Journal of Money and Economy
Vol. 20, No. 4, Fall 2025
pp. 601-648

Original Research Article

Optimal CBDC Design: Welfare Implications of CBDC in a Fiscally-Constrained Economy

Hassan Daliri*

Received: 29 Sep 2025 Approved: 18 Nov 2025

This paper develops a stylized New Keynesian DSGE model with imperfect banking competition and fiscal constraints to evaluate the welfare effects of different Central Bank Digital Currency (CBDC) designs. The model compares five monetary regimes: a conventional baseline, retail account-based CBDC, retail token-based CBDC, wholesale CBDC, and a hybrid CBDC. Results show that a retail, interest-bearing, account-based CBDC delivers the highest welfare gain, equivalent to a permanent 11.13% increase in consumption, driven by lower transaction costs, greater banking sector competition, and reduced labor tax distortions. A hybrid CBDC generates a moderate welfare gain of 6.04%, while the token-based and wholesale designs offer only marginal improvements. The analysis reveals that the welfare impact of CBDC adoption is highly sensitive to its design features, particularly the utility it provides, the interest rate spread, and the degree of competition it induces in the banking sector. These findings underscore the complexity of CBDC policymaking, where trade-offs between efficiency, inclusion, and financial sector dynamics must be carefully balanced. Policy recommendations emphasize prioritizing user-friendly, account-based CBDC frameworks, enhancing interoperability with existing systems, and adopting a gradual, flexible approach that aligns with country-specific fiscal and financial structures.

Keywords: Central Bank Digital Currency (CBDC); Welfare Analysis; DSGE Model; Fiscal Constraints; Macroeconomic Modeling
JEL Classification*:* E52, E58, E61, C68

1 Introduction

The emergence of Central Bank Digital Currencies (CBDCs) has become one of the most transformative developments in modern monetary policy and financial systems. CBDCs represent a digital form of sovereign money issued by central banks, offering the potential to enhance payment systems, improve financial inclusion, and facilitate the implementation of monetary policy. The

* Associate Professor of Economics, Department of Management and Economics, Faculty of Humanities and Social Sciences, Golestan University, Gorgan, Iran; h.daliri@gu.ac.ir

dynamic evolution of Central Bank Digital Currencies (CBDCs) paints a fascinating picture of financial innovation in action (Figure 1). Currently, 92 countries are actively researching CBDCs, demonstrating widespread recognition of their transformative potential. Another 27 nations have moved beyond theory to develop proof-of-concept models, while 22 economies - including financial powerhouses like China and the EU - are running live pilots, stress-testing these systems in real-world conditions (CBDC Tracker, 2026). The rollout phase reveals even more intriguing insights: while only 4 CBDCs have officially launched (notably the Bahamas' Sand Dollar and Nigeria's eNaira), the complete absence of inactive projects suggests unwavering global commitment to digital currency development. The 9 cancelled initiatives, such as Ecuador's ambitious but ill-fated 2014 attempt, serve as valuable case studies in the challenges of CBDC implementation, from technological hurdles to policy reversals (CBDC Tracker, 2026). What makes this global movement particularly compelling is its asymmetric progression - while small island nations lead in deployment, economic superpowers proceed more cautiously through extensive piloting. This dichotomy reflects the complex risk-reward calculus central banks face: smaller economies see CBDCs as tools for financial inclusion, while larger economies must weigh systemic impacts on their complex financial ecosystems. The sheer volume of research-stage projects (92) indicates we're still in the early chapters of what promises to be a revolutionary shift in global finance.

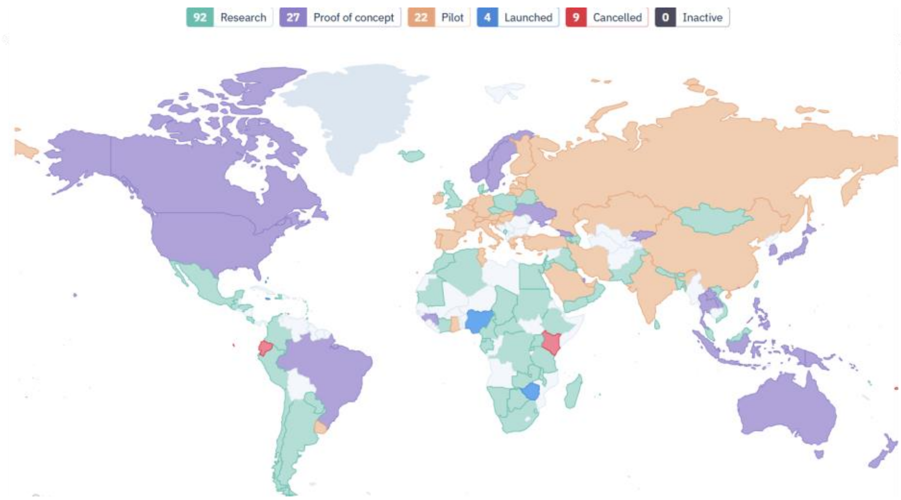

Figure 1. Today's Central Bank Digital Currencies Status
Source: CBDC Tracker, Database update: March 2025, https://cbdctracker.org/

As central banks around the world explore the design and implementation of CBDCs, understanding the economic implications of these new monetary instruments is critical. Specifically, assessing their welfare impacts in a context constrained by fiscal limitations is of paramount importance, as it allows policymakers to optimize their designs in a way that maximizes societal benefits.

In many economies, particularly those grappling with high levels of public debt, limited fiscal space, and rising social demands, the trade-offs associated with monetary and fiscal policy are particularly pronounced. These economies face significant constraints in deploying public resources effectively, making it essential to design financial innovations, such as CBDCs, in a manner that does not exacerbate existing fiscal pressures. Consequently, evaluating how different CBDC designs influence economic welfare, particularly in the context of fiscal constraints, is a crucial yet underexplored area of research. The impact of these designs on the broader economy, particularly in terms of welfare, efficiency, and equity, depends on how various key parameters interact with fiscal realities, and understanding this dynamic is central to achieving optimal CBDC design. A key challenge in the design of CBDCs is ensuring that they fulfill the dual objectives of enhancing economic efficiency while maintaining stability within the financial system. While the technological features of CBDCs – whether account-based or token-based –

are critical, their economic effects must be carefully assessed in terms of both their direct and indirect impacts on welfare. Central to these considerations is the role of transaction costs, bank markups, and the elasticity of demand for CBDCs, all of which can significantly alter the outcomes for consumers and businesses alike. Furthermore, the incorporation of these design features into an economy facing fiscal constraints adds another layer of complexity, as the interaction between monetary and fiscal policies will ultimately determine the success of CBDC implementation.

This paper seeks to address these issues by analyzing the welfare implications of various CBDC designs in a fiscally-constrained economy. Specifically, it explores how different CBDC architectures—account-based, token-based, wholesale, and hybrid models—perform under varying economic parameters, such as transaction costs, utility weights, and demand elasticities. The objective is to determine which design is most conducive to maximizing societal welfare while operating within the constraints imposed by fiscal limitations. The importance of this research lies in its potential to guide policymakers in selecting CBDC designs that align with the broader economic and fiscal goals of a country. Given the growing interest in CBDCs across both advanced and emerging economies, understanding how these digital currencies can be optimally integrated into existing financial systems is critical. By focusing on the welfare implications within a constrained fiscal context, this study provides valuable insights into how CBDC designs can help improve the efficiency of monetary and fiscal systems without exacerbating fiscal pressures.

In addressing these issues, this paper is structured as follows: First, it reviews the existing literature on CBDC design and welfare economics. Second, it outlines the methodology used to assess the welfare impacts of different CBDC models. Third, it presents the results of the analysis and discusses the policy implications of the findings. Finally, it concludes with recommendations for further research and policy considerations for the implementation of CBDCs in fiscally-constrained economies.

2 Conceptual Foundations and Literature Review

2.1 Type of CBDC and Central Bank Money

Table 1 and Figure 2 illustrate a classification system for money through a Venn diagram, commonly termed the money flower (Bech & Garratt, 2017). The diagram presents a comprehensive typology of modern money and digital payment instruments by mapping them across four intersecting dimensions:

digital form, central bank issuance, token-based infrastructure, and wide accessibility. Using a four-way Venn diagram, it illustrates the possible configurations of payment instruments depending on which of these attributes they exhibit, and highlights in grey the subset that constitutes Central Bank Digital Currency (CBDC). The blue oval represents instruments that are digital in nature. This includes both traditional bank deposits and various forms of central bank digital tokens. Bank deposits, while digital and widely accessible (falling also within the red oval), are not central bank liabilities and are therefore excluded from the green oval, which designates central bank-issued instruments. Conversely, central bank reserves and settlement accounts—included in both the blue and green ovals—are digital and issued by the central bank but are not widely accessible nor token-based, thus falling outside the red and orange regions. The red oval demarcates instruments that are widely accessible to the public. Instruments such as cash and bank deposits reside within this area, as do general purpose central bank accounts and general purpose central bank digital tokens. These instruments differ in both their technological form and their institutional backing. For example, while cash is central bank-issued and universally accessible, it is physical rather than digital. However, it is a token-based instrument, since ownership is verified through possession. Accordingly, cash lies within the token-based and central-bank-issued categories, but outside the digital domain. In contrast, general purpose central bank digital tokens occupy the central intersection of all four dimensions: they are digital, central bank-issued, token-based, and widely accessible—serving as a paradigmatic case of retail CBDCs. The orange oval identifies instruments that are token-based, typically designed for secure, pseudonymous transactions and decentralized verification. This includes both private digital tokens, which may be issued for general or wholesale purposes, and central bank digital tokens, which are further categorized by their intended user base. Wholesale CBDCs, for example, reside within the green, blue, and orange zones, indicating that they are central bank-issued, digital, and token-based, yet not widely accessible. The overlapping grey areas mark the various feasible implementations of CBDC. Specifically, these include: (i) central bank accounts for general purpose use, which, while not token-based, represent a direct digital claim on the central bank that is accessible to the public; (ii) central bank digital tokens for wholesale use, which are token-based but not widely accessible; and (iii) general purpose central bank digital tokens, which embody all four defining characteristics. These configurations underscore the flexibility of CBDC design and the policy trade-offs inherent in choosing between account-based and token-based architectures, retail versus wholesale models, and degrees of accessibility. By structuring the monetary landscape in this multidimensional space, the diagram not only clarifies the distinct positioning of existing instruments—such as bank deposits, cash, and private tokens—but also illuminates the conceptual space occupied by CBDCs. It reveals that CBDCs are not a monolithic category, but rather a spectrum of possibilities depending on technological infrastructure, institutional issuer, access conditions, and functional form.

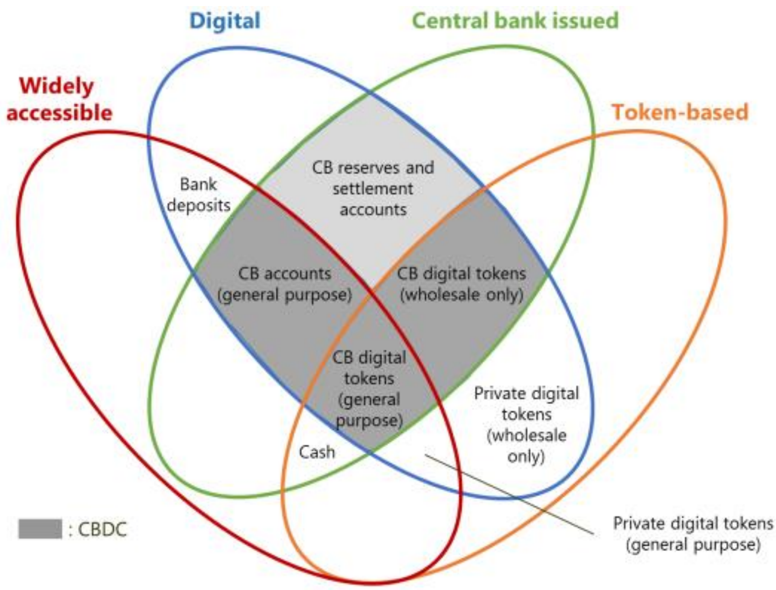

Figure 2. Money flower diagram (Bech & Garratt, 2017)

Table 1
Summary table of the Money Flower diagram

Type of Money	Digital	Central Bank Issued	Token-based	Widely Accessible
Bank deposits	✓	✗	✗	✓
CB reserves and settlement accounts	✓	✓	✗	✗
CB accounts (general purpose)	✓	✓	✗	✓
CB digital tokens (wholesale only)	✓	✓	✓	✗
CB digital tokens (general purpose)	✓	✓	✓	✓
Cash	✗	✓	✗	✓
Private digital tokens (wholesale only)	✓	✗	✓	✗
Private digital tokens (general purpose)	✓	✗	✓	✓

Source: Summarized by the author based on Bech & Garratt (2017)

Therefore, according to the above model, it can be concluded that, the development of Central Bank Digital Currencies (CBDCs) entails exploring diverse design pathways, each with distinct implications for monetary transmission, financial intermediation, and institutional architecture. These designs differ primarily in terms of access, technological form, intermediation model, and their intended impact on the financial system. A comparison with the conventional baseline system highlights the potential transformation CBDCs might induce. Therefore, in this article, we will model different types of conventional money and central bank digital money.

