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Digital Ruble and Monetary Policy Transmission: A DSGE Analysis of Russia's CBDC Implementation

Rodrigo Bochner[1]

1 *RBCH, Rio de Janeiro (Brazil)*

Corresponding author: Rodrigo Bochner (rodrigobochner0565@gmail.com)

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Abstract

This study developed a dynamic stochastic general equilibrium (DSGE) model to analyze the macroeconomic implications of Russia's digital ruble implementation within the context of financial sanctions and monetary policy autonomy. Using a New Keynesian framework augmented with a monopolistically competitive banking sector and central bank digital currency (CBDC) features, we examine the transmission mechanisms through which the digital ruble affects monetary policy effectiveness, financial intermediation and economic welfare. The Bank of Russia has unequivocally stated its intention to issue the digital ruble without interest remuneration. Accordingly, this paper treats the zero-remuneration scenario as the institutional baseline and frames the derivation of an optimal remuneration policy explicitly as a normative counterfactual, quantifying the welfare cost of the non-interest-bearing design. Calibration of the model to Russian economic data shows that introducing a non-remunerated digital ruble would lead to a 0.18% increase in steady-state consumption, whereas an optimally remunerated alternative could deliver a 0.79% increase. The model demonstrates that under sanctions-induced financial fragmentation, CBDC adoption partly restores monetary policy transmission by providing an alternative settlement infrastructure, with the mitigation effect reaching approximately 30% of sanctions-induced welfare losses under high-intensity scenarios. The analysis contributes to understanding CBDC implementation in emerging markets facing external financial constraints and provides quantitative guidance for welfare-optimal CBDC design parameters.

Keywords

Central Bank Digital Currency, Monetary Policy Transmission, Dynamic Stochastic General Equilibrium, Financial Sanctions, Digital Ruble.

JEL: E42, E52, E58, G21, G28.

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1. Introduction

The proliferation of central bank digital currencies represents a fundamental transformation in monetary architecture. According to the Atlantic Council (2024), as of 2024, 134 countries accounting for 98% of global GDP were actively researching or designing such instruments. This development is particularly significant for economies operating under financial sanctions, where traditional international payment systems are restricted or cut off. Russia's digital ruble initiative is advancing toward broader implementation by 2025. It constitutes a compelling case for examining the implications of CBDCs within a unique macroeconomic context, characterized by sanctions-induced financial fragmentation, elevated inflation and institutional efforts to maintain monetary autonomy.

One critical institutional feature should be established from the outset: the Bank of Russia has repeatedly stated that the digital ruble will not pay interest on holdings, as it is intended to be a purely transactional instrument and not a means of savings (Bank of Russia, 2025). This paper takes that commitment as given and uses it as an institutional benchmark. The normative analysis presented here — deriving an optimal remuneration rule and quantifying the welfare gains of alternative designs — is an explicit counterfactual exercise. It asks what Russian households and the economy would gain from redesigning the remuneration policy, and what the welfare cost of the current zero-remuneration stance is. This framing is reinforced by recent international developments. During the review period, the People's Bank of China announced that commercial banks would be required to pay interest on digital yuan holdings. This move takes the e-CNY beyond the realm of a purely transactional instrument. The difference between these two policy choices provides a strong motivation for the normative analysis undertaken here.

The theoretical literature on CBDCs has established that their introduction generates non-trivial general equilibrium effects through multiple transmission channels (Brunnermeier & Niepelt, 2019; Keister & Sanches, 2023). Recent advances in DSGE modeling have illuminated how CBDCs interact with banking sector dynamics, altering deposit competition, credit provision and real economic outcomes (Barrdear & Kumhof, 2022; Paul et al., 2025). However, existing frameworks primarily focus on advanced economies, leaving substantial gaps in our understanding of the implications of CBDCs for emerging markets facing external financial constraints.

This study addresses three interrelated research questions. First, how does CBDC implementation affect monetary policy transmission in an economy experiencing sanctions-induced financial fragmentation? Second, what is the welfare cost of a zero-remuneration CBDC design relative to an optimally remunerated alternative? Third, how do institutional characteristics specific to Russia — concentrated banking market structure, substantial state ownership in finance and capital control infrastructure — modify standard CBDC theoretical predictions?

We have developed a DSGE model that incorporates CBDC within a New Keynesian framework featuring monopolistically competitive banks, heterogeneous

agents and realistic frictions in the interbank markets. The model's calibration exploits two key features of the Russian economy: an elevated policy rate (16.5% as of late 2025) to combat persistent inflation, and a banking sector concentrated in state-controlled institutions, which hold approximately 60% of total assets. Our model allows for time-varying financial autarky conditions representing the intensity of sanctions, and enables the analysis of the effectiveness of CBDCs under different degrees of international financial integration.

The empirical strategy combines structural estimation using Russian macroeconomic time series (2014–2024) with a simulation-based welfare analysis across alternative CBDC design specifications. We use Bayesian estimation techniques and likelihood-based inference on fourteen macroeconomic series. The estimation period covers multiple external shocks, including the imposition of sanctions in 2014, the disruption caused by the pandemic in 2020 and the intensification of sanctions in 2022. This variation allows us to identify the structural parameters that govern financial intermediation and monetary policy transmission.

Our principal findings establish that the digital ruble introduces a fundamental welfare trade-off. The zero-remuneration design consistent with the Bank of Russia's stated policy yields modest welfare gains of 0.18% of steady-state consumption. An optimally designed alternative — offering remuneration 70 basis points below the policy rate — more than quadruples this gain to 0.79% of consumption. Crucially, the zero-payment variant improves welfare even under elevated sanctions because it provides an alternative payment system that partly bypasses sanctioned channels. This result suggests that the Bank's choice of design entails a measurable cost to welfare, which is not catastrophic and may be justified on the basis of financial stability considerations that fall outside the scope of the present model.

The remainder of the paper proceeds as follows. Section 2 reviews the relevant literature, positioning our contribution within existing scholarship. Section 3 presents the theoretical model. Section 4 describes the calibration and estimation strategy. Section 5 presents the main quantitative results. Section 6 examines robustness and extensions. Section 7 concludes with policy implications.

2. Literature review

2.1. Theoretical foundations of CBDC economics

The theoretical literature on CBDCs has evolved rapidly, yielding a number of key insights. Brunnermeier and Niebelt (2019) show that, under perfect substitutability conditions between central bank and private liabilities, the introduction of CBDCs has no effect on allocations or prices. This result of neutrality depends on the central bank's ability to adjust its balance sheet to exactly offset changes in the private sector's portfolio - a condition that, according to the Bank of Russia (2025),

it can approximately achieve using available instruments. However, perfect offset is unlikely in practice.

Subsequent theoretical work has relaxed the assumptions underlying neutrality. Keister and Sanches (2023) developed a framework where CBDCs compete with bank deposits as media of exchange, demonstrating that CBDC introduction can improve welfare by mitigating monopoly power in payment services. Their model predicts that the optimal CBDC policy involves setting the CBDC rate equal to the policy rate minus a markup reflecting the convenience yield of deposits. We evaluate this prediction against the Russian institutional context, where the convenience yield encompasses the entire rate differential under the zero-remuneration regime.

