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INNOVATIONS IN THE MODERN ECONOMY

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Digital ruble and monetary policy transmission under financial sanctions: a DSGE analysis

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Abstract. Russia's digital ruble initiative, with mass implementation scheduled for 2026, constitutes a critical case study for examining central bank digital currency (CBDC) effects in economies facing sanctions-induced financial fragmentation. Existing research predominantly calibrates to advanced economy institutions, leaving gaps in understanding how CBDCs interact with concentrated banking markets, impaired monetary transmission, and restricted international payment access characterizing sanctioned emerging markets. Given these challenges, this research analyzes the macroeconomic implications of Russia's digital ruble implementation under financial sanctions, deriving optimal CBDC remuneration policies that maximize household welfare while maintaining banking sector stability. The research employs a dynamic stochastic general equilibrium (DSGE) model incorporating CBDC within a New Keynesian framework featuring monopolistically competitive banks and heterogeneous household adoption patterns, calibrated to Russian macroeconomic data (2014–2024) using Bayesian estimation with fourteen quarterly time series. The findings indicate that CBDC introduction generates welfare gains of 0.79% of steady-state consumption under optimal remuneration, amplifying to 1.26% under high sanctions intensity as CBDC provides alternative payment infrastructure and restores monetary policy effectiveness. The optimal digital ruble remuneration maintains a 70 basis point spread below the policy rate, balancing household adoption against banking disruption. CBDC enhances monetary policy transmission, improving deposit rate pass-through from 45 to 72% and reducing the sacrifice ratio from 1.63 to 1.44. However, our closed-economy specification likely overstates welfare benefits by 30–50%, as it abstracts from exchange rate volatility and capital flow dynamics that dominated Russia's sanctions experience. This study contributes to understanding monetary innovation in sanctioned economies, offering practical guidance for emerging market central banks pursuing CBDC implementation under geopolitical pressure.

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Keywords: CBDC, sovereign digital currency, central bank money, economic sanctions, payment system resilience, dynamic stochastic general equilibrium model, banking competition, emerging markets, Russian Federation

Data Availability Statement. All data obtained during this study are included in this published article (and its supplementary information files).

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Цифровой рубль и механизм денежной трансмиссии при санкциях: анализ в рамках DSGE-модели

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Аннотация. Инициатива России по внедрению цифрового рубля, планируемая к массовому запуску в 2026 г., представляет собой важный прецедент для изучения воздействия цифровых валют центральных банков (ЦВЦБ) на экономики, испытывающие финансовую фрагментацию из-за санкций. Существующие исследования в основном ориентированы на институциональные характеристики развитых экономик, что ограничивает понимание взаимодействия ЦВЦБ с концентрацией банковского рынка, нарушенной монетарной трансмиссией и ограниченным доступом к международным платежам, присущим санкционированным развивающимся рынкам. В связи с этим в настоящем исследовании проанализированы макроэкономические последствия введения цифрового рубля в России в условиях финансовых санкций, а также разработаны оптимальные политики вознаграждения ЦВЦБ, направленные на максимизацию благосостояния домохозяйств при сохранении стабильности банковского сектора. Использована динамическая стохастическая модель общего равновесия (DSGE) в рамках новой кейнсианской парадигмы с монополистически конкурентными банками и неоднородным освоением технологии домохозяйствами, калиброванная на российских макроэкономических данных за период 2014–2024 гг. с помощью байесовского оценивания по четырнадцати квартальным временным рядам. Результаты показали, что внедрение ЦВЦБ приносит прирост благосостояния в размере 0,79% от устойчивого потребления при оптимальном вознаграждении, увеличиваясь до 1,26% при высокой интенсивности санкций, поскольку цифровой рубль обеспечивает альтернативную платежную инфраструктуру и восстанавливает эффективность монетарной политики. Оптимальный уровень вознаграждения по цифровому рублю удерживается с отставанием на 70 базисных пунктов от ключевой ставки, что обеспечивает баланс между освоением и распространением ЦВЦБ среди домохозяйств и минимизацией дестабилизации банковского сектора.

ЦВЦБ усиливает трансмиссию монетарной политики, повышая долю передачи депозитных ставок с 45 до 72% и снижая коэффициент жертвенности с 1,63 до 1,44. Однако закрытая спецификация модели может переоценивать выгоды для благосостояния на 30–50%, игнорируя волатильность обменного курса и динамику капитальных потоков, которые преобладали в опыте России в условиях санкций. Это исследование способствует углубленному пониманию монетарных инноваций в санкционированных экономиках и предоставляет прикладные рекомендации центральным банкам развивающихся стран, внедряющим ЦВЦБ в условиях геополитического давления.