A. Baseline (Conventional System): The current system operates under a two-tier structure, where central bank money is available to the public solely as physical cash, while digital payments are executed using commercial bank deposits, which are ultimately settled using central bank reserves in interbank markets. The central bank indirectly influences the economy through policy rates that affect interbank lending and deposit rates. Public access to central bank liabilities is limited, and commercial banks dominate the retail payment landscape, potentially exercising market power.

B. Retail CBDC (rCBDC): Retail CBDC scenarios envision central bank liabilities being made directly accessible to the general public (households and non-financial firms) in digital form. These designs may differ along the axis of account-based versus token-based implementation: b-1. Account-Based Retail CBDC and b-2. Token-Based Retail CBDC

B-1. Account-Based Retail CBDC: This model functions similarly to a digital deposit account held directly at the central bank (or through tightly regulated intermediaries). Identification mechanisms such as Know-Your-Customer (KYC) and Anti-Money Laundering (AML) compliance are essential.

B-2. Token-Based Retail CBDC: Here, the CBDC resembles a digital cash instrument, stored on digital devices or distributed ledgers, and transferred peer-to-peer via cryptographic authentication. Ownership is verified by token possession rather than identity.

Both retail models directly compete with commercial bank deposits and could significantly affect banking sector structure and liquidity creation.

C. **Wholesale CBDC (wCBDC):** Wholesale CBDCs are restricted-access digital instruments intended for use by commercial banks and selected financial institutions. They are aimed at improving the efficiency of large-value interbank settlements, securities transactions, and cross-border payments.

D. **Hybrid (Intermediated or Two-Tier) CBDC:** A hybrid model combines elements of retail and wholesale CBDCs. While the CBDC remains a direct liability of the central bank, distribution and customer interface are handled by licensed intermediaries such as commercial banks, payment service providers, or fintech firms. The central bank maintains the core infrastructure (ledger), but private agents manage onboarding, wallet provision, KYC/AML, and customer service.

Table 2 provides a summary of the most important similarities and differences between the five types of money in this article.

Table 2
Summary of Key Conceptual Dimensions

Dimension	Retail/Hybrid	Wholesale	Baseline (Cash + Deposits)
Access	General public	Financial institutions only	Cash (public), Deposits (banks)
Form	Account-based or Token-based	Digital account or token	Physical cash and digital bank deposits
Liability	Always central bank	Always central bank	Central bank (cash), Commercial banks (deposits)
Interest-bearing	Possible (especially for accounts)	Rare	Commercial deposits may pay interest
Intermediation	Direct (Retail) or via PSPs (Hybrid)	Banks only	Full commercial bank intermediation
Purpose	Payment efficiency, financial inclusion, competition	Settlement efficiency, systemic risk reduction	Status quo monetary function

Source: Research Results

2.2 Money, CBDC and Welfare: Literature Review

The introduction and adoption of Central Bank Digital Currencies (CBDCs) represent a significant transformation in the structure of monetary systems. Their potential to affect economic welfare stems from various direct and indirect channels. Economic welfare, defined broadly as the overall well-being and utility of individuals within an economy, can be influenced through at least five key channels: (1) efficiency in payments, (2) financial inclusion, (3) monetary policy transmission, (4) financial stability, and (5) privacy and trust.

Efficiency in Payments: CBDCs can improve the efficiency of the payment system by reducing transaction costs, enhancing settlement speed, and increasing competition in the payments sector (Bindseil, 2020; Alfonso et al., 2025). CBDCs offer increased safety, transparency (Ding et al., 2022; Sethaput & Innet, 2023) and efficiency through blockchain's programmability and auditability (Wang et al., 2022; C. Xu et al., 2022; Gupta et al., 2023). The availability of a low-cost, universally accessible digital currency provided by the central bank can reduce reliance on intermediaries and rent-extracting payment platforms (Bordo & Levin, 2017). CBDCs reduce friction in domestic and cross-border transactions by enabling instant, final settlement with low counterparty risk. Lower transaction costs increase real disposable income and consumption, thereby enhancing consumer welfare. CBDCs could cut remittance costs, critical for a region heavily reliant on migrant payments (Alfonso et al., 2025). Also, it has the potential to reduce cross-border payment fees, which is particularly important for remittance-dependent economies in Latin America and the Caribbean (LAC). (Demirgüç-Kunt et al., 2022; Bespalova et al., 2025). A core rationale for the issuance of Central Bank Digital Currencies (CBDCs) lies in their potential to enhance the efficiency of modern payment systems. Existing payment infrastructures are often fragmented, costly, and heavily reliant on proprietary platforms that extract economic rents, especially in oligopolistic retail and cross-border markets. CBDCs, as a publicly provided digital payment instrument, can help mitigate these inefficiencies through several key mechanisms. First, by bypassing intermediaries, CBDCs reduce dependency on commercial banks and fintech firms that typically charge high transaction fees, especially for underserved populations and cross-border remittances (Bindseil, 2020). A universally accessible digital currency issued by the central bank ensures broader inclusion by lowering entry barriers and transaction costs, thereby directly increasing the real disposable income of households. This, in turn, supports higher aggregate consumption and enhances consumer welfare, especially among lower-income groups that are more sensitive to transaction costs (Bordo & Levin, 2017). Second, CBDCs offer the possibility of instant, final settlement—often referred to as "atomic settlement"—which not only accelerates the speed of transactions but also reduces counterparty risk and delays associated with clearing and settlement processes. In traditional systems, multi-day settlement lags (e.g., T+2) introduce liquidity frictions and systemic vulnerabilities. With CBDCs, payments can be executed in real-time gross settlement (RTGS) frameworks, increasing economic velocity and lowering the cost of capital for firms and households (Adrian & Mancini-Griffoli, 2021). Third, CBDCs can stimulate competition in the payments sector by establishing a public benchmark for pricing and service quality. In doing so, they may reduce the dominance of large firms and private digital currencies, such as stablecoins (Alfonso et al., 2025). Moreover, CBDCs can lower cash-handling costs and help weaken monopolistic structures in payment systems (Soderberg, 2022; Bespalova et al., 2025). In monopolistic or duopolistic payment ecosystems dominated by credit card networks or mobile money providers, the introduction of a central bank-issued alternative can discipline excessive rent extraction and reduce platform lock-in effects (BIS, 2021; Brunnermeier et al., 2019). This competitive pressure not only reduces prices but encourages technological innovation, improving the quality and accessibility of payment services. Moreover, by standardizing payment protocols across platforms and borders, CBDCs have the potential to significantly lower cross-border transaction costs. Through the integration of interoperable CBDC infrastructures, central banks could eventually enable faster and more efficient international settlements, while reducing conversion and compliance frictions (Auer et al., 2021).The resulting efficiency gains would benefit not just consumers but also small and medium-sized enterprises (SMEs), facilitating international trade and enhancing global welfare. In sum, CBDCs enhance allocative and operational efficiency in payment systems by minimizing intermediation costs, accelerating settlement, reducing systemic frictions, and fostering competition. These improvements translate into higher consumption, greater inclusion, and more resilient monetary architectures, thereby generating significant welfare dividends for society.

Financial Inclusion: CBDCs can foster financial inclusion by providing unbanked and underbanked populations with access to secure digital payment methods without requiring a commercial bank account (Auer et al., 2020; Bespalova et al., 2025). CBDCs may enhance payment accessibility, though outcomes depend on design (Mancini-Griffoli et al., 2018; Vollmar & Wening, 2024). By offering a no-fee or low-fee digital currency option accessible via mobile devices or offline mechanisms, CBDCs reduce barriers to entry into the formal financial system. Greater access to financial services enhances consumption smoothing, investment in health and education, and resilience to shocks, contributing to improved welfare. CBDC could enhance financial stability by transforming the central bank into a dominant depositor. Unlike small depositors, the central bank internalizes systemic risks and has tools to preempt destabilizing runs.

Mechanisms Through Which CBDCs Enhance Financial Stability: a. Reduction in Maturity Transformation by Banks: The availability of a CBDC offers depositors an alternative to traditional bank deposits, prompting banks to adjust their funding strategies. Specifically, banks may reduce their reliance on short-term deposits to finance long-term loans, thereby decreasing their maturity mismatch. This adjustment lowers the banks' vulnerability to runs, as their obligations are better aligned with their assets. Keister and Monnet (2022) highlight that with access to CBDCs, banks engage in less maturity transformation, reducing exposure to depositor runs. b. Enhanced Monitoring and Early Intervention: CBDCs provide central banks with real-time data on fund flows, enabling timely detection of unusual withdrawal patterns indicative of emerging bank runs. This capability allows central banks to intervene promptly, addressing potential crises before they escalate. The anticipation of such swift interventions can deter depositors from initiating runs, knowing that the central bank is likely to act decisively to maintain stability. c. Provision of a Safe Asset during Financial Stress: In periods of financial uncertainty, CBDCs can serve as a secure store of value, offering the public a risk-free alternative to commercial bank deposits. This function can prevent panic-driven withdrawals from banks, as individuals have confidence in the stability and accessibility of their funds via CBDCs. The Federal Reserve's analysis indicates that CBDCs could provide a stable asset during times of financial stress, potentially mitigating the severity of bank runs. While the potential benefits of CBDCs for financial stability are significant, their realization depends on careful design and implementation. Digital CBDCs can ensure payment continuity during natural disasters when cash infrastructure fails. For instance, they facilitated efficient COVID-19 relief transfers by bypassing physical distribution bottlenecks (Alfonso et al., 2025).

Monetary Policy Transmission: CBDCs may strengthen the effectiveness of monetary policy transmission, particularly in a low interest rate environment, by allowing central banks to implement negative interest rates more effectively or distribute monetary stimulus directly to households (Keister and Sanches, 2021). Theoretical models suggest CBDCs could improve monetary policy transmission (Bindseil, 2020) and bank intermediation (Chiu et al., 2023), especially in low-cash environments. (Vollmar & Wening, 2024). CBDCs offer a digital alternative to declining cash usage (Khiaonarong & Humphrey, 2019) and counter private cryptocurrency threats to monetary sovereignty (Makarov & Schoar, 2021; Brunnermeier & Niepelt, 2019; Vollmar & Wening, 2024). CBDCs allow central banks to bypass intermediaries and interact directly with the public, enabling faster and more targeted policy implementation. Improved policy transmission can stabilize output and inflation more effectively, reducing volatility and uncertainty in the economy, thus increasing welfare. Central Bank Digital Currencies (CBDCs) hold significant potential to enhance the transmission mechanism of monetary policy, particularly under conditions of constrained monetary policy space such as near-zero or negative nominal interest rates (Keister & Sanches, 2021). Traditional monetary policy operates primarily through interest rate adjustments transmitted via the banking system. However, when commercial banks are unwilling or unable to pass negative rates to depositors, or when credit frictions impair lending responsiveness, conventional policy tools lose effectiveness (Brunnermeier & Niepelt, 2019). CBDCs address these transmission frictions through two key mechanisms. First, by allowing central banks to impose interest (including negative rates) directly on CBDC holdings, they circumvent the zero lower bound (ZLB) constraint inherent in cash-based systems (Keister & Sanches, 2021). Unlike physical cash—which provides a zero-yield floor—a programmable CBDC eliminates arbitrage opportunities, strengthening central banks' ability to stimulate demand through real rate adjustments (BIS, 2020). Second, CBDCs enable direct-to-household liquidity injections, bypassing financial intermediaries. During crises (e.g., pandemics or financial collapses), this facilitates faster and more targeted monetary stimulus, accelerating aggregate demand responses and stabilizing output/inflation (Auer et al., 2021). Empirical evidence suggests such direct transfers reduce economic uncertainty and volatility more effectively than conventional credit channels (Bordo & Levin, 2017). Additionally, CBDCs may reduce reliance on inefficient credit markets. By providing households direct access to central bank money, they democratize monetary policy benefits and mitigate financial inclusion asymmetries (Dyson & Hodgson, 2016). This enhances consumption/investment responsiveness to policy changes, improving countercyclical stabilization and reducing distributional disparities in policy effectiveness (Brunnermeier & Niepelt, 2019). CBDC enhances fiscal transparency by digitizing transactions, reducing informal economy leakage. Chinese provinces that piloted CBDC (2014–2021) saw higher tax revenues compared to non-pilot regions, using a difference-in-differences (DiD) analysis. Stronger impact in smaller provinces, suggesting CBDC's scalability benefits for local economies (Umar, 2025).

