \bar{P}^* = 1,\ \bar{P}_X^* = 1 \quad \text{(A12)}$$

Parameters w_{ex}, γ_M and γ_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.

Parameter		**Prior**	**M1 LC+CROR (Baseline)**	**M2 LC**	**M3 CROR**	**M4 None**
	Name	Type (mean,std.dev)	Mode (std.dev.)	Mode (std.dev.)	Mode (std.dev.)	Mode (std.dev.)
$\sigma(\eta_{A,t})$	Standard deviation of total productivity shock	Uniform	**0.1085** (0.0170)	**0.1119** (0.0166)	**0.1223** (0.0180)	**0.1233** (0.0179)
$\sigma(\eta_{b,t})$	Standard deviation of intertemporal preferences shock	Uniform	**0.0927** (0.0241)	**0.0910** (0.0226)	**0.1757** (0.0511)	**0.1607** (0.0467)
$\sigma(\eta_{S,t})$	Standard deviation of exchange rate policy shock	Uniform	**0.0403** (0.0054)	**0.0558** (0.0105)	**0.0448** (0.0071)	**0.0584** (0.0117)
$\sigma(\eta_{PR,t})$	Standard deviation of official rate shock	Uniform	**0.0016** (0.0002)	**0.0016** (0.0002)	**0.0016** (0.0002)	**0.0016** (0.0002)
$\sigma(\eta_{\mu,t})$	Standard deviation of markup shock	Uniform	**0.0839** (0.0135)	**0.0825** (0.0130)	**0.0697** (0.0112)	**0.0695** (0.0110)
$\sigma(\eta_{rp,t})$	Standard deviation of risk premium shock	Uniform	**0.0044** (0.0005)	**0.0044** (0.0004)	**0.0046** (0.0005)	**0.0045** (0.0005)
$\sigma(\eta_{B,t})$	Standard deviation of optimal foreign assets shock	Uniform	**4.0971** (0.9348)	**9.3969** (2.3661)	**4.1784** (1.0344)	**9.3812** (2.3943)
ρ_{PR}	Persistence parameter of official rate dynamics	Uniform	**0.6375** (0.0927)	**0.6396** (0.0923)	**0.6305** (0.0909)	**0.6326** (0.0908)
σ_C	Relative risk aversion coefficient	$\Gamma(2.0,1.0)$	**1.9623** (0.5138)	**2.0362** (0.4973)	**2.4854** (0.6931)	**2.4651** (0.6718)
σ_H	Inverse of Frisch wage elasticity of labor supply	$\Gamma(1.0,0.5)$	**2.3920** (0.8659)	**2.1725** (0.7687)	**1.7704** (0.6676)	**1.7764** (0.6570)
h	Habits parameter	B(0.5,0.1)	**0.7127** (0.0538)	**0.6968** (0.0544)	**0.7717** (0.0518)	**0.7536** (0.0540)
θ	Calvo parameter for prices	B(0.75,0.05)	**0.9105** (0.0138)	**0.9093** (0.0136)	**0.8955** (0.0158)	**0.8952** (0.0154)
θ_A	Share of temporarily liquidity constrained	B(0.4,0.1)	**0.2184** (0.0389)	**0.1953** (0.0367)		

	households					
θ_B	Probability of rationing credit at official rate	B(0.546,0.05)	**0.6637** (0.0496)		**0.6302** (0.0574)	
ϕ_K	Capital adjustment cost parameter	Γ(10,10)	**75.89** (21.37)	**72.82** (20.56)	**31.74** (12.34)	**30.54** (11.69)
τ	Sensitivity of risk premium to indebtedness level	Uniform	**0.0278** (0.0015)	**0.0277** (0.0014)	**0.0282** (0.0016)	**0.0281** (0.0015)
k_{IR}	Coefficient of exchange rate flexibility	Uniform	**0.2962** (0.0519)	**0.4588** (0.0798)	**0.3521** (0.0613)	**0.4820** (0.0886)
k_π	Taylor rule coefficient (reaction on inflation)	Uniform	**0.0425** (0.0315)	**0.0435** (0.0315)	**0.0437** (0.0308)	**0.0439** (0.0310)
k_S	Taylor rule coefficient (reaction on exchange rate)	Uniform	**0.0185** (0.0074)	**0.0208** (0.0074)	**0.0193** (0.0074)	**0.0214** (0.0073)
	Laplace approximation of natural logarithm of marginal density function		**1007.68**	**1000.83**	**1005.54**	**1001.40**