Ключевые слова: ЦВЦБ, суверенная цифровая валюта, деньги центрального банка, экономические санкции, устойчивость платежной системы, модель DSGE, банковская конкуренция, развивающиеся рынки, Российская Федерация

Заявление о доступности данных. Все данные, полученные в ходе этого исследования, включены в опубликованную статью (и дополнительные файлы к ней).

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Introduction

Central bank digital currencies (CBDCs) represent a fundamental transformation in monetary architecture, with 134 countries representing 98% of global GDP actively developing such instruments as of 2024. This phenomenon assumes particular significance for emerging market economies operating under financial constraints, where traditional international payment systems face disruption. Russia's digital ruble initiative, with mass implementation scheduled for 2026, constitutes a compelling case study for examining CBDC implications within a macroeconomic context characterized by sanctions-induced financial fragmentation.

The theoretical literature establishes that CBDC introduction generates non-trivial general equilibrium effects through multiple transmission channels (Brunnermeier, Niepelt, 2019; Keister, Sanches, 2023). Recent DSGE modeling demonstrates how CBDCs interact with banking sector dynamics, altering deposit competition and credit provision (Barrdear, Kumhof, 2022). However, existing frameworks predominantly calibrate to advanced economy institutions, leaving gaps in understanding CBDC implications for emerging markets facing external financial constraints.

This study addresses three research questions. First, how does CBDC implementation affect monetary policy transmission in an economy experiencing

sanctions-induced financial fragmentation? Second, what is the optimal CBDC remuneration policy balancing household welfare gains against banking sector disruption? Third, how do sanctions modify standard CBDC theoretical predictions? We acknowledge that our closed-economy framework abstracts from exchange rate dynamics, capital flows, and external debt constraints that proved central to Russia's 2022 sanctions experience, likely overstating quantitative welfare estimates while preserving qualitative insights.

We develop a DSGE model incorporating CBDC within a New Keynesian framework featuring monopolistically competitive banks and heterogeneous household adoption patterns. The model's calibration exploits unique features of the Russian economy: a policy rate of 16% (as of 2024), banking sector concentration with state-controlled institutions holding approximately 60% of total assets, and time-varying sanctions intensity parameters.

Findings establish that digital ruble introduction generates welfare effects of 0.79% of steady-state consumption under optimal remuneration policies, rising to 1.26% under high sanctions intensity. These gains arise through enhanced household liquidity services and intensified deposit market competition. The optimal CBDC remuneration emerges at 70 basis points below the policy rate, balancing adoption benefits against banking sector disruption. CBDC enhances monetary policy transmission, improving deposit rate pass-through from 45 to 72% and reducing the sacrifice ratio from 1.63 to 1.44.

This study analyzes the macroeconomic implications of Russia's digital ruble implementation under financial sanctions, deriving optimal CBDC remuneration policies that maximize household welfare while maintaining banking sector stability. Specifically, the research addresses three questions: (1) how does CBDC affect monetary policy transmission in a sanctions-constrained economy; (2) what is the optimal CBDC remuneration policy balancing household welfare against banking disruption; and (3) how do sanctions modify standard CBDC theoretical predictions.

Literature review

CBDC Theory and Monetary Policy

Brunnermeier and Niepelt (Brunnermeier, Niepelt, 2019) demonstrate that under perfect substitutability between central bank and private bank liabilities, CBDC introduction proves neutral in general equilibrium — a condition unlikely to hold in practice given operational constraints. Departing from this benchmark, Keister and Sanches (Keister, Sanches, 2023) develop a model where CBDCs competing with bank deposits can improve welfare by mitigating monopoly power in payment services.

Barrdear and Kumhof (Barrdear, Kumhof, 2022) extend this framework using a quantitative DSGE model calibrated to UK data, finding modest positive welfare effects from CBDC introduction. Their welfare decomposition reveals that approximately 60% of CBDC benefits arise from improved deposit market competition rather than direct liquidity services. Our modeling approach builds on their framework, extending it to emerging market contexts with sanctions-induced constraints. Chiu

et al. (Chiu et al., 2023) examine implications for bank market power, finding that optimal CBDC design depends critically on initial banking sector concentration.

Williamson (Williamson, 2022) analyzes CBDC as a flight-to-safety asset during financial stress, finding that CBDC availability can improve welfare by providing a risk-free payment instrument when private banking becomes unstable — particularly relevant for sanctioned economies. His framework complements our analysis of CBDC benefits under external financial constraints.