Financial Stability: Central Bank Digital Currencies (CBDCs) can influence financial stability through multiple and sometimes opposing mechanisms, contingent upon their specific design features, implementation strategy, and integration with the existing financial system. Their net effect on stability depends on how these mechanisms interact under different economic conditions. CBDCs can act as a stabilizing force by providing households and firms with access to a risk-free digital store of value that is backed by the central bank. In times of financial stress—such as banking crises or liquidity shocks—CBDCs can serve as a safe haven asset, mitigating panic-driven behaviors and preserving transactional continuity (Brunnermeier & Niepelt, 2019). COVID-19 and geopolitical sanctions (Boubaker et al., 2023) highlight CBDCs' potential for uninterrupted transactions during disruptions (Gupta et al., 2023). Unlike commercial bank deposits, CBDCs are free from credit risk and liquidity risk, thereby reducing systemic fragility. Moreover, a credible CBDC framework can increase trust in the overall monetary system, reinforcing the credibility of the central bank and dampening contagion effects during crises. CBDCs may also function as a circuit breaker for systemic liquidity shortages. In a well-designed two-tier system, where intermediaries still play a role, CBDCs can provide backup payment channels, enhancing operational resilience and reducing single points of failure in the financial architecture (Bindseil, 2020). Additionally, if designed with limits on individual holdings or tiered remuneration schemes, CBDCs can prevent excessive capital flight from bank deposits while still offering protection for small retail users. Conversely, CBDCs may pose risks to financial stability by undermining the traditional deposit-taking model of commercial banks. Since banks rely heavily on deposits as a low-cost and stable source of funding, widespread substitution of deposits into CBDCs could lead to bank disintermediation, raising banks' funding costs and potentially contracting credit supply to the real economy (Kumhof & Noone, 2018)[1]. In periods of elevated uncertainty, CBDCs could also facilitate digital bank runs, allowing depositors to swiftly move funds from commercial banks into CBDC accounts at minimal transaction cost. This could amplify rather than dampen systemic risk if no countervailing safeguards are in place. The very ease and immediacy of digital withdrawals might accelerate liquidity pressures on banks during market turbulence (Carstens, 2021).

Privacy and Trust: The design of CBDCs inherently raises profound questions about privacy, surveillance, and the evolving role of the state in individuals' financial lives. These concerns are not peripheral but central to the welfare outcomes of any CBDC system, as they directly influence user adoption, behavioral responses, and long-term confidence in the monetary framework. At the core of this debate is the trade-off between individual privacy and regulatory oversight. On one hand, enhancing privacy in digital payments supports users' expectations of financial autonomy and anonymity, features long associated with cash. A CBDC that preserves a high degree of transactional confidentiality can replicate some of the privacy-preserving features of physical currency, thereby fostering greater public trust, adoption, and economic participation (Buzuriu, 2024; Auer & Böhme, 2021). This, in turn, contributes positively to welfare, as trust is a prerequisite for voluntary engagement with digital financial infrastructures. Trust in the integrity,

[1] Dong and Xiao (2024) develop a theoretical model demonstrating that interest-bearing CBDCs can complement rather than displace bank deposits. Their key findings show that higher CBDC interest rates boost investment by encouraging entrepreneurs to deposit idle CBDC balances in banks, which then use these funds for lending. The model reveals that central banks can effectively manage potential disintermediation risks through two policy tools: adjusting the interest rate on reserves and modifying reserve requirement ratios. Importantly, the study finds that CBDC and traditional bank deposits can coexist when central banks strategically calibrate these interest rates, challenging conventional assumptions about CBDC's disruptive effects on banking systems (Dong and Xiao, 2024).

impartiality, and operational transparency of the central bank significantly amplifies the welfare-enhancing potential of CBDCs by reducing transaction frictions and promoting long-term financial planning (BIS, 2021; Agur et al., 2022). Traceable CBDC transactions may help shrink the large informal economy (Alfonso et al., 2025).

On the other hand, extensive surveillance capabilities—even if motivated by legitimate goals such as anti-money laundering (AML), counter-terrorism financing (CTF), or tax compliance—may erode perceived financial freedom. Perceived risks - financial (FR), regulatory (RR), security (SR), and inertia (IRA) - negatively impact trust and adoption (Kuehnlenz et al., 2023; Gupta et al., 2023). Awareness or fear of constant monitoring in one's economic activity can generate behavioral distortions, including reduced participation in formal financial systems, increased use of privacy-enhancing alternatives (e.g., cryptocurrencies), or even complete avoidance of digital currency adoption (Garratt& Oordt, (2021). Such welfare losses arise not only from constrained autonomy but also from the psychological and social costs of diminished informational self-determination. Moreover, differentiated privacy architectures—such as tiered anonymity models or privacy-by-default designs—can offer a middle path between full anonymity and full traceability. These designs may allow low-risk transactions to remain private while enabling conditional data access for high-value or suspicious transactions (Kahn et al., 2018). The credibility of such frameworks depends on legal safeguards, institutional independence, and clear communication strategies, all of which shape the public's perception of surveillance risks versus the benefits of regulatory protection. In sum, the welfare effects of CBDCs are critically mediated by their institutional trustworthiness and perceived privacy protections. A CBDC system that strikes a well-calibrated balance—protecting user privacy while ensuring sufficient oversight—can enhance confidence in the monetary system, improve inclusivity, and strengthen economic resilience. Conversely, poorly designed or overly intrusive CBDC systems may provoke public resistance, reduce adoption, and generate both direct welfare losses and broader socio-political frictions.

Dark side of CBDC: Another perspective on the effects of central bank digital money is that digital money can have a negative impact on welfare through the "Bank Disintermediation and Credit Crunch" channel. If households and firms shift deposits from commercial banks to CBDCs, banks may face funding shortages, leading to reduced credit availability and higher lending rates (Barrdear & Kumhof, 2022; Mancini-Griffoli et al., 2018; Bespalova et al., 2025). This could constrain economic growth, particularly in bank-dependent economies. A 2022 Bank of England study found that even a 15% deposit outflow to CBDCs could force banks to increase loan rates by 50 basis points, reducing investment and consumption (Kumhof & Noone, 2021). In Sweden (a cashless society pilot), concerns arose that an e-krona could crowd out private bank deposits, worsening credit conditions (Sveriges Riksbank, 2023). Empirical data from German banks (2000-2020) shows even 5-15% deposit conversion to CBDC would cause funding shortages and profit declines for deposit-dependent institutions (Burlon et al., 2022). Banks would face higher refinancing costs via interbank/central bank markets (Vollmar & Wening, 2024). Vollmar and Wening (2024) analyzes how CBDCs could affect deposit-dependent banks using unique data from German savings and cooperative banks. The findings reveal that even moderate deposit conversions to CBDC would have caused funding shortages and profit declines for most banks since 2000. The research provides valuable insights for commercial banks to assess CBDC's liquidity and profitability impacts, while helping central banks evaluate implementation costs across different interest rate scenarios. The results highlight significant challenges for traditional banking models in a CBDC environment (Vollmar and Wening, 2024). The development of central bank digital money could also lead to privacy erosion and reduced trust in money. A fully traceable CBDC could enable excessive government surveillance, discouraging usage and undermining monetary trust (Auer & Böhme, 2021). Privacy concerns hinder adoption (Tronnier & Qiu, 2024; Gupta et al., 2023). Public consultations and official assessments by the ECB indicate that a lack of cash-like privacy would be a primary dealbreaker for citizens. As highlighted by Panetta (2023), ensuring high privacy standards is a fundamental prerequisite; otherwise, the public will likely reject the digital euro (ECB, 2021, 2023; Panetta, 2023). If citizens perceive CBDCs as a tool for financial repression, they may revert to informal or foreign currencies, reducing monetary policy effectiveness. For instance, China’s digital yuan (e-CNY) has faced public hesitation and slow adoption, largely driven by privacy concerns and fears of pervasive state monitoring (Prasad, 2021; Chorzempa, 2022). A 2023 ECB survey found that 65% of EU citizens would reject a CBDC if it lacked cash-like privacy (Panetta, 2023). Macroeconomic Instability from Sudden CBDC runs could trigger macroeconomic instability. Unlike bank deposits (which have withdrawal limits), CBDCs allow instantaneous mass conversions out of commercial banks during crises, exacerbating bank runs (BIS, 2021). This could trigger financial instability, requiring costly bailouts. The 2023 U.S. banking crisis (Silicon Valley Bank collapse) showed how digital withdrawals can accelerate bank failures (FDIC, 2023). A BIS (2023) simulation found that unlimited CBDC holdings could increase systemic risk by 30% in stress scenarios. Paradoxically, central bank digital currencies (CBDCs) could lead to reduced financial inclusion. While they aim to improve access, digital divides (e.g., lack of internet connectivity) may exclude vulnerable populations, thereby exacerbating inequality (World Bank, 2021). Empirical evidence from Nigeria's eNaira shows extremely limited adoption among the unbanked population—often cited in single digits—primarily due to severe technological barriers such as low smartphone penetration and lack of internet access (Ree, 2023). India's digital rupee saw lower rural uptake compared to urban areas (RBI, 2023). Despite usefulness (PU), technological unfamiliarity may delay acceptance, as seen in India's partial mediation effect of trust (TAM model results) (Gupta et al., 2023). Foreign CBDCs/stablecoins could threaten monetary sovereignty (Alfonso et al., 2025). Crypto adoption may exacerbate currency substitution, capital flight, and tax evasion in LAC's vulnerable economies (Bespalova et al., 2025). "Digital dollarization" if foreign CBDCs undermine local currencies (CPMI, 2021; Bespalova et al., 2025). Dual currency systems may create operational complexities (Hong et al., 2018). Anonymity could enable money laundering (Bespalova et al., 2025; Auer et al., 2020). Anonymity features could facilitate corruption and informal transactions (Bespalova et al., 2025). The "CBDC trilemma" identifies tradeoffs between efficiency, stability, and price control (Schilling et al., 2020). Uneven reserve distribution and liquidity frictions could amplify risks (Adalid et al., 2022; Vollmar & Wening, 2024). Studies also show that a lack of real-world data from major economies creates uncertainty (Whited et al., 2022). Case studies from smaller adopters (Bahamas, Nigeria) may not scale to larger banking systems (Atlantic Council, 2022; Vollmar & Wening, 2024).

So in summary we can see that, Central Bank Digital Currencies (CBDCs) have the potential to significantly enhance economic welfare by improving payment efficiency, fostering financial inclusion, and strengthening monetary policy transmission. However, if not carefully designed, they could also introduce financial instability, such as bank disintermediation, liquidity risks, and threats to monetary sovereignty. The key challenge lies in structuring CBDCs with optimal features—such as interest-bearing mechanisms, tiered accessibility, and interoperability with private payment systems—to maximize their benefits while mitigating adverse effects. Policymakers must strike a delicate balance between innovation and stability, ensuring that CBDCs complement rather than disrupt existing financial ecosystems.

Ultimately, the success of CBDCs will depend on their ability to adapt to diverse economic contexts while safeguarding financial resilience.

3 Model

This paper develops and analyzes a New Keynesian Dynamic Stochastic General Equilibrium (DSGE) model to evaluate the steady-state welfare implications of introducing various forms of Central Bank Digital Currency (CBDC). The model incorporates several standard features, including capital accumulation with adjustment costs, external habit formation in consumption, monopolistic competition in goods markets leading to price markups, endogenous labor supply, a government sector with debt and distortionary labor taxation, simplified imperfect competition in banking deposit markets, and a Money-in-the-Utility (MIU) framework to capture potential liquidity services from cash and CBDC[1].

The economy is populated by a representative infinitely-lived household that maximizes expected lifetime utility subject to an intertemporal budget constraint. The representative household maximizes its expected lifetime utility:

$$E_0 \sum_{t=0}^{\infty} \beta^t U(C_t, C_{t-1}, N_t, \frac{M_t}{P_t}, \frac{M_t^{cbdc}}{P_t})$$

The period utility function U(.) is assumed to be additively separable:

$$U = \frac{(C_t - hC_{t-1})^{1-\sigma}}{1-\sigma} - \chi_n \frac{N_t^{1+\phi}}{1+\phi} + \chi_m \frac{\left(\frac{M_t}{P_t}\right)^{1-\nu_m}}{1-\nu_m} + \chi_{cbdc} \frac{\left(\frac{M_t^{cbdc}}{P_t}\right)^{1-\nu_{cbdc}}}{1-\nu_{cbdc}}$$

C_t, Consumption of the final good at time t; N_t, Hours worked; $\frac{M_t}{P_t}$: Real cash balances; $\frac{M_t^{cbdc}}{P_t}$: Real CBDC balances (active in relevant scenarios); $\beta \in$

[1] The current framework is intentionally designed as a simplified baseline model to capture the primary transmission channels of retail CBDC issuance under a fiscal constraint. Given that the macroeconomic implications of digital currency are still largely unexplored in the quantitative literature, this study provides a foundational structure that future research can build upon. More specifically, the model can be extended to incorporate richer fiscal feedback mechanisms, sovereign debt accumulation, heterogeneous households, financial sector frictions, and cross-country differences in digital currency adoption. Therefore, the present model should be viewed not as an exhaustive representation of the economy, but rather as a rigorous starting point that opens the path for continued theoretical development and empirical calibration as more comprehensive data become available.