Table A4. Correlations of historical and simulated series

	Historical data	**Simulated data M1**	**Simulated data M2**	**Simulated data M3**	**Simulated data M4**
		LC+CROR	**Only LC**	**Only CROR**	**None**
	Correlations with $P_{X,t}$				
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
	Correlations with C_t				
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		**89.2%**	**0.1%**	**10.5%**	**0.2%**

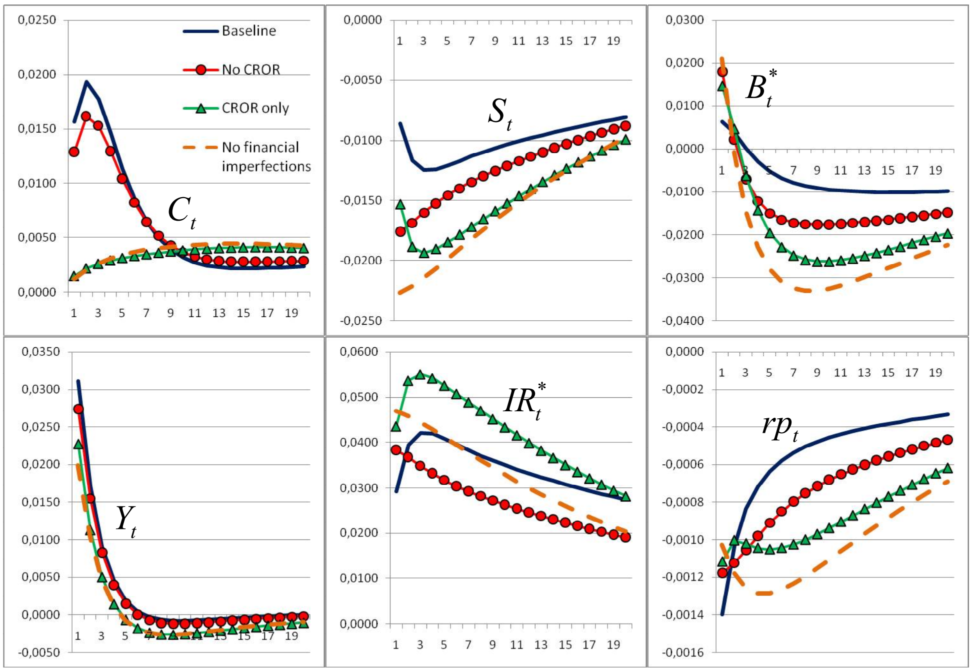

Figure A1. Impulse response function on 1 std. dev. oil price shock $\eta_{PX,t}$

