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HOUSEHOLD ALLOCATION OF THE NEXT GENERATION OF DIGITAL MONEY

by Marcello Pericoli *

Abstract

This paper examines how households allocate their holdings across three forms of digital money: central bank digital currencies (CBDCs), stablecoins and bank deposits. Each instrument provides a distinct combination of financial returns and transactional features, such as usability, programmability and privacy. The analysis shows that well-designed CBDCs can strengthen monetary sovereignty and improve household welfare even without remuneration, provided they are convenient and trusted. Stablecoins backed by weak reserve structures pose systemic risks and may destabilize the monetary system. Upgrading the payment infrastructure for bank deposits helps preserve the role of commercial banks and supports the transmission of monetary policy. The findings provide insights for central banks and regulators navigating the transition to a digital monetary environment.

JEL Classification: E42; E44; E58; G21; O33.

Keywords: CBDC; Stablecoins; Digital Payments; Household Portfolio Choice; General Equilibrium; Monetary Policy Transmission.

Sintesi

Il lavoro sviluppa un modello di equilibrio economico generale per studiare come le famiglie ripartiscono i propri fondi tra tre diverse forme di pagamento: valuta digitale di banca centrale (CBDC), stablecoin e depositi bancari. L'allocazione dipende dal trade-off tra rendimento finanziario e benefici non pecuniari (quali liquidità, programmabilità e privacy) offerti da ciascuna forma di moneta. L'analisi mostra che: l'introduzione di una CBDC priva di remunerazione può accrescere il benessere delle famiglie e rafforzare la sovranità monetaria quando la sua infrastruttura assicura un'elevata efficienza nei pagamenti e la massima fiducia istituzionale; le stablecoin con riserve fragili rappresentano un rischio sistemico e possono destabilizzare il sistema monetario; la combinazione tra tokenizzazione dei depositi e innovazione delle infrastrutture dei servizi di pagamento consente di preservare il ruolo delle banche commerciali nell'intermediazione finanziaria e sostenere la trasmissione della politica monetaria. I risultati forniscono indicazioni di policy per i regolatori nella transizione verso un ecosistema monetario digitale.

* Banca d'Italia, Directorate General for Payments and Market Infrastructures.

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1 Introduction*

This paper anticipates a foreseeable future in which households allocate their wealth across a range of money-like instruments to settle transactions. These include central bank digital currencies (CBDCs), stablecoins, traditional and tokenised bank deposits, as well as platform-based credits used within closed digital ecosystems. While all serve transactional purposes, they differ markedly in legal status, technological infrastructure, privacy, and settlement finality—the point at which a payment becomes irreversible and unconditional. As digital payment ecosystems evolve, their coexistence introduces new challenges for monetary policy transmission, financial intermediation, and regulatory design.

To study these mechanisms, we develop a general equilibrium model in which households optimise their portfolios over competing monetary instruments based on convenience-adjusted returns—that is, the sum of financial yields and nonpecuniary liquidity services. The model incorporates balance-sheet interactions across commercial banks, stablecoin issuers, and the central bank, capturing how household preferences affect equilibrium asset shares, interest-rate spreads, and systemic conditions. We characterise the conditions under which certain instruments dominate, coexist, or generate nonlinear comparative statics across adoption levels, including the possibility of threshold equilibria in portfolio allocation.

By grounding digital monetary competition in a formal macro-financial framework, this paper contributes to debates on CBDC design, the regulatory treatment of stablecoins, and the long-term stability of a multi-instrument monetary system. The findings provide a theoretical basis for developing replicable policy recommendations and constitute a first step toward calibration; Section 3.4 discusses candidate data sources and target moments.

The evolution of digital monetary instruments has spurred a growing body of research examining the implications of CBDCs, stablecoins, and digital payment systems on monetary policy, financial intermediation, and systemic stability. We review below the main strands of relevant literature, with a focus on recent contributions that align with the themes of this paper.

A foundational strand explores the macroeconomic and financial implications of CBDCs. Brunnermeier et al. (2019) analyse how CBDCs may reshape the banking system and monetary transmission, while Fernández-Villaverde et al. (2021) examine trade-offs in CBDC design related to privacy, inclusion, and financial stability. Andolfatto (2021) and Keister and Sanches (2022) study the effects of interest-bearing CBDCs on bank funding and credit provision. More recently, Ahner et al. (2024) and Carapella et al. (2024) provide comprehensive frameworks for assessing the financial stability implications of CBDC issuance.

The role of stablecoins has also received significant attention. Adrian and Mancini-Griffoli (2019, 2021) and Adrian (2022) highlight the risks of monetary fragmentation and loss of sovereignty posed by widespread stablecoin adoption. Committee on Payments and Market Infrastructures (2020), International Monetary Fund (2022b), Ahmed and Aldasoro (2025) and Fiedler et al. (2023) provide empirical evidence on the fragility of stablecoins under stress, while Chiu and Monnet (2024) explore the interaction between CBDC design and

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stablecoin usage in decentralised finance (DeFi) ecosystems. Finally, Carapella (2025) shows how stablecoin regulation can impact the stability of traditional financial institutions.

Recent theoretical advances have laid the groundwork for modelling household portfolio allocation across money-like instruments using convenience-adjusted returns within a general equilibrium framework. Our model builds directly on this foundation. Schilling et al. (2024) and Davoodalhosseini (2022) develop general equilibrium models in which households allocate across CBDC, deposits, and other liquid assets based on liquidity services and convenience yields; these models serve as a direct foundation for our framework, which incorporates similar arbitrage conditions and balance-sheet interactions. Chiu and Monnet (2024) extend this approach to a distributed-ledger setting, comparing stablecoins, tokenised deposits, and CBDC. Andolfatto (2021), Keister and Sanches (2022), and Paul et al. (2025) also feature general equilibrium environments where households choose between CBDC and deposits, with implications for bank intermediation and monetary policy.

From a broader currency-competition perspective, Benigno et al. (2022) and Brunnermeier et al. (2019) provide conceptual frameworks for understanding monetary competition in multi-instrument environments. In the context of monetary policy, Woodford (2001) and Benigno et al. (2022) examine unconventional policy tools in environments without government bond markets. Panetta (2022, 2023, 2025) emphasise the importance of CBDC design in preserving monetary sovereignty and financial stability, advocating for a public anchor in digital finance.

Central to this work is the recognition that money-like instruments offer nonpecuniary benefits—such as liquidity, ease of payment, programmability, and privacy, which we call *convenience*—in addition to their financial returns. Our model synthesises these insights by incorporating endogenous redemption risk and network effects into the convenience-yield framework, showing how policy design—such as CBDC remuneration and stablecoin regulation—can alter convenience, thereby reshaping portfolio allocations and monetary transmission.

Our paper advances the literature on monetary competition in digital environments along four dimensions. *First*, we provide a tractable three-way general equilibrium in which CBDC, commercial bank deposits, *and* stablecoins coexist within a single balance-sheet-consistent framework (Sections 3.1–3.3). Existing work typically analyses at most two instruments simultaneously (Schilling et al., 2024; Davoodalhosseini, 2022; Chiu and Monnet, 2024); the three-asset structure allows us to derive explicit cross-asset pricing constraints that cannot be obtained in bilateral models. *Second*, we derive in closed form the maximum fee that stablecoin issuers can charge without being driven out of the market by CBDC—a coexistence pricing bound, obtained from the interaction of household optimality, issuer zero-profit, and CBDC design, that to our knowledge has not been characterised analytically in the literature (Section 3.3.1). *Third*, we extend the issuer zero-profit condition to encompass risky reserve assets, showing that stablecoins backed by non-risk-free collateral must compensate investors for expected credit and liquidity premia, which bridges fragility themes from shadow banking (Gorton and Metrick, 2012) with digital money design (Section 4.3). *Fourth*, we decompose convenience yields into observable design features—liquidity, programmability, privacy, and return salience—via a feature aggregator, providing a structured mapping from regulatory and design levers to equilibrium portfolio shares (Section 3.6, Proposition 3.1). Relative to Chiu and Monnet (2024), we emphasise institutional zero-profit and prudential blocks that pin down interest-rate spreads and balance-sheet quantities; relative to Benigno et al. (2022), we add stablecoin supply constraints and redemption risk.

While the model is cast in steady state, comparative statics across equilibria capture threshold effects that would, in a dynamic extension, correspond to adoption transitions driven by network externalities and design changes.

This paper is structured as follows. Section 2 presents a taxonomy of current and future money-like instruments and documents the payment flows and transaction mechanisms available to households. Section 3 develops the general equilibrium model and derives results on household allocation of money-like instruments. Section 4 presents model extensions. Section 5 documents the implications of the new digital environment for monetary policy. Section 6 translates the analytical framework into policy prescriptions. Section 7 concludes.

2 Monetary Instruments and Convenience Yields

The architecture of money and payments has undergone significant transformation in recent decades. While physical cash and commercial bank deposits remain foundational, they are increasingly complemented—and in some cases challenged—by digital innovations. CBDCs, stablecoins, and platform-based balances now represent prominent contenders in the evolving monetary landscape. These instruments differ in issuer type, legal status, technological design, and settlement properties. This section provides a concise taxonomy and introduces the concept of convenience-adjusted returns that underpins the model of Section 3. A more detailed institutional description, including stablecoins issued by card networks, platform-based credits, and the BIS unified-ledger framework, is provided in Appendix A.1.

Central bank instruments. Central banks issue physical **cash** as a liability: universally accepted as legal tender, offering immediate settlement finality, full anonymity, and zero counterparty risk. **CBDCs** are digital liabilities of the central bank, redeemable at par with no counterparty risk. Accessible through digital wallets, CBDCs may incorporate programmability, interoperability, and privacy features, though their design must balance efficiency with financial stability.

Bank money. Commercial banks create deposit money through lending. **Bank deposits** carry counterparty risk but are redeemable in central bank money and backed by deposit insurance. **Tokenised deposits** are digital tokens transferable on permissioned DLT networks, combining the safety of conventional deposits with programmability and interoperability.

E-money. E-money represents a digitally stored monetary value issued by regulated institutions, fully backed by fiat currency and held in segregated accounts. Its convenience stems from broad merchant acceptance, seamless mobile integration, and low transaction costs.

Stablecoins. Stablecoins are digital tokens pegged to fiat currencies and backed by reserves such as bank deposits, securities, or CBDCs. Issued by non-financial intermediaries (NFIs), they offer speed, global reach, and programmability, but their fragile reserve structures and limited regulatory safeguards expose them to redemption risk. Their structural parallels with pre-crisis shadow banking instruments—promise of par convertibility, short-duration liquid assets, operation outside the regulatory perimeter—have led many observers to classify them as a modern form of "shadow money".[1]

Platform-based credits. Platform-based credits are internal digital balances issued by large technology firms (e.g., Amazon, Apple, PayPal), denominated in fiat units but not legal tender, transferable across institutions, or redeemable outside the issuing platform. Their monetary role is confined to internal settlement.

Table 1 provides a side-by-side comparison of key attributes across six categories of money-like instruments, highlighting differences in issuer type, legal status, privacy, interest-bearing capacity, and settlement finality.

Table 1: Comparison of Monetary Instruments

Feature	**Cash**	**CBDC**	**Bank Deposits**	**E-money**	**Stablecoins**	**Platform Balances**
Issuer	Central Bank	Central Bank	Commercial Bank	Regulated Firms	Private Firms	Private Firms
Form	Physical	Digital	Digital	Digital	Digital	Digital
Legal Tender	Yes	Possibly[a]	No	No	No	No
Privacy	High	Variable	Low	Low	Low[b]	Low
Interest-Bearing	No	Possibly[c]	Yes	No	No[d]	No
Settlement Finality	Yes	Yes	No	No	No	No

Note. *(a),(c)* See Appendix A.2 for CBDC legal status and remuneration. *(b)* In peer-to-peer DeFi environments, stablecoins may provide higher transactional privacy. *(d)* Some stablecoins integrated into DeFi protocols offer interest-like returns; see Appendix A.3.

Convenience-Adjusted Returns and Household Preferences

While these instruments differ in issuer type, settlement mechanism, and technological form, their role in household portfolios is ultimately determined by their relative attractiveness as stores of value and media of exchange. We model this through the concept of a *convenience-adjusted return*, defined as the sum of an instrument's financial yield and the nonpecuniary benefits it provides in facilitating transactions.

Formally, let i_j denote the nominal return on instrument j and θ_j its convenience yield, reflecting liquidity, accessibility, programmability, or privacy. The household evaluates each asset based on:

$$r_j = i_j + \theta_j. \qquad \text{(convenience adjusted return)}$$

In equilibrium, assets that offer higher convenience yields can compensate for lower or even zero financial returns. This concept provides a unified lens to compare traditional and digital money-like instruments in a general equilibrium setting, and is microfounded through the household optimisation problem of Section 3.2.1 (Schilling et al., 2024; Davoodalhosseini, 2022; Andolfatto, 2021; Keister and Sanches, 2022; Chiu and Monnet, 2024).

Monetary Flow Representation

Figure 1 illustrates the monetary flows across key sectors of the payment ecosystem. Households allocate funds among cash, CBDC, bank deposits, stablecoins, and platform balances. Banks intermediate deposits and issue loans, maintaining reserves at the central bank, while

[1]See Gorton and Metrick (2012) on the parallels between repo-backed shadow banking and money substitutes, and Financial Stability Board (2020) and BIS (2025) on the systemic impact of stablecoins.

NFIs issue stablecoins backed by reserves or bank deposits. The figure highlights the interdependencies and settlement layers of modern payment systems, and how shifts in household preferences can affect the balance sheets of both financial and non-financial actors.

Payment Channels and Settlement

This subsection maps how households use monetary assets to settle transactions and identifies the frictions associated with intermediaries, settlement systems, and redemption. A more detailed discussion of individual payment channels—including legacy infrastructure, fast-payment rails, tokenised deposits, and credit cards—is provided in Appendix A.1.

Table 2 classifies household payment instruments along three dimensions: the monetary medium used, the intermediaries involved, and the settlement type. Cash and CBDC offer final settlement with minimal intermediation. Bank deposits, e-money, stablecoins, and tokenised deposits introduce varying degrees of delay, counterparty risk, and legal complexity. E-money sits between deposits and stablecoins: like deposits, it is backed one-to-one by fiat and issued by licensed intermediaries; like stablecoins, it circulates on private ledgers without legal tender status.

Table 2: Household Payment Channels by Medium and Flow

Payment Type	**Medium Used**	**Intermediaries**	**Settlement Type**	**Merchant Receives**
Cash	Physical currency	None	Final (immediate)	Cash
CBDC	Digital tokens	CBDC wallet provider	Final (central bank ledger)	CBDC in wallet
Bank Transfer	Bank deposits	Commercial banks	Delayed or instant	Bank deposit
Card Payment	Bank deposits	Banks + Card network	Delayed (clearing)	Bank deposit
E-Money	Prepaid digital value fully backed by fiat	Licensed issuers + wallet provider	Near-final (issuer ledger)	E-money credit or bank deposit
Stablecoins	Private tokens	Issuers + blockchain	Near-final (token transfer)	Stablecoins
Platform Balance	Internal credits	Fintech / Platform	Internal	Platform credit or transfer
tokenised Deposits	Bank-issued tokens on DLT	Commercial banks + DLT infrastructure	Near-final (on-chain transfer, off-chain redemptions)	Bank deposit or tokenised claim

Note. "Final" settlement implies irrevocable transfer on physical or central bank balance sheets. "Near-final" refers to transfers recorded on issuer or DLT ledgers with potential settlement delays. "Delayed" applies to legacy banking rails with netting or clearing lags. E-money differs from stablecoins in that it is fully backed by segregated fiat deposits and issued under strict regulation. tokenised deposits preserve deposit safety while enabling programmable, on-chain payments. All payments are denominated in the same domestic unit of account.

Economic Drivers of Household Payment Choice

Each payment instrument can be viewed as a liquidity service asset, offering a combination of financial return and nonpecuniary convenience. Households allocate payment flows to maximise utility, choosing the instrument with the highest convenience-adjusted return given by equation (convenience adjusted return). Table 3 summarises the influence of interest-bearing status, liquidity, programmability, and privacy on the convenience yield of each instrument.

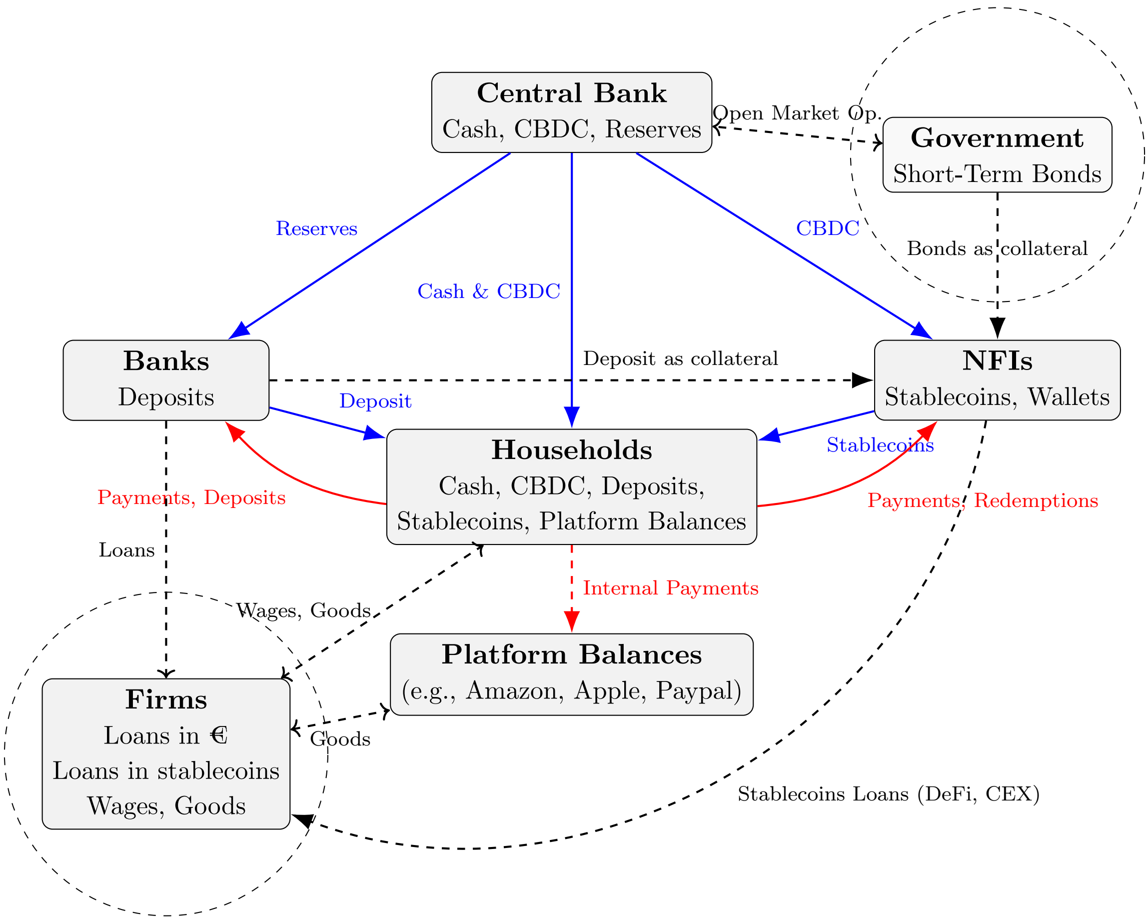

Figure 1: Monetary Flow Representation

Note. The schematic illustrates monetary flows among households, banks, the central bank, and non-financial intermediaries (NFIs). Blue arrows denote issuance flows (cash, CBDC, deposits, and stablecoins from issuers to households); red arrows denote payment and redemption flows from households back to banks and NFIs; dashed arrows denote collateral flows, optional platform balances, and firm-level credit. Households allocate funds across cash, CBDC, bank deposits, stablecoins, and platform balances. Deposits include tokenised deposits, which are issued by banks on distributed ledger infrastructure and combine the safety of conventional deposits with programmability and interoperability. "Redemptions" refer to the process whereby households exchange stablecoins back to the issuing NFI for central bank money or bank deposits. Government bonds are included as potential collateral for stablecoin issuance by NFIs; the framework remains valid if stablecoins are instead backed by bank deposits or central bank reserves. Firms are included to close the payment ecosystem; dashed circles around Government and Firms indicate that these sectors are present for completeness but are not part of the baseline model.