Banking Competition and Market Power

Banking sector market power critically affects CBDC transmission mechanisms. Drechsler et al. (Drechsler, Savov, Schnabl, 2017) establish empirically that U.S. banks with local market power partially insulate deposit rates from monetary policy changes, passing through only 25–40% of policy rate increases to deposit rates. Russia's banking sector exhibits substantial concentration, with state-controlled banks commanding approximately 60% of total assets as of 2024. Empirical work on Russian monetary policy transmission documents that policy rate changes transmit with substantial lags (6–9 months) and incomplete pass-through (approximately 60% over one year). CBDC introduction, by providing depositors an outside option, should theoretically constrain this market power.

Financial Sanctions and Economic Adaptation

Sanctions imposed on Russia following 2014 and intensified dramatically after February 2022 severed major banks from SWIFT international payment networks, froze approximately $300 billion in foreign exchange reserves, and severely restricted correspondent banking relationships. Dreger et al. (Dreger et al., 2016) analyze the 2014–2016 sanctions period, estimating GDP losses of 1–1.5% attributable to financial sector constraints. They identify impaired credit supply as the primary transmission mechanism, with sanctioned banks reducing lending by 15–20% relative to non-sanctioned institutions.

The broader literature on economic sanctions documents substantial macroeconomic impacts. Neuenkirch and Neumeier (Neuenkirch, Neumeier, 2015) conduct a comprehensive analysis of UN and US sanctions across 68 countries (1976–2012), finding that UN sanctions reduce GDP growth by 2.3–3.5 percentage points on average, with effects lasting approximately 10 years. Ahn and Ludema (Ahn, Ludema 2020) develop a theoretical framework showing that financial sanctions prove more effective than trade sanctions in imposing economic costs, as they disrupt intermediation channels essential for economic activity — precisely the mechanism this study model.

CBDCs may facilitate adaptation through several channels. First, CBDC-based payment systems can operate independently of traditional correspondent banking networks, enabling direct central bank-to-central bank settlement. Second, enhanced domestic payment infrastructure may partially substitute for lost international financial services.

Russian Research on Digital Ruble and Sanctions

The digital ruble project has generated substantial analysis within Russia's research community, though academic publications remain limited given the recent initiation of the program. The Bank of Russia has published technical documentation and concept papers outlining the digital ruble framework and implementation roadmap, providing institutional details that inform our calibration approach. Russian central bank officials have emphasized that the digital ruble design prioritizes minimizing disruption to commercial banking while enhancing payment system efficiency.

The Central Economics and Mathematics Institute (CEMI) has contributed theoretical foundations for modeling the Russian economy. Andreyev and Polbin (Andreyev, Polbin, 2022) develop a DSGE framework for Russia incorporating monetary policy, resource revenues, and the zero lower bound constraint, providing methodological precedents for our approach while highlighting the importance of external sector modeling we acknowledge as a limitation. Polbin and colleagues have extensively analyzed Russian macroeconomic dynamics using DSGE methods, establishing best practices for calibration to Russian data that we follow in the "Calibration and Estimation" section below.

Higher School of Economics researchers have examined sanctions impacts on Russian monetary policy transmission. Pestova and Mamonov (Pestova, Mamonov, 2019) document that 2014–2016 sanctions reduced deposit rate pass-through from approximately 65 to 45%, weakening monetary policy effectiveness. Our finding that CBDC improves pass-through from 45 to 72% directly addresses this sanctions-induced transmission impairment. Their empirical work provides the baseline pass-through estimates we use for model validation.

This Russian literature establishes several key points supporting our analysis: (1) sanctions impair monetary transmission through banking sector channels, documented empirically by HSE researchers; (2) DSGE modeling has been successfully applied to the Russian economy by CEMI scholars, demonstrating methodological feasibility; and (3) enhanced domestic financial infrastructure becomes more valuable under external constraints, a theme emphasized by Bank of Russia policy documents. Our contribution extends this foundation with a comprehensive quantitative framework calibrated to post-2022 conditions that explicitly incorporates CBDC within a sanctions environment.

DSGE Modeling of Payment Systems

The integration of payment systems and alternative currency forms into DSGE frameworks has evolved considerably. Foundational work by Woodford (Woodford, 2003) established the modern New Keynesian framework emphasizing interest rate policy over monetary aggregates, providing the theoretical foundation for our model structure. Ireland (Ireland, 2004) explicitly incorporated money demand through utility functions, while Christiano et al.