Barrdear and Kumhof (2022) constructed a quantitative DSGE model of CBDC macroeconomic effects and found that CBDC issuance equivalent to 30% of GDP could raise output by up to 3%, with gains arising primarily from reductions in real interest rates and distortionary tax financing. Their framework informs our modeling of the central bank balance sheet and reserves dynamics. More recently, Paul, Ulate and Wu (2025) constructed a quantitative New Keynesian DSGE model featuring monopolistically competitive banks with market power in both the deposit and loan markets. This model revealed a fundamental trade-off between household and bank welfare, which is used to structure the present analysis. The researchers found substantial welfare gains from introducing a CBDC with an optimal rate approximated by the rule of thumb max(0%, policy rate − 1%), calibrating their framework to the United States. Our analysis extends this framework to an emerging market context subject to financial sanctions.

Niepelt (2020) formalized how CBDC availability disciplines bank pricing by providing depositors with an explicit outside option. In his model, banks must offer deposit rates at least equal to the CBDC rate adjusted for convenience yield, implying that even a zero-remuneration CBDC sets an implicit floor for deposit market competition, though a lower one than an interest-bearing alternative. This result proves particularly relevant for our Russian calibration.

2.2. Empirical evidence on CBDC pilots

Given the recent nature of most initiatives, empirical evidence on actual CBDC implementations remains limited. The Bahamas' Sand Dollar, launched in October 2020, is the first retail CBDC to be deployed on a national scale. Allen et al. (2020) analyze the design considerations for CBDCs, identifying the following key drivers of adoption: the convenience of digital payments, the financial inclusion benefits for unbanked populations and the infrastructure for merchant acceptance. These findings help us calibrate the speed of CBDC adoption.

Evidence from the world's largest CBDC experiment is provided by China's e-CNY pilot, which began in 2019. Studies examining transaction data suggest that the e-CNY primarily substitutes cash and mobile payments rather than bank deposits (Auer et al., 2021), indicating a limited initial impact on deposit bases. Chinese authorities have

deliberately limited e-CNY holding amounts in order to minimize disruption to the banking sector — a design choice that mirrors the approach taken by the Bank of Russia with the 300,000-ruble holding limit announced for the digital ruble. Davoodalhosseini (2022) developed a quantitative DSGE model to analyze the macroeconomic effects of CBDCs, finding that introducing CBDCs improved welfare by strengthening competition in deposit markets, and that monetary policy became more effective through enhanced interest rate pass-through. Building on this framework, we adapted it to Russian institutional features.

2.3. Banking sector competition and CBDC

A critical transmission channel for CBDC effects operates through altered banking sector competition. Drechsler et al. (2017) established that banks with local market power partly insulate deposit rates from monetary policy changes — a phenomenon termed the "deposit channel." Banks in concentrated markets only pass through 25-40% of changes in policy rates to deposit rates. This implies substantial markdowns in deposit remuneration. CBDC's introduction provides depositors with an outside option for holding central bank liabilities, which should constrain market power, and even a zero remuneration CBDCs impose a competitive discipline on banks. Households now gain the option to exit the deposit market for transactional purposes, a threat that may affect pricing before being realized.

The literature on endogenous money creation (McLeay et al., 2014) is directly relevant to understanding how deposit outflows affect credit provision. Modern banks create deposits and loans simultaneously; their willingness to lend primarily depends on the availability of creditworthy borrowers and the cost of liquidity in interbank markets rather than on existing deposit volumes. This insight modifies the standard DSGE treatment of the deposit-credit link, a point that is addressed explicitly in the model's banking specification.

2.4. Sanctions and Financial Infrastructure

Russia's position as a major economy under comprehensive financial sanctions creates a distinct context for CBDC analysis. The literature documents substantial impacts on financial intermediation, international trade and macroeconomic performance (Gurvich & Prilepskiy, 2015; Ahn & Ludema, 2020). Sanctions imposed after 2014 and intensified in 2022 severed major Russian banks from SWIFT messaging networks, froze foreign exchange reserves and restricted correspondent banking relationships, generating substantial friction in international payments.

According to theoretical work on sanctions, affected countries will pursue a variety of adaptation strategies. These include diversifying trade towards non-sanctioning partners, developing alternative payment systems and increasing state involvement in finance (Felbermayr et al., 2020). CBDCs may facilitate certain adaptation strategies by enabling direct central bank-to-central bank settlement. However, Russia's access

to multilateral CBDC interoperability projects, such as mBridge, is limited due to sanctions-related considerations (BIS, 2022). The present model distinguishes between domestic payment system improvements and broader sanctions-channel effects that CBDCs cannot address.

2.5. Russia's monetary policy and financial system

The Central Bank of Russia switched to inflation targeting in 2014, keeping a floating exchange rate and using policy rates as its main instrument (Yudaev, 2018). During this period, the framework faced serious challenges from both the 2014 sanctions and the 2022 episodes, when the central bank used unconventional measures such as capital controls, currency interventions and targeted liquidity support.

The Russian banking sector is highly concentrated, with state-controlled banks - primarily Sberbank, VTB and Gazprom Bank - accounting for approximately 60% of the total assets in 2024. This concentration implies significant market power for the banking industry, although state ownership complicates analysis, as state banks may have objectives other than pure profit maximization (Abramov et al., 2017). Empirical studies of Russian monetary policy transmission (e.g. Napalkov et al., 2021) show that changes in the policy rate are passed on to retail rates with significant regional and sectoral variation. On average, approximately 60% of the policy rate is passed on to deposit rates over a period of one year, with lags of six to nine months. These estimates serve as calibration targets. The current analysis builds on this literature by examining how the introduction of a central bank digital currency (CBDC) modifies these transmission dynamics within Russia's specific institutional context.

3. Theoretical model

3.1. Model environment

We developed a closed-economy DSGE model in discrete time, indexed by t = 0, 1, 2, … The economy comprises five types of agent: households, final goods producers, intermediate goods producers, banks and a central bank. There are markets for goods, labour, bank deposits, bank loans and central bank digital currency.

The absence of an explicit foreign sector is a deliberate modelling choice rather than an oversight. The digital ruble operates exclusively as a domestic payment instrument and the Bank of Russia has explicitly ruled out international convertibility in the near term. This limits the channels through which CBDC can directly affect cross-border transactions. The effects of sanctions on international flows are incorporated through time-varying domestic autarky wedges. This reduced-form approach captures the consequences of aggregate productivity and intermediation costs without requiring

a full open-economy specification. Section 6.4 extends this framework to include exchange rate dynamics and confirms that the core domestic results remain robust despite this restriction.

The model's key innovation is the introduction of CBDC alongside traditional monetary aggregates within a framework that explicitly captures the market power of the banking sector and the pricing of credit on an endogenous basis. This enables the analysis of the effects of CBDC on household welfare and the cost of credit intermediation.

3.2. Households

The economy contains a unit mass of infinitely-lived households indexed by $i \in [0,1]$, heterogeneous in their valuation of CBDC relative to traditional payment instruments. Household i maximizes expected lifetime utility:

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[u\left(C_{i,t}, L_{i,t}\right) + \theta_i v\left(M^C_{i,t}, D_{i,t}, R_{i,t}\right) \right] \tag{1}$$

where $C_{i,t}$ denotes consumption, $L_{i,t}$ represents labor supply, $M^C_{i,t}$ is cash holdings, $D_{i,t}$ represents bank deposits, $R_{i,t}$ denotes CBDC holdings, $\beta \in (0,1)$ is the discount factor, and θ_i captures household-specific CBDC valuation intensity, distributed according to F(θ)with support $[\theta_{min}, \theta_{max}]$.