The introduction of fast-payment infrastructure raises θ_D, making deposits more attractive relative to stablecoins or CBDC. Increases in θ_S from DeFi integration or mobile usability shift allocations toward stablecoins. These mechanisms drive portfolio substitution and highlight the role of design, access, and infrastructure in shaping monetary competition.

Table 3: Convenience Features of Money-Like Instruments

Instrument	**Interest** i_j	**Liquidity**	**Programmability**	**Privacy**	**Typical** θ_j
Cash	0	Medium	None	High	Medium
CBDC	0	High	High	Low–Med	High
Bank Deposit (Legacy)	> 0	Medium	Low	Low	Medium
Bank Deposit (Fast Rail)	> 0	High	Low	Low	High
tokenised Deposit	> 0	High	High	Low–Med	High
E-Money	0	High	Medium	Low–Med	High
Stablecoin	0	High	High	Med–High	High
Platform Balance	0	Med–High	Medium	Low	Med–High

Note. Qualitative assessments of attributes contributing to each instrument's convenience yield θ_j. "Liquidity" refers to ease of transfer and broad acceptability. "Programmability" captures the ability to encode automated payments or smart contracts. "Privacy" reflects transactional anonymity or pseudonymity. Instrument features may vary across jurisdictions or issuers.

3 The Model

3.1 General equilibrium model

In the baseline model (Sections 3.2–3.3), convenience yields θ_j are treated as exogenous parameters capturing instrument-specific attributes—liquidity, programmability, and privacy—that are taken as given by households and issuers. Section 4.4 endogenises them as increasing functions of aggregate adoption shares x_j, introducing network externalities and the possibility of multiple equilibria. This two-step structure is adopted for expositional clarity: equation (2) characterises the fixed-point equilibrium that arises under endogenous yields and is stated here for completeness; the analytical solution in Section 3.3.2 and the simulations in Section 3.3.3 treat the θ_j as given.

We consider a monetary environment in which households allocate wealth across three representative instruments: commercial bank deposits (D), central bank digital currency (CBDC, M), stablecoins (S). These instruments capture the core categories of money-like assets in a digital economy: bank money, public money, and private money. While the baseline model focuses on this triad for tractability, the framework is flexible and can be extended to include other instruments within each category. For example, tokenised deposits or e-money can be incorporated under bank money, platform-issued tokens under private money, and cash or wholesale CBDC under public money. The analytical structure remains unchanged: households allocate across instruments by equalizing *convenience-adjusted returns*, and issuer behaviour is governed by zero-profit and balance-sheet constraints.

Our theoretical framework follows the general equilibrium approach of Schilling et al. (2024) and Davoodalhosseini (2022), where households allocate wealth across money-like instruments to equalise convenience-adjusted returns. The three "money-like" instruments – CBDC, bank deposits and stablecoins – interact with traditional bank reserves, R. For brevity, we make the following assumptions:

- households are endowed with an exogenous income stream, denoted by w—analogous to the fruit endowment à la Lucas—and there is no production;
- we abstract from cash holdings; however, cash can be incorporated without loss of generality into the household budget constraint and the central bank's balance sheet. Its inclusion would introduce an additional no-arbitrage condition linking the interest rates across money-like instruments;
- we abstract from digital tokens issued by platform firms. These instruments can be incorporated without loss of generality, but are typically best interpreted as digital representations of household deposits confined within closed-loop ecosystems;
- we do not include government bonds, although stablecoins are typically pegged to such assets. Instead, we assume that stablecoins are backed by central bank reserves, which serve as a proxy for government bonds due to their similar risk-free and liquid characteristics;
- we initially assume that the CBDC is remunerated at the policy reference rate. This assumption is later relaxed, allowing for a richer characterization of household portfolio choices.

The goal is to capture:

- how households choose among CBDC, bank deposits, and stablecoins;
- how banks and NFIs decide on issuance and balance-sheet composition;
- how the central bank (CB) manages CBDC issuance and reserves;
- arbitrage conditions that tie all "currency-equivalent" instruments together.

Throughout, we work in a closed economy with a continuum of identical households, one consolidated banking sector, and one consolidated NFI.

3.2 Setup

3.2.1 Households

Households (H) derive utility from consumption C and the convenience services provided by three money-like assets for transactions – e.g. CBDC (digital central-bank money), M, bank deposits, D, and stablecoins, S, issued by non financial intermediaries and backed one-for-one by deposits or central bank reserves. These convenience services are aggregated into a composite liquidity index, which enters the utility function alongside consumption.

Let C_t denote real consumption at time t, and let $\eta_{j,t}$ denote the quantity of monetary asset $j \in \{D, S, M\}$ held at time t. The household maximises expected lifetime utility:[2]

$$\max_{\{C_t, D_t, S_t, M_t\}} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t u(C_t, Q_t), \qquad \text{(consumer problem)}$$

with $\beta \in (0,1)$ the discount factor, and Q_t a CES (constant elasticity of substitution) aggregator over monetary instruments that captures their total convenience service:

$$Q_t = \left(\alpha_D D_t^{\frac{\sigma-1}{\sigma}} + \alpha_S S_t^{\frac{\sigma-1}{\sigma}} + \alpha_M (M_t)^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}}. \qquad \text{(liquidity index)}$$

where $\alpha_j > 0$ denotes the weight (or convenience parameter) of instrument j in providing liquidity, $\sigma > 0$ is the elasticity of substitution among instruments. The household faces a per-period budget constraint:

$$C_t + D_t + S_t + M_t \leq (1 + i_{D,t})D_{t-1} + (1 + i_{S,t})S_{t-1} + (1 + i_{M,t})M_{t-1} + \omega_t, \qquad \text{(BC)}$$

where $i_{j,t}$ is the return on asset $j \in \{D, S, M\}$ between $t-1$ and t and ω_t denotes real endowment income received at time t. Let Λ_t be the Lagrange multiplier on the budget constraint. The Lagrangian for this problem is:

$$\mathcal{L} = \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \Big\{ u(C_t, Q_t) + \Lambda_t [(1+i_{D,t})D_{t-1} + (1+i_{S,t})S_{t-1} + (1+i_{M,t})M_{t-1} + \omega_t - C_t - D_t - S_t - M_t] \Big\}.$$

We define $\partial u / \partial C_t = u_C$ and $\partial u / \partial Q_t = u_Q$ and obtain the first-order conditions (FOCs) with respect to consumption:

$$u_C = \Lambda_t$$

and asset holdings:

$$\frac{u_Q}{u_C} \cdot \frac{\partial Q_t}{\partial \eta_{j,t}} = 1 - \frac{\beta \mathbb{E}_t \left[\Lambda_{t+1}(1 + i_{j,t+1})\right]}{\Lambda_t}$$

where we divide both sides of each FOC by u_C and use the envelope condition $\Lambda_t = u_C$. These conditions describe the trade-off between consuming today versus gaining financial return and liquidity benefits from holding money-like assets. Define, for each monetary instrument $j \in \{D, S, M\}$, the endogenous convenience yield as:

$$\theta_j \equiv \frac{u_Q}{u_C} \cdot \frac{\partial Q_t}{\partial \eta_{j,t}}.$$

Under deterministic consumption or certainty equivalence, the marginal utility ratio simplifies:

$$\frac{\Lambda_{t+1}}{\Lambda_t} \approx \frac{u_{C,t+1}}{u_{C,t}} \approx \frac{1}{1+\psi}$$

[2]We assume that $u(0,0) = 0$, $u_C > 0$, $u_Q > 0$, $u_{CC} < 0$, $u_{QQ} < 0$, $u_{CC}u_{QQ} - \left(u_{CQ}\right)^2 \geq 0$ for joint concavity with respect to C and Q.

for a subjective discount rate ψ such that $\beta = \frac{1}{1+\psi}$. Then, taking expectations and inverting:

$$\mathbb{E}_t \left[\frac{\Lambda_t}{\Lambda_{t+1}} \right] \approx 1 + \psi$$

Hence, rearranging yields the convenience-adjusted return condition:

$$i_j + \theta_j \approx \psi = \frac{1}{\beta} - 1.$$

This provides a microfounded justification for the reduced-form arbitrage condition:[3]

$$i_D + \theta_D = i_S + \theta_S = i_M + \theta_M.$$

In this framework, the household's choice over deposits, stablecoins, and CBDC depends on both their financial return and their contribution to the overall liquidity aggregate Q_t. The CES structure allows for imperfect substitution: if one instrument becomes less convenient or pays a lower return, households may partially reallocate toward others depending on the elasticity σ.

The interaction between issuer design choices and household preferences determines the equilibrium distribution of monetary assets. Sectoral outcomes are jointly shaped by competition among issuers, regulatory constraints, and the relative convenience of each instrument. Design, risk, and access features directly influence the liquidity weights α_j, which in turn govern usage patterns and portfolio shares. In turn, the other three agents influence the $\alpha_j's$. Namely, banks supplies D_t in response to convenience-adjusted return and elasticity of substitution. NFIs compete for liquidity share S_t and ensure operational reliability and regulatory compliance (e.g., capital backing, audits). Finally, the central bank provides M_t, setting i_M and design features to influence its share.

Households hold CBDC (M_t), bank deposits (D_t), and stablecoins (S_t) to facilitate transactions and smooth consumption. These instruments are not productive assets but provide *liquidity services* that enable payments and enhance the utility derived from consumption. Formally, liquidity enters preferences through the composite index Q_t, which aggregates the convenience services of the available payment media. Each instrument offers a distinct mix of attributes—CBDC provides finality and public trust, deposits combine yield with broad acceptance, and stablecoins offer programmability and cross-platform functionality—captured by the convenience parameters α_j. Hence, households choose their portfolio to maximise the utility from consumption and transactional convenience, subject to the budget constraint. In equilibrium, holdings of CBDC, deposits, and stablecoins reflect the trade-off between financial returns and liquidity services, with relative shares determined by the *convenience-adjusted returns*. This formulation abstracts from explicit cash-in-advance constraints while preserving the essential role of monetary instruments as *media of exchange* that support household spending.[4]

[3]This approximation assumes low interest rates, stable consumption, and either log or CRRA utility. In stochastic settings, the exact expression retains the marginal utility ratio inside the expectation, but the logic of convenience-adjusted return equalization still applies.

[4]The liquidity aggregator Q_t can be interpreted as a reduced-form representation of an underlying pay-

The analysis in Sections 3.3–3.6 maintains this general specification. Section 3.8 adopts the CRRA parametrisation $u(C,Q) = \frac{C^{1-\sigma_C}-1}{1-\sigma_C} + \chi\,\frac{Q^{1-\sigma_Q}-1}{1-\sigma_Q}$ for the quantitative welfare comparisons, which satisfies all regularity conditions stated above and nests the log-linear specification used for illustration in Section 3.3.3.

3.2.2 Banks

Banks (B) act as financial intermediaries between depositors, borrowers, and the central bank. They create deposit money through lending, hold reserves with the central bank, and manage their balance sheets subject to liquidity and profitability constraints. The representative bank's balance sheet can be expressed as:

$$L + R_B = D + K, \qquad \text{(bank-balance)}$$

where L are loans extended to households or non-financial intermediaries, R_B are reserves held at the central bank, D denotes deposits held by households and NFIs, and K represents bank equity (capital). Banks face a reserve requirement, $R_B = \rho D$, with a reserve ratio $0 \leq \rho < 1$, and a capital (leverage) constraint, $L \leq \kappa\, K$ for some $\kappa > 1$.

Banks obtain funding primarily through deposits, remunerated at rate i_D, They lend to households or firms at a rate i_L. The bank's profit function is given by:

$$\Pi_B = i_L L + r^* R_B - i_D D - \gamma K, \qquad \text{(bank-profit)}$$

where i_L is the loan rate, $i_R = r^*$ is interest on reserves, i_D is the deposit rate and γ is the cost of capital (return demanded by shareholders). Banks choose D (hence $R_B = \rho D$) and L (subject to $L \leq \kappa K$) to maximise Π_B, given i_L, i_D, r^*, ρ, κ, and γ, subject to the balance sheet constraint and any regulatory or reserve requirements. In equilibrium, arbitrage and competition drive expected returns across funding sources toward parity once adjusted for risk and liquidity. A typical outcome is the following. If i_L is high enough relative to i_D and r^*, banks expand lending until the capital constraint binds. Deposit rate i_D is set at or just below the arbitrage level $(i_S + \theta_S) - \theta_D$ so that banks attract deposits but do not lose funding to stablecoins. In equilibrium, deposit-funded lending satisfies:

$$L = (1-\rho)D \quad \text{and} \quad L = \kappa\, K \quad \Longrightarrow \quad D = \frac{\kappa - 1}{1-\rho} K,$$

so higher capital or a lower reserve ratio expands deposits (all else equal).

Banks provide settlement services for deposit-based payments and access to credit, ensuring the convertibility of deposits into central bank money at par. This par convertibility anchors *singleness* within the monetary system, linking deposits to public money (reserves

ment constraint, such as $P_t C_t \leq \phi_D D_t + \phi_S S_t + \phi_M M_t$, where ϕ_j denotes the payment efficiency of each instrument. In this interpretation, Q_t corresponds to the shadow value of relaxing that constraint and summarizes the household's effective transaction capacity. This approach retains the microfoundations of a cash-in-advance framework while allowing for smooth substitution among monetary instruments via a CES specification.

and CBDC). Through their intermediation role, banks transmit monetary policy by adjusting loan and deposit rates in response to changes in the policy rate r^*, amplifying or dampening liquidity across the economy.

3.2.3 Non-Financial Intermediaries

Non-financial intermediaries (NFIs) represent private entities that issue stablecoins backed by liquid assets. Their balance sheet consists of stablecoin liabilities S and a portfolio of reserves and short-term investments as assets. The asset side may include central bank reserves R_S and other safe or interest-bearing instruments D_S, such as bank deposits or short-term securities. Hence,

$$R_S + D_S = S. \tag{NFI-balance}$$

The NFI collects funds from households through stablecoin issuance and invests them in interest-bearing assets. The flow of profits for the intermediary is given by

$$\Pi_{\text{NFI}} = r^* R_S + i_D D_S - i_S S - f_S S, \tag{NFI-profit}$$

where r^* and i_D denote the interest rates earned on reserves and other assets, respectively; i_S is the remuneration (if any) paid on stablecoin holdings; and f_S represents issuance or management fees. In the baseline configuration, reserves are fully backed by central bank assets, $R_S = S$ and $D_S = 0$, yielding

$$\Pi_{\text{NFI}} = (r^* - i_S - f_S)S.$$

Under perfect competition, NFIs earn zero economic profits, implying the equilibrium condition

$$i_S = r^* - f_S. \tag{NFI-zero-profit}$$

This zero-profit NFI condition ensures that the return on stablecoin liabilities equals the return on reserve assets net of fees. When the reserve pool includes riskier assets, the expected return $E[r_A]$ replaces r^*, and the condition generalises to

$$i_S = E[r_A] - f_S - \pi_{\text{risk}},$$

where π_{risk} captures expected credit and liquidity premia. This modification highlights that riskier backing structures may sustain higher nominal yields but at the cost of reduced stability and weaker par convertibility.

3.2.4 Central Bank

The central bank (CB) issues monetary liabilities in two forms: reserves held by banks (R), by NFIs (R_S), *cash* or central bank digital currency (CBDC) held by households (M). On the asset side, A_{CB}, it holds government bonds (B_{CB}) and loans to banks (L_{CB}). The balance sheet identity is given by

$$B_{CB} + L_{CB} = R_B + R_S + cash + M. \tag{CB-balance}$$

The central bank sets the policy rate r^*, which determines the remuneration on reserves. It can also choose to remunerate CBDC holdings at a rate i_M, subject to a potential holding limit $\bar{M}^c$. When $i_M < r^*$, households have an incentive to prefer bank deposits or stablecoins for yield, but the safety and liquidity of central bank money maintain its role as the anchor of the monetary system. The central bank's profit (seigniorage) can be expressed as

$$\Pi_{\text{CB}} = i_B B_{CB} + i_{CB} L_{CB} - r^*(R_B + R_S) - i_M M, \tag{CB-profit}$$

where i_B and i_{CB} denote the returns on government bonds and central bank loans, respectively. Profits are remitted to the government, ensuring that the monetary base expansion or contraction feeds back into the consolidated public sector balance sheet.

The central bank thus anchors the system's hierarchy of money: reserves define the risk-free benchmark rate r^* against which all other yields are priced, while its liabilities provide the ultimate settlement asset ensuring monetary *singleness*. In what follows, we take the CB's asset side,$B_{CB} + L_{CB}$, as exogenous (e.g. net purchases of government bonds), assume that *cash* is nil and the CB adjusts M endogenously to satisfy the public's demand for CBDC given i_M.

3.3 Equilibrium and Solution Strategy

This subsection consolidates the formal equilibrium relationships and a practical roadmap for solving the model. We first state the equilibrium conditions (household optimality, institutional zero-profit/pricing, and market clearing), then organise them into a step-by-step solution strategy that will be used in simulations and policy experiments.[5]

Convenience yields θ_j are not exogenous preference parameters but endogenous equilibrium outcomes. They represent the implicit return households obtain from holding a payment instrument beyond its financial yield, and they adjust to equilibrate the demand for and supply of liquidity services across instruments. In equilibrium, θ_j reflects institutional frictions, regulatory costs, and the aggregate adoption of each medium of exchange, so that convenience benefits and financial returns jointly determine portfolio shares. This interpretation clarifies the transition from the household's optimisation problem to the market equilibrium and underlies the possibility of multiple equilibria when network effects or perceived convenience depend on aggregate holdings.

[5] The model can be extended to introduce cash, which is issued by the central bank, has no interest and a convenience yield, θ_{cash}. Its existence lowers demand for CBDC or stablecoins unless the latter offer higher convenience. The arbitrage condition now ties four instruments instead of three, ensuring coexistence depends on relative convenience yields. In summary, cash dominates if $\theta_{\text{cash}} > \theta_M = i_S + \theta_S = i_D + \theta_D$ and, in this case, households will not hold CBDC or other digital assets. If the central bank enhances the convenience yield of CBDC (e.g., by introducing privacy features), then CBDC can compete directly with cash. This setup allows the modelling of transitions between steady-state equilibria from a cash-dominant to a digital-dominant system as a function of the θ-parameters and policy interest rates.

Throughout, η_j denotes the portfolio share of instrument j, defined as

$$\eta_j \;\equiv\; \frac{j}{M+D+S}, \qquad j \in \{M, D, S\},$$

which corresponds to $\eta_j = x_{j,t}/W$ in the notation of Section 3.2.1, where $W = M+D+S$ is aggregate wealth. With homogeneous agents, η_j also serves as the aggregate adoption share that enters the network-effect function $\theta_j = g_j(\eta_j)$; the two coincide in equilibrium.

The equilibrium portfolio shares η_j can be expressed explicitly through a *softmax* mapping of convenience-adjusted returns:

$$\eta_j = \frac{\exp\big((i_j + \theta_j)/\tau\big)}{\sum_{k\in\{M,D,S\}} \exp\big((i_k + \theta_k)/\tau\big)}, \tag{1}$$

where $\tau > 0$ governs the sensitivity of portfolio allocation to relative convenience-adjusted returns.