(Christiano, Eichenbaum, Evans, 2005) introduced financial frictions through costly state verification. Gertler and Karadi (Gertler, Karadi, 2011) developed models of banking sector capital constraints that inform our treatment of credit provision under sanctions-induced stress. Recent work more explicitly models banking competition and payment system choices, providing the direct foundation for our CBDC analysis.

Methods

Model Environment

We develop a closed-economy DSGE model featuring five agent types: households, final goods producers, intermediate goods producers, banks, and a central bank. Time is discrete and indexed by $t = 0, 1, 2, \ldots$. The model's key innovation involves introducing CBDC alongside traditional monetary aggregates within a framework explicitly capturing banking sector market power and sanctions-induced financial constraints.

Households

The economy contains a continuum of infinitely-lived households indexed by $i \in [0,1]$, heterogeneous in their valuation of CBDC services. Household i maximizes expected lifetime utility:

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

where $C_{i,t}$ denotes consumption, $L_{i,t}$ labor supply, $M_{i,t}^C$ cash holdings, $D_{i,t}$ bank deposits, $R_{i,t}$ CBDC holdings, $\beta \in (0,1)$ represents the discount factor, and θ_i captures household-specific CBDC valuation distributed according to cumulative distribution function $F(\theta)$.

The period utility function takes the standard form:

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

where $\eta \in (0,1)$ governs the consumption-leisure trade-off and $\sigma > 0$ represents relative risk aversion. The liquidity services function captures substitution relationships among payment instruments:

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

where $\psi > 0$ scales the importance of liquidity services; $\alpha \in (0,1)$ represents cash's expenditure share; $\gamma \in (0,1 - \alpha)$ represents CBDC's share, and $\chi > 0$ governs the elasticity of substitution. Households face the budget constraint:

$$P_t C_{i,t} + M_{i,t}^C + D_{i,t} + R_{i,t} = W_t L_{i,t} + \left(1 + i_t^D\right) D_{i,t-1} + \left(1 + i_t^R\right) R_{i,t-1} + M_{i,t-1}^C + \Pi_{i,t} + T_t,$$

where P_t denotes the price level, W_t the nominal wage, i_t^D the deposit rate, i_t^R the CBDC remuneration rate, $\Pi_{i,t}$ profits, and T_t lump-sum transfers.

Production and Price Setting

A representative final goods producer aggregates differentiated intermediate goods using CES technology:

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

where $\epsilon > 1$ denotes the elasticity of substitution. Intermediate goods producers operate under monopolistic competition with Cobb-Douglas production:

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

Firms set prices subject to Calvo (Calvo, 1983) nominal rigidity, generating a New Keynesian Phillips curve:

$$\pi_t = \beta E_t \left[\pi_{t+1}\right] + \kappa \left(mc_t - \overline{mc}\right),$$

where $\kappa = (1 - \phi)(1 - \beta\phi)/\phi$ governs the slope.

Banking Sector

Banks operate under monopolistic competition in deposit and loan markets. Bank *b* faces deposit demand:

$$D_{b,t} = \left(\frac{i_{b,t}^D}{i_t^D} \right)^{\eta_D} D_t$$

with $\eta_D > 1$ the elasticity of substitution. First-order conditions yield symmetric equilibrium expressions:

$$i_{b,t}^{D} = \frac{\eta_D}{\eta_D - 1}\left(i_t^{CB} + \tau_t^{D}\right);$$

$$i_{b,t}^{L} = \frac{\eta_L}{\eta_L - 1}\left(i_t^{CB} + \tau_t^{L}\right),$$

where i_t^{CB} represents the policy rate and τ_t^D, τ_t^L capture funding costs and credit risk premia. Banking market power generates spreads between policy rates and retail rates.

Central Bank and CBDC Policy

The central bank conducts monetary policy through the policy rate i_t^{CB} and CBDC remuneration i_t^R. The policy rate follows a Taylor (Clarida, Galí, & Gertler, 1999) rule:

$$i_t^{CB} = \rho_i i_{t-1}^{CB} + \left(1-\rho_i\right)\left[\bar{i}^{CB} + \phi_\pi\left(\pi_t - \bar{\pi}\right) + \phi_y \log\left(Y_t / \bar{Y}\right)\right] + \epsilon_t^i,$$

CBDC remuneration follows:

$$i_t^R = \max\left(0, i_t^{CB} - \delta_t\right),$$

where $\delta_t \geq 0$ represents the spread between the policy rate and CBDC remuneration.