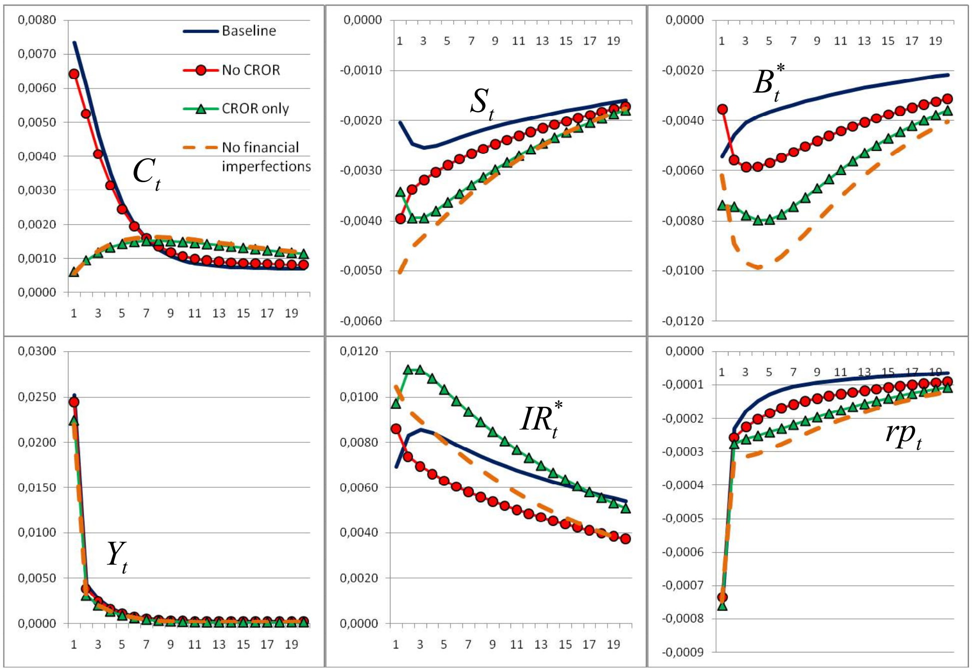

Figure A2. Impulse response function on the 1 std. dev. total factor productivity shock $\eta_{A,t}$

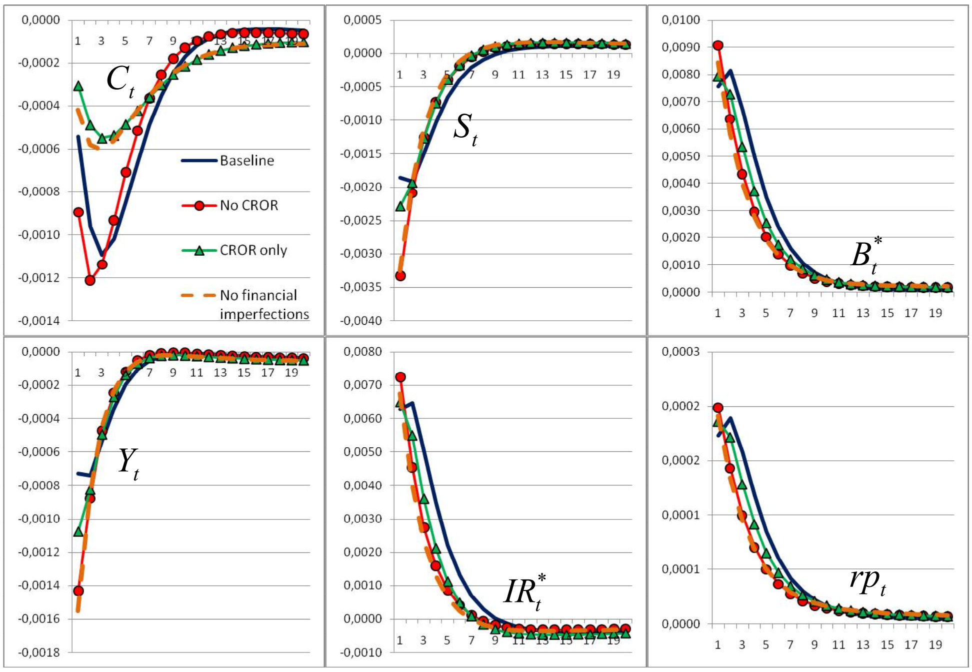

Figure A3. Impulse response function on the 1 std. dev. official rate shock $\eta_{PR,t}$