The period utility function takes the form:

$$u(C,L) = \frac{\left(C^{\eta}\left(1-L\right)^{1-\eta}\right)^{1-\sigma}}{1-\sigma} \tag{2}$$

where $\eta \in (0,1)$ represents the consumption share in the utility bundle and $\sigma > 0$ denotes relative risk aversion. The liquidity services function captures substitution relationships between payment instruments:

$$v\left(M^C, D, R\right) = \psi \frac{\left(\left(M^C\right)^{\alpha} D^{1-\alpha-\gamma} R^{\gamma}\right)^{1-\chi}}{1-\chi} \tag{3}$$

where $\psi > 0$ scales liquidity service utility, $\alpha \in (0,1)$ represents cash share in the liquidity basket, $\gamma \in (0,1)$ captures CBDC share, and $\chi > 0$ denotes the elasticity of liquidity services. The specification implies that cash, deposits, and CBDC are imperfect substitutes.

Households face the budget constraint:

$$P_t C_{i,t} + M^C_{i,t} + D_{i,t} + R_{i,t} + B_{i,t} =$$
$$= W_t L_{i,t} + \left(1 + i^D_t\right) D_{i,t-1} + \left(1 + i^R_t\right) R_{i,t-1} + M^C_{i,t-1} + \left(1 + i^B_t\right) B_{i,t-1} + \Pi_{i,t}$$

Optimal choices satisfy first-order conditions:

$$\lambda_{i,t} = \beta E_t\left[\lambda_{i,t+1}\frac{P_t}{P_{t+1}}\left(1+i_t^B\right)\right]$$

$$\frac{W_t}{P_t} = \frac{(1-\eta)C_{i,t}^{\eta}\left(1-L_{i,t}\right)^{-\eta}(1-\sigma)}{\lambda_{i,t}}$$

$$\lambda_{i,t} = \beta E_t\left[\lambda_{i,t+1}\frac{P_t}{P_{t+1}}\left(1+i_t^D\right)\right] + \theta_i\frac{\partial v}{\partial D_{i,t}}$$

$$\lambda_{i,t} = \beta E_t\left[\lambda_{i,t+1}\frac{P_t}{P_{t+1}}\left(1+i_t^R\right)\right] + \theta_i\frac{\partial v}{\partial R_{i,t}} \tag{4}$$

These conditions determine the portfolio trade-off: households equate the marginal utility of nominal wealth across all instruments, accounting for both financial returns and liquidity services. Condition (8) is particularly important: when $i_t^R = 0$ (the Bank of Russia's stated policy), the CBDC rate term vanishes and households hold CBDC purely for its liquidity services $\theta_i\left(\partial v / \partial R_{i,t}\right)$. The liquidity service differential between CBDC and deposits determines adoption in this regime.

3.3. Final goods producers

A representative final goods producer operates under perfect competition, aggregating a continuum of differentiated intermediate goods $j \in [0,1]$:

$$Y_t = \left(\int_0^1 Y_{j,t}^{(\epsilon-1)/\epsilon}\,dj\right)^{\epsilon/(\epsilon-1)} \tag{5}$$

where $\epsilon > 1$ is the elasticity of substitution. Cost minimization yields demand:

$$Y_{j,t} = \left(\frac{P_{j,t}}{P_t}\right)^{-\epsilon} Y_t \tag{6}$$

and the aggregate price index:

$$P_t = \left(\int_0^1 P_{j,t}^{1-\epsilon}\,dj\right)^{1/(1-\epsilon)} \tag{7}$$

3.4. Intermediate goods producers

Intermediate goods producer j operates under monopolistic competition with Cobb-Douglas technology:

$$Y_{j,t} = A_t K_{j,t}^{\alpha} L_{j,t}^{1-\alpha} \tag{8}$$

Real marginal cost is:

$$MC_t = \frac{1}{A_t}\left(\frac{r_t}{\alpha}\right)^{\alpha}\left(\frac{W_t / P_t}{1-\alpha}\right)^{1-\alpha} \tag{9}$$

Firms face Calvo (1983) price stickiness, with fraction $1 - \phi$ of firms resetting prices each period. A resetting firm maximizes:

$$E_t \sum_{k=0}^{\infty} (\beta\phi)^k \Lambda_{t,t+k}\left[P_{j,t} Y_{j,t+k} - P_{t+k} MC_{t+k} Y_{j,t+k}\right] \tag{10}$$

subject to demand (10), yielding optimal reset price:

$$\frac{P^*_{j,t}}{P_t} = \frac{\epsilon}{\epsilon - 1} \frac{E_t \sum_{k=0}^{\infty} (\beta\phi)^k \Lambda_{t,t+k} MC_{t+k} Y_{t+k} P^{\epsilon}_{t+k}}{E_t \sum_{k=0}^{\infty} (\beta\phi)^k \Lambda_{t,t+k} Y_{t+k} P^{\epsilon-1}_{t+k}} \tag{11}$$

The aggregate price level evolves as:

$$P_t = \left[(1-\phi)\left(P^*_t\right)^{1-\epsilon} + \phi P^{1-\epsilon}_{t-1}\right]^{1/(1-\epsilon)} \tag{12}$$

3.5. Banks

The banking sector comprises a continuum of monopolistically competitive banks $b \in [0,1]$. Each bank accepts deposits $D_{b,t}$, holds reserves $S_{b,t}$ at the central bank, and extends loans $L_{b,t}$ to firms. The balance sheet identity is:

$$L_{b,t} + S_{b,t} = D_{b,t} + E_{b,t} \tag{13}$$

where $E_{b,t}$ represents bank equity, and banks face reserve requirements $S_{b,t} \geq \rho D_{b,t}$.

An important qualification applies to equation (17): in practice, banks extend credit by simultaneously creating deposits, rather than relending pre-existing deposits (McLeay et al., 2014). While the balance sheet identity holds ex post, the direction of causality is from credit to deposits, and not the reverse. This implies that CBDC-induced deposit outflows affect bank profitability and the marginal cost of liquidity without mechanically constraining lending capacity. This distinction shapes our interpretation of simulation results in Section 5.

The deposit demand faced by Bank B exhibits elasticity $\eta_D > 1$:

$$D_{b,t} = \left(\frac{i^D_{b,t}}{\bar{i}^D_t}\right)^{\eta_D} \bar{D}_t \tag{14}$$

Loan demand exhibits elasticity $\eta_L > 1$:

$$L_{b,t} = \left(\frac{i^L_{b,t}}{\bar{i}^L_t}\right)^{-\eta_L} \bar{L}_t \tag{15}$$

Bank b maximizes expected discounted profits:

$$E_t \sum_{k=0}^{\infty} \beta^k \Lambda_{t,t+k} \left[\left(i^L_{b,t+k} - i^{CB}_{t+k} \right) L_{b,t+k} - \left(i^{CB}_{t+k} - i^D_{b,t+k} \right) D_{b,t+k} + i^{CB}_{t+k} E_{b,t+k} \right] \tag{16}$$

First-order conditions with respect to deposit and loan rates yield:

$$i^D_{b,t} = \frac{\eta_D - 1}{\eta_D} \cdot i^{CB}_t$$

$$i^L_{b,t} = \frac{\eta_L}{\eta_L - 1} \times i^{CB}_t \tag{17}$$

These expressions are central to the model's banking transmission mechanism. Since $\eta_D > 1$, equation (21) implies $(\eta_D - 1)/\eta_D < 1$, so deposit rates lie *below* the policy rate, consistent with banks exercising markdown power over depositors. Since $\eta_L > 1$, equation (22) implies $\eta_L/(\eta_L - 1) > 1$, so loan rates lie *above* the policy rate, which is consistent with markup power over borrowers. In symmetric equilibrium, the deposit markdown factor is $(\eta_D - 1)/\eta_D$ and the loan markup factor is $\eta_L/(\eta_L - 1)$, generating the spread patterns documented in Russian banking data.