Sanctions Modeling

Financial sanctions are modeled through time-varying constraints affecting banking operations. A sanctions intensity variable $\xi_t \in [0,1]$ evolves according to:

$$\xi_t = \rho_\xi \xi_{t-1} + \left(1-\rho_\xi\right)\bar{\xi} + \epsilon_t^\xi.$$

Sanctions affect the economy through three channels. First, banking costs increase: $\omega_t = \omega_0 + \omega_1 \xi_t$. Second, sanctions reduce effective productivity:

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

where $\tau(\xi_t) = \tau_0 + \tau_1 \xi_t$. Third, sanctions constrain access to international payment systems:

$$F_t^{CB} \leq \left(1-\xi_t\right)\overline{F}^{CB}.$$

Equilibrium

A competitive equilibrium consists of sequences of prices and allocations such that households optimize, firms optimize production and pricing decisions, banks optimize deposit and loan rates, the central bank follows policy rules, and all markets clear.

Calibration and Estimation

Parameter Calibration

We calibrate key structural parameters to match Russian macroeconomic data for 2014–2024. The discount factor $\beta = 0.9875$ implies an annual real interest rate of 5%. Capital depreciation $\delta_K = 0.025$ corresponds to 10% annual depreciation. The capital share $\alpha = 0.45$ reflects Russian national accounts data.

Banking sector parameters merit particular scrutiny given Russia's institutional specificity. The deposit demand elasticity $\eta_D = 5.0$ derives from two sources: (1) regression analysis of bank-level deposit flows on interest rate differentials for 2018–2023, yielding elasticity estimates of 4.2–5.8 (following (Drechsler Drechsler, Savov, Schnabl, 2017) methodology); (2) consistency with observed deposit rate spreads of 450–550 basis points relative to policy rates. The loan supply elasticity $\eta_L = 4.0$ produces lending spreads of approximately 700 basis points, matching empirical averages.

Household CBDC valuation parameters are calibrated to match stated-preference survey data from Bank of Russia consumer surveys (2023), which indicate that 15–20% of respondents would "definitely" or "probably" adopt CBDC at remuneration 70–100 basis points below policy rates (Table 1).

Table 1

Calibrated Parameters

Parameter	Value	Description
β	0.9875	Discount factor
σ	2.0	Risk aversion
η	0.35	Consumption weight
α	0.45	Capital share
δ_K	0.025	Capital depreciation
ϵ	6.0	Demand elasticity
η_D	5.0	Deposit elasticity
η_L	4.0	Loan elasticity
ρ^{RR}	0.04	Reserve requirement

Source: R. Bochner`s calculation, with the parameters described above.

Bayesian Estimation

We estimate seven parameters using Bayesian methods with fourteen quarterly time series spanning 2014Q1–2024Q2. The estimation employs the Random Walk Metropolis-Hastings algorithm with 500,000 iterations, discarding the first 100,000 as burn-in. Posterior means and credible intervals for all seven estimated parameters are presented in Table 2.

Table 2

Estimated Parameters

Parameter	Posterior Mean	90% Credible Interval
ϕ (Price stickiness)	0.78	[0.72. 0.84]
ρ_i (Interest smoothing)	0.82	[0.76. 0.88]
ϕ_π (Inflation response)	1.83	[1.52. 2.18]
ϕ_y (Output response)	0.15	[0.08. 0.24]
ρ_ξ (Sanctions persistence)	0.88	[0.81. 0.94]
ω_1 (Banking cost impact)	0.048	[0.032. 0.066]
τ_1 (Productivity effect)	0.028	[0.019. 0.039]

Source: R. Bochner`s calculation, with the parameters described above

The Calvo parameter $\phi = 0.78$ implies an average price duration of 4.5 quarters. The inflation response coefficient $\phi_\pi = 1.83$ exceeds unity, satisfying the Taylor principle. The sanctions persistence parameter $\rho_\xi = 0.88$ indicates highly persistent effects with a half-life of approximately 5.4 quarters.

Quantitative Results

Baseline CBDC Implementation Effects

We analyze digital ruble introduction under baseline remuneration policy ($\delta = 0.7\%$, optimal as demonstrated below) and medium sanctions intensity ($\xi = 0.45$). CBDC adoption reaches 15.2% of GDP at the new steady state achieved after approximately two years. Bank deposits decline by 10.5% below the pre-CBDC baseline, with banks responding by raising deposit rates by 45 basis points. Credit provision contracts, with bank lending falling 6.8% below baseline. Investment declines 3.2% below baseline in the short run as firms face tighter financing constraints, with output settling 0.9% below the pre-CBDC steady state.

However, household welfare improves despite output decline. Consumption ultimately settles 0.3% above baseline as household gains from two sources dominate income effects. First, CBDC provides direct liquidity services valued at 0.6% of consumption in utility-equivalent terms. Second, intensified banking competition raises deposit remuneration, generating transfers worth 0.4% of consumption. Total welfare gains reach 0.79% of steady-state consumption.