Remark 3.1. ***Softmax as discrete-choice approximation of CES demand.*** *Two routes justify equation* (1). First, *from the CES first-order conditions, the ratio of holdings satisfies*

$$\frac{\eta_j}{\eta_k} = \left(\frac{\alpha_j}{\alpha_k}\right)^{\sigma} \left(\frac{i_k + \theta_k}{i_j + \theta_j}\right)^{\sigma}.$$

For large σ (high substitutability), this ratio is increasingly sensitive to differences in convenience-adjusted returns and the allocation approximates a winner-takes-most rule; the softmax provides a smooth interpolation of this limit with temperature $\tau = 1/\sigma$. Second, *if households face idiosyncratic preference shocks that are i.i.d. Extreme Value Type I (Gumbel), the optimal discrete-choice probability for instrument j is exactly the multinomial logit $\eta_j = e^{r_j/\tau}/\sum_k e^{r_k/\tau}$ (McFadden, 1974), which coincides with equation* (1)*. Under either interpretation, the softmax is consistent with utility maximisation and provides a tractable, differentiable closed-form allocation rule. Setting $\tau \to 0$ recovers the corner solution in which all wealth goes to the highest-r_j instrument.*

This representation provides a closed-form behavioural foundation for the allocation rule $\eta_j = T_j(\theta_M, \theta_D, \theta_S)$ defined below, linking the share of each instrument directly to its convenience-adjusted return.

$$\theta_j = g_j(\eta_j), \qquad g_j'(\cdot) > 0, \quad g_j''(\cdot) \geq 0,$$

where $g_j(\cdot)$ denotes the convenience function specific to each payment instrument. This specification reflects that the perceived ease of use, acceptance, and interoperability of a monetary instrument increase with its overall circulation. For example, a widely used stablecoin benefits from stronger network externalities in platform payments, while a broadly adopted CBDC enhances payment convenience through interoperability and reduced counterparty risk. The equilibrium convenience yields θ_j thus embody both institutional characteristics and endogenous comparative statics across adoption levels. When the slope of $g_j(\eta_j)$ is sufficiently steep, small changes in perceived convenience or regulatory conditions can generate multiple steady-state equilibria, corresponding to regimes of CBDC dominance, deposit dominance, or stablecoin prevalence.

The dependence of convenience yields on adoption creates a fixed-point structure in equilibrium. Given the convenience-adjusted returns, households optimally allocate their liquidity across instruments, generating portfolio shares

$$\eta_j = T_j(\theta_M, \theta_D, \theta_S),$$

where $T_j(\cdot)$ is obtained from the first-order conditions of the household problem, is continuous and bounded, and satisfies $\sum_j \eta_j = 1$. Substituting the endogenous convenience yields $\theta_j = g_j(\eta_j)$, the equilibrium adoption shares solve the system of fixed-point conditions

$$\eta_j = T_j\big(g_M(\eta_M), g_D(\eta_D), g_S(\eta_S)\big), \qquad j \in \{M, D, S\}. \tag{2}$$

Equation (1) provides the operational link between convenience-adjusted returns and the equilibrium mapping $T_j(\cdot)$, ensuring that portfolio shares respond smoothly to relative changes in financial returns or convenience benefits. In turn, equation (2) applies under the endogenous extension of Section 4.4 and characterises the endogenous steady-state distribution of liquidity across instruments given their network-dependent convenience yields.

Under the stated regularity conditions the existence of an equilibrium follows from Brouwer's fixed-point theorem. Multiple steady states arise when the feedback from adoption to convenience and back to adoption is sufficiently strong: locally, this corresponds to a condition on the Jacobian of the right-hand side (informally, when the spectral radius of the derivative matrix exceeds one). In scalar intuition, multiplicity can be anticipated when

$$g_j'(\eta_j)\,\frac{\partial T_j}{\partial \theta_j} > 1$$

(for the relevant instrument and evaluation point), i.e. the endogenous amplification via network effects exceeds the stabilizing response of household portfolio choice.

3.3.1 Equilibrium

An equilibrium of the model is defined by $\big(C, M, D, S, R_B, L, K, R_S, \theta_M, \theta_D, \theta_S, i_M, i_D, i_S, i_L\big)$, such that the following conditions are satisfied.

Households allocate wealth across CBDC (M), deposits (D), and stablecoins (S) to equalise convenience-adjusted returns:

$$i_M + \theta_M = i_D + \theta_D = i_S + \theta_S \equiv \psi, \tag{return parity}$$

and satisfy the per-period budget constraint given by equation (BC), normalised to a stationary setting by taking $D_{-1} = D$, $S_{-1} = S$, $M_{-1} = M$.

Banks, with balance given by equation (bank-balance) and profit by equation (bank-profit), under competition have zero profits, e.g. $\Pi_B = 0$, and price deposit with:

$$i_D = i_M + \theta_M - \theta_D = i_S + \theta_S - \theta_D. \tag{bank-pricing}$$

Combining equations (bank-balance)–(bank-profit) yields the bank zero-profit condition

$$\kappa i_L + \frac{\kappa - 1}{1-\rho}\rho r^* - \frac{\kappa - 1}{1-\rho} i_D - \gamma = 0. \qquad \text{(bank-zero-profit)}$$

Stablecoin issuers (NFIs), with full reserve backing at the central bank, $R_S = S$, and zero-profit due to competition, price stablecoins with:

$$i_S \;=\; r^* - f_S. \qquad \text{(NFI-zero-profit)}$$

CBDC and stablecoin coexist. Coexistence requires both assets to lie within a narrow band of relative pricing — the "pricing bound". When CBDC is non-interest-bearing ($i_M = 0$), combining equations (return parity) and (NFI-zero-profit) pins down the maximal fee compatible with coexistence:

$$f_S = r^* + \theta_S - \theta_M. \qquad \text{(CBDC–S coexistence)}$$

The coexistence of CBDCs and stablecoins is called a pricing bound because it defines the equilibrium range within which both instruments can circulate at par — a range determined by the trade-off between safety, yield, and convenience. This bound reflects i) arbitrage limits between public and private money; ii) regulatory or technological frictions (e.g., convertibility delays, network segmentation); iii) safety differentials — CBDC is risk-free while stablecoin depends on reserve quality; iv) convenience differences — stablecoins may have higher usability in DeFi or platforms. So the "pricing bound" encapsulates a general equilibrium constraint: both instruments can coexist only if their convenience-adjusted returns stay sufficiently close. This equality defines a pricing bound because it pins the maximum deviation in return between CBDC and stablecoin before agents arbitrage away the difference by reallocating liquidity. In fact, if $i_S + \theta_S - f_S > \theta_M$ households shift into stablecoins, while if $i_S + \theta_S - f_S < \theta_M$ they prefer CBDC.

Markets clear. Portfolio allocations satisfy equation (return parity), given aggregate wealth W. Under imperfect substitution (e.g., for computation or empirical mapping), a smooth share rule can be used:

$$\eta_j = \frac{e^{i_j + \theta_j}}{e^{i_M + \theta_M} + e^{i_S + \theta_S} + e^{i_D + \theta_D}}. \qquad j \in \{M, D, S\}, \qquad \text{(allocation)}$$

with $M = \eta_M W$, $D = \eta_D W$, $S = \eta_S W$.[6]

The balance sheets of all institutional sectors are jointly determined. Each institution satisfies a standard identity $\mathcal{A}_j = \mathcal{L}_j + \mathcal{E}_j$, for $j \in \{CB, B, S\}$, where $\mathcal{A}_j$ are total assets, $\mathcal{L}_j$ liabilities, and $\mathcal{E}_j$ equity or net worth. The *central bank* issues monetary liabilities in the form of reserves held by banks (R_B), reserves held by non-financial intermediaries (R_S), and retail CBDC (M). Its balance sheet is given by $\mathcal{A}_{CB} = R_B + R_S + M + \mathcal{E}_{CB}$.

[6] *Smooth share rule (softmax).* We use the multinomial-logit mapping $\eta_j = \exp\{r_j\}/\sum_k \exp\{r_k\}$ (temperature $\tau = 1$) to obtain a smooth, interior allocation across instruments as a function of convenience-adjusted returns $r_j = i_j + \theta_j$. The rule approximates the argmax as a continuous, differentiable choice; adding a constant to all r_j leaves shares unchanged. More generally, a temperature $\tau > 0$ controls sensitivity: $\partial \ln(\eta_j/\eta_k)/\partial(r_j - r_k) = 1/\tau$.

Changes in M or in the policy rate r^* alter the size and composition of $\mathcal{A}_{CB}$, anchoring the overall liquidity of the system. *Banks* issue deposits D and hold assets $\mathcal{A}_B = L + R_B$, consisting of private loans and reserves. Their balance sheet satisfies $\mathcal{A}_B = D + \mathcal{E}_B$, with $\mathcal{E}_B$ representing bank equity, set equal to K in the baseline model. The reserve ratio and capital ratio determine leverage and liquidity. Variations in household deposit demand or in the policy rate translate into balance-sheet adjustments across L and R. *NFIs* issue stablecoins S backed by reserve-like assets R_S and other holdings D_S, such that $\mathcal{A}_S = R_S + D_S = S + \mathcal{E}_S$. Here, $\mathcal{E}_S$ denotes NFI equity, set to zero in the baseline model. The stablecoin supply S adjusts to portfolio reallocations between private and public digital money. *Households* hold wealth $W = M + D + S$, implying that aggregate assets and liabilities are consistent: $\mathcal{A}_{CB} + \mathcal{A}_B + \mathcal{A}_S = M + D + S + \mathcal{E}_{CB} + \mathcal{E}_B + \mathcal{E}_S$. Shifts in household portfolios redistribute funding across institutions without affecting aggregate wealth. The central bank preserves monetary singleness by ensuring full convertibility between deposits, stablecoins, and CBDC at par, while policy adjustments in r^* influence the composition of liquidity and the size of institutional balance sheets.

Equilibrium implies a hierarchy of balance sheets anchored in central bank money. The CB defines the risk-free benchmark r^* and provides the settlement asset; banks intermediate between the CB and households by issuing deposits redeemable in reserves; NFIs operate on the periphery, issuing stablecoins redeemable through reserve or fiat channels. When monetary or market conditions shift, equilibrium adjustments occur through balance-sheet reallocation—rather than relative price changes—preserving parity among monetary instruments.

All in all, the model equilibrium is characterised by i) the equalization of convenience-adjusted returns across CBDC, deposits, and stablecoins, ii) zero profit conditions for banks and NFIs, iii) consistent allocation of wealth, reserves, and loans given reserve requirements and capital constraints, and iv) the fact that the central bank's balance sheet adjusts CBDC issuance endogenously to meet public demand.

3.3.2 Solution Strategy and Interpretation

Convenience yields θ_j are taken as given; their endogenisation is deferred to Section 4.4. To compute the equilibrium, we begin by fixing the exogenous parameters:

- **Policy and structural primitives:** discount rate ψ, reserve requirement ρ, capital ratio κ, cost of equity γ, convenience yields $\theta_M, \theta_D, \theta_S$, and the stablecoin fee f_S.
- **Policy rate:** r^*, which determines the remuneration on reserves and indirectly affects other rates.
- **CBDC remuneration:** i_M, which may be zero or positive depending on design.

The solution proceeds in a logical sequence:

Step 1: Stablecoin Pricing (Issuer Zero-Profit Condition) Under full reserve backing and perfect competition, the stablecoin issuer earns zero economic profit and fix pricing with the pricing equation (NFI-zero-profit). This anchors private money returns to the central bank's policy stance.

Step 2: Deposit Pricing (Household Parity Condition) Households equalise convenience adjusted returns across instruments and banks fix pricing with (bank-pricing), or equivalently with $i_D = i_M + \theta_M - \theta_D$, if CBDC remuneration is binding.

Step 3: Coexistence Check (CBDC vs. Stablecoins) If CBDC pays zero interest ($i_M = 0$), verify whether the chosen fee f_S allows coexistence. The coexistence bound is given by equation (CBDC–S coexistence). If f_S exceeds this bound, CBDC dominates; if smaller, stablecoins dominate; equality implies coexistence.

Step 4: Loan Rate (Bank Zero-Profit Condition) Given i_D and r^*, compute the loan rate i_L using the bank's zero-profit condition equation (bank-zero-profit).

Step 5: Portfolio Allocation With convenience-adjusted returns equalised, determine household portfolio shares:

- **Interior solution:** Apply a smooth share rule (softmax) given by equation (allocation).
- **Corner solution:** If design or fees create strong dominance, allocate all wealth to the instrument with the highest convenience-adjusted return.

Step 6: Balance Sheet Consistency Enforce institutional constraints: $R_B = \rho D$ (bank reserves), $R_S = S$ (NFI reserves). The central bank's reserve liability equals $R_B + R_S = \rho D + S$. Verify that the bank's balance sheet identity $L + R_B = D + K$ holds.

The comparative statics are discussed in Section 3.5.

3.3.3 Simulation

To illustrate the model's implications, we simulate a simple numerical example in which households allocate their financial wealth across CBDC, stablecoins, and bank deposits based on their respective *convenience-adjusted returns* – e.g. $r_j = i_j + \theta_j, \quad j \in \{M, S, D\}$ – and that households allocate their portfolio shares using a softmax function – e.g. $\eta_j = e^{r_j} / \big(e^{r_m} + e^{r_S} + e^{r_D}\big)$. The softmax allocation rule is consistent with the CES model; see the Remark 3.1 following equation (1). This functional form captures imperfect substitution and bounded reallocation elasticity, and reflects the intuition that households increasingly favour the asset offering the highest convenience-adjusted return, without immediately abandoning the others.

We fix the convenience yield of bank deposits at $\theta_D = 0.015$ and explore how changes in the convenience yields of CBDC (θ_M) and stablecoins (θ_S) affect equilibrium portfolio shares. We assume CBDC pays zero interest ($i_M = 0$), and that stablecoins incur a platform fee f_S, yielding $i_S = r^* - f_S$ with $r^* = 0.02$ and $f_S = 0.004$. Deposits earn a market-determined rate i_D set to ensure convenience-adjusted return parity, but held constant in the simulation for simplicity. Parameter values are consistent with the baseline calibration of Section 3.4; Table 4 reports the full set of targets and sources. The results are shown in Figure 2.

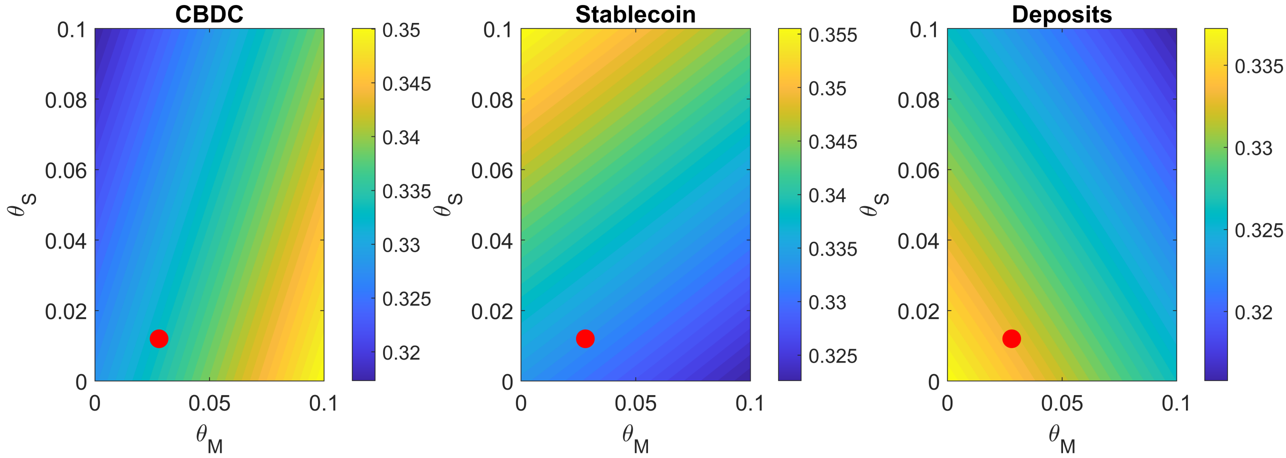

Figure 2: Equilibrium shares of CBDC, stablecoins, and deposits

Note. Equilibrium shares of CBDC, stablecoins, and bank deposits as functions of the convenience yields θ_M and θ_S, holding θ_D fixed at its baseline value; the circle marks the baseline calibration (θ_M, θ_S) of Table 4. The left panel shows the CBDC share increasing in θ_M and decreasing in θ_S. The centre panel shows the mirror behaviour for stablecoins. The right panel shows the deposit share, which is high when neither CBDC nor stablecoin convenience is sufficiently large to attract household portfolios. Even modest changes in convenience yields can induce large shifts across all three instruments.

The plots show how threshold equilibria in portfolio allocation emerge: when the convenience-adjusted return of one instrument becomes marginally more attractive than the others, households reallocate abruptly. This nonlinear sensitivity underscores the strategic role of design features (e.g., programmability, privacy, integration) in shaping digital money adoption.

The simulation abstracts from general equilibrium feedback effects—such as interest rate responses, lending constraints, or bank behaviour—but captures the essential mechanism: households equalise convenience-adjusted returns and tilt their portfolio toward the most attractive instruments. The framework provides a tractable tool for studying monetary design and competition in a digital environment. Our treatment of CBDC and stablecoin coexistence parallels the comparative analysis in Chiu and Monnet (2024), but can extend it by incorporating endogenous redemption risk (Section 4.3) and network effects (Section 4.4).

While the preceding subsections have focused on the formal solution strategy and its numerical illustration, the broader economic meaning of these mechanisms warrants a distinct discussion. Section 3.5 therefore steps beyond the computational framework to interpret the comparative statics in policy terms, highlighting how design choices—such as CBDC features, stablecoin fees, and prudential constraints—shape equilibrium outcomes. This separation ensures that readers interested in systemic implications and policy levers can engage with the analysis without navigating the technical details of the solution algorithm.

While the simulation abstracts from a formal calibration, Section 3.4 anchors the key parameters—reserve ratios, convenience yields, and the stablecoin fee—to empirical targets and supervisory benchmarks, providing a quantitative backbone for the comparative-statics mechanisms illustrated above.

3.4 Quantitative Framework

The calibration strategy follows recent general-equilibrium studies of digital money and banking transmission (Andolfatto, 2021; Keister and Sanches, 2022; Benigno et al., 2022; Brunnermeier et al., 2019), which align steady-state balance sheets with observed ratios of loans, deposits, and reserves. Key parameters are anchored to empirical estimates of liquidity and convenience premia (Krishnamurthy and Vissing-Jorgensen, 2012; Nagel, 2021), implying spreads of 20–50 basis points between public and private safe assets. The elasticity of substitution across monetary instruments, σ, and the convenience coefficients θ_j are chosen to reproduce realistic cross-sectional holdings of deposits and stablecoins in advanced economies. Policy counterfactuals—changes in r^*, CBDC design convenience θ_M, and quantity caps $\bar{M}$ or $\bar{S}$—mirror the comparative-statics approach in Paul et al. (2025), and are evaluated within the steady-state system derived in Section 3.3.1.

We discipline the model with supervisory and market targets, then study policy and design shocks in turn.

Targets and parameterisation. We calibrate (ρ, κ, γ) to regulatory and supervisory moments; r^* reflects the baseline monetary stance; $(\theta_M, \theta_D, \theta_S)$ proxy instrument usability—CBDC wallet design and public trust, fast-payment rail coverage, and DeFi or platform integration, respectively; f_S captures issuer pricing; σ governs substitutability. Table 4 reports the baseline.