(0,1), Subjective discount factor; $h \in [0,1)$: External habit formation parameter; $\sigma > 0$ Coefficient of relative risk aversion (inverse of the intertemporal elasticity of substitution for consumption); If $\sigma = 1$, the consumption term becomes $ln\ (C_t - hC_{t-1})$; $\chi_n > 0$ Weight on the disutility of labor. This parameter is calibrated.

$\phi > 0$ Inverse of the Frisch elasticity of labor supply; $\chi_m > 0$ Weight on the utility derived from real cash balances; $\chi_{cbdc} > 0$ Weight on the utility derived from real CBDC balances (scenario-dependent, $\chi_{cbdc} = 0$ if CBDC is inactive or provides no direct utility); $\nu_m > 0, \nu_{cbdc} > 0$ Parameters governing the curvature of utility with respect to real balances (related to the interest elasticity of money demand); If $\nu_x = 1$, the term becomes logarithmic, $\ln \frac{X_t}{P_t}$.

The household faces a sequence of flow budget constraints:

$$P_tC_t + P_tI_t + B_t + M_t + D_t + M_t^{cbdc} \leq W_t^{gross}N_t + R_{k,t}K_{t-1} + D_{iv_t} + (1 + i_{t-1})B_{t-1} + \left(1 + i_{d,t-1}\right)D_{t-1} + \left(1 + i_{cbdc,t-1}\right)M_{t-1}^{cbdc} + M_{t-1} - T_t^{total}$$

where: P_t Price level of the final good; I_t: Investment expenditure; B_t, M_t, D_t, M_t^{cbdc}: Nominal end-of-period holdings of government bonds, cash, bank deposits, and CBDC, respectively; W_t^{gross}: Gross nominal wage rate paid by firms; K_{t-1} Capital stock decided at $t - 1$; $R_{k,t}$ Nominal rental rate for capital services paid by firms; D_{iv_t} Nominal dividends received from firms and banks; i_{t-1}, $i_{d,t-1}$, $i_{cbdc,t-1}$: Nominal interest rates on bonds, deposits, and CBDC from t-1 to t.

T_t^{total} Total nominal taxes paid by the household. We assume

$$T_t^{total} = \tau_{n,t}W_t^{gross}N_t + P_tT_{lump,t}$$

Where $\tau_{n,t}$, is the proportional labor income tax rate and $T_{lump,t}$ are lump-sum taxes/transfers.

Capital accumulates according to:

$$K_t = (1 - \delta)K_{t-1} + I_t\left[1 - S\left(\frac{I_t}{I_{t-1}}\right)\right]$$

with investment adjustment costs $S(x) = \frac{\emptyset_I}{2}(x - 1)^2$, where δ is the depreciation rate and $\emptyset_I \geq 0$ governs the cost magnitude.

Final Good Producers: Perfectly competitive firms aggregate differentiated intermediate goods $Y_t(j)$ using a standard CES aggregator with elasticity of substitution $\epsilon_p > 1$

$$Y_t = [\int_0^1 Y_t(j)^{\frac{\epsilon_p - 1}{\epsilon_p}} dj]^{\frac{\epsilon_p}{\epsilon_p - 1}}$$

Profit maximization yields the demand for each intermediate good j:

$$Y_t(j) = (\frac{P_t(j)}{P_t})^{-\epsilon_p} Y_t$$

The zero-profit condition yields the aggregate price level:

$$P_t = [\int_0^1 P_t(j)^{1-\epsilon_p} dj]^{\frac{1}{1-\epsilon_p}}$$

Intermediate Good Producers A continuum of firms indexed by $j \in [0,1]$, each producing a differentiated good $Y_t(j)$ under monopolistic competition.

Objective: Maximize the present discounted value of profits:

$$\max E_0 \sum_{t=0}^{\infty} \beta^t (\frac{\Lambda_t}{\Lambda_0}) \Pi_t(j)$$

Where $\Pi_t(j) = P_t(j) Y_t(j) - W_t^{gross} N_t(\mathrm{j}) + R_{k,t} K_{t-1}(j)$

The constraint is given by the following production function: $Y_t(j) = A_t K_{t-1}(j)^{\alpha} N_t(\mathrm{j})^{1-\alpha}$; We assume $A_t = A$ is constant in the steady state.

FOCs (Factor Demand): Firms minimize costs by setting the marginal rate of technical substitution equal to the factor price ratio, and hiring factors until marginal products equal real factor prices divided by the real marginal cost: $MC_{real,t} = \frac{MC_t}{P_t}$.

$$\frac{W_t^{gross}}{R_{k,t}} = \frac{MPL(j)}{MPK(j)}$$

$$W_t^{gross} = MC_t * MPL(j) = MC_t * (1-\alpha) \frac{Y_t(j)}{N_t(\mathrm{j})}$$

$$R_{k,t} = MC_t * MPK(j) = MC_t * \alpha \frac{Y_t(j)}{K_{t-1}(j)}$$

Pricing: In a dynamic setting with Calvo pricing, firms that can reset prices choose $P_t^*(j)$optimally. In steady state, all firms set the same price, $P(j) = P$, which is a constant markup $\mu_p = \frac{\epsilon_p}{\epsilon_p - 1}$ over the nominal marginal cost MC. So, $P = \mu_p * MC \rightarrow MC_{real} = \frac{1}{\mu_p}$.

Commercial Banks (Simplified) Banks are modeled implicitly as setting the deposit rate i_d with a markup $\mu_d > 1$ over the risk-free policy rate, reflecting imperfect competition or other frictions.

$$i_d + 1 = (\frac{1}{\mu_d})(1 + i)$$

The markup μ_d is assumed to be potentially affected by the presence and type of CBDC (lower μ_d with more competition).

Government spending G is assumed to be a constant fraction of steady-state output Y:

$$G = G_Y^{ratio} Y$$

where G_Y^{ratio} is the government spending-to-GDP ratio.

The government issues nominal bonds B_t and targets a constant steady-state debt-to-GDP ratio $b_y^{target} = \frac{(B/P)}{Y}$. In steady state, assuming the price level $P = 1$, this simplifies to: $b_y^{target} Y = B$

The government finances spending G and interest payments on debt iB using labor income taxes $T_n = \tau_n W^{gross} N$ and potentially lump-sum taxes, T_{lumb}. We assume $T_{lump} = 0$ in steady state. The labor tax rate τ_n adjusts endogenously to satisfy the government budget constraint in steady state.

$$G + iB = \tau_n W^{gross} N$$

Substituting $B = b_y^{target} Y$ and, $W^{gross} = W_{real} P (with\, P = 1)$, the steady-state budget constraint becomes: $G_Y^{ratio} Y + i b_y^{target} Y = \tau_n W_{real} N$.

In the steady state, the central bank sets the nominal policy interest rate i to be consistent with the household's intertemporal Euler equation and a zero inflation target:

$$i + 1 = \frac{1}{\beta}$$

This ensures no arbitrage in household saving behavior in the steady state.

In scenarios where the CBDC is interest-bearing, the central bank sets the nominal CBDC rate i_{cbdc} relative to the policy interest rate, incorporating a fixed spread:

$$i_{cbdc} = \max(0, i + i_{cbdc-spread}^{fixed})$$

This specification ensures the CBDC interest rate remains non-negative and can reflect policy design choices.

In this model, transaction costs are introduced as a simple proportional loss of output due to frictions in the payment system. Specifically, a constant fraction $\tau \in (0,1)$, denoted by the parameter τ, is assumed to be lost from total output Y in each period due to transaction inefficiencies. This implies: $TC = \tau Y$

The parameter τ is scenario-dependent and can vary across simulations. In particular, it may be lower in scenarios with Central Bank Digital Currency (CBDC), reflecting the assumption that CBDC improves payment efficiency and reduces transaction costs.

steady-state

A steady-state equilibrium consists of constant allocations and prices that simultaneously satisfy the optimality conditions of households and firms, market clearing conditions, and the constraints of the government, banks, and central bank. The variables are:

Allocations:$\{C, N, K, Y, I, G, TC, B, M_{real}, D_{real}, CBDC_{real}\}$
And, Prices/Rates is: $\{W_{real}, RK_{real}, i, i_d, i_{cbdc}, \Lambda, Q = 1, \tau_n\}$

Table 3
Steady-State Equilibrium Definition

Household Optimality Conditions	
Euler Equation for Bonds	$1 = \beta(1 + i)$
Euler Equation for Capital	$RK_{real} = (1/\beta) - (1 - \delta)$
Labor-Leisure Trade-off	$\chi_n N^{\phi} = \Lambda(1 - \tau_n)W_{real}$
Money Demand Condition	$\Lambda \cdot i = \chi_m M_{real}^{-\nu_m}$
CBDC Demand Condition if $\boldsymbol{\chi_{cbdc} > 0}$	$\Lambda \cdot (i - i_{cbdc}) = \chi_{cbdc} \cdot CBDC_{real}^{-\nu_{cbdc}}$
Marginal Utility of Consumption	$\Lambda = U_C(C, parameters)$
Firm Optimality Conditions	
Production Function	$Y = AK^{\alpha}N^{1-\alpha}$
Marginal Product of Capital	$MPK = \alpha \cdot (Y/K)$
Marginal Product of Labor	$MPL = (1 - \alpha) \cdot (Y/N)$
Factor Prices under Markup	$W_{real} = (MPL/\mu_p), RK_{real} = (MPK/\mu_p)$
Bank Behavior	
Gross Deposit Interest Rate	$1 + i_d = (1/\mu_d)(1 + i)$
Government Budget Constraint and Fiscal Rule	
Public Spending (proportional to output)	$G = G_Y^{ratio}Y$
Public Debt Target (constant debt-to-GDP ratio)	$b_y^{target}Y = B$
Budget Constraint	$G + iB = \tau_n W_{real} N$
Central Bank Policy	
Policy Rate Rule	$i + 1 = (1/\beta)$
CBDC Interest Rate	$i_{cbdc} = \max(0, i + i_{cbdc-spread}^{fixed})$
lump-sum tax	*0*
Definitions and Market Clearing Conditions	
Investment	$I = \delta K$
Transaction Costs	$TC = \tau Y$
Goods Market Clearing	$Y = C + G + I + TC$

Source: Research Findings

3.1 Explanation of CBDC Scenarios Modeled

The analysis compares a baseline Conventional monetary system with four distinct Central Bank Digital Currency (CBDC) scenarios. These scenarios differ primarily in how CBDC interacts with households and the financial system, which is captured through specific parameter variations within the DSGE model structure. The key differentiating factors are household access, CBDC characteristics (interest-bearing, utility), impact on bank competition, and impact on overall payment system efficiency.

- **Scenario 1, Conventional:** This is the baseline scenario representing the current system with physical cash and commercial bank deposits as the primary means of payment and store of value available to households. It serves as the benchmark against which CBDC scenarios are evaluated. In this scenario, no CBDC is active. The model uses baseline parameters for bank competition and transaction costs. The utility weight for CBDC is zero, while the weight for cash is at its baseline positive value.