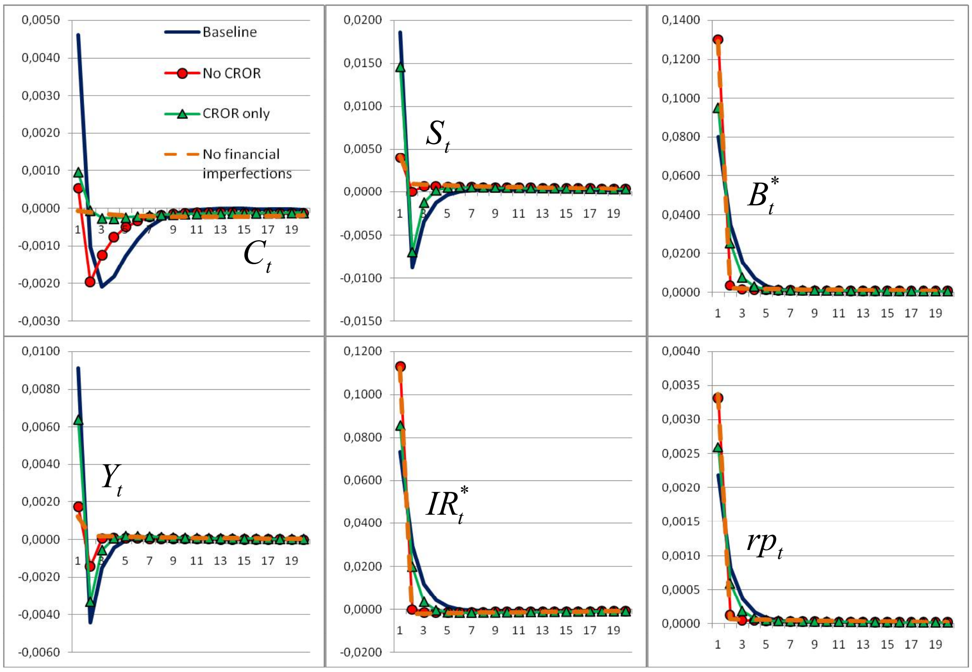

Figure A4. Impulse response function on the 1 std. dev. exchange rate policy shock $\eta_{S,t}$

Appendix C. Results of the model simulation assuming no CROR

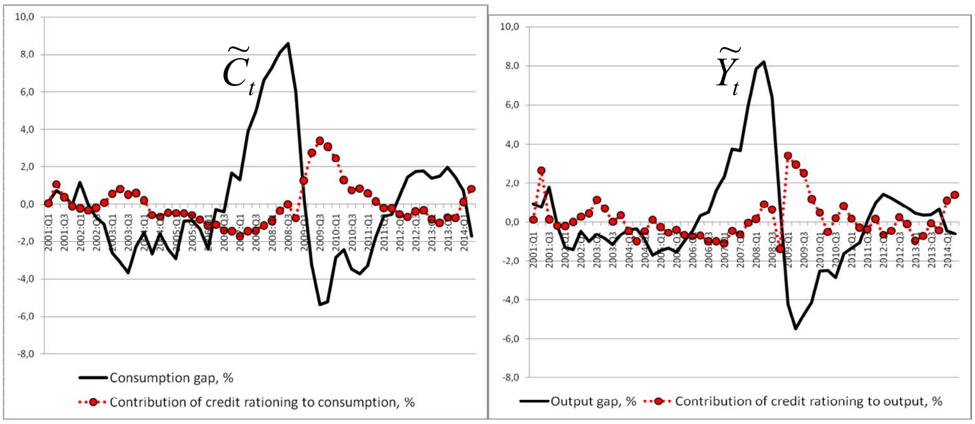

Figure A5. Contribution of CROR to the dynamics of consumption C_t and output Y_t compared with observable deviations of these variables from their trends.