3.6. Central bank and CBDC

The central bank conducts monetary policy using the policy rate i^{CB}_t as its primary instrument, following a Taylor rule:

$$i^{CB}_t = (1 - \rho_i)\bar{i}^{CB} + \rho_i i^{CB}_{t-1} + (1 - \rho_i)\left[\phi_\pi (\pi_t - \bar{\pi}) + \phi_y (y_t - \bar{y}) \right] + \epsilon^i_t \tag{18}$$

The central bank issues CBDC with remuneration rate i^R_t, modeled as:

$$i^R_t = \max\left(0, i^{CB}_t - \delta\right) \tag{19}$$

where $\delta \geq 0$ represents the spread between the policy rate and CBDC remuneration. The Bank of Russia's current policy corresponds to $\delta \to \infty$ (equivalently $i^R_t = 0$ always). The welfare-maximizing counterfactual derives the optimal δ^* and interprets the difference in welfare as the cost of the non-remuneration commitment. Intermediate values of δ represent partial policy rate transmission to CBDC holders.

The central bank's balance sheet identity is:

$$S_t + A^{CB}_t = R_t + M^C_t \tag{20}$$

where S_t denotes total bank reserves, A^{CB}_t represents central bank assets, R_t is aggregate CBDC outstanding, and M^C_t is currency in circulation.

3.7. Market clearing and equilibrium

Goods market equilibrium requires that

$$Y_t = C_t + I_t + G_t \tag{21}$$

Investment follows standard capital accumulation with adjustment costs:

$$K_{t+1} = (1-\delta_K)K_t + I_t\left[1 - \frac{\kappa}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2\right] \tag{22}$$

Money market equilibrium conditions are

$$\int_0^1 M_{i,t}^C \, di = M_t^C, \ \int_0^1 D_{i,t} \, di = D_t, \ \int_0^1 R_{i,t} \, di = R_t \tag{23}$$

A recursive competitive equilibrium consists of sequences of prices $\{P_t, W_t, r_t, i_t^D, i_t^L, i_t^B, i_t^{CB}, i_t^R\}_{t=0}^{\infty}$ and quantities $\{C_{i,t}, L_{i,t}, M_{i,t}^C, D_{i,t}, R_{i,t}, Y_t, K_t, I_t\}_{t=0}^{\infty}$, such that: (i) households optimize given prices and policy; (ii) firms optimize given prices; (iii) banks optimize given deposit and loan demands; (iv) the central bank follows policy rules (23) and (24); and (v) all markets clear per conditions (26)–(28).

3.8. Welfare analysis

We evaluate alternative CBDC policies using the utilitarian social welfare function:

$$W = E_0 \sum_{t=0}^{\infty} \beta^t \int_0^1 \left[u\left(C_{i,t}, L_{i,t}\right) + \theta_i v\left(M_{i,t}^C, D_{i,t}, R_{i,t}\right)\right] dF(\theta) \tag{24}$$

The changes in welfare caused by the introduction of CBDCs are expressed in terms of consumption-equivalent units, i.e. the percentage increase in household consumption in all time periods and states, making households indifferent to the no-CBDCs baseline and with-CBDCs scenario.

4. Calibration and estimation

4.1. Calibration strategy

We employ a hybrid strategy combining direct calibration of steady-state parameters with Bayesian estimation of parameters governing dynamics. Table 1 presents calibrated parameters. The time period is one quarter. We set $\beta = 0.9875$, implying an annual real interest rate of approximately 5%, consistent with Russian data averages over 2014–2024. Capital depreciation $\delta_K = 0.025$ corresponds to 10% annual depreciation. The labor share $1 - \alpha = 0.55$ reflects Russian national accounts data (Rosstat, 2024).

Table 1. Calibrated parameters

Parameter	Symbol	Value	Target/Source
Discount factor	β	0.9875	5% annual real rate
Capital depreciation	δ_K	0.025	10% annual depreciation
Capital share	α	0.45	Labor share = 0.55 (Rosstat)
Consumption share in utility	η	0.30	Hours worked = 0.33
Risk aversion	σ	2.0	Standard macro literature
Elasticity between intermediates	ϵ	6.0	20% steady-state markup
Reserve requirement ratio	ρ	0.04	Bank of Russia requirement
Government spending/GDP	g_y	0.20	Fiscal accounts average

The elasticity $\epsilon = 6$ implies a 20% steady-state markup within the range estimated for Russian manufacturing (Basu & Fernald, 1997). Banking sector parameters require particular attention. We calibrate deposit demand elasticity $\eta_D = 5.0$ and loan demand elasticity $\eta_L = 4.0$. Equations (21) and (22) imply deposit rates of 80% of the policy rate (around 400 basis points lower than the 16.5% policy rate) and loan rates of 133% of the policy rate (around 800 basis points higher). These values are consistent with observed Russian banking spreads (Napalkov et al., 2021).

4.2. Bayesian estimation

We estimate nine parameters that govern model dynamics using Bayesian methods. We exploit fourteen quarterly macroeconomic time series for Russia, covering the period from 2014 Q1 to 2024 Q2. These include real GDP, consumer spending, investment, CPI inflation, policy rate, interest rates on deposits and loans, real wages and hours worked, money in circulation (M2), bank reserves, and government debt. We also use residually estimated total factor productivity.

Table 2 presents prior distributions, posterior means, and 90% credible intervals.

Estimation proceeds by constructing the model's state-space representation and computing the likelihood via the Kalman filter. We employ the Random-Walk Metropolis-Hastings algorithm with 500,000 draws, discarding the first 100,000 as burn-in. The acceptance rate is 28.4%, which lies within the recommended range for efficient posterior exploration. The effective sample size (ESS) exceeds 2,000 draws for all structural parameters, confirming adequate posterior mixing. Table 3 below reports the correspondence between observed series and their measurement equations in the state-space representation, along with Brooks-Gelman convergence statistics (all $\hat{R} < 1.01$).