- **Scenario 2, Retail CBDC (Account):** This scenario assumes a direct account-based CBDC provided by the central bank to households and firms. It is often envisioned as a highly efficient digital payment instrument and potentially interest-bearing. In this scenario, Households have access to CBDC. It is assumed to provide significant direct liquidity/convenience utility (χ_{cbdc} is set to a relatively high positive value, e.g., 0.08). It potentially substitutes for cash, so the utility weight of cash (χ_m) is assumed lower than baseline (e.g., 0.05). It can bear interest close to the policy rate ($i_{cbdc-spread}^{fixed}$ is small and negative, e.g., -0.001). Crucially, it is assumed to significantly increase competition in the banking sector, leading to a *very low* μ_d (e.g., 1.005, close to perfect competition). It is also assumed to be highly efficient, resulting in a *very low* transaction cost parameter (τ, e.g., 0.002).
- **Scenario 3, Retail CBDC (Token):** This represents a token-based CBDC, potentially offering more anonymity (like digital cash) but typically assumed to be non-interest-bearing and perhaps slightly less convenient or efficient for certain transactions compared to an account-based system. In this scenario, Households have access CBDC. It provides direct utility, but potentially less than the account version (χ_{cbdc} is positive but lower, e.g., 0.04). It substitutes less for cash (χ_m is reduced from baseline but higher than in the Account scenario, e.g., 0.07). It is explicitly non-interest-bearing ($i_{cbdc-spread}^{fixed}$ is set to $[-i^{ss}]$ to yield, $i_{cbdc} = 0$). It exerts less competitive pressure on banks than the account version, resulting in a *moderately lower* μ_d (e.g., 1.02). Its efficiency is better than conventional but less than account-based, reflected in a *moderately low* τ (e.g., 0.005).
- **Scenario 4, Wholesale CBDC:** This framework involves a CBDC restricted to commercial banks and other large financial institutions for interbank settlements and wholesale payments. Because households do not interact with it directly, they lack access to the CBDC, resulting in zero direct utility ($\chi_{cbdc} = 0$). Cash utility (χ_m) remains at baseline. Any benefits are assumed to be indirect, potentially improving interbank efficiency. In this specific parameterization, it was modeled with the *same*

μ_d (1.03) and τ (0.008) as the conventional scenario, implying *negligible assumed pass-through* of efficiency gains to the wider economy.

- **Scenario 5, Hybrid CBDC:** This represents a two-tier model where the central bank issues the CBDC liability, but household access and use it via private sector intermediaries (banks, payment service providers). In this scenario, Households have access to CBDC. It provides direct utility (χ_{cbdc} positive, potentially lower than direct Retail Account due to intermediation, e.g., 0.06). It substitutes for cash (χ_m reduced, e.g., 0.06). It can be interest-bearing, but the net rate received by users might be affected by intermediaries ($i_{cbdc-spread}^{fixed}$ is slightly more negative than Retail Account, e.g., -0.002). It increases bank competition, but perhaps less than a direct retail account model as incumbent banks retain a role (μ_d is low but higher than Retail Account, e.g., 1.01). Payment efficiency is high, but potentially slightly lower than the direct model (τ is low but higher than Retail Account, e.g., 0.004).

Table 4
Key Differentiating Parameter Values across Scenarios

Parameter	Conventional	Retail (Account)	Retail (Token)	Wholesale	Hybrid
CBDC Active for household	False	True	True	False	True
CBDC Utility Weight χ_{cbdc}	0.0	0.08	0.04	0.0	0.06
Cash Utility Weight χ_m	0.1	0.05	0.07	0.1	0.06
CBDC Interest Spread $i_{cbdc-spread}^{fixed}$	-0.0025	-0.001	(≈-0.01)*	-0.0025	-0.002
Bank Deposit Markup μ_d	1.03	1.005	1.02	1.03	1.01
Transaction Cost τ	0.008	0.002	0.005	0.008	0.004

Note: Values are based on the final Python code provided.$-i^{ss} \approx 0.0101$. The specific numerical values chosen are illustrative and represent strong assumptions about the relative impacts, particularly the large benefits assumed for the Retail Account scenario. Source: Research Findings.

Table 5 also shows the values of other model parameters.

Table 5

Baseline Model Parameter Calibration

Parameter Name	Symbol	Value	Source
Preferences			
Subjective Discount Factor	β	0.99	Standard quarterly calibration (e.g., Smets & Wouters, 2007)
Risk Aversion (IES Inverse)	σ	1.5	Common value in range [1, 2] (e.g., Christiano et al., 2005)
Inverse Frisch Elasticity	φ	2.0	Mid-range value from macro-labor literature
Labor Disutility Weight	χ_n	40.419	Calibrated internally to target N ≈ 0.33
Habit Formation Parameter	h	0.7	Common estimate (e.g., Smets & Wouters, 2007; CEE, 2005)
Cash Elasticity Parameter	ν_m	1.0	Assumption (Log Utility form)
Technology & Production			
Capital Share	α	0.33	Standard value based on national accounts
Capital Depreciation Rate	δ	0.025	Standard quarterly value (10% annual) (e.g., CEE, 2005)
Total Factor Productivity (Scale)	A	1.0	Normalization
Elasticity of Subst. (Goods)	ϵ_p	6.0	Implies 20% price markup (Smets & Wouters, 2007)
Investment			
Investment Adj. Cost Parameter	$\emptyset_I$	2.5	Common value (e.g., Christiano et al., 2005)
Government			
Gov. Spending / GDP Ratio	G/Y	0.20	Standard Calibration
Target Debt / GDP Ratio	B/Y	0.60	Standard Target

Source: Research Findings

4 Results

This section describes the results of the steady-state model simulation. First, it compares the scenarios in the steady state, and then presents a sensitivity analysis for each scenario based on changes in parameter values.

4.1 Steady State

Figure 3 presents the steady-state equilibrium levels of real money balances held by the representative household under alternative monetary policy regimes, with a comparative visualization of real cash holdings (M/P, light blue bars) and real Central Bank Digital Currency (CBDC) holdings (CBDC/P, light red bars). These asset allocations are endogenously determined within a Money-in-the-Utility (MIU) framework, where, in equilibrium, the marginal utility of holding each monetary instrument must equal its respective opportunity cost. Specifically, the opportunity cost of cash is the nominal policy interest rate (i), while for CBDC it is given by the spread between the policy rate and the CBDC interest rate ($i - i_{cbdc}$). Under both the Conventional and Wholesale CBDC scenarios, households exclusively hold real cash balances, with no demand for CBDC. Real cash holdings are identical across these regimes—approximately 2.2 units—reflecting the absence of a retail-accessible CBDC in either case ($\chi_{cbdc} = 0$). This outcome is consistent with a setting in which physical cash remains the sole liquid monetary instrument, and its holdings are optimized based on its utility weight (χ_m), elasticity (ν_m), and its opportunity cost (i). The equivalence of outcomes between these two scenarios further suggests that any indirect effects of a wholesale CBDC—via marginal changes in banking sector costs or markups—do not significantly affect the household's marginal utility of income (Λ) or the cost of holding money in this calibration. In contrast, the Retail CBDC (Account-based) scenario introduces a profound reallocation in the household's liquidity portfolio. Real cash balances fall markedly to roughly 1.1 units, while CBDC holdings surge to an unprecedented level of approximately 17.5 units. This drastic substitution is the result of three jointly powerful assumptions: a steep reduction in the utility weight on cash ($\chi_m = 0.05$), capturing a diminished role for physical currency; a high utility weight on CBDC ($\chi_{cbdc} = 0.08$), indicating strong user preference; and a near-zero opportunity cost, achieved by setting the CBDC interest rate only slightly below the policy rate ($i^{fixed}_{cbdc-spread} = -0.001$). Together, these assumptions produce a setting in which the marginal utility from holding CBDC far exceeds its opportunity cost, inducing households to hold large quantities of it. Simultaneously, the reduced attractiveness and unchanged cost of cash suppress its demand. This configuration illustrates the high substitution potential of a well-designed, interest-bearing, account-based CBDC, which can effectively displace physical cash in equilibrium. The Hybrid CBDC scenario yields intermediate results, with real cash holdings declining to about 1.3 units and CBDC balances reaching 6.7 units. This reflects a more balanced policy design, where the CBDC is endowed with a moderate utility weight ($\chi_{cbdc} = 0.06$) and pays an interest rate slightly further below the policy rate (spread = −0.002). Cash retains some utility ($\chi_m = 0.06$), though lower than in the baseline. These parameters result in partial substitution: the CBDC offers sufficient utility and favorable remuneration to encourage uptake, but to a lesser extent than the pure Retail Account version. Consequently, both instruments coexist in the household's liquidity portfolio, with CBDC displacing cash only partially. Finally, the Retail CBDC (Token-based) scenario shows a modest rebalancing. Real cash balances fall slightly to around 1.5 units, and CBDC holdings are positive but very limited, amounting to just 0.8 units. This restrained adoption pattern aligns with the design of a non-interest-bearing digital cash substitute. With $i_{cbdc} = 0$, the opportunity cost of holding token-based CBDC is equivalent to that of cash (equal to i). Moreover, its utility contribution is modest ($\chi_{cbdc} = 0.04$), and cash remains relatively attractive ($\chi_m = 0.07$). In such a configuration, households derive some marginal benefit from the CBDC, leading to minimal adoption, but the high opportunity cost and limited utility prevent it from becoming a dominant monetary instrument. Cash remains a more prevalent store of liquidity in this setting, though some displacement occurs. In summary, the figure illustrates the profound sensitivity of household portfolio choices to CBDC design features within the MIU framework. Interest remuneration and perceived utility—captured respectively by the opportunity cost ($i - i_{cbdc}$) and utility weights (χ_{cbdc}, χ_m)—are pivotal determinants of CBDC uptake. The account-based CBDC scenario demonstrates the potential for extensive substitution away from physical cash when the CBDC is perceived as highly beneficial and has a near-zero holding cost. Conversely, token-based CBDCs, which resemble digital analogues of cash with no interest and modest utility, generate only marginal shifts in money holdings. Hybrid designs fall between these extremes, producing partial reallocation depending on the attractiveness of the CBDC features intermediated to the user. These findings underscore the importance of careful calibration of CBDC parameters, particularly in relation to their utility yield and opportunity cost, when assessing their potential macroeconomic and monetary policy implications.

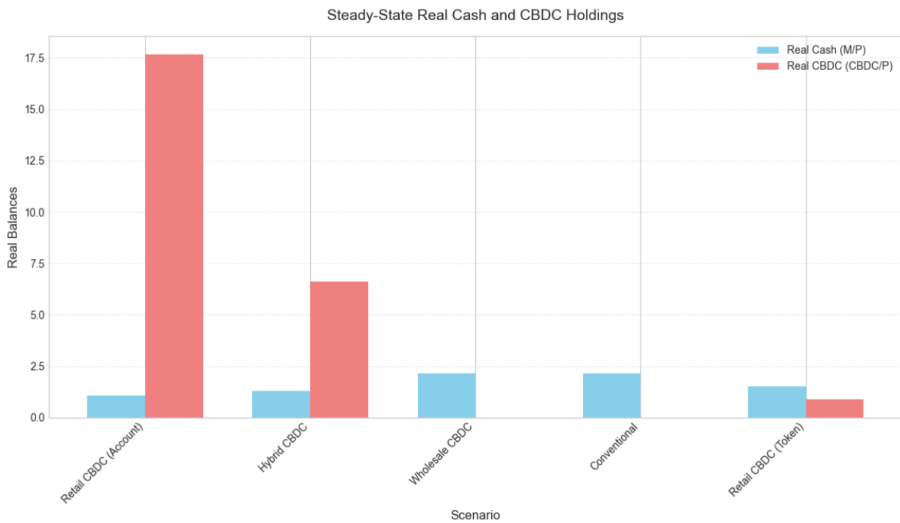

Figure 3. Steady-State Real Cash and CBDC Holdings
Source: Research Findings

Figure 4 presents a radar chart that offers a comprehensive visual comparison of the steady-state macroeconomic performance across various Central Bank Digital Currency (CBDC) implementation scenarios, benchmarked against the Conventional monetary system. The Conventional baseline scenario, plotted as a collapsed shape at the radar chart's center, serves as the reference point. By construction, it scores zero on all axes, enabling an intuitive assessment of net gains associated with alternative CBDC architectures. Among these alternatives, the Retail CBDC in an account-based form (depicted by the blue line) exhibits the most favorable outcomes, consistently achieving near-maximum or maximum scores across nearly all dimensions. It offers the highest consumption-equivalent welfare gain (CE%), substantial reductions in real transaction costs as a share of GDP (TC Saving), and a marked decline in banking sector markup (Competition Gain), alongside a significant reduction in distortionary labor taxes. These superior outcomes are largely attributable to highly favorable design assumptions embedded in the model: namely, the near-elimination of bank deposit markups and a minimal transaction cost parameter. These features jointly amplify economic efficiency and output, broadening the fiscal base and thereby enabling both tax reduction and improved household welfare. As a secondary but important effect, these compounded gains allow households to allocate some benefits toward increased leisure, leading to a substantial positive score in the Leisure Gain dimension. The Hybrid CBDC model, represented by the green line, also performs strongly across most axes, consistently ranking second after the Retail Account-based model. While it delivers slightly smaller gains in efficiency and market competition, it nonetheless provides significant welfare improvements. Interestingly, the Hybrid model yields the highest score in terms of Leisure Gain, which may reflect a favorable balance between increased efficiency and a moderated expansion in output, allowing households to substitute labor for leisure more effectively. The relative moderation in tax relief and welfare gain underscores the Hybrid model's partially intermediary-based structure, which limits the full extent of pro-competitive dynamics compared to a direct account-based implementation. In contrast, the Retail CBDC in token-based form (illustrated by the cyan line) demonstrates only moderate improvements across the performance dimensions. While it does achieve positive results in transaction cost reduction and market competition, the overall gains are significantly smaller than those of the Account and Hybrid scenarios. The token-based model generates a modest welfare improvement and displays the lowest leisure gain among all scenarios offering improvements. This outcome aligns with the theoretical characterization of token-based CBDC as non-interest-bearing and potentially less efficient or user-friendly than account-based alternatives. The limited reductions in the relevant model parameters (bank markups and transaction costs) constrain its ability to stimulate economic activity and welfare meaningfully. Consequently, the token model appears to channel its minor gains more into consumption than leisure or fiscal space expansion. Finally, the Wholesale CBDC scenario, shown in brown or dark grey and located near the radar chart's origin, offers negligible improvements over the Conventional baseline across all dimensions. This muted performance is a direct result of the model's calibration, wherein Wholesale CBDC does not engage directly with households and is assumed to generate minimal or zero transmission of efficiency gains to the broader economy. In this configuration, neither the banking markup nor the transaction cost parameters differ significantly from the baseline, thereby nullifying potential gains in welfare, efficiency, competition, or fiscal outcomes. Overall, the radar chart facilitates a nuanced, multidimensional evaluation of the comparative macroeconomic impacts of different CBDC designs. In summary, the radar chart illustrates a clear ranking of scenarios: Retail Account-based CBDC emerges as the most transformative under optimistic assumptions, followed by Hybrid, Token, and Wholesale. The results highlight how the design of CBDC—and the strength of its associated efficiency and competition channels—critically determines its welfare impact. The complementary sensitivity heatmaps should be consulted to assess the robustness of these outcomes to alternative calibrations of key structural parameters.