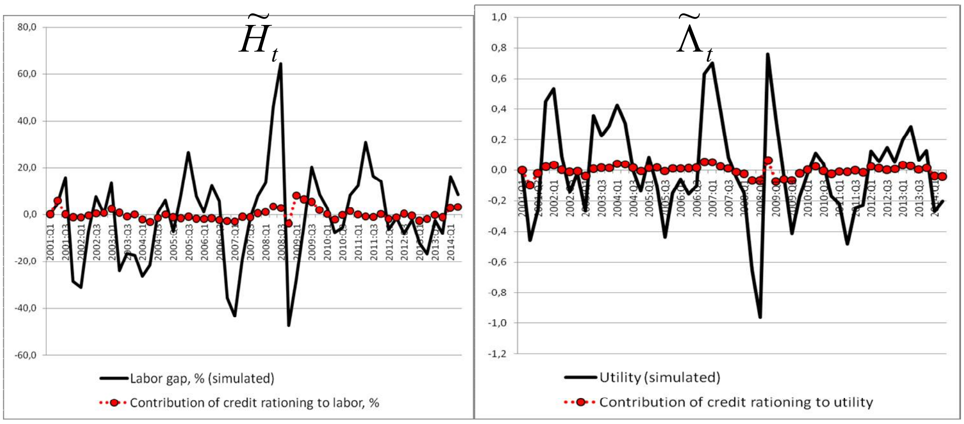

Figure A6. Contribution of CROR to the dynamics of worked hours H_t and utility Λ_t compared with simulated deviations of these variables from their steady state values in the baseline model.

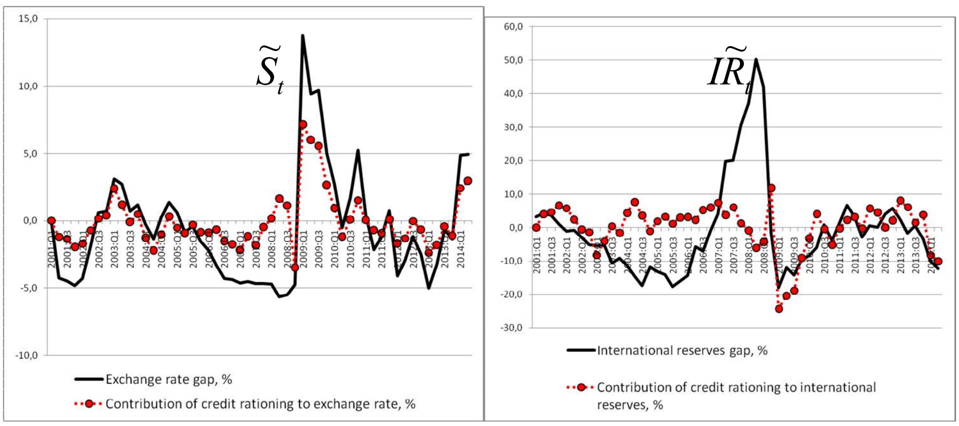

Figure A7. Contribution of CROR to the dynamics of exchange rate S_t and international reserves IR_t compared with observable deviations of these variables from their trends.