Table 2. Estimated Parameters

Parameter	Prior Distribution	Prior Mean	Posterior Mean	90% Credible Interval
Price stickiness (ϕ)	Beta(3,1)	0.75	0.78	[0.72, 0.84]
Investment adjustment cost (κ)	Gamma(2,2)	4.0	5.2	[3.8, 6.9]
Interest smoothing (ρ_i)	Beta(4,2)	0.67	0.82	[0.76, 0.88]
Inflation response (ϕ_π)	Gamma(1.5,0.5)	1.5	1.83	[1.52, 2.18]
Output response (ϕ_y)	Gamma(0.125,0.05)	0.125	0.15	[0.09, 0.22]
Liquidity utility weight (ψ)	Gamma(0.05,0.02)	0.05	0.038	[0.021, 0.057]
TFP persistence (ρ_A)	Beta(4,1)	0.80	0.85	[0.79, 0.91]
Sanctions persistence (ρ_ξ)	Beta(5,2)	0.71	0.88	[0.83, 0.93]
Shock std. deviations	Inv-Gamma(2,0.1)	Various	—	—

Table 3. Measurement equations and convergence diagnostics

Observed Series	Model Variable	Measurement Equation	$\hat{R}$
Real GDP growth	ΔY_t	$\Delta y_t^{obs} = \Delta Y_t + \epsilon_t^Y$	1.003
Consumption growth	ΔC_t	$\Delta c_t^{obs} = \Delta C_t + \epsilon_t^C$	1.004
Investment growth	ΔI_t	$\Delta i_t^{obs} = \Delta I_t + \epsilon_t^I$	1.005
CPI inflation	π_t	$\pi_t^{obs} = \pi_t + \epsilon_t^\pi$	1.002
Policy rate	i_t^{CB}	$r_t^{obs} = i_t^{CB} + \epsilon_t^r$	1.001
Deposit rate	i_t^D	$d_t^{obs} = i_t^D + \epsilon_t^D$	1.004
Lending rate	i_t^L	$l_t^{obs} = i_t^L + \epsilon_t^L$	1.003
Real wages	W_t / P_t	$w_t^{obs} = W_t / P_t + \epsilon_t^W$	1.006
Hours worked	L_t	$h_t^{obs} = L_t + \epsilon_t^h$	1.005
Currency in circulation	M_t^C	$m_t^{obs} = M_t^C + \epsilon_t^M$	1.004
Broad money (M2)	$M_t^C + D_t$	$m2_t^{obs} = M_t^C + D_t + \epsilon_t^{M2}$	1.003
Bank reserves	S_t	$s_t^{obs} = S_t + \epsilon_t^S$	1.002
Government debt	B_t	$b_t^{obs} = B_t + \epsilon_t^B$	1.004
TFP (residual)	A_t	$a_t^{obs} = A_t + \epsilon_t^A$	1.003

The estimated price stickiness $\phi = 0.78$ implies an average price duration of 4.5 quarters, somewhat higher than in advanced economies but consistent with estimates for emerging markets with higher inflation volatility. Strong interest rate smoothing ($\rho_i = 0.82$) reflects the Bank of Russia's gradualist approach to rate adjustments. The inflation response coefficient $\phi_\pi = 1.83$ satisfies the Taylor principle, consistent with the central bank's inflation targeting commitment (Yudaeva, 2018).

4.3. CBDC-specific parameters

We calibrate the share parameter of the CBDC, meaning that the CBDC will ultimately capture roughly 15-20% of the liquidity services provided. This is based on surveys conducted by the Bank of Russia, which suggest that around 30% of households would be willing to use the digital ruble for regular transactions within the first two years of its release (Bank of Russia, 2025). Under the zero-remuneration baseline, adoption is substantially lower, as the financial incentive to substitute from interest-bearing deposits disappears; in that scenario, adoption is driven purely by transactional convenience.

Household CBDC valuation intensity is distributed as $\theta_i \sim LogNormal(\mu_\theta, \sigma_\theta)$, with $\mu_\theta = -0.5$ and $\sigma_\theta = 0.8$. This generates approximately 30% of households with high CBDC valuation ($\theta_i > 1.2$), 40% with moderate valuation and 30% with weak preference.

4.4. Sanctions modeling

A sanctions intensity state variable $\xi_t \in [0,1]$ evolves as

$$\xi_t = \rho_\xi \xi_{t-1} + (1-\rho_\xi)\bar{\xi} + \epsilon_t^\xi \tag{25}$$

Sanctions affect the economy through two domestic channels. First, they raise banking sector operational costs through a wedge:

$$Banking\ cost\ wedge = \omega(\xi_t) \cdot (Bank\ assets), \quad \omega(\xi_t) = \omega_0 + \omega_1 \xi_t \tag{26}$$

with $É_0$=0.01 and $É_1$=0.03. Second, sanctions reduce total factor productivity:

$$\log A_t = (1 - \tau(\xi_t)) \log \bar{A} + \epsilon_t^A, \quad \tau(\xi_t) = \tau_0 \xi_t \tag{27}$$

with $\tau_0 = 0.08$, generating a maximum TFP reduction of 8% under full sanctions intensity, in line with estimates of sanctions' aggregate productivity effects (Gurvich & Prilepskiy, 2015). We acknowledge that this simplified approach cannot capture the micro-level mechanics of trade route disruption, correspondent banking fragmentation, or technology transfer restrictions. The Limitations section revisits this point.

4.5. Model Validation

Before conducting policy analysis, we validate the model against key Russian macroeconomic moments.

Table 4. Model validation — selected second moments

Moment	Data	Model	Source
σ(GDP)	2.8%	2.6%	Rosstat, 2014–2024
σ(Consumption)/σ(GDP)	0.72	0.68	National accounts
σ(Investment)/σ(GDP)	3.15	3.22	National accounts
σ(Inflation)	1.9%	1.8%	Rosstat CPI
Corr(GDP, Consumption)	0.85	0.82	National accounts
Corr(GDP, Investment)	0.88	0.84	National accounts
Corr(Policy rate, Inflation)	0.64	0.61	CBR, Rosstat
Deposit rate spread	4.8%	4.6%	CBR banking statistics
Lending rate spread	7.2%	7.4%	CBR banking statistics

The model successfully replicates output volatility, relative volatilities of consumption and investment, and key correlation patterns. The banking sector's spreads align closely with the empirical averages, confirming the specification in the equations (21) and (22). The impulse responses to a tightening of monetary policy by 100 basis points show a decline in output with a trough after three to four quarters, and a temporary widening of deposit spreads before they revert — patterns consistent with the pass-through evidence for Russia documented by Napalkov et al. (2021).

5. Results

5.1. Baseline CBDC implementation effects

We analyze the effects of introducing a digital ruble under two scenarios: the Bank of Russia's announced non-remuneration policy (i.e. "i" → 0, or equivalently, "δ" → 0) and a welfare-maximizing counterfactual ("δ" → 0.7%). This is done under average macroeconomic conditions and sanctions intensity $\xi = 0.45$.

Even under zero remuneration, CBDC adoption remains limited, reaching only around 3.2% of GDP in a steady state. Adoption is driven entirely by transactional

convenience rather than yield-seeking and is concentrated among high-'θ'- households, i.e. younger, digitally active individuals whose transactional gains from CBDC are sufficient to offset the opportunity cost of holding a non-interest-bearing instrument instead of bank deposits.

Under the optimal counterfactual ($\delta^* = 0.7\%$), adoption reaches 15.2% of GDP, as the positive rate differential attracts a broader household base. The comparison between these two scenarios forms the basis for the welfare analysis that follows.

The impacts on the banking sector under the counterfactual scenario reflect the dual mechanisms of substitution and competition. In steady state, bank deposits decline by 10.5% relative to the no-CBDC baseline; in response, banks raise deposit rates by around 45 basis points to retain depositors. This competitive response is the primary mechanism through which the interest-bearing design generates welfare. It is substantially reduced — though not entirely eliminated — under zero remuneration, where deposit flight is smaller and the competitive threat is less severe.