This welfare decomposition reveals that approximately 51% of total welfare gains arise from competitive pressure on deposit rates rather than direct CBDC liquidity services, emphasizing that CBDC effects depend critically on initial banking sector market power.

Optimal CBDC Remuneration

To derive optimal remuneration policy, we trace welfare across a grid of CBDC spread values $\delta \in [0,3\%]$. Welfare exhibits an inverted-U shape, reaching maximum at $\delta^* = 0.7\%$. Welfare effects across the full range of remuneration policies are reported in Table 3.

Table 3

Welfare Effects Under Alternative CBDC Remuneration Policies

CBDC Spread, %	Welfare Change, %	CBDC/GDP, %	Deposit Change, %	Loan Change, %	Output Change, %
0.0	+0.34	22.1	–15.8	–10.2	–1.8
0.3	+0.58	18.6	–13.2	–8.6	–1.4
0.7*	**+0.79**	**15.2**	**–10.5**	**–6.8**	**–0.9**
1.0	+0.67	12.8	–8.2	–5.3	–0.7
1.5	+0.48	9.2	–5.6	–3.6	–0.5
2.0	+0.38	6.8	–3.8	–2.4	–0.3
3.0	+0.18	3.2	–1.7	–1.1	–0.1

*Optimal policy.

Source: R. Bochner`s calculation, with the parameters described above.

At very low spreads ($\delta < 0.5\%$), excessive CBDC adoption triggers severe banking sector disruption, and resulting output losses begin to dominate household benefits. At optimal remuneration, CBDC achieves 15.2% of GDP adoption — substantial but not excessive. Banking sector stress remains manageable with 10.5% deposit decline and 6.8% credit contraction. The optimal spread of 70 basis points reflects the trade-off between adoption benefits and disruption costs specific to Russia's institutional context.

CBDC Effects Under Financial Sanctions

We conduct comparative statics across sanctions intensity levels: low ($\xi = 0.2$), medium ($\xi = 0.45$), and high ($\xi = 0.8$). Results across all three sanctions intensity levels are reported in Table 4.

Table 4

Sanctions Effects on CBDC Welfare Gains

Sanctions Intensity	Welfare (No CBDC), %	Welfare (Optimal CBDC), %	Net CBDC Benefit, %	Optimal Spread, %	CBDC Adoption, %
0.2 (Low)	–0.82	–0.38	+0.44	0.85	14.1
0.45 (Medium)	–2.14	–1.35	+0.79	0.70	15.2
0.8 (High)	–4.26	–3.00	+1.26	0.55	16.8

Source: R. Bochner`s calculation, with the parameters described above.

Within our closed-economy framework, welfare gains from CBDC introduction increase substantially with sanctions intensity. Under low sanctions, CBDC generates improvements of 0.44%. Under high sanctions, gains reach 1.26% — nearly triple the low-sanctions effect.

This amplification operates through three mechanisms. First, sanctions increase banking sector operating costs, raising the wedge between policy rates and retail rates. CBDC circumvents these costs by providing direct central bank intermediation. Second, sanctions impair monetary policy transmission by disrupting interbank markets. Under high sanctions, pass-through from policy rates to deposit rates falls to 42% (versus 68% under low sanctions). CBDC remuneration provides an alternative transmission mechanism. Third, sanctions reduce international payment system access, increasing the value of robust domestic payment infrastructure.

Critically, CBDC does not eliminate sanctions effects. Even with optimal CBDC implementation, welfare under high sanctions (–3.00%) remains substantially below no-sanctions levels. However, within our model's assumptions, CBDC mitigates approximately 30% of sanctions-induced welfare costs.

Monetary Policy Effectiveness

CBDC introduction enhances monetary policy transmission effectiveness. We analyze transmission by comparing impulse responses to a 100 basis point contractionary monetary policy shock under three scenarios: no CBDC, optimal CBDC ($\delta = 0.7\%$), and high remuneration CBDC ($\delta = 0.3\%$).

Peak output decline increases from –0.52% (no CBDC) to –0.68% (optimal CBDC) to –0.81% (high remuneration CBDC), reflecting stronger transmission. Peak inflation decline increases from –0.32 percentage points (no CBDC) to –0.41 pp (optimal CBDC) to –0.48 pp (high remuneration CBDC). The cumulative pass-through of policy rate changes to deposit rates after four quarters improves from 45% (no CBDC) to 72% (optimal CBDC) to 88% (high remuneration CBDC). This dramatic improvement reflects the constraining effect of CBDC as outside option limiting banks'ability insulate deposit rates from policy changes.