Scope and limitations of the calibration. The quantitative exercise is best understood as a benchmark calibration rather than a full structural estimation. Some parameters—the reserve ratio ρ and the capital multiple κ—are directly anchored to institutional and supervisory benchmarks (International Monetary Fund, 2022a; Basel Committee on Banking Supervision, 2024). Others, most importantly the convenience yields θ_M, θ_D, and θ_S, cannot be observed directly and are disciplined by empirical estimates of liquidity premia (Krishnamurthy and Vissing-Jorgensen, 2012; Nagel, 2021) together with economically motivated ranking restrictions across instruments. In this sense, the calibration is illustrative but not arbitrary: it is designed to reproduce a plausible baseline in which deposits remain dominant, CBDC derives value from safety and convenience rather than remuneration alone, and stablecoins face a disadvantage unless they compensate households through functional or network-related benefits. A fuller empirical implementation would require matching observed payment shares, substitution elasticities, and usage patterns across competing digital payment instruments.

Solution algorithm. Given (r^*, i_M), compute interest rates (i_S, i_D, i_L) via the NFI zero-profit condition (NFI-zero-profit), the bank pricing condition (bank-pricing), and the bank zero-profit condition (bank-zero-profit). Map rates to portfolio shares using the return parity condition (return parity) or the softmax allocation rule (allocation). Clear balance sheets using the institutional constraints $R_B = \rho D$, $R_S = S$, and $L + R_B = D + K$. When network effects are present (Section 4.4), iterate holdings until convergence and detect multiplicity by grid sweeps over (θ_M, θ_S).

Table 4: Baseline Parameters and Targets

Parameter	Value (annual)	Target / Rationale
Reserve ratio ρ	0.01	Retail reserve requirement $\sim$1%
Capital multiple κ	6.0	Moderate leverage; $L \leq \kappa K$
Equity service wedge γ	0.0052	Calibrated s.t. $\gamma(\kappa - 1) \approx 2.6\%$
Policy rate r^*	0.020	Neutral stance (2%)
CBDC convenience θ_M	0.028	Safety, public trust, wallet usability
Deposit convenience θ_D	0.015	Broad acceptance, fast-payment rails
Stablecoin convenience θ_S	0.012	Programmability, platform reach
Stablecoin fee f_S	0.004	40 bps issuer operational cost
Elasticity of substitution σ	2.5	Moderate substitutability across instruments

Note. The policy rate $r^* = 2\%$ reflects a neutral monetary stance. The reserve ratio $\rho = 1\%$ is a typical retail requirement (International Monetary Fund, 2022a); $\kappa = 6$ represents moderate leverage, consistent with observed Tier 1 capital ratios of approximately 14% for large European banks (Basel Committee on Banking Supervision, 2024). The equity wedge γ is chosen such that $\gamma(\kappa - 1) \approx 2.6\%$, delivering a realistic loan–deposit spread of roughly 250 basis points. Convenience yields capture nonpecuniary attributes: CBDC ($\theta_M = 2.8\%$) emphasises safety and public trust, deposits ($\theta_D = 1.5\%$) broad acceptance via payment rails, and stablecoins ($\theta_S = 1.2\%$) programmability; values are consistent with empirical liquidity premia in the range of 20–73 basis points (Krishnamurthy and Vissing-Jorgensen, 2012; Nagel, 2021). The stablecoin fee $f_S = 0.4\%$ reflects operational costs (Financial Stability Board, 2020), while $\sigma = 2.5$ ensures partial rather than perfect substitutability.

Sanity checks. *(i)* $i_S = r^* - f_S = 1.6\%$ (NFI zero-profit condition); *(ii)* $i_D = (i_S + \theta_S) - \theta_D = 1.3\%$, approximately 80 bps below r^* (return parity); *(iii)* $i_L \approx 3.8\%$, yielding a 250 bps loan–deposit spread (bank zero-profit condition); *(iv)* the coexistence condition (CBDC–S coexistence) is satisfied since $f_S = 0.4\% r^* + \theta_S - \theta_M = 1.2\%$.

Baseline equilibrium. Table 5 reports equilibrium rates and portfolio shares under the baseline parameterisation. Deposit and stablecoin rates lie below the policy rate by 70 and 40 basis points, respectively; CBDC is unremunerated, yielding a spread of -200 bps relative to r^*. The loan–deposit margin is 250 bps, consistent with the bank leverage wedge $\gamma(\kappa - 1)$. These values form the benchmark against which the policy counterfactuals below are evaluated.

Policy counterfactuals. We consider seven interventions: *(i)* a +100 bps increase in the policy rate Δr^*; *(ii)* an improvement in CBDC convenience $\Delta\theta_M > 0$, representing design enhancements such as privacy or programmability; *(iii)* a binding cap $\bar{M}$ on CBDC holdings (Section 4.1); *(iv)* a binding cap $\bar{S}$ on stablecoin supply (Section 4.2); *(v)* the introduction of risky reserve assets for stablecoin issuers, calibrated as a 25 bps credit premium π_{risk} (Section 4.3); *(vi)* high network effects biased toward CBDC adoption (Section 4.4); and *(vii)* a preference heterogeneity shift toward technologically sophisticated households (Section 4.5).

Table 6 reports the steady-state responses of interest rates and portfolio shares. On the pricing side, deposit and stablecoin rates adjust via the zero-profit conditions (NFI-zero-profit) and (bank-pricing), while the loan rate inherits the bank reserve schedule via (bank-zero-profit). On the allocation side, portfolio shares move with changes in convenience-

Table 5: Baseline Equilibrium: Rates, Shares, and Balance-Sheet Quantities

	CBDC	**Deposits**	**Stablecoins**	**Notes**
Rate (i_j)	0.000	0.013	0.016	
Share (η_j)	0.30	0.35	0.35	$\eta_M + \eta_D + \eta_S = 1$
Quantities	0.30	0.35	0.35	$W = 1$ normalisation
Loan rate i_L	$\frac{i_D - \rho r^*}{1-\rho} + \gamma(\kappa - 1) = 3.80\%$			
Bank reserves R_B	$\rho D = 0.0035$			
Stablecoin reserves R_S	$S = 0.35$			
Bank capital K	$\frac{(1-\rho)D}{\kappa - 1} = 0.07$			
Bank loans L	$\kappa K \approx 0.42$			
Liquidity index Q	1 (normalisation)			

Notes. The table reports the steady-state allocation under the normalisation $W = 1$, so that quantities coincide with portfolio shares ($M = \eta_M$, $D = \eta_D$, $S = \eta_S$). The liquidity index is normalised to $Q = 1$, fixing the units of the CES aggregator without affecting equilibrium allocations. Bank reserves satisfy $R_B = \rho D$ and stablecoin reserves satisfy $R_S = S$. Bank capital is pinned by $K = (1-\rho)D/(\kappa - 1)$ and loans satisfy the leverage constraint $L = \kappa K$. The loan rate follows from the bank zero-profit condition (bank-zero-profit).

adjusted returns: instruments whose return increases gain market share, and the remaining assets lose share mechanically since the η_j sum to one. The magnitude of reallocation reflects the elasticity of substitution σ embedded in the softmax rule (allocation). Even small convenience differentials produce sizeable shifts in the composition of liquidity holdings, consistent with the threshold-equilibrium dynamics characterised in Section 4.4.

Table 6: Policy Counterfactuals: Interest-Rate and Portfolio-Share Responses

Scenario	Δi_D (bps)	Δi_L (bps)	Δi_M (bps)	Δi_S (bps)	$\Delta \eta_M$ (pp)	$\Delta \eta_D$ (pp)	$\Delta \eta_S$ (pp)
(1) Policy rate hike (Δr^*=+100 bps)	+90	+100	0	+100	−0.3	+0.2	+0.1
(2) CBDC design improvement ($\Delta\theta_M = +50 \quad bps$)	0	0	0	0	+1.0	−0.5	−0.5
(3) CBDC cap ($\bar{M} = 0.10\,W$)	+5	+10	0	0	−3.0	+1.5	+1.5
(4) Stablecoin cap ($\bar{S} = 0.10\,W$)	+5	+10	0	+100	+1.8	+1.2	−3.0
(5) Risky reserves (π_{risk}=25 bps)	+8	+12	0	+25	−0.4	+0.1	+0.3
(6) High network effects (bias to CBDC)	0	0	0	0	+0.6	−0.3	−0.3
(7) Heterogeneity shift (tech-savvy ↑)	0	0	0	0	−0.6	−0.2	+0.8

Notes. Each row reports the change in equilibrium interest rates (bps) and portfolio shares (percentage points) relative to the baseline in Table 5. Δi_j denotes the change in the rate on instrument j; $\Delta \eta_j$ the change in its portfolio share. Shares sum to zero across instruments by construction. Scenario (2) reflects a +50 bps increase in θ_M. Scenarios (3)–(5) correspond to Sections 4.1–4.3; scenarios (6)–(7) to Sections 4.4–4.5.

Remark: Cross-Border Considerations

Cross-border considerations and foreign exchange risk are formalised in Appendix A.5. The domestic framework of Sections 3.2–3.6 remains fully applicable in the absence of foreign instruments: the coexistence bound, pricing conditions, and portfolio shares derived above hold without modification when all instruments are denominated in domestic currency.

3.5 Comparative Statics and Policy Interpretation

The preceding analysis has established the formal structure of the model, demonstrated its numerical properties, and anchored the key parameters to empirical targets (Section 3.4). We now turn to a more interpretative discussion of the comparative statics, emphasising their economic meaning and policy relevance in light of the baseline calibration.

The central insight is that equilibrium allocations are highly sensitive to both financial and nonpecuniary attributes of monetary instruments. If the convenience yield of stablecoins θ_S increases—perhaps because of broader merchant acceptance or deeper DeFi integration—NFIs can sustain larger fees f_S without losing market share; if such adjustments are infeasible, households reallocate aggressively toward stablecoins. Policy rates exert a similarly powerful influence: an increase in r^* raises the return on reserves and, through the zero-profit condition, stablecoin remuneration, compelling banks to raise deposit rates and tighten credit supply via the zero-profit constraint. Institutional constraints such as reserve requirements and capital ratios amplify this sensitivity, linking prudential regulation directly to monetary transmission.

These comparative statics illustrate that convenience is not a passive attribute but a policy lever. Small adjustments in design parameters can produce nonlinear effects, including discontinuous transitions across steady states where one instrument rapidly displaces others. Section 3.6 formalises this intuition by introducing a feature-based representation of convenience and mapping specific design levers—interoperability, user experience, and privacy layers—into equilibrium outcomes.

3.6 Convenience as a Policy Tool in Digital Finance

3.6.1 Features of Convenience

Building on Section 3.1, we decompose θ_j into measurable components—liquidity, programmability, and privacy—via a feature-based aggregator, enabling comparative statics grounded in observable design levers. Fast-payment rails, open-banking integration, and tokenisation raise the programmability and interoperability of deposits, increasing θ_D and allowing banks to retain a central role in digital ecosystems without sacrificing safety.[7] In what follows, households choose portfolio holdings across CBDC (M), stablecoins (S), and deposits (D), consistent with the baseline model of Section 3.2.

[7] Tokenised deposits—bank-issued tokens on permissioned DLT networks—represent the leading example of such enhancements. We treat them as a special case of D with higher feature scores (L_D, P_D), consistent with the monetary hierarchy (CBDC at the core, bank money in the middle, NFIs at the periphery) and the BIS (2025) unified-ledger vision.

We define the feature vector $\mathbf{f}_j = (L_j, P_j, V_j, i_j)$ for each instrument $j \in \{M, S, D\}$, where L_j captures liquidity and acceptance, P_j programmability, V_j privacy, and i_j the financial return.[8] The convenience yield is modelled as a CES aggregator:

$$\theta_j(\mathbf{f}_j) = \left(\omega_L L_j^\delta + \omega_P P_j^\delta + \omega_V V_j^\delta + \omega_R i_j^\delta\right)^{1/\delta}, \qquad \sum_{\ell \in \{L,P,V,R\}} \omega_\ell = 1, \quad \omega_\ell \geq 0.$$

Proposition 3.1 (Feature-based convenience and portfolio shares)**.** *Let $\mathbf{f}_j = (L_j, P_j, V_j, i_j)$ denote the feature vector of instrument $j \in \{M, S, D\}$. The convenience yield $\theta_j(\mathbf{f}_j)$ is strictly increasing in each component. Consequently:* (i) *an increase in any feature raises the portfolio share η_j, ceteris paribus;* (ii) *an improvement in CBDC features tightens the coexistence bound, reducing the maximum fee stablecoin issuers can sustain without being displaced;* (iii) *deposits can match stablecoin programmability while retaining institutional safety, provided $\theta_D(\mathbf{f}_D) \geq \theta_S(\mathbf{f}_S)$.*

Proof. Parts *(i)* and *(iii)* follow from the monotonicity of the CES aggregator in each argument and the softmax allocation rule (1). Part *(ii)* follows from differentiating the coexistence bound (CBDC–S coexistence) with respect to θ_M: $\partial f_S^{\max}/\partial\theta_M = -1 < 0$. □

Instrument weights in the liquidity aggregator Q_t are endogenous:

$$Q_t = \left(\alpha_M(\mathbf{f}_M)\, M_t^{\frac{\sigma-1}{\sigma}} + \alpha_S(\mathbf{f}_S)\, S_t^{\frac{\sigma-1}{\sigma}} + \alpha_D(\mathbf{f}_D)\, D_t^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}}, \qquad \alpha_j(\mathbf{f}_j) = \theta_j(\mathbf{f}_j)^\nu.$$

We retain the sectoral pricing blocks of Section 3.3.1:

$$i_S = r^* - f_S, \tag{NFI-zero-profit}$$
$$i_D = i_M + \theta_M - \theta_D = i_S + \theta_S - \theta_D, \tag{deposit pricing}$$
$$i_M = r^*. \tag{CBDC pricing}$$

Given feature vectors $\{\mathbf{f}_M, \mathbf{f}_S, \mathbf{f}_D\}$ and policy parameters $\{r^*, f_S\}$, an equilibrium consists of rates (i_M, i_S, i_D), portfolio shares (η_M, η_S, η_D), and quantities (M, S, D) such that: (i) households equalise convenience-adjusted returns via (1); (ii) bank and NFI zero-profit conditions (NFI-zero-profit)–(deposit pricing) hold; (iii) markets clear, $\Omega_j = \eta_j W$ for $j \in \{M, S, D\}$.

Figure 3 illustrates dominance regions based on $r_j = i_j + \theta_j$. Boundaries where $r_j = r_k$ define indifference curves; the diagram partitions the space into **A** (CBDC dominance), **B** (deposit dominance), and **C** (stablecoin dominance). The left panel maps dominance in the space of CBDC programmability (P_M) and deposit programmability (P_D): increasing P_M shifts the vertical boundary rightward; increasing P_D shifts the horizontal boundary upward. The right panel maps dominance in the space of deposit liquidity (L_D) and stablecoin fee (f_S): the $r_D = r_S$ boundary slopes downward because higher L_D increases θ_D, requiring lower f_S for stablecoins to remain competitive.

[8] We allow for return salience, whereby a fraction of the financial yield contributes to perceived convenience via weight ω_R. Setting $\omega_R = 0$ eliminates salience and avoids double-counting of i_j.

Three design hierarchies emerge from the comparative statics. First, programmability leads: if P_D rises, θ_D increases and deposits displace stablecoins unless f_S falls or CBDC programmability improves. Second, the privacy edge matters: if V_M increases, θ_M rises, CBDC gains share, and the coexistence bound caps f_S via $i_S = r^* - f_S$. Third, faster deposit rails raise L_D and reduce stablecoin demand unless DLT on/off-ramps improve commensurately.

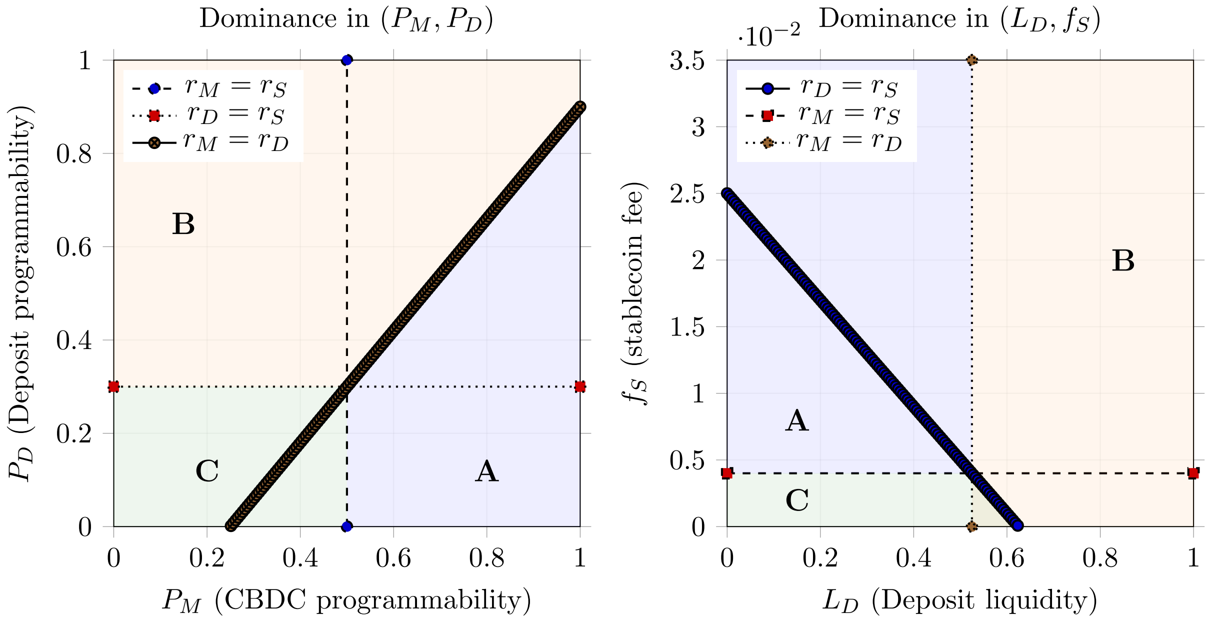

Figure 3: Phase diagrams showing dominance regions based on convenience-adjusted returns

Note. Left panel ((P_M, P_D) space): indifference boundaries where $r_M = r_S$ (vertical dashed), $r_D = r_S$ (horizontal dotted), and $r_M = r_D$ (oblique solid) partition the space into region **A** (CBDC dominance), **B** (deposit dominance), and **C** (stablecoin dominance). Increasing P_M shifts the vertical boundary rightward; increasing P_D shifts the horizontal boundary upward. **Right panel** ((L_D, f_S) space): the $r_D = r_S$ boundary slopes downward because higher deposit liquidity L_D raises θ_D, requiring stablecoins to reduce f_S to sustain parity. The horizontal boundary ($r_M = r_S$) shows that f_S must fall as θ_M rises, while the vertical boundary ($r_M = r_D$) indicates that CBDC–deposit competition is insensitive to f_S. Parameters are illustrative and consistent with the parity conditions of Section 3.3.1.

3.6.2 Special Case: Zero-Interest CBDC ($i_M = 0$)

We consider the case in which CBDC pays zero interest, $i_M = 0$, while households choose money-like assets based on convenience-adjusted returns $r_j = i_j + \theta_j$, $j \in \{M, S, D\}$. Let $\theta_M \equiv \Theta(L_M, P_M, V_M)$ be the CBDC convenience yield implied by its design features. In an interior allocation, equalisation of convenience-adjusted returns becomes

$$\theta_M = i_D + \theta_D = i_S + \theta_S, \qquad \text{(CBDC conv.)}$$

so that CBDC competes purely via θ_M. Stablecoins earn $i_S = r^* - f_S$, giving the deposit rate:

$$i_D = \theta_M - \theta_D. \qquad \text{(deposit rate)}$$

By the coexistence bound (CBDC–S coexistence) derived in Section 3.3.1, the maximum fee consistent with coexistence is $f_S = r^* + \theta_S - \theta_M$. Imposing $f_S \geq 0$ yields the *coexistence threshold*

$$\theta_M \ \leq \ r^* + \theta_S, \qquad \text{(coexistence threshold)}$$

beyond which stablecoins exit the market. Analogously, equation (deposit rate) links the deposit rate to CBDC convenience; if i_D must satisfy the bank zero-profit bound (bank-zero-profit), that constraint translates into an admissible range for $\theta_M - \theta_D$. Three regimes follow directly from Figure 3:

- **CBDC dominance.** Once equation (coexistence threshold) binds, any nonnegative f_S fails to match CBDC and stablecoins vanish. Similarly, if $\theta_M - \theta_D$ exceeds the bank's feasible i_D, deposits cannot match CBDC either.
- **Coexistence.** When θ_M is intermediate, banks set $i_D = \theta_M - \theta_D$ and NFIs set $f_S = r^* + \theta_S - \theta_M$, equalising $r_M = r_D = r_S$. Portfolio shares follow the softmax rule (1).
- **Stablecoin or deposit dominance.** If θ_M is low, households tilt toward private or bank instruments delivering higher $i_j + \theta_j$.