The implications of the credit provision require careful consideration. As noted in Section 3.5, deposit volumes do not automatically determine lending capacity. However, CBDC-induced deposit outflows do affect the marginal cost of bank liquidity. Banks that lose lower-cost deposit funding may have to turn to more expensive interbank or central bank refinancing, which would compress their net interest margins. In the model, this manifests as a 5.1% decline in loans to enterprises relative to the no-CBDC baseline two years after introduction under the counterfactual. This is driven by reduced profitability rather than a mechanical balance-sheet constraint. Under zero remuneration, the equivalent effect is approximately 1.6%, reflecting more modest adoption.

Real economic effects are caused by the credit mechanism described above. In the short run, investment falls 3.2% below the baseline under the interest-bearing counterfactual, resulting in a persistent 0.9% reduction in long-term output. Consumption exhibits a more nuanced trajectory. An initial decline of -0.4%, as households anticipate a lower future income is followed by a recovery and a long run gain of +0.3%. This reflects the benefits of realized liquidity services and deposit competition. Under zero remuneration, however, these dynamics are compressed: the real disruption is smaller, as are the household welfare gains.

5.2. Welfare analysis

Welfare exhibits an inverted-U shape in relation to the remuneration rate. The design that maximizes welfare offers CBDC rate that is 70 basis points below the policy rate. At Russia's current policy rate of 16.5%, this corresponds to an instrument rate of 15.8%. The welfare cost of the Bank of Russia's commitment to zero remuneration is the difference between the counterfactual of +0.79% and the baseline of +0.18%. This equates to approximately 0.61% of steady-state consumption. This is the quantitative answer to the normative question raised in the Introduction.

Table 5. Welfare effects under alternative CBDC remuneration policies

CBDC Spread δ	CBDC Rate i^R	Welfare Change	CBDC/GDP	Deposit Change	Loan Change
∞ (current policy)	0%	+0.18%	3.2%	−1.7%	−1.1%
3.0%	$i^{CB} - 3\%$	+0.18%	3.2%	−1.7%	−1.1%
2.0%	$i^{CB} - 2\%$	+0.38%	6.8%	−3.8%	−2.4%
1.5%	$i^{CB} - 1.5\%$	+0.52%	9.4%	−5.6%	−3.6%
1.0%	$i^{CB} - 1\%$	+0.67%	12.8%	−8.2%	−5.3%
0.7%*	$i^{CB} - 0.7\%$	+0.79%	**15.2%**	**−10.5%**	**−6.8%**
0.5%	$i^{CB} - 0.5\%$	+0.68%	17.4%	−12.3%	−7.9%
0.0%	i^{CB}	+0.34%	22.1%	−15.8%	−10.2%

* Welfare-maximizing counterfactual

Decomposing the counterfactual welfare gain:

- Direct liquidity benefit: +0.82% of consumption;
- Deposit competition effect: +0.45% of consumption;
- Credit provision cost: −0.38% of consumption;
- Volatility effect: −0.22% of consumption (CBDC amplifies responses to certain shocks).

The first two channels are dominant, confirming that the main source of welfare gains is on the side of households rather than from production.

5.3. Optimal CBDC remuneration and its state dependence

The welfare-maximizing spread $\delta^* = 0.7\%$ is approximately invariant to the level of the policy rate, which has important practical implications. At Russia's current elevated policy rate of 16.5%, the optimal CBDC rate is about 15.8%. Should the policy rate decline to 5% as inflation stabilizes, the optimal CBDC rate would fall to approximately 4.3%. This state-contingent optimal policy maintains CBDC adoption at a relatively stable level across different monetary policy stances, avoiding large adoption swings that could destabilize bank funding structures.

The non-monotonic welfare response to remuneration deserves emphasis. At very high remuneration (low δ), the welfare gain reverses because deposit outflows become so large that the credit contraction and volatility costs dominate household liquidity gains. At zero remuneration, gains are real but modest. The intermediate optimum at δ * = 0.7% is not a knife-edge result: welfare remains relatively stable around the optimum, meaning that slight deviations from the exact optimal spread have minimal impact on welfare.

5.4. CBDC effects under financial sanctions

We compare CBDC welfare implications under low sanctions ($\xi = 0.2$), medium sanctions ($\xi = 0.45$, baseline) and high sanctions ($\xi = 0.8$).

Table 6. Sanctions intensity and CBDC welfare gains

Sanctions Intensity ξ	Welfare Gain	CBDC Adoption	Banking Cost Wedge	Policy Pass-Through
0.2 (Low)	+0.44%	14.1%	1.6%	0.68
0.45 (Medium)	+0.79%	15.2%	2.4%	0.58
0.8 (High)	+1.26%	16.8%	3.4%	0.42

All figures refer to the welfare-maximizing counterfactual ($\delta^* = 0.7\%$). Pass-through is defined as the change in the deposit rate resulting from a change in the policy rate.

The welfare gains from CBDC rise with the intensity of sanctions for two reasons. Firstly, as the banking cost wedge ω ("ξ" _"t") increases, households benefit relatively more from CBDC as an alternative payment infrastructure that bypasses constrained banking services. Second, sanctions impair the transmission of monetary policy by fragmenting the interbank market: the pass-through of the policy rate to deposit rates decreases from 0.68 with low sanctions to 0.42 with high sanctions. CBDC remuneration provides an alternative transmission channel, one that is independent of bank intermediation chains, enhancing policy effectiveness precisely when conventional channels are most impaired.

Importantly, CBDCs do not neutralize sanctions. Without CBDCs, under high sanctions, welfare losses amount to approximately 4.2% relative to a no-sanction baseline. With CBDC availability, these losses are reduced to 2.9%. This means that CBDCs offset roughly 30% of the welfare costs induced by sanctions. The remaining 70% is due to trade disruption, access restrictions to technology, and productivity impacts that payment system enhancements cannot address.

5.5. Distributional effects

Welfare gains vary substantially across household types. Households with CBDC valuation θ_i in the bottom quartile ($\theta_i < 0.65$) experience gains of 0.22% of consumption, while those in the top quartile ($\theta_i > 1.35$) enjoy gains of 1.48% of consumption. The relationship is strongly positive and convex: high-θ_i households adopt more intensively and derive larger direct liquidity benefits.

Crucially, all types of households benefit from the introduction of CBDC under the optimal counterfactual. Even those who never adopt CBDCs benefit from indirect deposit competition as banks improve deposit terms in response to competitive threats, regardless of whether individual households switch. This externality ensures

that CBDC does not exacerbate inequality despite heterogeneous adoption. Survey evidence from the Bank of Russia (2025) suggests that digital payment adoption correlates with education, income and urban residence, implying that direct CBDC benefits may accrue disproportionately to more advantaged groups but the deposit competition externality partly compensates those who do not adopt.

5.6. Monetary policy effectiveness

Table 7. Monetary policy transmission with and without CBDC

Scenario	Output Response	Inflation Response	Deposit Pass-Through	Sacrifice Ratio
No CBDC	−0.52%	−0.32 pp	0.45	1.63
CBDC (optimal $\delta^* = 0.7\%$)	−0.68%	−0.41 pp	0.72	1.44
CBDC (high remuneration, $\delta = 0.2\%$)	−0.79%	−0.48 pp	0.84	1.31

Figures refer to peak impulse responses following a 100-basis-point contractionary monetary policy shock.

CBDC improves the transmission of monetary policy in several ways. Deposit pass-through increases from 45% (no CBDC) to 72% (optimal CBDC) because banks must compete more aggressively for deposits when households possess a close substitute. The sacrifice ratio — output loss per unit of disinflation — falls from 1.63 to 1.44, indicating that disinflation can be achieved at a lower cost to output.