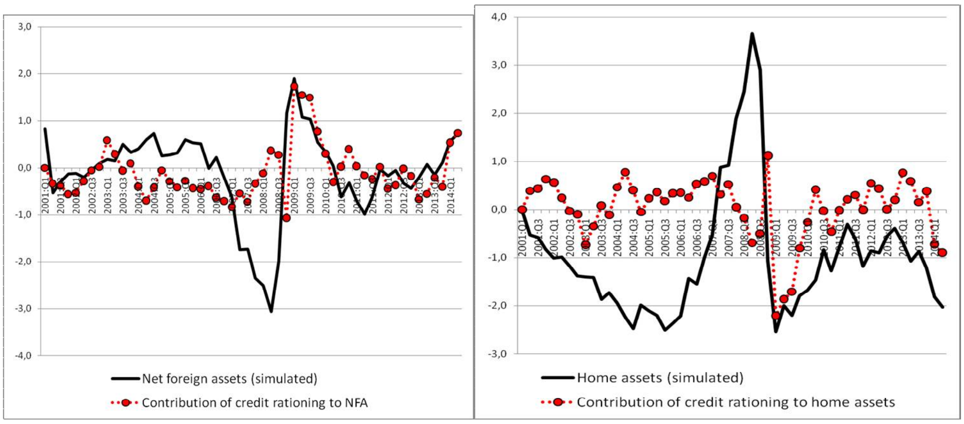

Figure A8. Contribution of CROR to the dynamics of net foreign assets B_t^* and home assets B_t compared with simulated deviations of these variables from their steady state values in the baseline model.

Appendix D. Results of welfare optimization

Table A5. Results of welfare optimization in inflation targeting regime

		Model with optimal parameters for inflation targeting regime		
Parameter	Baseline M1 model	E1. No additional restrictions on k_S	E2. Low k_S	E3. Moderate k_S
k_π	0.043	**7.077**	**7.423**	**7.957**
k_Y	0	**1.156**	**1.339**	**1.630**
k_S	0.019	0	0.02	0.05
k_{IR}	0.296	∞	∞	∞
θ_B	0.664	0	0	0
μ_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	$1.25\cdot10^{-3}$	$1.38\cdot10^{-3}$	$1.38\cdot10^{-3}$	$1.39\cdot10^{-3}$
EH_t^2	$4.03\cdot10^{-2}$	$3.27\cdot10^{-2}$	$3.30\cdot10^{-2}$	$3.35\cdot10^{-2}$
$E\pi_t^2$	$5.93\cdot10^{-5}$	$6.16\cdot10^{-5}$	$6.15\cdot10^{-5}$	$6.13\cdot10^{-5}$
ES_t^2	0.0035	2.8118	0.0664	0.0321

Table A6. Results of welfare optimization over probability of rationing credit at official rate θ_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_π	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
θ_B	0.664	**0.151**	0
μ_v	-0.1014	-0.0998	-0.0999
Improvement in comparison with Baseline M1 model	–	0.16%	0.15%
EC_t^2	$1.25\cdot10^{-3}$	$1.41\cdot10^{-3}$	$1.45\cdot10^{-3}$
EH_t^2	$4.03\cdot10^{-2}$	$3.87\cdot10^{-2}$	$3.86\cdot10^{-2}$
$E\pi_t^2$	$5.93\cdot10^{-5}$	$5.80\cdot10^{-5}$	$5.79\cdot10^{-5}$
ES_t^2	0.00353	0.00302	0.00294

Table A7. Results of the model simulation for different monetary regimes.

Parameter	Baseline M1 model	Model E3: Optimal inflation targeting	Classic Taylor rule	Classic Taylor rule with optimal θ_B	Fixed exchange rate	Fixed official rate	Optimal Taylor rule
Abbreviation		OIT	CTR		FER	FOR	OTR
k_π	0.043	**7.957**	1.5	1.5	0	0	0
k_Y	0	**1.630**	0.125	0.125	0	0	**0.292**
k_S	0.019	0.05	0.01	0.01	0	10^{-5}	10^{-5}
k_{IR}	0.296	∞	∞	∞	0	∞	∞
θ_B	0.664	0	0	**0.215**	0	0	0
μ_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	$1.25\cdot10^{-3}$	$1.39\cdot10^{-3}$	$1.96\cdot10^{-3}$	$1.91\cdot10^{-3}$	$1.19\cdot10^{-3}$	$1.05\cdot10^{-3}$	$0.58\cdot10^{-3}$
EH_t^2	$4.03\cdot10^{-2}$	$3.35\cdot10^{-2}$	$3.54\cdot10^{-2}$	$3.56\cdot10^{-2}$	$4.20\cdot10^{-2}$	$3.22\cdot10^{-2}$	$3.17\cdot10^{-2}$
$E\pi_t^2$	$5.93\cdot10^{-5}$	$6.13\cdot10^{-5}$	$6.95\cdot10^{-5}$	$6.97\cdot10^{-5}$	$6.00\cdot10^{-5}$	$6.36\cdot10^{-5}$	$9.24\cdot10^{-5}$
ES_t^2	0.0035	0.0321	0.0315	0.0313	0	0.0151	0.1139

Appendix E. Sensitivity of the main results to non-tradable sector share.