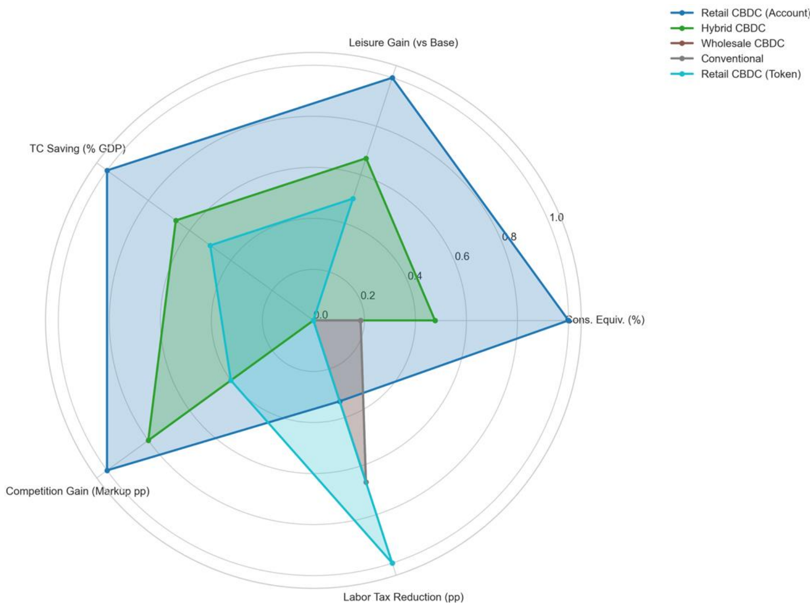

Figure 4. Comparative Scenario Analysis of CBDC Implementations

Note: <u>Cons. Equiv. (%):</u> The primary measure of overall welfare gain, expressed as the percentage increase in permanent consumption required for the household in the Conventional scenario to achieve the welfare level of the alternative scenario. Higher values indicate greater welfare gains. <u>Leisure Gain (vs Base):</u> Calculated as the percentage point decrease in steady-state labor supply (N) compared to the Conventional baseline (-ΔN pp). A higher value signifies more leisure time enjoyed by households, which enhances welfare. <u>TC Saving (% GDP):</u> The reduction in real transaction costs as a percentage of GDP, compared to the Conventional baseline's TC/GDP ratio. A higher value indicates greater improvements in payment system efficiency. <u>Competition Gain (Markup pp):</u> The reduction in the bank deposit markup (μ_d) in percentage points compared to the Conventional baseline. A higher value implies greater pro-competitive effects exerted by the CBDC scenario. <u>Labor Tax Reduction (pp):</u> The reduction in the endogenously determined steady-state labor tax rate (τ_n) in percentage points compared to the Conventional baseline. A higher value signifies lower distortionary taxation required to meet the government budget constraint, which is welfare-improving. Source: Research Findings

4-1-1- Conclusion from Numerical Results

Table 6 presents a detailed summary of steady state outcomes for five alternative monetary scenarios simulated within the MIU Markup Dynamic Stochastic General Equilibrium (DSGE) model. All reported percentage and percentage point (pp) changes are expressed relative to the Conventional scenario baseline, allowing for a clear assessment of relative performance across key macroeconomic indicators.

The results reveal a clear welfare ranking among the scenarios. The Retail CBDC in its account-based form yields the highest welfare improvement, equivalent to a permanent consumption gain of 11.13% relative to the Conventional baseline. This is followed by the Hybrid CBDC, which delivers a notable 6.04% welfare gain. The Retail CBDC in token-based form offers a more modest welfare increase of 1.40%, while the Wholesale CBDC and Conventional scenarios yield nearly identical welfare levels. The welfare differences across scenarios align closely with the key structural drivers of efficiency in the model: reductions in bank deposit markups and transaction costs. The Retail Account scenario assumes the most aggressive improvements on these fronts—a 2.5 percentage point decrease in deposit markups and a 0.6% reduction in transaction costs as a share of GDP. These strong pro-competitive and efficiency-enhancing assumptions directly translate into higher consumption and leisure, and ultimately greater household utility. The Hybrid CBDC scenario follows closely with assumed reductions of 2.0 pp in markups and 0.4% in transaction costs, producing a similarly robust welfare gain. The Retail Token scenario, with only moderate improvements in these dimensions (1.0 pp markup reduction and 0.3% TC saving), generates correspondingly lower welfare benefits. These findings emphasize that welfare improvements in the model are tightly linked to increased payment efficiency and enhanced market competition. The labor supply responses also reinforce the welfare ranking. Scenarios with higher welfare gains are associated with declines in steady-state labor input, indicating that households choose to allocate a portion of their gains toward increased leisure. The largest decline in labor supply is observed under the Retail Account scenario, with a 0.142 percentage point reduction relative to the baseline. The Hybrid and Token scenarios follow with smaller declines of 0.095 pp and 0.071 pp, respectively. The reallocation of time from work to leisure in the top-performing scenarios further underscores the strength of the underlying efficiency gains.

Finally, the absolute levels of labor supply, consumption, and welfare offer context to the relative metrics. The calibrated labor supply hovers around the target of 0.33, while consumption increases in line with welfare gains. As expected with a CRRA utility specification, the absolute welfare levels are negative, but their relative magnitudes align with the CE% ranking.

Table 6

Steady-state outcomes and tangible performance indicators for the scenarios

Scenario	Cons. Equiv.	Delta N	TC Saving	Markup Reduct.	N	C	Welfare
Retail CBDC (Account)	11.129	-0.142	0.600	2.500	0.329	0.546	-5.189
Hybrid CBDC	6.036	-0.095	0.400	2.000	0.329	0.545	-5.301
Wholesale CBDC	3.200	-0.000	0.000	0.000	0.330	0.543	-5.366
Conventional	0.000	0.000	0.000	0.000	0.330	0.543	-5.366
Retail CBDC (Token)	1.398	-0.071	0.300	1.000	0.330	0.544	-5.409

Note: Cons. Equiv. (%): Consumption Equivalent welfare gain relative to the Conventional baseline (%). Higher values indicate greater welfare improvement. Delta N (pp): Change in steady-state labor supply (N) relative to Conventional (percentage points). Negative values indicate increased leisure. TC Saving (% GDP): Reduction in transaction costs as a percentage of steady-state GDP, relative to the Conventional scenario's TC/GDP ratio (%). Higher values indicate greater efficiency gains. Markup Reduct. (pp): Reduction in the bank deposit markup (μ_d) relative to the Conventional scenario (percentage points). Higher values indicate stronger pro-competitive effects. N (Level): Absolute steady-state labor supply (fraction of time endowment). C (Level): Absolute steady-state consumption level. Welfare (Level): Absolute steady-state utility level (raw value from the utility function). Source: Research Findings.

In summary, the quantitative results provide strong support for the Retail Account CBDC as the most effective design in terms of improving steady-state welfare, primarily through enhanced banking sector competition and reductions in transaction costs. The Hybrid model captures a large portion of these gains, while the Retail Token model offers only marginal improvements. The Wholesale CBDC, when parameterized identically to the Conventional baseline, delivers negligible macroeconomic effects.

4.2 Sensitivity Analysis

The tangible economic impacts of different Central Bank Digital Currency (CBDC) designs can be assessed through several key indicators, including consumption equivalence, transaction cost savings, markup reduction, labor supply, and overall welfare levels. As summarized in the comparative Table 6, the retail CBDC (account-based) scenario exhibits the highest consumption equivalent gain (11.13%) and the most substantial transaction cost savings (0.60% of GDP), paired with a significant reduction in market markup (2.5 percentage points). In contrast, token-based retail CBDCs and wholesale CBDCs offer more modest gains, with the wholesale design matching the conventional system in terms of welfare and efficiency. These aggregate outcomes are further unpacked through heatmap-based panel analyses of the retail account-based CBDC scenario, revealing deeper insights into the driving mechanisms behind welfare dynamics.

Scenario 1: Retail CBDC (Account-Based)

In Figure 5 (Bank Markup and Transaction Costs), welfare outcomes are shown to be highly sensitive to both the markup imposed by banks and the underlying transaction costs. The most favorable welfare conditions emerge when both of these frictions are minimized. Notably, reductions in transaction costs exert a slightly greater effect on improving welfare than do reductions in markup, suggesting that enhancing payment system efficiency and fostering banking sector competition are pivotal for realizing the full benefits of retail CBDCs. Figure 6 (CBDC Utility and Interest Rate Spread) emphasizes the importance of the CBDC’s utility value to users and its yield relative to the policy interest rate. Welfare losses diminish as the CBDC becomes more useful and the interest rate spread narrows. A well-designed CBDC that offers direct utility and a competitive return enhances household welfare, while poor design—especially when accompanied by a significant negative spread—can result in substantial welfare deterioration. As shown in Figure 7 (CBDC Utility Weight and Elasticity of Substitution) welfare loss decreases markedly as the utility weight of the CBDC (χ) increases, with only moderate sensitivity to the elasticity parameter (ν). The lowest welfare loss is achieved when CBDC is highly valued (high χ) and its demand is highly responsive to the interest rate (low ν). This underscores that strong consumer preference for CBDC is the primary welfare driver, while elasticity of money demand plays a secondary but non-negligible role. Overall, these results underscore that the design of retail account-based CBDCs must focus on reducing frictions in the payment system, enhancing the utility and competitiveness of the digital currency, and aligning with users’ behavioral preferences. Policy design that neglects these aspects may forfeit substantial welfare gains and risk replicating the inefficiencies of the conventional banking framework.

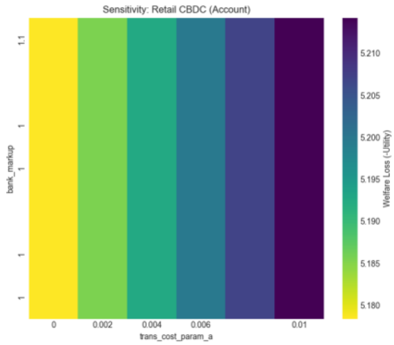

Figure 5. Bank Markup and Transaction Cost
Source: Research Findings

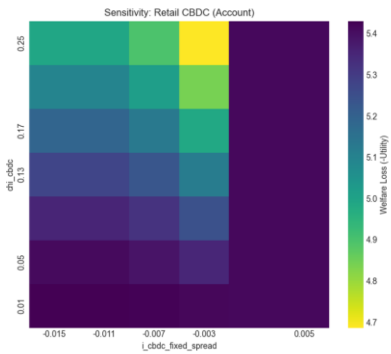

Figure 6. CBDC Utility and Interest Rate Spread
Source: Research Findings

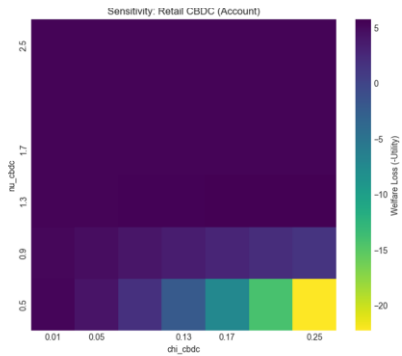

Figure 7. CBDC Utility Weight and Elasticity
Source: Research Findings

Scenario 2: Retail CBDC (Token-Based)

The welfare implications of a token-based retail CBDC reveal a pattern of modest efficiency improvements relative to account-based designs. As shown in Table 6, the token model yields limited consumption equivalent gains (1.40%) and marginal transaction cost savings (0.30% of GDP), accompanied by only a slight reduction in bank markups (1 percentage point). These results underscore the importance of underlying frictions and design choices in shaping the macroeconomic benefits of CBDC adoption.