3.7 Model Summary and Policy Interpretation

This subsection recaps the steady-state general equilibrium environment and discusses the economic meaning of the comparative statics in light of the baseline calibration of Section 3.4.

Households derive utility from consumption and the liquidity services of CBDC, deposits, and stablecoins, and equalise convenience-adjusted returns across assets so that $i_M + \theta_M = i_D + \theta_D = i_S + \theta_S \equiv \psi$ (return parity). Stablecoins are issued by NFIs fully backed by central bank reserves; under perfect competition the zero-profit condition implies $i_S = r^* - f_S$ (NFI-zero-profit). When CBDC is non-remunerated, the admissible fee range is pinned down by the coexistence bound (CBDC–S coexistence) derived in Section 3.3.1: higher CBDC convenience tightens the room for stablecoin fees. Banks hold required reserves $R_B = \rho D$ and extend loans subject to leverage $L \leq \kappa K$; the bank zero-profit condition pins down the loan rate given (ρ, κ, γ). Market clearing requires $R_B = \rho D$, $L + R_B = D + K$, and $R_S = S$, so that sectoral constraints and pricing conditions jointly determine interest-rate spreads and asset shares.

The central insight of the comparative statics is that equilibrium allocations are highly sensitive to both financial and nonpecuniary attributes of monetary instruments. Consider first the role of convenience. If θ_S increases—perhaps because of broader merchant acceptance or deeper DeFi integration—the attractiveness of stablecoins rises relative to CBDC, forcing NFIs to adjust fees or face reallocation. Policy rates exert a similarly powerful influence: an increase in r^* raises the return on reserves and, through the zero-profit condition, stablecoin remuneration, compelling banks to raise deposit rates and pushing up loan rates via the zero-profit constraint. Institutional constraints also matter: a higher reserve ratio ρ raises deposit funding costs and, to restore profitability, banks tighten credit supply.

The introduction of a CBDC with enhanced convenience features—programmability, privacy, or offline functionality—can dramatically shift the competitive balance. By raising θ_M, the central bank narrows the coexistence margin for stablecoins: the fee f_S that issuers can charge without losing parity declines, and if the bound becomes binding, stablecoins may exit the market. Competition among issuers accelerates this dynamic, as downward pressure on fees erodes profitability. The quantitative counterfactuals in Table 6 provide a numerical backbone for these mechanisms, while the welfare results in Table 7 confirm that CBDC design improvements dominate rate-based interventions in terms of liquidity gains.

These comparative statics illustrate that convenience is not a passive attribute but a policy lever. Small adjustments in design parameters can produce nonlinear effects, including discontinuous transitions across steady states where one instrument rapidly displaces others. Section 3.6 formalises this intuition by mapping specific design levers—interoperability, user experience, and privacy layers—into equilibrium outcomes via a feature-based representation of convenience yields.

3.8 Welfare Implications of Digital Money Design

The preceding sections characterise how monetary instruments coexist in equilibrium. The policy rate r^* governs the pecuniary margin, while convenience yields θ_j and design features drive the nonpecuniary margin. Balance-sheet frictions (ρ, κ, γ) and network effects determine how these margins transmit to relative rates and portfolio shares; quantity constraints on M or S generate scarcity premia. The calibrated baseline of Section 3.4 anchors these mechanisms to empirical targets, providing a quantitative foundation for the welfare comparisons that follow.

Preferences. Following Brunnermeier and Niepelt (2019) and building on Brunnermeier et al. (2019) and Benigno et al. (2022), we specify household preferences as

$$u(C, Q) = \frac{C^{1-\sigma_C} - 1}{1 - \sigma_C} + \chi \frac{Q^{1-\sigma_Q} - 1}{1 - \sigma_Q}, \tag{3}$$

where $\sigma_C, \sigma_Q > 0$ denote curvature parameters governing risk aversion and liquidity substitutability, and $\chi > 0$ measures the relative weight of liquidity services in utility. Q is the CES liquidity index defined in Section 3.2, aggregating the convenience services of CBDC, deposits, and stablecoins. This structure extends the Lucas–Stokey and Woodford monetary utility frameworks (Lucas and Stokey, 1987; Woodford, 2001) to an environment with heterogeneous digital assets providing convenience yields and transaction services, and generalises the simpler log-linear specification used for illustration in Section 3.3.3.

This specification captures the insight of Brunnermeier and Niepelt (2019) that the value of a monetary asset depends not only on its pecuniary return but also on its *monetary service value*—its convenience yield, safety, and network of acceptance. The welfare effects of policy or design interventions can therefore be decomposed into (i) pecuniary components, driven by interest-rate changes, and (ii) nonpecuniary components, driven by shifts in the effective convenience of each instrument. In the steady state, the marginal rate of substitution between liquidity and consumption is

$$\frac{u_Q}{u_C} = \chi \frac{C^{\sigma_C}}{Q^{\sigma_Q}},$$

and total welfare changes satisfy $du = u_C\, dC + u_Q\, dQ$, providing a tractable mapping between balance-sheet reallocations and welfare effects across monetary regimes.

Welfare metric. To express welfare differences in economically interpretable units, we compute consumption-equivalent variations. The consumption-equivalent gain Δ of moving from a baseline allocation to a counterfactual is defined implicitly by

$$u(C^{\,\text{base}} + \Delta,\, Q^{\,\text{base}}) = u(C^{\,\text{cf}},\, Q^{\,\text{cf}}),$$

so that $\Delta > 0$ indicates that the counterfactual is equivalent to receiving an additional Δ units of consumption in the baseline. Under the CRRA specification given by equation (3), this yields a closed-form expression that depends on both the consumption and liquidity components of the welfare change, ensuring that improvements in Q enter the metric at their marginal utility value.

Quantitative results. Table 7 reports steady-state welfare changes, decomposed into consumption effects ($\Delta C/C$), changes in the liquidity index ($\Delta Q/Q$), and the resulting utility variation ($\Delta u/u$) relative to the calibrated baseline of Section 3.4. Parameters are set to $\chi = 0.20$, $\sigma_C = 2$, and $\sigma_Q = 2$.

Three patterns emerge from the table. *First*, a 100-basis-point policy-rate hike generates a moderate utility loss of approximately -1.2 per cent relative to the baseline. The decline in liquidity services ($\Delta Q/Q < 0$) dominates the modest rise in consumption, yielding a net reduction in welfare. *Second*, improvements in CBDC design—modelled as an increase in the convenience parameter θ_M—produce substantial welfare gains of approximately $+3.2$ per cent. Although consumption falls slightly, the associated rise in liquidity services ($\Delta Q/Q > 0$) more than compensates, illustrating how convenience-enhancing design changes can raise welfare even without altering nominal interest rates (Andolfatto, 2021; Keister and Sanches, 2022; Paul et al., 2025). *Third*, quantity constraints have sharply asymmetric effects. A binding CBDC cap generates welfare losses that increase with the stringency of the constraint. In scenario (3), calibrated to a cap of 10 per cent of household wealth—an extreme case chosen to illustrate the mechanism—the utility loss reaches -17 per cent. A cap calibrated to realistic retail holdings, such as the €3,000 threshold under discussion for the digital euro, would bind for a much smaller fraction of households and generate correspondingly smaller welfare effects. In contrast, a stablecoin cap raises welfare modestly by shifting portfolios toward instruments with higher effective liquidity value, producing $\Delta Q/Q > 0$ despite a small decline in consumption.

Scenarios involving risky reserves and stronger network effects produce small but nontrivial welfare changes: improvements in Q tend to outweigh modest reductions in C, yielding positive welfare gains in the network-effects case. Scenario (7) considers a shift in the distribution of household preferences toward technologically sophisticated agents, as formalised in the heterogeneous-agent extension of Section 4.5. The reallocation toward stablecoins driven by higher θ_S among tech-savvy households reduces aggregate liquidity services ($\Delta Q/Q < 0$), since stablecoins carry a lower convenience weight in the baseline calibration, resulting in a welfare loss of approximately -2.6 per cent. This result underscores the distributional dimension of digital money design: policies that improve CBDC usability for the general population may fail to retain technologically sophisticated households if stablecoin programmability remains superior. Overall, the table highlights that liquidity effects, rather than consumption movements, are the primary drivers of welfare differences across monetary regimes.

Table 7: Welfare Effects under Policy Counterfactuals

Scenario	$\Delta C/C$ (%)	$\Delta Q/Q$ (%)	$\Delta u/u$ (%)
Baseline (steady state)	0.00	0.00	0.00
(1) Policy-rate hike ($\Delta r^* = +100$ bps)	+0.01	−0.02	−1.18
(2) CBDC design improvement ($\Delta\theta_M = +50$ bps)	−0.03	+0.05	+3.17
(3) CBDC holding cap ($\bar{M} = 0.10\,W$)	+0.17	−0.28	−16.72
(4) Stablecoin issuance cap ($\bar{S} = 0.10\,W$)	−0.02	+0.03	+1.79
(5) Reserve-risk premium ($\pi_{S\text{-risk}} = +50$ bps)	+0.02	−0.03	−1.60
(6) Network effect increase (bias to CBDC, $\Delta\nu = +0.3$)	−0.02	+0.03	+2.04
(7) Heterogeneity shift (tech-savvy households ↑)	+0.03	−0.04	−2.63

Note. Deltas are relative to the baseline (Tables 4–5); scenarios correspond to those in Table 6. Utility parameters: $\chi = 0.20$, $\sigma_C = 2$, $\sigma_Q = 2$. Welfare effects are percentage deviations from the baseline steady state. $\Delta C/C$ and $\Delta Q/Q$ denote the consumption and liquidity components of total utility, respectively, computed from the separable specification given by equation (3). All quantities are expressed as ratios to steady-state nominal wealth W. Positive values indicate welfare gains relative to the baseline. Design improvements ($\Delta\theta_M > 0$) enhance welfare primarily via higher liquidity services, while caps on CBDC or stablecoin holdings reduce Q and overall welfare. Rate-based shocks produce smaller, mixed effects, as consumption and liquidity move in opposite directions. Scenario (7) simulates a preference shift toward technologically sophisticated households with higher θ_S; the welfare loss reflects the lower convenience weight of stablecoins in the aggregate calibration (Section 4.5). The welfare ranking is robust to alternative values of $\sigma_C \in \{1, 2, 3\}$, $\sigma_Q \in \{1, 2\}$, and $\chi \in \{0.10, 0.20, 0.30\}$; see Table 8.

The welfare ranking is robust to alternative preference specifications. Reducing σ_Q to 1 (log liquidity utility) or increasing χ to 0.30 preserves the sign and ordering of all welfare comparisons; only the magnitudes change. Similarly, setting $\sigma_C = 1$ (log consumption utility) leaves the qualitative conclusions unchanged. This robustness reflects the dominance of the liquidity channel: since $\Delta Q/Q$ consistently exceeds $\Delta C/C$ in absolute value across all scenarios, the welfare ranking is insensitive to the precise curvature assumed for the consumption margin.

Table 8 confirms this formally, reporting the consumption-equivalent variation Δ/C_0 under scenarios (2) and (3) across 18 combinations of $\chi \in \{0.10, 0.20, 0.30\}$ and $\sigma_Q \in \{1, 2, 3\}$, with $\sigma_C = 2$ throughout. For scenario (2), gains are uniformly positive across all cells, ranging from +0.01 to +0.03 per cent of baseline consumption, and scale linearly with χ. For scenario (3), losses are uniformly negative, ranging from -2.92 to -11.00 per cent, and increase with both χ and σ_Q, reflecting the amplified role of liquidity compression when households value liquidity services more highly.

The welfare analysis summarises steady-state gains and losses associated with monetary

Table 8: Welfare Robustness: Sensitivity to Preference Parameters

Scenario	χ	**$\Delta u/u$ (%) by σ_Q**		
		$\sigma_Q = 1$	$\sigma_Q = 2$	$\sigma_Q = 3$
(2) CBDC design improvement ($\Delta\theta_M = +50$ bps)	$\chi = 0.10$	+1.42	+1.58	+1.63
	$\chi = 0.20$	+2.84	+3.17	+3.26
	$\chi = 0.30$	+4.26	+4.75	+4.89
(3) CBDC holding cap ($\bar{M} = 0.10\,W$)	$\chi = 0.10$	−7.52	−8.36	−8.61
	$\chi = 0.20$	−15.03	−16.72	−17.22
	$\chi = 0.30$	−22.55	−25.08	−25.83

Note. Each cell reports $\Delta u/u$ (percentage deviation from baseline) for the indicated scenario under alternative combinations of the liquidity weight χ and the liquidity curvature σ_Q. The consumption curvature is set to $\sigma_C = 2$ throughout; results are virtually identical for $\sigma_C \in \{1, 3\}$. Baseline values (used in Table 7) correspond to $\chi = 0.20$ and $\sigma_Q = 2$, highlighted in bold. The sign and ranking of all welfare comparisons are preserved across all 18 cells: CBDC design improvements always generate positive welfare gains, while binding CBDC caps always generate losses. The magnitude scales linearly with χ (the weight of liquidity in utility) and is approximately linear in σ_Q over the range considered.

policy, design adjustments, and quantity constraints in the baseline digital monetary system. These outcomes reflect how each policy lever alters convenience-adjusted liquidity services and reallocates household portfolios across CBDC, deposits, and stablecoins. In the sections that follow (Sections 4 and 5), we broaden the framework to incorporate additional frictions and institutional features—reserve-risk premia, issuance constraints, network externalities, and heterogeneous preferences—that modify liquidity premia and portfolio responses, thereby shaping the mechanisms underlying the welfare results in Table 7.

4 Model Extensions and Frictions

This section introduces frictions and design features that enrich the baseline framework. Sections 4.1 and 4.2 examine quantity constraints on CBDC and stablecoins that break return parity. Section 4.3 analyses how risky reserve assets reduce stablecoin convenience yields and amplify the fragility documented in Section 4.2. Section 4.4 endogenises convenience yields, showing how the reserve-risk channel of Section 4.3 can trigger self-reinforcing adoption collapses via network effects. Section 4.5 introduces preference heterogeneity, which smooths but does not eliminate these threshold dynamics. Section 4.6 sketches a production-sector extension left for future research.

These mechanisms interact with monetary policy (Section 5) and regulatory design (Section 6), linking convenience yields and financial returns to institutional choices. The resulting portfolio shifts—including discontinuous transitions across steady states where small changes in convenience can trigger large reallocations across CBDC, deposits, and stablecoins—are characterised in those sections using the equilibrium conditions derived here.

4.1 CBDC with Holding Limits

Suppose the central bank imposes a holding cap on M, denoted by $\bar{M}$:

$$M \leq \bar{M}.$$

If the unconstrained optimum, denoted by an asterisk, satisfies $M^* > \bar{M}$, the cap becomes binding and the household reallocates the excess balance to alternative instruments such as bank deposits or stablecoins. In other words, once the limit is reached, any additional demand for "safe" liquidity must be met through these substitutes. In this case, the arbitrage condition becomes:

$$i_M + \theta_M > \max\{i_D + \theta_D,\ i_S + \theta_S\}.$$

The household sets $M = \bar{M}$ and chooses the remainder of the portfolio by maximizing utility subject to the new effective returns.

This introduces a kink in the convenience-adjusted return schedule and creates segmentation in money-like asset demand. The CBDC cap thus protects deposits and stablecoins from full displacement, and allows the central bank to retain control over CBDC expansion.

4.2 Stablecoins with Constrained Supply

The return parity condition (return parity) assumes that each instrument is available in sufficient quantity and backed by reliable reserves. In practice, stablecoins may face supply constraints and redemption risk that break this parity. Unlike the CBDC holding limit of Section 4.1, which is a policy choice by the central bank, stablecoin supply can be constrained by state-contingent fragility that similarly breaks return parity.

Historical motivation. The 2008 Global Financial Crisis provides a useful analogy: mortgage-backed securities appeared stable under normal conditions but proved fragile under stress due to the declining quality of underlying assets (Gorton, 2010). Stablecoins backed by bank deposits or short-term commercial paper exhibit analogous latent run risk (Fiedler et al., 2023). Three recent episodes illustrate the failure modes.

TerraUSD (2022). An algorithmic stablecoin pegged to the U.S. dollar through a mint-burn mechanism with LUNA collapsed, erasing over $40 billion in market value and triggering regulatory scrutiny worldwide.

Tether (USDT, 2021–22). Repeated delays in auditing reserve composition and reliance on less-liquid assets created persistent doubts about solvency; although Tether has since shifted toward more conservative holdings (primarily T-bills), the episode illustrated the importance of credible reserve disclosures.

USD Coin (USDC, 2023). USDC temporarily depegged following its exposure to Silicon Valley Bank, highlighting the interconnectedness of stablecoins and traditional banking failures—a channel formalised in Section 4.3.

These cases reveal that stablecoins, while often behaving like money in day-to-day use, are exposed to credit, liquidity, and operational risks not typically associated with sovereign currency.

Model. Let stablecoin supply S_t be backed by reserves R_t, consisting of short-term sovereign debt and bank deposits. Let ϑ denote the proportion of high-quality liquid assets (HQLA) in R_t,[9] and λ_t the redemption pressure as an increasing function of macroeconomic stress y_t:

$$S_t = \vartheta R_t - \lambda_t(y_t). \tag{4}$$

Stability requires:

$$\frac{\partial \lambda_t}{\partial y_t} > \left| \frac{\partial(\vartheta R_t)}{\partial y_t} \right| \quad \Rightarrow \quad \text{fragility under stress,}$$

since $\partial(\vartheta R_t)/\partial y_t < 0$: higher stress depresses the market value of reserves even when they consist of HQLA such as short-term sovereign debt.

The TerraUSD and USDC episodes illustrate the two failure modes captured by the model. TerraUSD combined effectively zero reserve quality ($\vartheta \approx 0$, algorithmic backing) with high redemption elasticity (λ large), producing a sharp and irreversible collapse. The USDC depeg resembled a high-ϑ, lower-λ scenario: temporary stress without structural insolvency, consistent with the prediction that higher reserve quality reduces fragility even under significant redemption pressure.

Equilibrium with constrained supply. In the presence of the constraint (4), households may not be able to hold the optimal quantity S^* that satisfies return parity. The arbitrage condition breaks down and a scarcity premium emerges:

$$i_S + \theta_S > i_M + \theta_M = i_D + \theta_D.$$

The equilibrium allocation satisfies:

$$S_t = \min\{S^*,\ \vartheta R_t - \lambda_t(y_t)\},$$

where S^* is the unconstrained optimal quantity based on convenience-adjusted returns. During periods of high stress ($y_t \uparrow$), redemption pressure $\lambda_t(y_t)$ increases, reducing S_t and forcing households to reallocate toward CBDC and deposits. This mechanism captures endogenous fragility and nonlinear portfolio shifts under stress, and provides the micro-foundation for the reserve-risk scenario (5) of Tables 6 and 7.