The sacrifice ratio improves from 1.63 (no CBDC) to 1.44 (optimal CBDC), implying that disinflation becomes less costly in output terms when CBDC enhances

transmission. These results carry important implications for monetary policy conduct: enhanced transmission effectiveness proves valuable for achieving inflation targets but requires more cautious policy calibration.

Discussion and Policy Implications

Alternative Banking Structures

CBDC effects depend critically on initial banking sector market power. We conduct robustness exercises varying the deposit and loan demand elasticities.

High competition scenario ($\eta_D = 10$, $\eta_L = 8$): Under this structure, optimal CBDC remuneration falls to $\delta^* = 1.4\%$ and welfare gains decline to +0.23% of consumption. The reduced benefits reflect diminished scope for competition-enhancing effects when banking is already relatively competitive.

High concentration scenario ($\eta_D = 3$, $\eta_L = 2.5$): Optimal CBDC remuneration rises to $\delta^* = 0.35\%$ and welfare gains increase to +1.12% of consumption. The amplified benefits underscore that CBDC provides greatest value in environments with significant banking market power.

Alternative CBDC Designs

Quantity limits: Suppose households face maximum CBDC holdings of 500 000 rubles, constraining approximately 40% of households. Welfare gains decline to +0.54% (versus +0.79% baseline), though banking sector disruption also moderates, with deposit decline limited to –7.2% versus –10.5% baseline. Quantity limits thus offer a mechanism to reduce financial stability risks at the cost of foregone welfare gains.

Tiered remuneration: Under a structure paying full optimal remuneration on balances up to 100,000 rubles but zero remuneration above this threshold, welfare gains reach +0.71% of consumption, only modestly below the uniform remuneration baseline. Banking disruption also moderates slightly (–9.1% deposit decline). Tiered remuneration thus offers attractive properties, achieving most welfare benefits while reducing both fiscal costs and stability risks.

Non-remunerated CBDC: A CBDC paying zero remuneration generates minimal welfare gains of only +0.18% of consumption, confirming that remuneration proves essential for substantial CBDC benefits.

Interaction with Macroprudential Policy

Enhanced central bank lending facilities: Suppose the central bank offers banks access to refinancing at the policy rate plus 50 basis points. This facility substantially mitigates banking sector disruption. Under optimal CBDC remuneration with enhanced lending facilities, deposit decline moderates to –6.2% (versus –10.5% baseline) and credit contraction to –4.1% (versus –6.8% baseline). Welfare gains remain at +0.76%, nearly unchanged from baseline, suggesting that lending facilities successfully address stability concerns without sacrificing CBDC benefits.

Policy Recommendations

The analysis yields several recommendations for CBDC implementation in emerging market economies:

1. **Adopt modest positive remuneration.** Central banks should remunerate CBDC at rates modestly below the policy rate. Our estimates suggest an optimal spread of approximately 50–100 basis points for economies with banking sector characteristics similar to Russia's.

2. **Calibrate remuneration to banking sector structure.** Economies with highly concentrated banking should adopt remuneration closer to the policy rate to maximize competition benefits. Economies with relatively competitive banking should adopt lower remuneration to avoid excessive disruption.

3. **Consider tiered remuneration schemes.** Tiered structures achieve most welfare benefits while limiting fiscal costs and reducing tail risks from excessive CBDC adoption.

4. **Implement gradually through pilot programs.** Transition dynamics reveal temporary welfare losses during the first 2–4 quarters. Policymakers should implement CBDC gradually through geographic or demographic pilot programs.

5. **Prepare complementary macroprudential measures.** Central banks should stand ready to deploy enhanced lending facilities or other liquidity support if deposit outflows exceed anticipated levels.

6. **Emphasize sanctions mitigation in sanctioned economies.** For economies facing sustained financial sanctions, CBDC implementation should prioritize features facilitating alternative payment infrastructure.

7. **Recalibrate monetary policy rules.** Enhanced transmission effectiveness following CBDC adoption necessitates adjustments to monetary policy conduct.

Closed-Economy Framework Limitations

Our closed-economy specification constitutes a significant methodological simplification requiring explicit acknowledgment. The 2022 sanctions generated substantial shocks precisely through external channels: exchange rate volatility (ruble depreciation exceeding 40% in March 2022), capital flight (estimated $150 billion outflows in 2022), disrupted correspondent banking relationships, and ruptured supply chains.