Further exploration through multi-dimensional policy experiments sheds light on the mechanisms at play. In Figure 8 (Bank Markup and Transaction Costs), the structure of welfare loss mirrors that of the account-based model, with the bottom-left quadrant again yielding the most favorable outcomes—i.e., low markup and low transaction costs. However, across all parameter values, the welfare losses in the token-based setup are consistently higher. This suggests that while transaction efficiency and competitive pressure in the banking sector remain vital drivers of welfare, the token-based infrastructure is inherently less effective in mitigating these frictions compared to account-based systems. Figure 9 (Utility Weights of CBDC and Cash) emphasizes the critical role of user preferences. Increasing the utility weight of the CBDC leads to marked welfare gains, while assigning greater utility to cash results in slight welfare deterioration. This pattern highlights that welfare is most enhanced when consumers directly value CBDC use, particularly given that cash, by nature, carries higher opportunity costs due to its zero return. The implication is clear: successful CBDC adoption depends on incentivizing usage through superior functionality, accessibility, and potential interest-bearing features that reduce reliance on traditional cash holdings. Figure 10 (Demand Elasticities of CBDC and Cash) reveals relatively flat welfare gradients across varying elasticities of money demand. Changes in responsiveness of CBDC or cash holdings to interest rate differentials have minimal effects on welfare within the tested range. This contrasts with the account-based model, where elasticity played a more noticeable secondary role. In the token-based context, it becomes apparent that welfare is largely governed by intrinsic utility benefits rather than marginal changes in interest sensitivity. In sum, the analysis suggests that while token-based CBDCs can offer welfare improvements, they are less potent compared to account-based alternatives. Maximizing the effectiveness of a token-based system requires a strong focus on increasing the intrinsic utility of CBDC use and minimizing frictions in the transactional environment. Without these considerations, the model points to only modest welfare enhancements over the conventional monetary system.

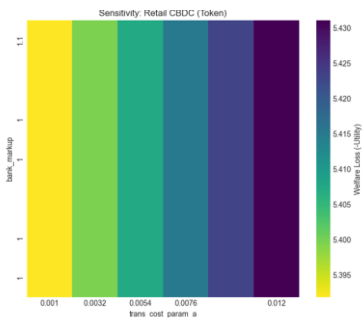

Figure 8. Bank Markup and Transaction Cost
Source: Research Findings

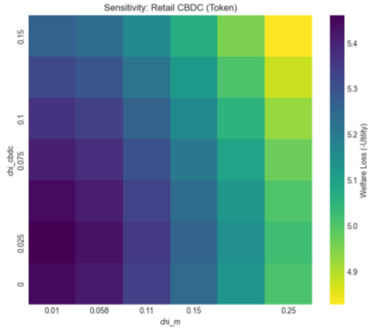

Figure 9. Utility Weights of CBDC and Cash
Source: Research Findings

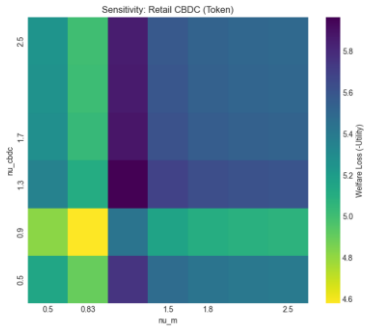

Figure 10. Demand Elasticities of CBDC and Cash
Source: Research Findings

Scenario 3: Wholesale CBDC

The introduction of a wholesale central bank digital currency (CBDC) yields no net welfare improvement compared to the baseline, as indicated by the unchanged consumption-equivalent measure (%3.20) and the absence of transaction cost savings or markup reductions. These modest results reflect the design of wholesale CBDCs, which primarily target interbank settlement layers rather than directly interacting with households or retail payment systems. Figure 11 (Bank Markup and Transaction Costs) explores the indirect effects of wholesale CBDC adoption through changes in banking sector efficiency. The analysis reveals only marginal increases in welfare loss as bank markups and transaction costs rise, with the overall range of variation significantly narrower than in retail CBDC scenarios. This muted sensitivity suggests that the wholesale CBDC's influence on end-user welfare is weak under current calibration assumptions. Its effects operate mainly through systemic efficiency improvements in financial intermediation rather than direct enhancements in household consumption or labor allocation. In contrast, Figure 12 (Government Debt and Spending Ratios) underscores a much more pronounced source of welfare variation, driven by macro-fiscal conditions. As the debt-to-GDP ratio or the government spending share rises, welfare losses increase substantially. This is attributable to the higher labor tax burdens required to sustain elevated public spending or service larger debt levels. The resulting distortions reduce household consumption and labor supply, eroding overall welfare. Importantly, this outcome is structural and applies regardless of CBDC type, reflecting broader fiscal trade-offs inherent in any monetary regime. In summary, while wholesale CBDCs may offer operational advantages in payment systems and interbank settlement, their macroeconomic welfare effects are relatively modest unless accompanied by substantial improvements in fiscal discipline or broader monetary architecture reform. Their effectiveness as a standalone tool for welfare enhancement is limited compared to more consumer-facing CBDC models.

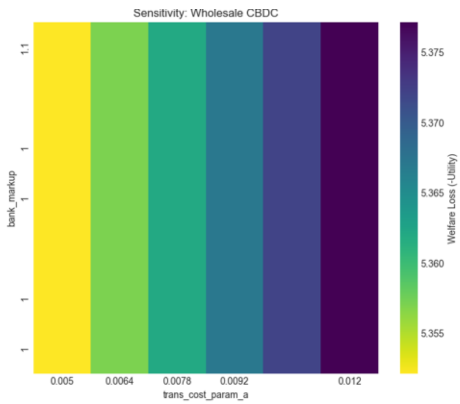

Figure 11. Bank Markup and Transaction Cost
Source: Research Findings

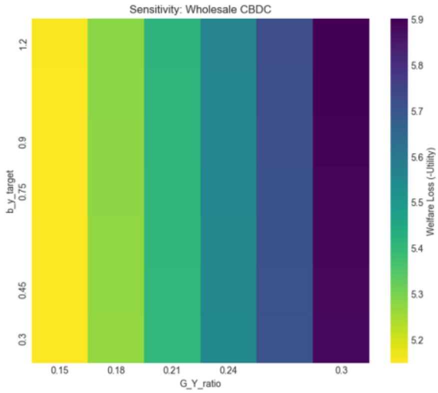

Figure 12. Government Debt and Spending Ratios
Source: Research Findings

Scenario 4: Hybrid CBDC

The hybrid CBDC model—positioned between account-based and token-based structures—yields moderate welfare improvements, with a consumption-equivalent gain of 6.04%. This intermediate performance reflects the model's dual structure: it retains some benefits of disintermediation while still relying partially on existing financial intermediaries. Figure 13 (Bank Markup and Transaction Costs) reveals that welfare losses increase as both bank markup and transaction cost parameters rise, echoing the pattern observed in the retail account-based scenario. However, the intensity of welfare loss is lower than in the token-based model and higher than in the fully direct account model. This outcome reflects the hybrid CBDC's limited ability to reduce financial frictions due to its continued dependence on intermediated payment infrastructures. While efficiency gains are realized, they are not as pronounced as those in a purely account-based system. Figure 14 (CBDC Utility Weight and Interest Rate Spread) highlights that welfare outcomes improve significantly with greater utility derived from CBDC use and a narrower or positive interest rate spread relative to the policy rate. These results reinforce the critical importance of user-facing design features across all CBDC models. Regardless of the delivery architecture, welfare gains are maximized when the digital currency is both useful and competitively remunerated. In the hybrid context, these parameters partially offset the structural limitations imposed by intermediary reliance. In summary, the hybrid CBDC offers a pragmatic compromise between full centralization and market intermediation. While its welfare benefits are not as large as those from a fully direct model, it remains a viable option—particularly in regulatory environments where complete disintermediation is infeasible. Its effectiveness depends heavily on maximizing user utility and minimizing frictions in the payment system.

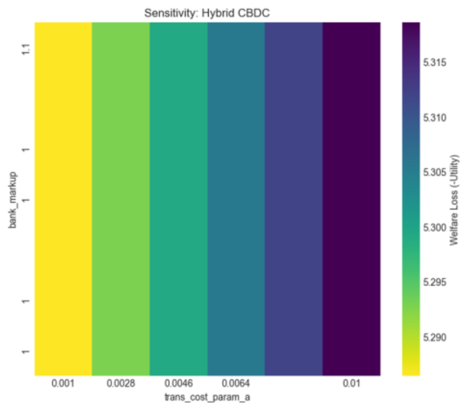

Figure 13. Bank Markup and Transaction Cost
Source: Research Findings

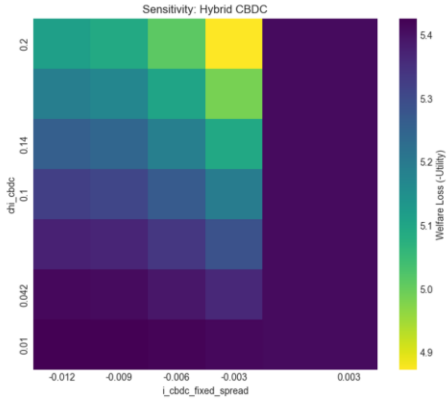

Figure 14. CBDC Utility Weight and Interest Rate Spread
Source: Research Findings

5 Conclusion

This study has systematically evaluated the macroeconomic and welfare implications of various CBDC architectures through rigorous model simulations and sensitivity analyses in a fiscally constrained economic environment. Our investigation reveals profound differences in outcomes based on CBDC design choices, with significant policy ramifications. The steady-state results demonstrate that retail account-based CBDCs emerge as the most transformative model, delivering an impressive 11.13% consumption-equivalent welfare gain. This superior performance stems from three synergistic mechanisms: (1) massive migration from physical cash to digital balances due to CBDC's attractive features, (2) substantial 2.5 percentage point reduction in bank deposit markups through enhanced competition, and (3) meaningful 0.6% GDP reduction in transaction costs. The model also captures important behavioral adjustments, including a 0.142 percentage point labor supply reduction as households reallocate time toward leisure and consumption activities - a non-trivial welfare-enhancing effect in our constrained economy. The hybrid model presents a compelling middle ground, achieving 6.04% welfare gains by balancing efficiency improvements with continued financial intermediation. In contrast, token-based retail CBDCs show limited efficacy (1.40% gain), constrained by their non-interest-bearing nature and inferior transaction efficiency. Wholesale CBDCs prove largely inconsequential for household welfare, serving primarily as a back-end settlement tool without direct consumer benefits. Our multidimensional performance assessment consistently confirms this hierarchy across all evaluated metrics.

The sensitivity analysis provides crucial insights into the drivers of these outcomes. For retail account-based CBDCs, welfare proves most responsive to transaction cost reductions and interest rate spread compression. Notably, the model demonstrates that payment efficiency gains outweigh equivalent reductions in banking markups - an important finding for policymakers prioritizing design features. The hybrid model's intermediate position reflects its dual sensitivity to both CBDC utility parameters and intermediation frictions. Token-based systems show more muted responses, with adoption primarily driven by cash substitution rather than financial attractiveness.

However, these optimistic results must be interpreted in light of several important model limitations. Our framework abstracts from critical financial stability considerations like bank runs and liquidity crises - particularly relevant given CBDCs' potential to disrupt traditional banking. The steady-state approach cannot capture complex transition dynamics or short-term adjustment costs. Perhaps most significantly, the representative agent framework masks potential distributional consequences across income groups and regions, while the absence of crisis scenarios limits our understanding of CBDC performance under stress conditions.

These findings yield several concrete policy recommendations: 1- *Design Primacy*: Central banks should prioritize retail account-based architectures with interest-bearing capabilities, as these deliver the most comprehensive welfare benefits through multiple transmission channels. 2- *Competition Management*: While CBDCs can discipline bank markups, complementary measures like tiered remuneration or adjusted deposit insurance may be needed to prevent excessive disintermediation. 3- *Implementation Strategy*: A phased approach - potentially beginning with hybrid implementations - could help manage transition risks while building institutional and technological capacity. 4- *Holistic Integration*: CBDC systems should be designed for interoperability with private payment networks to maximize network effects and avoid market fragmentation. 5- *Institutional Preparedness*: The limited impact of wholesale CBDCs suggests they should be considered as part of broader financial infrastructure reforms rather than standalone solutions.