4.3 Stablecoins with Risky Reserve Assets

The fragility documented in Section 4.2 depends critically on the quality of stablecoin reserves: a low share of HQLA (ϑ small) amplifies redemption pressure and accelerates supply contraction. This section examines the asset side of stablecoin issuers directly, showing how risky reserve portfolios alter pricing, convenience yields, and systemic stability.

In the baseline setup, stablecoin issuers hold central bank reserves as backing assets, ensuring par convertibility and a risk-free return r^*. Under perfect competition, the issuer's

[9] HQLA are assets that can be readily converted into cash with little or no loss of value under stress. Under the Basel III Liquidity Coverage Ratio framework, Level 1 HQLA include central bank reserves and sovereign debt; Level 2 assets include high-grade corporate bonds and covered bonds subject to haircuts.

zero-profit condition implies $i_S = r^* - f_S$, where f_S denotes the per-unit issuance fee or margin. This relationship presumes that reserves are perfectly safe and liquid. However, in practice, many stablecoins invest in riskier instruments—such as short-term securities, commercial paper, or repo agreements—to earn a positive spread over r^*. When the reserve pool yields a stochastic return r_A, the zero-profit condition generalises to:

$$i_S = \mathbb{E}[r_A] - f_S - \pi_{\text{risk}},$$

where π_{risk} captures expected losses and liquidity premia arising from asset risk. Since $\mathbb{E}[r_A] > r^*$, stablecoins backed by riskier assets can, in principle, pay higher rates to users or sustain higher fees. Yet, the associated credit and liquidity risks compromise their stability and redemption certainty.

This structure closely parallels pre-crisis shadow banking instruments such as MMFs and repo-backed liabilities. Like MMFs, stablecoins promise par convertibility and immediate liquidity while holding non-zero-risk assets. When the perceived quality of reserves deteriorates, redemption pressure can trigger fire sales and amplify financial stress. Such dynamics can generate a *scarcity premium* during normal times—where the safest stablecoins command higher valuations—and a *run premium* during crises, where risky tokens lose par value.

In Section 4.2, where stablecoins were backed by central bank reserves, the equilibrium reflected their technological and transactional advantages, yielding the condition $i_S + \theta_S > i_D + \theta_D$. Once risk enters the reserve portfolio, however, perceived liquidity and safety diminish, reducing the convenience yield θ_S. Deposits, being safer and supported by prudential guarantees, regain a relative advantage. Consequently, the relationship reverses:

$$i_S + \theta_S < i_D + \theta_D,$$

indicating that risk impairs the liquidity services and monetary equivalence of the instrument.

As in the shadow banking system, regulatory safeguards—such as full reserve segregation, mandatory transparency, and access to liquidity backstops—can mitigate these distortions and restore parity. From a systemic perspective, the choice of reserve composition determines both the private profitability and the fragility of stablecoins. A regime anchored in risk-free central bank assets sustains monetary singleness and full confidence, while one reliant on risky securities introduces credit spreads, undermines par convertibility, and weakens monetary transmission. The calibration of f_S and reserve rules thus becomes a central policy lever to balance innovation with stability.

4.4 Network Effects and Endogenous Convenience Yields

The reserve-risk channel of Section 4.3 reduces the convenience yield θ_S, lowering stablecoin adoption. When convenience yields depend endogenously on adoption, this reduction is self-reinforcing: lower θ_S reduces η_S, which further lowers θ_S via network effects, potentially shifting the system to a low-adoption equilibrium.

A distinctive feature of digital monies is that their convenience depends on their own adoption: the liquidity of deposits grows with merchant acceptance, the usefulness of stablecoins increases with smart-contract infrastructure, and the interoperability of CBDC rises as more platforms connect. These network effects are central to currency-competition models (Benigno et al., 2022; Brunnermeier et al., 2019) and to the literature on platform externalities (Rochet and Tirole, 2003; Katz and Shapiro, 1985). We capture them by endogenising convenience yields.

Assumption 4.1 (Endogenous convenience)**.** The convenience yield of instrument j is

$$\theta_j = \bar{\theta}_j + \nu\, \eta_j,$$

where $\bar{\theta}_j$ is the intrinsic (feature-based) component and $\nu > 0$ measures the strength of network externalities.

Given convenience-adjusted returns $r_j = i_j + \bar{\theta}_j + \nu\eta_j$, households allocate via the softmax rule (1), so adoption and convenience are jointly determined through the fixed-point condition $\eta = T(\eta)$.

Proposition 4.1 (Multiplicity with strong network effects)**.** *If $\nu > 4$, the fixed-point system admits multiple equilibria. Low-adoption equilibria are self-fulfilling (low η_j implies low θ_j); high-adoption equilibria are sustained by strong endogenous convenience; intermediate equilibria are unstable.*

Proof (sketch). The adoption mapping $\eta' = \Lambda(a + \nu\eta)$, where Λ is the logistic function, has slope $\nu\Lambda(1 - \Lambda)$ with maximum $\nu/4$ at $\Lambda = 1/2$. When $\nu < 4$ the slope is everywhere below one and the mapping crosses the 45° line once (unique stable equilibrium). When $\nu > 4$ the mapping becomes S-shaped and crosses the 45° line three times: two stable fixed points separated by an unstable one (saddle–node bifurcation). By Brouwer's theorem, at least one fixed point always exists. The threshold $\nu > 4$ is analogous to the critical-mass condition in Katz and Shapiro (1985): below it, the market converges to a unique interior equilibrium; above it, threshold crossings generate dominance regimes. □

Figure 4 illustrates the three regimes using a fixed-point diagram: the horizontal axis shows the current adoption share η and the vertical axis shows the updated share $\eta' = \Lambda(a + \nu\eta)$ implied by the model; steady-state equilibria occur where the mapping crosses the 45° line. For $\nu = 6$ (strong network effects), the S-shaped mapping generates two stable fixed points ($\eta^* = 0.12$ and 0.95) separated by an unstable one (0.34), illustrating how sufficiently strong endogenous convenience creates multiple steady states: the equilibrium outcome depends on initial conditions, and small changes in intrinsic convenience $\bar{\theta}_j$ can shift the system discontinuously from one stable regime to another.

Policy interventions that raise intrinsic convenience $\bar{\theta}_j$—through design choices, interoperability standards, or regulatory support—shift the system toward the high-adoption equilibrium. Conversely, adverse shocks can move the economy toward a low-adoption trap. The welfare results in Table 7 (scenario 6) quantify the gains from a positive CBDC network-effect shock ($\Delta\nu = +0.3$), yielding a utility gain of approximately +2.0 per cent relative to the baseline.

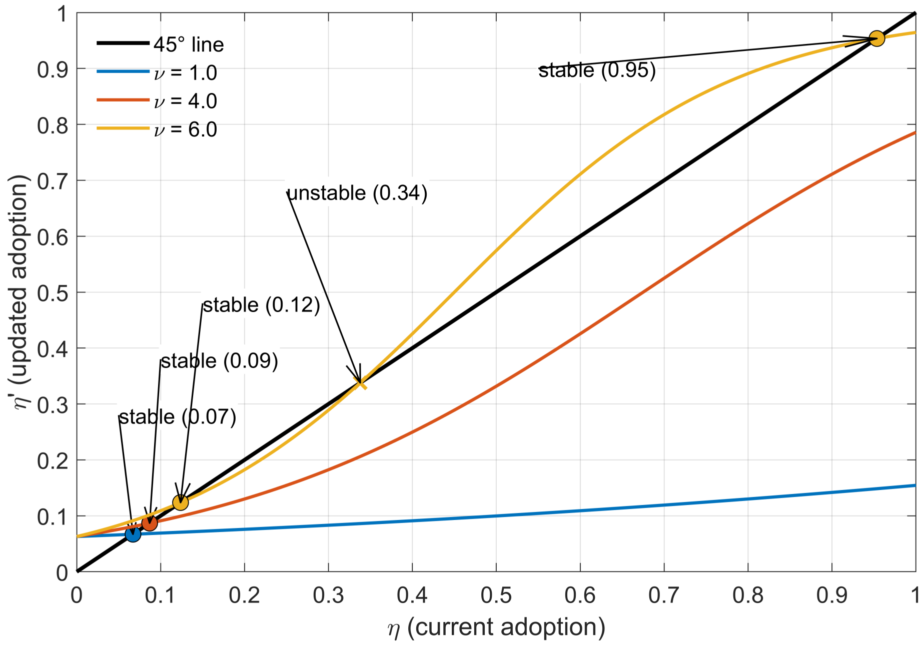

Figure 4: Fixed-Point Diagram: Stable and Unstable Adoption Equilibria

Note. Fixed-point diagram for the adoption mapping $\eta' = \Lambda(a + \nu\eta)$, where Λ is the logistic function and η' denotes the updated adoption share implied by the current share η. Fixed points—where the mapping intersects the 45° line—are the steady-state equilibria of the model. Intersections from above are stable (circles); intersections from below are unstable (cross). For $\nu = 1$ (weak network effects), a unique stable equilibrium at $\eta^* = 0.07$. For $\nu = 4$ (threshold), the mapping is near-tangent to the 45° line, yielding a unique but fragile equilibrium (0.09). For $\nu = 6$ (strong network effects), three intersections emerge: two stable ($\eta^* = 0.12$ and 0.95) separated by an unstable one (0.34), illustrating how strong endogenous convenience generates multiple steady states.

4.5 Heterogeneous Agents

With homogeneous agents, the threshold equilibria of Section 4.4 generate sharp discontinuous transitions. Heterogeneous preferences spread households across the basins of attraction of different steady states, smoothing transitions at the aggregate level while preserving their systemic relevance.

This section relaxes the assumption of exogenous convenience yields maintained in Sections 3.2–3.4, allowing θ_j to depend on equilibrium adoption shares as in equation (5).

The baseline model assumes homogeneous preferences. In practice, households differ in their valuations of privacy, liquidity, and programmability (McFadden, 1974; Chiu and Monnet, 2024), shaping the relative attractiveness of instruments and generating richer adoption patterns.

With heterogeneous households, the individual portfolio share η_j^h varies across types $h \in H$, where $n_h > 0$ denotes the population share of type h (with $\sum_{h \in H} n_h = 1$), and the aggregate $\bar{\eta}_j = \sum_{h \in H} n_h \eta_j^h$ no longer coincides with the individual share. The network-effect function therefore depends on the aggregate: $\theta_j = \bar{\theta}_j + \nu \bar{\eta}_j$.

Assumption 4.2 (Heterogeneous convenience preferences)**.** Each household type h has feature weights $\{\varpi_m^h\}$ in the CES convenience aggregator:

$$\theta_j^h = \left(\sum_{m=1}^{4} \varpi_m^h \, f_{j,m}^{\frac{\varrho-1}{\varrho}} \right)^{\frac{\varrho}{\varrho-1}} + \nu \, \bar{\eta}_j, \qquad \sum_m \varpi_m^h = 1, \quad \varpi_m^h > 0.$$

Aggregate convenience is $\theta_j = \sum_{h\in H} n_h \, \theta_j^h$.

Each type allocates via the softmax rule (1) and aggregate holdings are $\bar{\eta}_j = \sum_{h\in H} n_h \eta_j^h$. A tractable special case—consistent with the continuum specification of Section 3.2.1—sets $\theta_M(\epsilon) = \bar{\theta}_M + (1-\epsilon)\chi$ and $\theta_S(\epsilon) = \bar{\theta}_S + \epsilon\chi$ for $\epsilon \in [0,1]$, so that types with low ϵ are CBDC-friendly and types with high ϵ favour stablecoins (Benigno et al., 2022).

Proposition 4.2 (Multiplicity with heterogeneous preferences)**.** *With heterogeneous convenience valuations and network effects, multiple equilibria may coexist. Types placing higher weight on privacy coordinate on CBDC; types valuing programmability coordinate on stablecoins. Small shifts in the population distribution $\{n_h\}$ can change the dominant equilibrium regime.*

Proof (sketch). The aggregate best-response mapping $T_j(\eta) = \sum_{h\in H} n_h \, \eta_j^h(\eta)$ is continuous and maps the compact simplex into itself; by Brouwer's theorem a fixed point exists. Multiplicity arises when the population-weighted elasticity $\mathbb{E}_h[\partial\theta_j^h/\partial\bar{\eta}_j]$ multiplied by the logit slope exceeds unity—the same condition as in Proposition 4.1, now aggregated across types; see Katz and Shapiro (1985) for an analogous result in platform-competition models. □

Heterogeneity highlights the distributional effects of digital money design (Brunnermeier et al., 2019). A CBDC offering enhanced privacy disproportionately benefits privacy-preferring households; programmable stablecoins favour users valuing automation and interoperability. The welfare implications of a shift toward technologically sophisticated agents are quantified in scenario (7) of Table 7, which yields a utility loss of approximately −2.6 per cent when stablecoin-preferring households gain population share.

4.6 Production and Government Sector

This subsection sketches an extension of the baseline framework to include a production sector and a government, providing a formal bridge between digital-finance allocation and aggregate activity. The extension is not calibrated in the present paper and is left for future research; it is included here to illustrate how the monetary block of Sections 3.2–3.8 can be embedded in a broader macro-financial model.

Firms. A representative firm produces a single final good that serves as numéraire. Output follows a standard Cobb–Douglas technology:

$$Y_t = A_t K_t^{\alpha} N_t^{1-\alpha},$$

where A_t is total factor productivity, K_t capital, and N_t labour. Firms hire labour and rent capital competitively at real factor prices w_t and $r_{K,t}$, respectively, and distribute profits fully to households.

Investment is financed via bank loans. In equilibrium, the loan rate i_L determines the user cost of capital, linking the monetary block to the real side through

$$r_{K,t} = i_L - \pi_t, \tag{5}$$

where π_t denotes the inflation rate. Monetary frictions therefore affect output via the cost of external finance and, indirectly, through household portfolio allocation across CBDC, deposits, and stablecoins. A higher i_L—arising, for instance, from tighter bank capital constraints or a rise in the policy rate—raises the user cost of capital and depresses investment, introducing a real channel through which digital-money design affects aggregate output.

Government and Policy Instruments. The government issues bonds B_G, levies lump-sum taxes T, and holds an account at the central bank. Its flow budget constraint is

$$G_t + i_B B_G = T_t + \Delta B_G + \Delta L_{CB,G},$$

where G_t are expenditures and $L_{CB,G}$ denotes net central bank credit to the government. In normal times $\Delta L_{CB,G} = 0$; unconventional operations (e.g., direct monetary financing) relax this condition. The consolidated public sector (government plus central bank) thus controls the supply of risk-free assets and influences the composition of private balance sheets.

Fiscal and monetary policy interact through the risk-free rate r^* and through liquidity provision by the central bank. Fiscal adjustments feed into household wealth and portfolio choice:

$$W_t = Y_t - T_t + i_B B_G + \text{Div}_t, \tag{6}$$

where Div_t are profits from financial intermediaries rebated to households. In the baseline monetary block (Sections 3.2–3.4), W is normalised to one for tractability; equation (6) provides the micro-foundation for this normalisation in the production extension. In the steady state, the government budget is balanced ($T = G + i_B B_G$) unless policy experiments specify otherwise.

Discussion. Introducing production and a government sector provides a formal link between digital-finance allocation and aggregate activity. The interest-rate channel operates through i_L (equation (5)), while the convenience-yield channel affects money demand and thereby the marginal cost of funds to firms. Fiscal variables (G, T, B_G) alter household wealth and the composition of safe assets, influencing the equilibrium mix of CBDC, deposits, and stablecoins. A full quantitative analysis of these interactions—including the calibration of production parameters (α, A_t) and the study of fiscal–monetary coordination in a digital environment—constitutes a natural avenue for future research, complementing the directions outlined in Section 7.

5 Monetary Policy in a Digital Environment

The emergence of digital money instruments such as CBDCs and stablecoins is reshaping the transmission mechanisms of monetary policy. In this new landscape, monetary policy is no longer solely a matter of interest rate setting; it increasingly depends on the design features of the instruments themselves—such as programmability, privacy, and interoperability. Building on the frictions analysed in Sections 4.1–4.3, this section examines how tiered CBDC remuneration and interest-bearing stablecoins reshape monetary policy transmission in a digital financial ecosystem where households allocate portfolios based on convenience-adjusted returns. The central bank sets the policy rate r^*, which governs the interest on reserves and indirectly influences deposit and stablecoin rates.

The competition between CBDCs and stablecoins can either amplify or attenuate policy transmission, depending on the structure of financial returns and the nonpecuniary convenience yields associated with each instrument. Moreover, the presence of interest-bearing stablecoins may exert upward pressure on deposit rates offered by banks, compressing their net interest margins and altering the traditional channels of monetary intermediation.

CBDC Design and Tiering. To mitigate disintermediation of the banking sector, the central bank implements a tiered CBDC remuneration schedule. Let $i_M^{(1)}$ denote the rate applied to balances up to a threshold $\overline{M}$, and $i_M^{(2)}$ the rate on balances above the threshold, with $i_M^{(2)} < i_M^{(1)}$:

$$i_M(M) = \begin{cases} i_M^{(1)}, & M \le \overline{M}, \\ i_M^{(2)}, & M > \overline{M}. \end{cases}$$

The schedule nests a non-remunerated CBDC ($i_M^{(1)} = i_M^{(2)} = 0$), a policy-rate-remunerated CBDC ($i_M^{(1)} = r^*$, $i_M^{(2)} < r^*$), and penalty rates $i_M^{(2)} < 0$ on large balances. When $i_M^{(2)}$ is sufficiently low relative to deposit and stablecoin returns, households optimally choose $M = \overline{M}$, making tiered remuneration equivalent to the hard cap of Section 4.1. This design preserves CBDC's role as a retail payment medium while discouraging its use as a large-scale store of value.[10]

Interest-Bearing Stablecoins. We assume that stablecoins pay a nominal interest rate $i_S > 0$, reflecting the return on collateral minus issuer costs. A representative stablecoin issuer invests a fraction $\beta_R \in [0, 1)$ of collateral in central bank reserves remunerated at r^* and a fraction $\beta_D \in [0, 1)$ in bank deposits at rate i_D, with $\beta_R + \beta_D \le 1$. Under perfect competition:

$$i_S = \beta_R r^* + \beta_D i_D - f_S. \tag{7}$$

Setting $\beta_R = 1$, $\beta_D = 0$ recovers the baseline form $i_S = r^* - f_S$ (NFI-zero-profit). When the reserve pool includes riskier assets, the generalised condition of Section 4.3 applies and $\pi_{\text{risk}} > 0$ reduces the effective return.

Portfolio Allocation and Pass-Through. Combining the return parity condition, the stablecoin pricing condition (7), and the bank zero-profit condition yields an explicit expres-

[10] The penalty on excess balances avoids conflict with γ, the equity service wedge in the bank zero-profit condition (bank-zero-profit).

sion for the deposit rate:

$$i_D = \frac{\beta_R}{1-\beta_D} r^* - \frac{f_S}{1-\beta_D} + \frac{\theta_S - \theta_D}{1-\beta_D}, \tag{8}$$

so that the policy-rate pass-through to deposits is $\partial i_D/\partial r^* = \beta_R/(1-\beta_D)$, and the loan-rate pass-through is $\partial i_L/\partial r^* = \beta_R/(1-\beta_D) - \rho/(1-\rho)$. Two cases are instructive. When stablecoins are fully backed by reserves ($\beta_R = 1$, $\beta_D = 0$), pass-through is complete and monetary policy transmits through all three instruments simultaneously. By contrast, when a non-remunerated CBDC pins household parity at $i_M^{(1)} = 0$, deposit rates are insulated from r^* and loan-rate pass-through may turn negative. This mechanism is absent from bilateral models of CBDC and deposits, and directly motivates the design choices discussed in Section 6.

Policy Design Trade-offs. Interest-bearing stablecoins strengthen the link between the policy rate and household portfolio decisions, broadening the transmission channel. However, they also introduce complexity: stablecoin returns depend on the issuer's collateral structure and fee schedule, which are outside direct central bank control. Tiered CBDC remuneration and holding limits can mitigate large deposit outflows but may increase the sensitivity of bank and issuer balance sheets to interest rate changes.