An amplified output response requires careful interpretation. The finding that CBDC holdings react more elastically to changes in interest rates than deposits reflects the portfolio rebalancing mechanism. As the policy rate increases, households optimize equation (8) by comparing the CBDC rate, which changes mechanically with the policy rate according to equation (24), with the deposit rate, which adjusts more slowly due to banking market power according to equation (21).When the CBDC rate rises faster than the deposit rate, households holding CBDC wealth adjust their portfolio allocations. This substitution effect occurs among liquid asset holders and does not imply that all Russian households reduce their liquid holdings when the rates rise. Indeed, aggregate household savings tend to increase during periods of monetary tightening in Russia, which is consistent with observed deposit growth. The amplification arises from the relative reallocation of portfolios between CBDC and deposits, rather than from an aggregate reduction in household savings.

Similarly, the result showing that inflation falls more rapidly with CBDC is conditional on the central bank maintaining the CBDC remuneration rule (24). However, if the CBDC rate were to decline rapidly following the policy rate, households might liquidate their CBDC holdings to spend on consumption, creating an inflationary offset. The model's result is valid when the rule is followed credibly; Section 7.3 discusses limitations to credibility.

5.7. Transition dynamics

Consistent with adoption evidence from Sand Dollar and e-CNY implementations documented in cross-country CBDC surveys, CBDC adoption follows an S-shaped curve, reaching 50% of its long-run level after approximately six quarters and 90% after fifteen quarters (Auer et al., 2021). Banking sector variables adjust more rapidly as banks respond preemptively to anticipated competition. Total deposits decline to 80% of their long-term level within one year. However, investment follows a more volatile path. It starts with a sharp initial decline of 5.2% below the baseline level at the trough, reflecting the short-term credit cost compression mechanism. This is followed by a partial recovery towards the long-term level, which is 2.8% below the baseline.

Welfare during the transition initially dips 0.15% below the no-CBDC baseline in the first four quarters, as banking sector disruption precedes the materialization of household benefits. Welfare surpasses the no-CBDC baseline after five quarters and reaches 90% of its long-run gain within three years. These transition dynamics suggest that policymakers should anticipate a 12–18-month adjustment period, during which temporary support for the banking sector may be warranted although the magnitudes are manageable, and welfare losses will remain below 0.2% of consumption throughout.

6. Robustness and extensions

6.1. Alternative banking sector specifications

Under perfect banking competition ($\eta_D, \eta_L \to \infty$), CBDC welfare effects decline sharply to +0.23% of consumption, as the deposit competition channel that generates most welfare gains in the baseline disappears. This result underscores the fact that CBDC offers the greatest welfare benefits in concentrated banking markets — a situation that is particularly relevant to Russia, where state banks dominate and markdowns are high. Under higher concentration ($\eta_D = 3.5$, $\eta_L = 3.0$), welfare gains rise to +1.12% of consumption.

We also examine an endogenous markup specification where deposit demand elasticity varies countercyclically (Drechsler et al., 2017): households search more actively for deposit rates during recessions, increasing η_D and reducing bank market power precisely when it is most harmful. This countercyclical variation suggests that the welfare gains of CBDCs fluctuate over the business cycle. They reach their highest values during economic expansions, when banking markups are high, and their lowest values during economic contractions. In quantitative terms, the cyclical variation increases average welfare gains by around 0.06 percentage points relative to the constant-elasticity baseline.

6.2. Alternative CBDC design features

Non-remunerated CBDC (institutional baseline). Setting $i_t^R = 0$ permanently yields welfare gains of +0.18% of consumption — the benchmark consistent with the Bank of Russia's stated policy. Adoption falls to 3.2% of GDP and the deposit competition channel weakens substantially as the competitive threat that CBDCs pose to banks is primarily transactional rather than financial. The welfare gain is nonetheless positive because even non-remunerated CBDC improves payment system efficiency and provides modest competitive discipline.

Quantity limits. Russia's digital ruble design includes a holding limit of 300,000 rubles per household (approximately $3,300 at current exchange rates). We evaluate the welfare implications of this limit under the optimal counterfactual. Quantity limits reduce CBDC adoption from 15.2% to 11.8% of GDP, lowering welfare gains to +0.54% of consumption. However, they also reduce banking sector disruption (−7.2% deposit decline versus −10.5% baseline), which may be a deliberate policy choice to protect financial stability. The Bank of Russia's limit is consistent with the aim of keeping aggregate deposit displacement at a level that the banking sector can absorb without facing systemic consequences.

Tiered remuneration. A two-tier system, in which holdings up to 100,000 rubles receive $i^{CB} - 0.5\%$, and holdings above this threshold receive zero, generates welfare gains of +0.71% of consumption, slightly below the flat optimal policy but with less disruption to the banking system. This design offers a practical compromise between the current zero-remuneration policy and the full welfare-maximizing counterfactual.

State-contingent remuneration. Countercyclical remuneration, which reduces 'δ' during recessions, improves welfare by an additional 0.08% of consumption relative to the constant-spread baseline. However, implementation challenges and communication difficulties likely outweigh this modest gain. Nevertheless, the result suggests a direction for future policy refinement.

6.3. Financial stability considerations

Although the model does not explicitly consider bank failure risk, the large deposit outflows induced by interest-bearing CBDC could threaten the stability of the banking sector during periods of stress. In a combined stress scenario involving a negative total factor productivity (TFP) shock, an elevated risk premium and reduced interbank lending, the introduction of a CBDC exacerbates deposit outflows by 18.2%, compared to 10.5% in normal times, as households treat the CBDC as a safe haven, analogous to a flight to quality. This amplification resembles traditional bank run dynamics, manifesting as a shift towards central bank liabilities rather than cash withdrawals.

To mitigate these stability risks, the central bank could reduce the remuneration of CBDCs by 200 basis points during periods of stress, relative to the normal policy rule. This would substantially limit peak deposit outflows to −11.3%, while preserving most of the gains in terms of welfare. The Bank of Russia's decision to forgo remuneration

altogether can partly be read as a preemptive solution to precisely this concern: a non-remunerated CBDC poses a much smaller flight-to-quality risk because it offers no financial advantage over bank deposits during tranquil times.

6.4. International dimension

We extend our closed-economy framework to include a simplified foreign sector with exchange rate determination. The introduction of CBDC appreciates the ruble by around 3.2% in the medium term, as it reduces household demand for foreign currency holdings. However, exchange rate volatility increases by 15% if the CBDC facilitates cross-border payments, as the effectiveness of capital controls diminishes. Net welfare effects in the open-economy extension remain positive (+0.64% of consumption), slightly below the closed-economy baseline (+0.79%), because appreciation reduces export competitiveness.

Russia's policy approach emphasizes domestic CBDC use with tight restrictions on international convertibility. Under these constraints, exchange rate channels remain limited, supporting the closed-economy framework as an adequate baseline for the main analysis.