Looking ahead, several research directions emerge as critical. Future work should incorporate financial stability considerations, heterogeneous agents, and crisis scenarios to provide more robust policy guidance. Additionally, empirical validation through pilot programs will be essential to test our model's predictions against real-world behavior.

In conclusion, our analysis demonstrates that CBDCs hold substantial promise for enhancing economic welfare in fiscally constrained environments, but their ultimate impact will be profoundly shaped by design choices and implementation strategies. The potential benefits are significant - from improved payment efficiency to enhanced monetary policy transmission - but realizing these gains requires careful navigation of the trade-offs between innovation and stability, competition and intermediation, technological potential and practical constraints. As central banks worldwide contemplate CBDC adoption, this study provides both a framework for evaluating options and a caution against underestimating the complexity of this monetary innovation.

References

Adalid, R., Álvarez-Blázquez, Á., Assenmacher, K., Burlon, L., Dimou, M., López-Quiles, C., ... & Veghazy, A. V. (2022). Central bank digital currency and bank intermediation (ECB Occasional Paper Series No. 293). European Central Bank.

Adrian, T., & Mancini-Griffoli, T. (2021). The rise of digital money. Annual Review of Financial Economics, 13(1), 57-77.

Agur, I., Ari, A., & Dell'Ariccia, G. (2022). Designing central bank digital currencies. *Journal of Monetary Economics*, 125, 62-79.

Alfonso, V. C., Kamin, S., & Zampolli, F. (2025). Central bank digital currencies (CBDCs) in Latin America and the Caribbean. *Latin American Journal of Central Banking*, *6*(1), 100140.

Atlantic Council. (2022). *Central Bank Digital Currency Tracker*. *https://www.atlanticcouncil.org/cbdctracker/*

Auer, R., & Böhme, R. (2021). *Central bank digital currency: the quest for minimally invasive technology*. BIS Working Papers No. 948. https://www.bis.org/publ/work948.htm

Auer, R., Cornelli, G., & Frost, J. (2020). *Rise of the central bank digital currencies: drivers, approaches and technologies. BIS Working Papers*, No. 880. https://www.bis.org/publ/work880.htm

Auer, R., Haene, P., & Holden, H. (2021). *Multi-CBDC arrangements and the future of cross-border payments*. BIS Papers No. 115. https://www.bis.org/publ/bppdf/bispap115.htm

Bank for International Settlements (BIS). (2020). *Central bank digital currencies: Foundational principles and core features.* https://www.bis.org/publ/othp33.htm

Bank for International Settlements (BIS). (2023). *Advancing CBDC for a Digital Future*. Annual Report.

Bank for International Settlements, (2021). *Central bank digital currencies for cross-border payments*, ISBN 978-92-9259-476-3. This publication is available on the BIS website (www.bis.org).

Bank for International Settlements. (2021). *Central bank digital currencies: Financial stability implications.* BIS Papers No. 123. https://www.bis.org/publ/othp42_fin_stab.pdf

Barrdear, J., & Kumhof, M. (2022). The macroeconomics of central bank digital currencies. *Journal of Economic Dynamics and Control, 142, 104148*

Bech, M. L., & Garratt, R. (2017). Central bank cryptocurrencies. *BIS Quarterly Review September*.

Bespalova, O., Appendino, M., Bhattacharya, R., Aguilar, J. F. C., Geng, N., Komatsuzaki, T., Lesniak, J., Lian, W., Marcelino, S., Villafuerte, M., & Yakhshilikov, Y. (2025). Crypto assets and CBDCs in Latin America and the Caribbean: Opportunities and risks. *Latin American Journal of Central Banking*. Advance online publication. https://doi.org/10.1016/j.latcb.2024.100157

Bindseil, U. (2020). *Tiered CBDC and the Financial System*. ECB Working Paper No. 2351. https://www.ecb.europa.eu/pub/pdf/scpwps/ecb.wp2351~c8c18bbd60.en.pdf

Bordo, M. D., & Levin, A. T. (2017). *Central bank digital currency and the future of monetary policy*. National Bureau of Economic Research Working Paper No. 23711. https://doi.org/10.3386/w23711

Boubaker, S., Karim, S., Naeem, M. A., & Sharma, G. D. (2023). Financial markets, energy shocks, and extreme volatility spillovers. *Energy Economics*, *126*, 107031.

Brunnermeier, M. K., & Niepelt, D. (2019). On the equivalence of private and public money. *Journal of Monetary Economics*, 106, 27–41. https://doi.org/10.1016/j.jmoneco.2019.07.004

Brunnermeier, M. K., James, H., & Landau, J. P. (2019). *The digitalization of money*. NBER Working Paper No. 26300. National Bureau of Economic Research.

Burlon, L., Montes-Galdon, C., Muñoz, M., & Smets, F. (2022). *The optimal quantity of CBDC in a bank-based economy* (ECB Working Paper No. 2689). European Central Bank. https://doi.org/10.2139/ssrn.4175853

Buzuriu, B. C. (2024). Central Bank Digital Currencies and Financial Stability: Literature Review and New Questions. Timisoara Journal of Economics and Business, 17(1), 41-64.

Carstens, A. (2021). *Digital currencies and the future of the monetary system*. BIS, Hoover Institution Speech.

CBDC Tracker. (202). https://cbdctracker.org/

CBDC Tracker. (2026). https://cbdctracker.org

Chiu, J., Davoodalhosseini, M., Jiang, J. H., & Zhu, Y. (2023). Bank market power and central bank digital currency: Theory and quantitative assessment. *Journal of Political Economy*, *131*(5), 1213–1248. https://doi.org/10.1086/722517

Chorzempa, M. (2022). *The Cashless Revolution: China's Reinvention of Money and the End of America's Domination*. PublicAffairs.

Christiano, L. J., Eichenbaum, M., & Evans, C. L. (2005). Nominal rigidities and the dynamic effects of a shock to monetary policy. *Journal of Political Economy, 113(1), 1–45*. https://doi.org/10.1086/426038

Committee on Payments and Market Infrastructures. (2022, May). *Extending and aligning payment system operating hours for cross-border payments: Consultative report*. Bank for International Settlements.

Demirgüç-Kunt, A., Klapper, L., Singer, D., & Ansar, S. (2022). *The Global Findex Database 2021: Financial inclusion, digital payments, and resilience in the age of COVID-19*. World Bank.

Ding, S., Cui, T., Wu, X., & Du, M. (2022). Supply chain management based on volatility clustering: the effect of CBDC volatility. *Research in International Business and Finance, 62, 101690*.

Dong, M., & Xiao, S. X. (2024). Idle liquidity, CBDC and banking. *European Economic Review, 164*, 104700.

Dyson, B., & Hodgson, G. (2016). *Digital cash: Why central banks should start issuing electronic money.* Positive Money. https://positivemoney.org/wp-content/uploads/2016/01/Digital_Cash_WebReady.pdf

European Central Bank (ECB). (2021). *Report on the public consultation on a digital euro*. Frankfurt: ECB.

European Central Bank (ECB). (2023). *Study on the payment attitudes of consumers in the euro area (SPACE) – 2022*. Frankfurt: ECB.

Federal Deposit Insurance Corporation. (2023). Banking crisis review. FDIC Quarterly Report. https://www.fdic.gov/analysis/quarterly-banking-profile

Garratt, R. J., & Van Oordt, M. R. (2021). Privacy as a public good: a case for electronic cash. *Journal of Political Economy*, *129*(7), 2157-2180.

Gupta, S., Pandey, D. K., El Ammari, A., & Sahu, G. P. (2023). Do perceived risks and benefits impact trust and willingness to adopt CBDCs? *Research in International Business and Finance, 66, 101993*. https://doi.org/10.1016/j.ribaf.2023.101993

Hong, K., Park, K., & Yu, J. (2018). Crowding out in a dual currency regime? Digital versus fiat currency. *Emerging Markets Finance and Trade, 54(11), 2495-2515*.

Kahn, C. M., Rivadeneyra, F., & Wong, T. N. (2018). *Should the central bank issue e-money?* (No. 2018-58). Bank of Canada Staff Working Paper.

Keister, T., & Sanches, D. (2021). *Should central banks issue digital currency?* FRB of Philadelphia Working Paper No. 21-37, Available at SSRN: https://ssrn.com/abstract=3966817 or http://dx.doi.org/10.21799/frbp.wp.2021.37

Keister, T., & Monnet, C. (2022). Central bank digital currency: Stability and information. *Journal of Economic Dynamics and Control, 142, 104501*.

Khiaonarong, T., & Humphrey, D. (2019). Cash use across countries and the demand for central bank digital currency. *Journal of Payments Strategy & Systems, 13*(1), 32–46.

Kuehnlenz, S., Orsi, B., & Kaltenbrunner, A. (2023). Central bank digital currencies and the international payment system: The demise of the US dollar. *Research in International Business and Finance, 64,* 101834. *https://doi.org/10.1016/j.ribaf.2022.101834*

Kumhof, M., & Noone, C. (2018). *Central bank digital currencies—design principles and balance sheet implications*. Bank of England Staff Working Paper No. 725.

Kumhof, M., & Noone, C. (2021). Central bank digital currencies: Design principles for financial stability. *Economic Analysis and Policy*, 71, 553-572. *https://doi.org/10.1016/j.eap.2021.06.012*

Makarov, I., & Schoar, A. (2021). *Blockchain analysis of the bitcoin market* (NBER Working Paper No. 29396). National Bureau of Economic Research. *https://doi.org/10.3386/w29396*

Mancini-Griffoli, T., Martinez Peria, M. S., Agur, I., Ari, A., Kiff, J., Popescu, A., & Rochon, C. (2018). *Casting light on central bank digital currencies* (IMF Staff Discussion Note No. SDN/18/08). International Monetary Fund. https://www.imf.org/en/Publications/Staff-Discussion-Notes/Issues/2018/11/13/Casting-Light-on-Central-Bank-Digital-Currencies-46233

Panetta, F. (2023). *A digital euro: widely available and easy to use*. Introductory statement at the Committee on Economic and Monetary Affairs (ECON) of the European Parliament, Brussels. European Central Bank.

Prasad, E. S. (2021). *The future of money: How the digital revolution is transforming currencies and finance.* Harvard University Press.

Ree, J. (2023). *Nigeria's eNaira, One Year After*. International Monetary Fund (IMF) Working Paper No. 2023/104.

Reserve Bank of India (RBI). (2023). *Report on Currency and Finance (RCF): India's Digital Revolution*. Reserve Bank of India.

Schilling, L., Fernández-Villaverde, J., & Uhlig, H. (2020). *Central bank digital currency: When price and bank stability collide* (NBER Working Paper No. 28237). National Bureau of Economic Research. https://doi.org/10.3386/w28237

Sethaput, V., & Innet, S. (2023). Blockchain application for central bank digital currencies (CBDC). *Cluster Computing, 26(1), 1–15*. https://doi.org/10.1007/s10586-022-03962-z

Smets, F., & Wouters, R. (2007). Shocks and frictions in US business cycles: A Bayesian DSGE approach. *American Economic Review, 97(3), 586–606.* https://doi.org/10.1257/aer.97.3.586

Soderberg, G. (2022). *Behind the scenes of central bank digital currency: Emerging trends, insights, and policy lessons* (FinTech Notes No. 2022/004). International Monetary Fund.

Sveriges Riksbank (2023). *The e-krona pilot: Phase 4 report.* https://www.riksbank.se/globalassets/media/rapporter/e-krona/2024/e-krona-pilot-phase-4.pdf .

Tronnier, F., & Qiu, W. (2024). How do privacy concerns impact actual adoption of central bank digital currency? An investigation using the e-CNY in China. *Quantitative Finance and Economics*, *8*(1), 126-152.

Umar, M. (2025). Does CBDC launch increase tax collection? Empirical evidence from China. *Finance Research Letters, 71*, 106486.

Vollmar, S., & Wening, F. (2024). The impact of CBDC on a deposit-dependent banking system. *Journal of Financial Stability, 73*, 101283.

Wang, Y.-R., Ma, C.-Q., & Ren, Y.-S. (2022). A model for CBDC audits based on block chain technology: Learning from the DCEP. *Research in International Business and Finance*, *63*, 101781. *https://doi.org/10.1016/j.ribaf.2022.101781*

Whited, T. M., Wu, Y., & Xiao, K. (2022). Will central bank digital currency disintermediate banks? *Available at SSRN 4112644*.

World Bank. (2021). *Central bank digital currencies for cross-border payments*. World Bank.

Xu, A., Qiu, K., Jin, C., Cheng, C., & Zhu, Y. (2022). Regional innovation ability and its inequality: Measurements and dynamic decomposition. *Technological Forecasting and Social Change*, *180*, 121713.