If one instrument offers a significantly higher convenience yield—due to programmability, privacy, or liquidity—households may allocate disproportionately toward it regardless of small differences in financial return. In such cases, the effectiveness of monetary policy depends not only on interest rate differentials but also on the design and usability of digital instruments. A well-designed CBDC must therefore offer sufficient convenience to remain competitive, while regulatory oversight must ensure that stablecoin rate-setting aligns with broader policy objectives.

Implications. Monetary policy regains effectiveness primarily through the financial return channel, provided that convenience yields do not dominate household preferences. The central bank can influence portfolio allocation not only by adjusting interest rates but also by enhancing the nonpecuniary attributes of CBDC—programmability, privacy, and interoperability—and by calibrating tiering thresholds and penalties on excess holdings.

Stablecoins—whether interest-bearing or not—introduce a competitive floor to the effective return on money-like instruments. If their convenience yield is high, they may dominate household portfolios unless the CBDC is designed to match or exceed their utility. This dynamic has direct implications for the demand for bank deposits and, consequently, for the transmission of monetary policy through the banking system.[11]

The coexistence of tiered CBDC and interest-bearing stablecoins requires a rethinking of monetary policy implementation. Central banks must closely monitor shifts in household portfolio preferences, as changes in perceived convenience yields can lead to discontinuous portfolio shifts among CBDC, deposits, and stablecoins, affecting liquidity conditions and

[11] The formal treatment of foreign-denominated instruments, cross-border payments, and currency substitution is in Appendix A.5, which embeds FX expectations and liquidity features into convenience-adjusted returns and discusses design and regulatory levers.

the effectiveness of monetary control. To preserve financial stability, tiering mechanisms and holding limits on CBDC are essential to mitigate large-scale disintermediation while preserving the role of commercial banks in credit intermediation.

These implications underscore the importance of regulatory and design choices, which are developed in Section 6.

6 Policy, Regulatory Implications and Architecture

This section integrates the policy insights from the model. Our framework shows that household portfolios are shaped by convenience-adjusted returns, $r_j = i_j + \theta_j$, and that equilibrium outcomes reflect the equalisation of these returns across instruments. Institutional constraints (bank and NFI zero-profit conditions) and policy levers (CBDC design, reserve remuneration, issuer fees) map directly into these convenience components and thus into equilibrium shares. We use this lens to organise the policy drivers, design levers, and regulatory choices that determine whether CBDC, deposits, and stablecoins coexist or whether one instrument dominates. The current regulatory architectures in the European Union, the United States, and the United Kingdom are summarised in Table 11 and discussed in detail in Appendix A.4.

As shown by equation (2), the interaction between endogenous convenience yields and network effects can generate multiple equilibria in the allocation of liquidity across instruments. Policy design therefore operates not only through the direct interest-rate channel but also through the behavioural elasticity embedded in the softmax mapping (1), which determines how households reallocate across CBDC, deposits, and stablecoins in response to changes in convenience or remuneration. Enhancing CBDC usability or tightening stablecoin regulation shifts the equilibrium toward public money dominance, while weaker CBDC design or insufficient oversight may reinforce private monetary equilibria driven by network externalities.

Policy Drivers: Sovereignty, Stability, and Transmission. Stablecoins may weaken monetary policy transmission and pose systemic risks. When stablecoins are pegged to foreign currencies, they can operate as de facto substitutes for domestic money, particularly in cross-border contexts or in jurisdictions with weaker monetary credibility. In our model, a high convenience yield for foreign-pegged stablecoins, θ_S, combined with competitive returns, tilts portfolios toward S and weakens demand for domestic instruments. This substitution attenuates monetary transmission and raises unhedged FX exposure. A domestic CBDC with sufficiently high θ_M serves as a public anchor that counterbalances this pressure.

Policy operates through both the financial channel (i_j) and the design channel (θ_j). Under perfect competition, the NFI zero-profit condition implies $i_S = r^* - f_S$, where r^* is the policy rate on reserves and f_S the stablecoin fee. Combining this with return equalisation yields the coexistence bound (CBDC–S coexistence) of Section 3.3.1: higher policy rates strengthen transmission via stablecoins, while increases in CBDC convenience θ_M tighten the fee ceiling for stablecoins to remain competitive.

Stablecoins also exhibit run-like redemption dynamics. Under stress, reserve opacity or supply constraints create scarcity premia, breaking parity and triggering discontinuous portfolio shifts toward CBDC and deposits. These shifts are amplified when θ_S is adoption-sensitive (Section 4.4). Robust reserve quality, transparency, and redemption rights reduce the likelihood and severity of such breaks, as formalised in Sections 4.2 and 4.3.

Regulatory oversight of stablecoins is critical. Systemic resilience requires robust frameworks that enforce reserve transparency, guarantee redemption rights, and establish clear operational standards for issuers.

Finally, competition on convenience compresses bank margins. The parity condition requires deposit pricing $i_D = i_M + \theta_M - \theta_D = i_S + \theta_S - \theta_D$, so higher $\theta_S - \theta_D$ forces banks to raise deposit rates, with loan rates adjusting via the bank zero-profit condition (bank-zero-profit). Tiered remuneration, CBDC holding caps, and improved deposit rails (raising θ_D) mitigate disintermediation while preserving payment efficiency.

All in all, monetary policy in a digital environment is shaped less by interest rate differentials and more by the structural design of digital instruments and their associated convenience yields.

Design and Market Dynamics: From Levers to Outcomes. CBDC can be designed as an explicit policy instrument. Privacy layers, programmability, interoperability, and resilient user experience raise θ_M without requiring interest remuneration. By the coexistence bound (CBDC–S coexistence), stronger θ_M compresses admissible f_S, shifting portfolios toward CBDC and deposits. The welfare results in Table 7 confirm that CBDC design improvements dominate rate-based interventions: a +50 bps increase in θ_M yields a utility gain of approximately +3.2 per cent relative to the baseline, compared with a loss of −1.2 per cent from a 100 bps policy-rate hike. Tiered remuneration and holding limits help preserve CBDC's role as a retail payment medium while curbing large-scale asset substitution that could destabilise bank funding.

Enhancing deposit rails also matters. Instant payments and tokenised deposits increase θ_D by improving liquidity and programmability. A higher θ_D lowers the deposit rate needed to satisfy parity, supporting bank intermediation while limiting pressure from CBDC and stablecoins. Tokenised deposits may replicate stablecoin features while retaining the safety of the banking system.

Stablecoin design likewise shapes outcomes. Issuer fees f_S, reserve quality, and redemption mechanics determine both i_S and perceived risk. Under stress, constrained supply raises the shadow value of S and can temporarily violate parity, generating scarcity premia and discontinuous portfolio shifts. Prudential requirements that maintain reserve quality and orderly redemption reduce such nonlinear responses.

Finally, adoption-driven convenience yields $\theta_M(\nu_M)$ and $\theta_S(\nu_S)$ (Section 4.4) imply potential multiple equilibria. Small improvements in CBDC design can shift the system toward CBDC dominance, while stronger stablecoin adoption can entrench private digital money. Heterogeneous household preferences (Section 4.5) smooth these transitions but do not eliminate their systemic relevance. The welfare costs of binding quantity constraints—which in the extreme case of scenario (3) reach −17 per cent for a cap set at 10 per cent of household wealth—underscore the importance of calibrating these design levers carefully. Retail caps at realistic levels, such as the €3,000 threshold under discussion for the digital euro, would generate substantially smaller effects.

7 Conclusion

This paper develops a unified framework to analyse household portfolio allocation across CBDC, commercial bank deposits, and stablecoins. By modelling convenience-adjusted returns as the sum of financial yields and nonpecuniary benefits, we show that households allocate wealth toward the instrument offering the highest total return. Our results highlight the central role of convenience yields in shaping equilibrium outcomes, particularly in the presence of frictions, redemption risks, and network effects.

The analysis reveals that, under realistic assumptions about reserve quality, redemption costs, and regulatory constraints, CBDC and bank deposits tend to dominate stablecoins in equilibrium. CBDCs, as public liabilities with legal tender status and zero credit risk, offer a robust and resilient form of digital money. Bank deposits, supported by deposit insurance and mature infrastructure, continue to provide a stable and convenient medium for payments and savings. In contrast, stablecoins—despite their programmability and global reach—are exposed to fragility under stress, especially when backed by imperfect collateral or subject to redemption constraints.

Our simulations and comparative statics demonstrate that even modest improvements in the convenience yield of CBDC (e.g., through programmability, privacy, or interoperability) can significantly shift household preferences away from stablecoins. Similarly, regulatory enhancements to bank-based payment systems (e.g., instant payments, open banking) increase the attractiveness of deposits. The welfare analysis of Section 3.8 quantifies these effects: a binding CBDC cap calibrated to 10 per cent of household wealth—an extreme scenario chosen to illustrate the mechanism— generates a utility loss of approximately 17 per cent, while CBDC design improvements yield utility gains of about 3 per cent relative to the baseline. Retail caps at realistic levels would generate substantially smaller welfare effects. These findings suggest that public and regulated private money can coexist and complement each other, but that the long-term viability of stablecoins depends critically on their ability to match the safety, transparency, and convenience of sovereign and bank-issued instruments.

In conclusion, the preference for CBDC and bank deposits in our model reflects not only their financial returns but also their institutional credibility and systemic integration. As digital money ecosystems evolve, policy design and regulatory clarity will be essential to ensure that innovation supports monetary sovereignty, financial inclusion, and macro-financial stability. These findings resonate with Panetta (2025)'s call for a central bank-led transformation of the digital monetary landscape.

Finally, the growing use of stablecoins and tokenised instruments in cross-border payments raises new challenges for monetary sovereignty and exchange rate management—particularly in emerging markets (International Monetary Fund, 2022c). When foreign-denominated stablecoins become de facto mediums of exchange, domestic monetary policy transmission may weaken and currency substitution pressures may rise. These dynamics underscore the importance of international coordination in the regulation of digital assets, the design of interoperable CBDCs, and the development of trusted domestic alternatives that combine digital convenience with macroeconomic stability.

Directions for Future Research

While the model developed in this paper provides a useful starting point for analysing household allocation across CBDCs, stablecoins, and bank deposits, several avenues for future research remain open.

First, while this paper introduces heterogeneous convenience preferences in Section 4.5, a full quantitative treatment—including empirical estimation of preference distributions and adoption patterns across demographic groups—remains an avenue for future research. Such an extension would allow the model to better capture the distributional consequences of digital money design for financial inclusion and inequality.

Second, the model assumes perfect convertibility between digital instruments. However, operational, regulatory, and liquidity risks—especially under market stress—may hinder immediate or frictionless conversion. Incorporating these frictions would improve the model's realism and its ability to simulate stress scenarios.

Third, the current framework is cast in steady state, and the comparative statics across equilibria only implicitly capture the threshold effects that a fully dynamic model would formalise. Extending the analysis to an explicit intertemporal setting—for instance, a discrete-time model with forward-looking households and sluggish adoption—would allow the study of gradual diffusion paths, the speed of transitions between steady states, and the role of expectations in coordinating households toward CBDC or stablecoin dominance. Such a dynamic extension would also make it possible to analyse transitional welfare costs and the optimal timing of policy interventions, questions that are central in the literature on monetary innovation and financial adoption but lie beyond the scope of the present paper.

Fourth, the model could be enriched by incorporating service fees and transaction costs—such as cardholder fees or merchant fees—which play a significant role in household and merchant payment choices. Benchmark data from existing payment systems could be used to calibrate these costs.

Finally, while the policy discussion emphasises the potential of CBDCs to strengthen monetary sovereignty, it could be complemented by scenarios in which CBDCs might instead erode banking sector stability. This dual perspective would align with recent empirical and theoretical work (Auer et al., 2024).

As Melville writes in *Moby Dick* when describing the classification of whales: "I promise nothing complete." Likewise, this model is intentionally simple, and its value lies in providing a tractable foundation for further theoretical and empirical exploration.

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A Appendix

A.1 Taxonomy of Monetary Instruments

This appendix provides detailed institutional descriptions of monetary instruments that are referenced in the main text but whose elabouration would interrupt the analytical flow of Sections 2 and 2.

A.1.1 Stablecoins Issued by Card Networks and Platforms

Credit card networks (e.g., Visa, Mastercard) and large digital platforms (e.g., PayPal, Amazon, Meta) have incentives to issue stablecoins as a strategic response to token-based infrastructures offering instant settlement, programmability, and global interoperability.[12] For card networks, stablecoins can reduce interchange fees, eliminate chargeback risks, and enable micropayments. Their existing compliance infrastructure (AML/KYC) and regulatory credibility position them well to issue fiat-referenced tokens under emerging legal frameworks.

For digital platforms, stablecoins extend closed-loop balances into transferable, programmable instruments, enhancing liquidity and user engagement across shopping, streaming, and financial services. They also strengthen ecosystem lock-in through reward programmes and embedded financial features. From a balance-sheet perspective, platform-issued stablecoins resemble synthetic liabilities backed by cash or custodial deposits. When convenience yields are sufficiently high due to integration and usability, households may reallocate wealth toward these instruments even without explicit interest payments.

A.1.2 Platform-Based Credits

Platform-based credits are internal digital balances issued by large technology or e-commerce firms and used exclusively within their closed-loop ecosystems. Users acquire these credits by transferring fiat money to the platform, which holds corresponding funds in custodial accounts at commercial banks. These instruments are denominated in fiat units but are not legal tender, transferable across institutions, or redeemable outside the issuing platform.[13]

Settlement with external merchants requires the platform to move funds through the banking system or stablecoin rails, highlighting their dependence on traditional financial infrastructure. Consequently, their monetary role is confined to internal settlement, and

[12] Recent analyses have highlighted the strategic incentives for global card networks to issue or support stablecoins as a means to retain transaction volume, reduce settlement frictions, and extend their role in digital money ecosystems (Crisanto et al., 2024; BIS, 2025; Aldasoro et al., 2025). See also BCG (2025), McKinsey & Company (2025), and Ernst & Young (2025) for discussions of how Visa and Mastercard have explored tokenised settlement models and stablecoin partnerships.

[13] By *platform-based credit* we mean credit originated and distributed within payment/commerce platforms—e.g., Buy-Now-Pay-Later at checkout, marketplace seller financing, mobile-money overdrafts, and credit lines embedded in instant account-to-account rails (e.g., UPI, PIX). See BIS (2019) for the foundational policy framing on big tech in finance; Cornelli et al. (2020) for cross-country evidence on fintech and big tech credit volumes and drivers; Gambacorta et al. (2022) and Huang et al. (2025) for theory on platform lending advantages vs banks; Worldpay (2025) and McKinsey & Company (2024) for market sizing; and Consultative Group to Assist the Poor (2018) on mobile-money credit (e.g., M-Shwari).

their inclusion in household portfolios reflects convenience rather than fungibility or legal protection.

A.1.3 The BIS Unified-Ledger Framework

The 2025 BIS Bulletin (Aldasoro et al., 2025) extends the taxonomy of monetary instruments by proposing a unified ledger that integrates tokenised central bank reserves, commercial bank money, and financial assets within a programmable infrastructure. Their framework evaluates digital money along three dimensions: *singleness*, *elasticity*, and *integrity*. Stablecoins fall short on all three criteria: their values fluctuate, issuance mechanisms are limited, and compliance standards remain weak. Platform balances, being confined to closed ecosystems and lacking regulatory safeguards, fall short even more clearly. By contrast, the BIS advocates tokenisation under central bank leadership as a means to evolve existing infrastructures, enhancing efficiency and cross-border settlement while preserving the two-tier financial system.

A.1.4 Payment Infrastructure: Legacy Rails and Fast Payments

Before the emergence of fast payment systems, most retail bank transfers operated on legacy infrastructure such as Real-Time Gross Settlement (RTGS), Automated Clearing House (ACH) networks, or batch-based settlement systems.[14] These systems typically involve processing delays, limited operating hours, and multi-day settlement cycles, particularly for interbank or cross-border transactions. Consequently, the convenience yields associated with deposit-based payments under legacy systems are lower than those available through more immediate or programmable alternatives.

Retail fast payment systems—such as Brazil's PIX, India's UPI, and the EU's TIPS infrastructure—allow instant, low-cost settlement of deposit-based payments through public digital infrastructure, thereby raising the transactional utility of commercial bank deposits. In the model, this effect is captured through a higher convenience yield θ_D, which improves the relative attractiveness of deposits in household portfolios, particularly for small-value, high-frequency transactions. A fast payment system like TIPS may reduce demand for CBDC or stablecoins in retail payments, enhance deposit stickiness, and strengthen monetary policy transmission through the banking system.

A.1.5 tokenised Deposits

tokenised deposits represent a novel form of digital money that combines the legal and institutional features of traditional bank deposits with the technological advantages of blockchain infrastructure. Unlike stablecoins, which are typically issued by non-bank entities and backed by off-chain reserves, tokenised deposits are issued by regulated commercial banks and represent direct claims on deposit accounts. They are recorded on distributed ledgers and can

[14] RTGS systems settle individual transactions immediately and irrevocably, typically between financial institutions. ACH systems process payments in batches, often with a delay of one or more business days. Batch-based settlement systems group multiple transactions and settle them at fixed intervals on a net basis.

be transferred peer-to-peer, enabling programmable payments and atomic settlement.[15]

Their programmability and interoperability with DeFi platforms enhance their convenience yield θ_D relative to traditional deposits, particularly in use cases involving automated payments, escrow services, or cross-border transactions. Adoption depends on: the extent of integration into digital wallets, regulatory clarity governing issuance and use, and the perceived safety and liquidity of the issuing bank. Where these conditions are met, tokenised deposits may compete directly with stablecoins and CBDCs.

A.1.6 Credit Cards

Credit card payments are a form of deferred settlement, where the issuing bank extends short-term credit to the household. Transactions are processed through card networks (e.g., Visa, Mastercard), with settlement occurring between the merchant's acquiring bank and the cardholder's issuing bank. Credit cards offer high convenience, fraud protection, and rewards programmes, while providing liquidity through revolving credit that allows households to smooth consumption over time. At the same time, they involve interest charges if balances are not paid in full and risks of over-indebtedness.

From a financial economics perspective, credit cards combine a payment function with a credit instrument, introducing intertemporal trade-offs in household utility maximisation: the marginal utility of current consumption is weighed against future repayment obligations. The effective cost depends on the interest rate, repayment behaviour, and associated fees or rewards.

A.1.7 Cross-Border Payments and FX Risk

The denomination and composition of stablecoin reserves shape their macro-financial implications. Domestic-currency pegged stablecoins, backed by local bank deposits or short-term sovereign debt, can reinforce monetary policy transmission if reserves remain within the jurisdiction and issuers are well-regulated. By contrast, foreign-currency pegged stablecoins introduce de facto currency substitution in domestic markets, reducing demand for local currency assets, increasing FX mismatches, and weakening monetary sovereignty. These risks are particularly acute in emerging markets, where adoption of foreign-denominated stablecoins may amplify exchange rate volatility and cross-border spillovers.

Traditional correspondent banking channels are slow, costly, and involve multiple intermediaries. Stablecoins and tokenised deposits enable rapid cross-border transfers, often outside formal banking systems. Current CBDC designs remain focused on domestic use, though pilot projects such as mBridge and Icebreaker test multilateral interoperability.[16]

Large-scale adoption of foreign-backed stablecoins in underdeveloped currency regimes could amplify exchange rate volatility and cross-border spillovers (International Monetary

[15] Currently, tokenised deposits are implemented in an account-based form, where ownership is verified through the identity of the account holder. In the future, token-based implementations are expected, where ownership is proven by possession of a digital token and transfers occur peer-to-peer on a distributed ledger.