6.5. Parameter sensitivity

Table 8. Sensitivity of CBDC welfare gains to parameter values

Parameter	Baseline Value	Range Examined	Welfare Range	Sensitivity
Risk aversion (σ)	2.0	[1.0, 4.0]	[+0.62%, +0.91%]	Moderate
Deposit elasticity (η_D)	5.0	[3.0, 8.0]	[+0.52%, +1.18%]	High
Price stickiness (ϕ)	0.78	[0.50, 0.90]	[+0.71%, +0.84%]	Low
Investment adjustment cost (κ)	5.2	[2.0, 10.0]	[+0.68%, +0.88%]	Low
Liquidity weight (ψ)	0.038	[0.02, 0.06]	[+0.45%, +1.08%]	High
CBDC share (γ)	0.15	[0.08, 0.25]	[+0.38%, +1.12%]	High
Sanctions persistence (ρ_ε)	0.88	[0.70, 0.95]	[+0.74%, +0.82%]	Low

Welfare estimates are most sensitive to banking sector parameters (η_D) and liquidity utility parameters (ψ, γ), and least sensitive to real rigidities (ϕ, κ). Across the full parameter grid (625 combinations), welfare gains under the optimal counterfactual remain positive in 98.4% of cases, with median +0.73% and 90% interval [+0.35%, +1.22%]. The zero-remuneration baseline yields positive welfare gains across all parameter combinations examined, confirming that even the Bank of Russia's current design generates real — if modest — welfare improvements.

7. Policy implications and conclusions

7.1. Summary of main findings

This study develops and estimates a DSGE model to analyze Russia's digital ruble implementation under financial sanctions. The analysis proceeds from the Bank of Russia's institutional commitment to non-remuneration and treats the derivation of an optimal interest-bearing design as an explicit normative exercise. Five main findings emerge.

First, a non-remunerated digital ruble — consistent with the Bank of Russia's announced policy — generates welfare gains of approximately 0.18% of steady-state consumption, driven primarily by transactional efficiency improvements and modest competitive discipline on the deposit market.

Second, the welfare cost of non-remuneration is approximately 0.61% of steady-state consumption relative to the welfare-maximizing counterfactual ($\delta^* = 0.7\%$). Whether this cost is worth bearing depends on the financial stability benefits of the non-remuneration commitment, which the present model does not fully capture.

Third, CBDC provides greater welfare benefits under elevated sanctions intensity: gains under high sanctions amount to 1.26% of consumption under the optimal counterfactual, compared to 0.44% under low sanctions. Even the zero-remuneration design yields larger welfare gains as sanctions intensity rises, because the alternative payment infrastructure benefit grows with the degree of impairment of conventional channels.

Fourth, CBDC enhances monetary policy transmission, improving deposit pass-through and reducing the sacrifice ratio. These improvements are larger under interest-bearing designs.

Fifth, welfare gains from CBDC are heterogeneous across households but positive for all types — including those who never adopt CBDC — through the indirect deposit competition channel.

7.2. Policy recommendations

On remuneration policy. The Bank of Russia's zero-remuneration commitment is defensible from a financial stability perspective, particularly during the transition phase, but it entails a quantifiable welfare cost. A graduated approach, beginning with zero remuneration and implementing the 300,000-ruble holding limit before revisiting the remuneration after confirming the stability of the deposit system, would enable the central bank to ascertain the scale of adoption and substitution before committing to a more ambitious design.

On gradual implementation. Transition dynamics confirm that the first 12–18 months following CBDC introduction involve temporary banking sector stress. A phased rollout through pilot programmes and regional sequencing would help to

smooth these dynamics. Any standing facilities that provide banks with liquidity support during the transition period should be announced in advance to prevent precautionary credit tightening.

On banking sector monitoring. A decline in deposits of more than 12–15%, or a significant slowdown in credit growth, should prompt a review of policy. This could involve temporary reductions in CBDC remuneration (in an interest-bearing design), tightening of holding limits, or activation of liquidity support. These thresholds are unlikely to be reached under zero remuneration.

On monetary policy. CBDC amplifies monetary policy transmission, requiring greater precision in rate calibration. Forward guidance becomes more powerful with CBDC in circulation; central banks should factor enhanced interest rate sensitivity into their communication strategies.

On sanctions mitigation. For economies operating under financial sanctions, CBDC implementation should prioritize features that strengthen domestic payment infrastructure: robust settlement systems and operational resilience independent of Western financial networks. Our estimates suggest that CBDC can offset approximately 30% of sanctions-induced welfare losses through these domestic channels. With respect to multilateral CBDC initiatives such as mBridge, participation by a fully sanctioned economy faces significant political and institutional barriers, as the admissibility of sanctioned countries to such cooperative frameworks is ultimately determined by member consensus rather than technical capacity alone. Consequently, the cross-border dimension of CBDC should be treated as a long-term aspiration, not a tactical tool for immediate policy implementation.

On distributional reach. In order to ensure that the benefits of CBDCs reach all segments of the population, it will be necessary to address the heterogeneous welfare effects, as well as providing public information campaigns, technical assistance for elderly and rural households, and attention to geographic digital infrastructure disparities.

7.3. Limitations and Future Research

First, the framework treats all banks symmetrically. Russia's banking sector exhibits substantial heterogeneity between large state-controlled institutions and smaller private banks, with different competitive dynamics and CBDC exposure profiles. Future work should incorporate bank-level heterogeneity.

Second, financial sanctions are modeled through reduced-form productivity and cost wedges rather than explicit micro-foundations of trade disruption, correspondent banking fragmentation or technology transfer restrictions. This limits the precision with which the model can assess CBDC's role in sanctions adaptation and motivates future work with a more structurally grounded sanctions block.

Third, the analysis assumes that CBDC remuneration policy credibly follows the announced rules. In practice, policy credibility may prove imperfect in economies with histories of monetary instability. Incorporating endogenous credibility and learning

dynamics, which are particularly relevant in the event of a potential future shift from zero to positive remuneration, could modify welfare conclusions and optimal design parameters.

Fourth, the closed-economy baseline, while appropriate for the domestic-only digital ruble, becomes limiting when assessing CBDC's indirect effects on Russia's international financial positioning. The open-economy extension in Section 6.4 identifies non-trivial exchange rate effects that warrant fuller modeling in future work.

Fifth, the model abstracts from cybersecurity and operational risk, treating CBDC as a perfectly reliable technology. Real-world implementation involves cyber threats, system outages and privacy concerns that could affect adoption dynamics and welfare calculations.

Sixth, empirical validation is still limited by the lack of live digital ruble transaction data. As Russia's CBDC initiative generates micro-level evidence, empirical tests of the substitution and competition effects modeled here will be valuable.

7.4. Conclusion

Russia's digital ruble is a significant monetary innovation, the macroeconomic implications of which extend well beyond the modernization of the payment system. This analysis shows that, even under the Bank of Russia's conservative non-remuneration design, introducing a central bank digital currency (CBDC) yields positive welfare gains — modest in normal conditions, but meaningfully larger under intensified financial sanctions, when the benefit of an alternative payment infrastructure becomes most valuable. The quantifiable welfare cost of foregoing interest remuneration is substantial at approximately 0.61% of steady-state consumption. However, this may be a rational price to pay for greater assurance of financial stability during the uncertain transition period.

The broader lesson for emerging markets operating under external financial constraints is that CBDC design involves a genuine trade-off between household welfare maximization and banking sector stability. The optimal resolution of this trade-off depends on institutional specifics, such as banking concentration, the credibility of monetary policy and the severity of external constraints, which vary considerably across economies. The analytical framework presented here provides a basis for the quantitative evaluation of these trade-offs, and will contribute to the growing body of literature as CBDC adoption expands globally.

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