For clarifying the role of non-tradable sector in the model and for checking main results robustness I repeat main steps of the research assuming different shares of non-tradable sectors in home produced goods.

Table A8. Posterior modes for different Γ_{MN}

	Prior	$\Gamma_{MN}=0.1$	$\Gamma_{MN}=0.333$ **(Baseline)**	$\Gamma_{MN}=10$	$\Gamma_{MN}=1000$
Share of non-tradable in home produced goods		90.(90)%	75%	9.(09)%	0.1%
	Type (mean,std.dev)	Mode	Mode	Mode	Mode
$\sigma(\eta_{A,t})$	Uniform	0,1080	0.1085	0,1092	0,1096
$\sigma(\eta_{b,t})$	Uniform	0,0902	0.0927	0,1004	0,1012
$\sigma(\eta_{S,t})$	Uniform	0,0406	0.0403	0,0401	0,0401
$\sigma(\eta_{PR,t})$	Uniform	0,0016	0.0016	0,0016	0,0016
$\sigma(\eta_{\mu,t})$	Uniform	0,0846	0.0839	0,0811	0,0809
$\sigma(\eta_{rp,t})$	Uniform	0,0044	0.0044	0,0044	0,0044
$\sigma(\eta_{B,t})$	Uniform	4,3185	4.0971	3,5907	3,5542
ρ_{PR}	Uniform	0,6370	0.6375	0,6391	0,6391
σ_C	Γ(2.0,1.0)	1,8920	1.9623	2,1567	2,1782
σ_H	Γ(1.0,0.5)	2,4129	2.3920	2,3913	2,3855
h	B(0.5,0.1)	0,7148	0.7127	0,7126	0,7129
θ	B(0.75,0.05)	0,9113	0.9105	0,9078	0,9077
θ_A	B(0.4,0.1)	0,6619	0.6637	0,6643	0,6643
θ_B	B(0.546,0.05)	0,2128	0.2184	0,2308	0,2322
ϕ_K	Γ(10,10)	77,531	75.89	74,530	74,416
τ	Uniform	0,0277	0.0278	0,0276	0,0275
k_{IR}	Uniform	0,3007	0.2962	0,2937	0,2937
k_π	Uniform	0,0427	0.0425	0,0424	0,0423
k_S	Uniform	0,0185	0.0185	0,0184	0,0184

Table A9. Results of optimization procedures for different Γ_{MN}

Share of non-tradable	Model E3: Optimal inflation targeting (OIT) 75% (Baseline)	Model E3: Optimal inflation targeting (OIT) 0.1%	Classic Taylor rule with optimal θ_B (CTR) 75% (Baseline)	Classic Taylor rule with optimal θ_B (CTR) 0.1%	Optimal Taylor rule (OTR) 75% (Baseline)	Optimal Taylor rule (OTR) 0.1%	Model with optimal probability of rationing credit at official rate and historical coefficients 75% (Baseline)	Model with optimal probability of rationing credit at official rate and historical coefficients 0.1%
k_π	**7.957**	**7.844**	1.5	1.5	0	0	0.043	0.042
k_Y	**1.630**	**1.859**	0.125	0.125	**0.292**	**0.346**	0	0
k_S	0.05	0.05	0.01	0.01	10^{-5}	10^{-5}	0.019	0.018
k_{IR}	∞	∞	∞	∞	∞	∞	0.296	0.294
θ_B	0	**0.382**	**0.215**	**0.440**	0	0	**0.151**	**0.328**