[16] *mBridge* is a multi-CBDC platform jointly developed by the BIS Innovation Hub and several central banks (Hong Kong, Thailand, UAE, China) to enable cross-border wholesale CBDC settlement. *Project Icebreaker*, led by the BIS Innovation Hub Nordic Centre with the central banks of Israel, Norway, and Sweden, explores a hub-and-spoke model for retail CBDC interoperability.

Fund, 2022c). A domestic CBDC with sufficiently high θ_M, combined with robust deposit rails that lift θ_D, limits substitution toward foreign-pegged instruments. Conversely, widespread use of foreign-pegged stablecoins weakens domestic monetary transmission and raises unhedged FX exposures. The main regulatory levers are: raising θ_M through CBDC design improvements (privacy, programmability, user experience); enhancing deposit rails to raise θ_D; constraining foreign-pegged tokens through transparency, reserve quality, and redemption requirements; and ensuring orderly FX conversion corridors to reduce expectation-driven reallocations.

A.2 CBDC in the world

Table 9 summarizes the status, remuneration treatment, and legal-tender framework of selected retail and hybrid CBDC projects as of April 2026. It distinguishes among launched projects, live pilots, and jurisdictions that remain in research or technical-preparation phases. Most live retail CBDCs—such as those in the Bahamas, Nigeria, and Jamaica—do not remunerate holdings. In other jurisdictions, remuneration remains either undecided, not specified, or contingent on the final design of the project. CBDC remuneration is an important design choice, as it may affect monetary policy transmission, financial stability, bank disintermediation risks, and the competitive balance between public and private forms of digital money.

The table also shows that CBDC projects differ not only in remuneration design but also in their legal basis and operational architecture. In particular, some projects are conceived as retail CBDCs directly usable by the public, whereas others are better described as hybrid or wholesale-first platforms. More generally, a tiered CBDC architecture refers to an institutional arrangement in which issuance, distribution, and customer-facing services are divided across different layers of participants, typically involving the central bank and supervised intermediaries. This structure is often proposed to balance efficiency, scalability, and financial stability.

A.3 Interest on Stablecoins

While most stablecoins are issued as non-interest-bearing instruments, an increasing number of arrangements built around stablecoins allow users to obtain yield-like returns through associated savings, lending, or platform-based reward mechanisms. These returns may arise through decentralized lending protocols, tokenised savings arrangements, or reward-sharing programs operated by custodial platforms. Such designs challenge the traditional view of stablecoins as passive digital payment tokens and raise regulatory, monetary, and competitive considerations.

Yield related to stablecoins can take various forms:

- **DeFi-based lending returns:** Stablecoins used in decentralized finance (DeFi) protocols may generate returns through lending pools or related credit intermediation arrangements. These yields are determined by protocol conditions and are subject to market risk, liquidity risk, counterparty risk, and smart-contract risk.
- **Custodial or platform-based rewards:** Some centralized issuers or affiliated platforms may earn income on reserve assets and share part of that income with users

Table 9: Selected retail and hybrid CBDC projects: status, remuneration and legal-tender treatment (April 2026)

Jurisdiction	**Project / CBDC**	**Stage**	**Remuneration**	**Legal tender**	**Comments**
Bahamas	Sand Dollar	Launched	No	Yes	Retail CBDC in circulation; central-bank e-money framework.
Nigeria	eNaira	Launched	No	Yes	Retail CBDC; official legal-tender status maintained.
Jamaica	JAM-DEX	Launched	No	Yes	Retail CBDC; wallet holdings do not earn interest.
ECCU	DCash	Pilot concluded	No	No (currently)	Pilot ended in Jan. 2024; relaunch under preparation ("DCash 2.0").
China	e-CNY	Pilot	No	Yes	Retail pilot at scale; positioned as M0 and non-interest-bearing.
Sweden	e-krona	Research / readiness	Undecided	Undecided	Technical pilot ended in 2023; no issuance decision.
European Union	Digital euro	Next phase / technical preparation	Not specified	Yes, if issued	ECB moved to next phase in Oct. 2025; issuance contingent on legislation.
India	Digital Rupee (e₹)	Pilot	No	Yes	Retail and wholesale pilots; RBI states e₹ is legal tender.
Brazil	Drex	Pilot	N.A.	Not specified	Wholesale-first / platform-based pilot; end users are not direct participants.
South Korea	Project Hangang	Live pilot	N.A.	No / not applicable	Unified-ledger pilot combining wholesale CBDC and tokenised deposits.
Canada	Digital Canadian Dollar	Research / contingency planning	Undecided	Undecided	Retail CBDC work scaled down; preparedness motive remains.

Notes: "Launched" denotes public rollout; "Pilot" denotes limited live testing; "Research / readiness" denotes preparatory work without issuance decision. "Legal tender" refers to currently applicable status unless otherwise noted. "N.A." indicates that remuneration is not meaningfully specified for projects centred on wholesale settlement infrastructure or tokenised deposit experimentation rather than a retail balance directly held by the public. For the digital euro, legal-tender treatment is intended in the legislative design, but issuance remains conditional on adoption of the EU legal framework.

through reward programs or account-based incentives. In such cases, the token itself remains non-interest-bearing on-chain, while the return is delivered through the surrounding platform environment.

- **tokenised savings arrangements:** In some decentralized ecosystems, the base stablecoin remains non-interest-bearing, but users can move into a related savings token or savings module that accrues yield. These arrangements make the distinction between payment token and savings instrument more explicit, while still linking both to the same monetary ecosystem.

In the context of this model, such yield-bearing arrangements may influence household portfolio decisions by effectively raising the financial return i_S associated with stablecoin-based holdings. However, these returns often come with greater complexity, additional risk exposure, or lower immediacy of use in payments. Regulatory treatment also varies across jurisdictions. In the European Union, MiCAR distinguishes in particular between e-money tokens and asset-referenced tokens, while in the United States the legal treatment of stablecoins remains subject to evolving federal legislative and supervisory frameworks. Table 10 summarizes the main forms and selected examples.

Table 11 summarizes the main regulatory developments across the three jurisdictions and maps each framework to its likely impact on the model's key parameters. Section A.4 discusses the EU, US, and UK cases in greater detail, with attention to the implementation stage reached as of April 2026.

A.4 Regulation in the EU, the US and the UK

Table 11 summarizes the main regulatory developments across the three jurisdictions and maps each framework to its likely impact on the model's key parameters. The following subsections discuss the EU, US, and UK cases in greater detail, with attention to the implementation and consultation stages reached as of April 2026.

European Union: MiCA, PSD3/PSR, and the Digital Euro

In the European Union, the Markets in Crypto-Assets Regulation (European Parliament and Council, 2023) now provides the primary framework for stablecoins. MiCA applies to issuers of asset-referenced tokens (ARTs) and e-money tokens (EMTs) from **30 June 2024**, with the remainder of the regime applying from **30 December 2024**.[17] The EBA has consulted on *redemption plan* guidelines to ensure orderly redemptions for ARTs/EMTs if obligations cannot be met (European Banking Authority, 2024). In our model, MiCA (i) tightens issuer economics by constraining fees and reserves (downward pressure on f_S), (ii) reduces run risk and scarcity premia in stress by improving reserve transparency and redemption governance (lower $\lambda_t(y_t)$ in Section 4.2), and (iii) tempers network externalities for systemically significant tokens, moderating multiple-equilibria dynamics in Section 4.4.

[17] MiCA application dates and scope: Regulation (EU) 2023/1114, Titles III–IV apply from 30/06/2024; full application from 30/12/2024. See also European Banking Authority (2024) for the EBA consultation on redemption plan guidelines.

Table 10: Yield mechanisms across selected stablecoins and related yield-bearing arrangements (April 2026)

Token / Instrument	**Issuer type**	**Yield mechanism**	**Direct yield to holder?**	**Comments**
USDC	Custodial (Circle)	No native holder yield; reserve income retained by issuer	No	Fiat-backed stablecoin redeemable 1:1; reserve assets include cash and short-dated government instruments.
USDT	Custodial (Tether)	No native holder yield; issuer retains reserve income	No	Fiat-backed stablecoin; holders may earn yield only via third-party platforms, lending, or other DeFi uses.
DAI	Decentralized / protocol-based (legacy Maker ecosystem)	No native yield on the token itself; yield available through savings wrappers	No	Legacy decentralized stablecoin; remains convertible 1:1 into USDS in the Sky architecture.
USDS / sUSDS	Decentralized / protocol-based (Sky)	Savings-rate mechanism via tokenised savings wrapper	Yes, via sUSDS	Sky's updated savings architecture replaces the older DSR-centric framing; yield is accessed through the savings token rather than the base token alone.
PYUSD	Custodial (PayPal / Paxos)	Off-wallet rewards program on balances held within PayPal / Venmo	Yes, subject to program terms	Rewards are variable and paid in PYUSD; distinct from native on-chain interest embedded in the token contract.
aUSDC	DeFi wrapper token (Aave)	Lending-protocol yield accrual	Yes	Interest-bearing claim on supplied USDC within Aave; exposed to protocol, liquidity, and smart-contract risk.

Notes: The table distinguishes between (i) *base stablecoins*, which generally do not embed a native yield for end users, and (ii) *related yield-bearing arrangements*, through which yield may be passed on to holders. For custodial fiat-backed stablecoins such as USDC and USDT, reserve income is typically retained by the issuer rather than automatically distributed to token holders. In decentralized settings, yield is more often generated through protocol-level savings modules or lending wrappers. As of April 2026, PYUSD is a notable exception among major custodial stablecoins insofar as eligible balances held within the PayPal/Venmo environment can receive rewards, although this remains a platform program rather than a native on-chain interest feature. Regulatory treatment varies by structure and jurisdiction.

Table 11: Regulatory roadmap for digital money and stablecoins

Jurisdiction	Framework	Key provisions	Model impact
EU	MiCA (in force; ART/EMT titles applicable from 2024)	Reserve, governance, disclosure and redemption requirements for ARTs and EMTs; supervisory framework for issuers and crypto-asset service providers	$f_S \downarrow$, $\lambda_t \downarrow$, $\pi_{\text{risk}} \downarrow$
	PSD3 / PSR (legislative process ongoing)	Verification of payee, anti-fraud tools, liability rules, and broader modernization of payment services	$\theta_D \uparrow$
	Digital euro (next phase / technical readiness)	Offline functionality, privacy safeguards, intermediated distribution, possible holding limits, legal-tender design if issued	$\theta_M \uparrow$, $f_S^{\max} \downarrow$
US	OCC IL 1183 and related letters (2025)	Reaffirms permissibility of custody, stablecoin reserve deposits, and DLT-based payment activities for national banks; prior non-objection step rescinded	$\pi_{\text{risk}} \downarrow$, $\lambda_t \downarrow$
	Federal stablecoin bills under consideration	Proposed federal frameworks emphasise 1:1 reserves, disclosure, redemption rights, and AML/CFT standards for payment stablecoins	$\lambda_t \downarrow$, $f_S \downarrow$
	NYDFS stablecoin guidance	Segregated backing, redemption at par, attestations, and reserve management requirements	Peg stability $\uparrow$, $\pi_{\text{risk}} \downarrow$
UK	FCA CP25/14 and BoE systemic stablecoin consultation	Proposed issuance, custody, backing-asset, redemption, and systemic-risk rules for fiat-backed stablecoins used in payments	$f_S \downarrow$, $\lambda_t \downarrow$, Singleness $\uparrow$
	Crypto promotions regime	Financial-promotion restrictions, disclosure standards, and consumer-protection safeguards	Over-adoption $\downarrow$

Note. Each row maps a regulatory development to its likely effect on the model's key parameters. f_S denotes the stablecoin issuer fee; λ_t captures redemption fragility under stress (Section 4.2); θ_D and θ_M denote the convenience yields of deposits and CBDC; π_{risk} is the reserve-risk premium (Section 4.3); and $f_S^{\max}$ is the maximum stablecoin fee consistent with coexistence with CBDC. Arrows indicate the expected direction of effect ($\uparrow$ increase, $\downarrow$ decrease). Status as of April 2026.

More broadly, the EU is modernising the payments acquis via *PSD3* and a new horizontal *Payment Services Regulation (PSR)*. The Council agreed its position in June 2025 to strengthen anti-fraud tools (e.g., IBAN/name matching), transparency, and access to payment systems (Council of the European Union, 2025). In our framework, better rails primarily raise the deposit convenience yield θ_D, tightening $i_D + \theta_D = i_S + \theta_S$ and limiting disintermediation.

Finally, the Digital Euro legislative proposal remains under parliamentary scrutiny (ECB in the preparation phase since October 2023). Its envisaged features (offline privacy, mandatory acceptance) would lift CBDC convenience θ_M and tighten the coexistence bound $f_S = r^* + \theta_S - \theta_M$ (European Central Bank, 2024).

United States: Federal–State Mosaic and Prudential Anchors

At the prudential level, the Office of the Comptroller of the Currency (OCC) in 2025 reaffirmed that national banks may (i) provide crypto custody (IL 1170), (ii) hold 1:1 stablecoin reserves (IL 1172), and (iii) use stablecoins/DLT for payments (IL 1174), and it *rescinded* the prior supervisory non-objection step (IL 1183), integrating these activities into regular supervision (Office of the Comptroller of the Currency, 2025). In August 2025, the Federal Reserve likewise *sunset* its 2023 Novel Activities Supervision Program and returned monitoring of banks' crypto/fintech activities to the standard supervisory process (Board of Governors of the Federal Reserve System, 2025). These steps anchor stablecoin backing in supervised banking, lowering perceived redemption risk (downward pressure on the default probability π in Section 4.3) and narrowing the conditions under which scarcity premia break parity (Section 4.2).

On the legislative front, Congress considered the *GENIUS Act* (S. 919), reported by the Senate Banking Committee in March 2025, which would require 1:1 reserves, disclosure, and tailored AML while defining permitted issuers; the House's *Clarity for Payment Stablecoins Act* (H.R. 4766) advanced in 2024 (U.S. Senate Banking Committee, 2025; U.S. House of Representatives, 2024). While passage remains uncertain, stronger reserve and redemption rules reduce run risk (λ_t) and compress f_S toward $r^* - i_S$, thereby tightening the coexistence bound with CBDC and deposits.

State regimes remain influential. The NYDFS stablecoin guidance mandates fully backed reserves, T+2 redemptions at par, segregation, and monthly attestations—directly addressing run dynamics and peg stability in our model (New York State Department of Financial Services, 2022).

United Kingdom: Phase-in Regime for Fiat-Backed Stablecoins

The UK is phasing in a regime for fiat-backed stablecoins used as means of payment. HM Treasury set the policy perimeter; the FCA is developing issuance and custody rules for fiat-backed stablecoins (Financial Conduct Authority, 2023a), and the Bank of England proposed a regime for *systemic* payment systems using stablecoins (Bank of England, 2023). In our mapping, FCA rules shape issuer costs and redemption certainty (affecting f_S and λ_t), while the BoE's systemic regime protects the singleness of money when stablecoins scale (limiting expectation-driven breaks of $i_j + \theta_j$ parity).

In parallel, the UK's crypto financial-promotions regime (in force since 2023) raises disclosure and consumer-protection standards, tempering mis-selling and over-adoption (Financial Conduct Authority, 2023b). Faster domestic rails and tokenised-deposit initiatives lift θ_D, preserving bank intermediation within the model's parity conditions $i_D + \theta_D = i_S + \theta_S = i_M + \theta_M$.

A.5 Cross-Border Digital Money and FX Risk

Digital monetary instruments increasingly intersect with cross-border payments and foreign exchange (FX) exposures. We extend the model to allow households to hold a foreign-denominated money-like instrument M^f (e.g., a USD-pegged stablecoin or a tokenised foreign-currency deposit), with nominal return i_f and convenience yield θ_f. Let q_t denote the domestic-currency price of foreign currency (the exchange rate). The convenience-adjusted return in domestic currency is

$$r_f \;=\; (1 + i_f) \cdot \mathbb{E}_t\left[\frac{q_{t+1}}{q_t}\right] \;+\; \theta_f - 1. \qquad \text{(foreign return)}$$

Households compare r_f to domestic convenience-adjusted returns when allocating portfolios across CBDC, (M), bank deposits, (D), and stablecoins, (S):

$$i_M + \theta_M \;=\; i_D + \theta_D \;=\; \max\left\{\, i_S + \theta_S,\; r_f \,\right\}. \qquad \text{(parity with foreign currency)}$$

When r_f exceeds the domestic level, portfolios tilt toward M^f, determining the substitution of domestic currency. Conversely, a sufficiently high θ_M (from design features such as privacy, programmability, and interoperability) can anchor demand for domestic instruments even when foreign yields are attractive.

Dominance and substitution conditions. Foreign instruments dominate when

$$(1 + i_f) \cdot \mathbb{E}_t\left[\frac{q_{t+1}}{q_t}\right] + \theta_f \; - 1 > \; i_j + \theta_j \quad \text{for all } j \in \{M, D, S\}.$$

Equivalently, taking $j = M$ for concreteness,

$$\theta_M \;<\; (1 + i_f) \cdot \mathbb{E}_t\left[\frac{q_{t+1}}{q_t}\right] - i_M \;+\; \theta_f - 1.$$

Expected domestic-currency depreciation, higher i_f, or higher θ_f raise the right-hand side and increase substitution pressure.

Cross-border payments. Traditional correspondent banking imposes delays, fees, and settlement frictions; by contrast, foreign-denominated stablecoins and tokenised deposits enable near-instant cross-border transfers. In the model, this shows up as higher θ_f (liquidity/interoperability). On/off-ramps and merchant acceptance also raise θ_f via network effects.

Policy transmission and sovereignty. When NFIs back foreign-denominated tokens with high-quality liquid assets, competition often pins i_{Sf} to the foreign policy rate net of fees. Through equations (foreign return)–(parity with foreign currency), foreign monetary conditions and FX expectations can then transmit directly into domestic portfolios. A domestic CBDC with sufficiently high θ_M (and robust deposit rails that lift θ_D) limits substitution. Conversely, widespread use of foreign-pegged stablecoins can weaken domestic transmission and raise unhedged FX exposures.[18]

Design and regulatory levers. The main levers map one-for-one into the convenience-adjusted framework:

1. **Raise $\boldsymbol{\theta_M}$ (CBDC design):** privacy layers, programmability, user experience (UX),[19] and interoperability raise θ_M and shift the parity in equation (parity with foreign currency) toward domestic instruments.

2. **Enhance deposit rails (raise $\boldsymbol{\theta_D}$):** instant payments and tokenised deposits increase liquidity/programmability, reducing the deposit-rate premium needed to retain funding.

3. **Constrain foreign-pegged tokens when warranted:** transparency, reserve quality, redemption rights, and, where appropriate, usage limits for domestic retail reduce effective θ_f and mitigate runs or dollarization dynamics.

4. **Orderly FX conversion and interoperability:** well-designed conversion corridors lower volatility in $\mathbb{E}_t[q_{t+1}/q_t]$ and reduce sharp, expectation-driven reallocations.

Remark A.1. **Network Effects.** *If θ_f depends positively on adoption (network effects), equation* (parity with foreign currency) *can exhibit multiple equilibria. Small improvements in θ_M or domestic rails can shift the system toward the high-adoption domestic equilibrium.*

[18]Examples include the use of USDT and USDC in informal remittance corridors across Latin America, West Africa, and Southeast Asia, where dollar-backed stablecoins are increasingly used as substitutes for local currencies in peer-to-peer transactions and e-commerce. In some cases, platforms and mobile apps allow users to hold balances and make payments directly in stablecoins, bypassing traditional banks and FX controls (Aldasoro et al., 2025; ECB Crypto-Assets Task Force, 2020).

[19]*UX* stands for *User Experience*. It refers to the overall quality of a user's interaction with a system or application, including ease of use, accessibility, speed, reliability, and perceived trust. In the context of digital money, UX encompasses wallet design, onboarding simplicity, transaction speed, and interoperability, all of which influence the convenience yield of an instrument.

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