By abstracting from these channels, our quantitative estimates likely overstate CBDC welfare benefits and understate macroeconomic costs. Specifically:

Exchange rate channel: Sanctions-induced currency depreciation increases import costs and generates balance sheet effects for foreign-currency-denominated debt. CBDC cannot directly address these pressures. An open-economy extension would likely show smaller welfare gains as exchange rate volatility partially offsets domestic financial improvements.

Capital flow constraints: Our model excludes sudden stops and capital flight dynamics that dominated Russia's 2022 experience. CBDC provision may actually

exacerbate capital flight risks if it facilitates easier portfolio reallocation, a concern our framework cannot capture.

External debt and reserves: Frozen foreign exchange reserves (approximately $300 billion) and restricted external debt servicing generated substantial economic costs absent from our model. These effects likely dominated the domestic financial frictions we analyze.

Direction of bias: We expect these omissions bias our welfare estimates upward by 30–50%. The true CBDC welfare gain under high sanctions likely approximates 0.6–0.9% rather than our estimated 1.26%. However, the qualitative result — that CBDC effectiveness increases under sanctions — likely remains robust as alternative domestic payment infrastructure gains value when international systems are constrained.

Future research should extend this framework to small open economy specifications incorporating exchange rate determination, international reserve dynamics, and capital flow management. Such extensions would provide more realistic quantitative guidance for emerging market CBDC policy under sanctions.

Conclusion

This study develops and estimates a DSGE model analyzing Russia's digital ruble implementation under financial sanctions, deriving optimal CBDC remuneration policies that balance household welfare gains against banking sector disruption. Our principal findings establish that CBDC introduction generates positive welfare effects of 0.79% of steady-state consumption under optimal remuneration policies within our closed-economy framework, with benefits amplifying substantially to 1.26% under high sanctions intensity.

The optimal CBDC remuneration policy emerges from balancing competing forces. Household welfare gains arise through enhanced liquidity services and intensified deposit market competition constraining banking sector market power. These benefits must be weighed against banking sector disruption that reduces credit provision, contracts capital accumulation, and lowers steady-state output. Our calibration to Russian institutional features implies an optimal spread of 70 basis points below the policy rate. A central contribution concerns CBDC effectiveness under financial sanctions. The model predicts that CBDC provides substantially greater welfare benefits in sanctioned economies by offering alternative payment infrastructure and enhancing monetary policy effectiveness when international financial integration is constrained. While CBDC cannot eliminate sanctions effects entirely, our estimates suggest it can offset approximately 30% of sanctions-induced welfare losses within the model's closed-economy assumptions — a substantial mitigation for economies facing prolonged external financial restrictions.

The analysis demonstrates that CBDC enhances monetary policy transmission, improving deposit rate pass-through from 45 to 72% and reducing the sacrifice ratio from 1.63 to 1.44. This enhanced effectiveness proves valuable for inflation targeting regimes but requires more cautious policy rate calibration to avoid excessive output volatility.

However, our closed-economy framework constitutes a significant limitation. By abstracting from exchange rate dynamics, capital flows, and external debt constraints that dominated Russia's 2022 sanctions experience, our quantitative welfare estimates likely overstate true magnitudes by 30–50%. Open-economy extensions incorporating these critical channels would provide more realistic quantitative guidance while likely preserving the qualitative insight that CBDC effectiveness increases under external financial constraints.

Beyond Russia's specific context, this study contributes to understanding CBDC implications for emerging markets more broadly. The fundamental trade-off identified — household welfare gains through liquidity services and competition effects versus banking sector disruption reducing credit provision — applies generically across economies, though optimal policies vary with institutional contexts. The results suggest that banking sector structure critically determines CBDC effects. Emerging markets with concentrated banking systems benefit more from CBDC introduction than advanced economies with competitive banking sectors. However, they also face greater financial stability risks from rapid deposit disintermediation, necessitating careful remuneration calibration and complementary macroprudential measures.

From a policy perspective, the analysis supports gradual CBDC implementation with modest positive remuneration, tiered remuneration structures targeting smaller holders, and preannounced liquidity support facilities to address banking sector stress. For sanctioned economies specifically, CBDC design should prioritize alternative payment infrastructure development and interoperability with partner countries' systems. The digital ruble represents a significant monetary innovation with potential to reshape Russia's financial architecture. This study provides quantitative guidance for its optimal design, demonstrating that appropriately calibrated CBDC implementation can generate meaningful welfare improvements while maintaining financial stability, though the magnitude of benefits depends critically on proper modeling of external sector constraints that our framework acknowledges but does not fully incorporate.

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