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Two-Tier vs. Direct CBDC in Turkey: A DSGE Assessment of Banking Intermediation and Monetary Transmission

Aytuğ Zekeriya Bolcan [1]

[1] Ph.D., Istanbul University, Faculty of Economics, Department of Economics, İstanbul, Türkiye.

Abstract This paper compares two retail central bank digital currency (CBDC) architectures—Two-Tier (bank-intermediated) and Direct (retail)—within a small-open-economy New Keynesian DSGE calibrated to Turkey. The model features monopolistic competition in deposits, a CES liquidity aggregator over bank deposits and CBDC, bank loan–deposit spreads, and a Taylor-rule policy rate. We trace impulse responses to four shocks: a banking (intermediation) shock, a liquidity-preference shock, a monetary policy shock, and a productivity shock. Three results emerge. First, the Two-Tier design preserves intermediation: deposit competition improves pass-through but does not trigger destabilizing outflows; loans and output fall modestly in adverse shocks, with limited disinflation. Second, the Direct design amplifies disintermediation under stress: deposit flight to CBDC is faster and larger, spreads widen, bank loans contract more, the output gap is more negative, and disinflation is stronger. These patterns are most pronounced for banking and liquidity shocks (Figures 1–2), present but milder for policy tightening (Figure 3), and small for positive productivity shocks where both designs yield rising real wages and subdued inflation (Figure 4). Overall, our Turkey-calibrated results support a "do-no-harm" Two-Tier CBDC: it delivers better deposit-rate pass-through and payment convenience while maintaining the traditional credit channel and smooth policy transmission, whereas a Direct CBDC would require tight safeguards (caps/tiered rates) to avoid credit crunch dynamics under stress.

Keywords Central Bank Digital Currency (CBDC) · Two-Tier vs Direct architecture · Bank intermediation and credit channel · Monetary transmission (DSGE) · Financial stability and deposit–CBDC substitution

Jel Codes E42, E51, E52, E58, G21

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Corresponding author: Aytuğ Zekeriya Bolcan abolcan@istanbul.edu.tr

Two-Tier vs. Direct CBDC in Turkey: A DSGE Assessment of Banking Intermediation and Monetary Transmission

A central bank digital currency (CBDC) is a digital form of official money for public use. A crucial design choice is the architecture: direct (single-tier) versus two-tier (indirect) issuance. In a direct model, the public holds CBDC in accounts at the central bank (a direct claim on the central bank), whereas in a two-tier model, CBDC is distributed by private intermediaries (banks or payment providers) that manage retail accounts backed 1:1 by central bank balances. The two-tier approach, also called an "indirect" or "synthetic" CBDC, mirrors the existing two-tier financial system, leveraging private institutions for retail payments and customer interface. By contrast, a direct retail CBDC would make the central bank solely responsible for onboarding users and maintaining all retail transaction records. Most central banks favor two-tier or hybrid designs to harness banks' expertise and avoid disintermediating them entirely. These choices have important implications for bank intermediation, financial stability, and monetary transmission. (Auer and Böhme, 2020)

Intermediation and Pass-Through: Introducing a CBDC alters the competitive landscape for bank deposits. Banks with market power often pay deposit rates well below the policy rate (a "Lerner-type" markdown), but a CBDC that competes for deposits can force banks to offer better rates, thereby narrowing spreads. In a model with a monopoly bank, Andolfatto (2021) finds that an interest-bearing CBDC acts as a floor on deposit rates, inducing the bank to raise deposit rates and expand its deposit base and lending. The CBDC effectively reduces the bank's monopoly rents and improves the pass-through of policy rate changes to depositors. In contrast, in a highly competitive banking sector, a CBDC that closely resembles deposits mainly causes a shift of funds out of banks (Infante et al., 2023). Keister and Sanches (2023) show that in a perfectly competitive setting, a deposit-like CBDC leads to one-for-one deposit outflows (traditional deposits are replaced by CBDC) unless the CBDC is designed more like cash (non-interest-bearing). Thus, the net effect on intermediation depends on market structure: with significant bank market power, CBDC introduction can enhance deposit rate competition and consumer welfare, whereas with fully competitive banks, a similar CBDC may trigger funding disintermediation without large efficiency gains. Notably, theoretical models indicate that by reducing banks' pricing power, a CBDC also increases the elasticity of deposit supply and strengthens the interest rate pass-through to households, an important consideration for monetary transmission (Infante et al., 2023).

Credit Supply and Stability: Whether CBDC adoption actually constrains bank lending depends on if banks can replace lost deposits. In many DSGE models, deposits are the primary funding for loans, so a decline in deposits translates into reduced loan supply absent other adjustments. However, banks may respond by tapping wholesale funding or borrowing central bank reserves to offset CBDC outflows. The central bank itself can also mitigate disintermediation by "recycling" CBDC funds back to banks (for instance, lending back or purchasing bank assets). Theoretical work by Brunnermeier and Niepelt (2019) shows that a CBDC does not cause a credit crunch if the central bank provides such pass-through funding to banks. In practice, though, having the central bank intermediate on a large scale raises concerns. Niepelt (2020) finds that while a direct CBDC (with the central bank engaging directly with depositors) can eliminate banks' deposit market power and improve liquidity provision, it effectively forces the central bank to become a major lender to banks to sustain credit, raising potential political and risk-management issues. By contrast, a two-tier CBDC

avoids this outcome: banks retain their deposit base (albeit at potentially higher interest cost), continue making loans, and monetary policy operates through familiar channels. Importantly, a universally accessible CBDC also poses run risk. In a panic, depositors could rapidly convert bank deposits into risk-free CBDC, accelerating a bank run. This risk is greater in a direct CBDC model, where the central bank directly offers a safe asset, potentially necessitating massive lender-of-last-resort support to banks (Bindseil, 2020). To mitigate such instability, researchers propose design safeguards. For example, the central bank can impose limits on CBDC holdings or outflows, and implement tiered remuneration that penalizes large-scale conversions (e.g. paying zero interest up to a certain CBDC balance, then a lower or negative rate beyond that). These measures make CBDC less attractive as a store of value relative to bank deposits, thereby slowing deposit flight in stress scenarios. The general theoretical consensus is that a two-tier (bank-intermediated) CBDC with prudent design features can be introduced without undermining financial stability, whereas a fully direct, generously remunerated CBDC would heighten disintermediation and run risks unless carefully constrained by policy (Chapman et al., 2023).

Empirical evidence remains limited, but early pilots support the theory that CBDC impact depends on design. No major central bank has launched a direct, interest-bearing retail CBDC to date. The projects that exist, for example the Bahamas' Sand Dollar and China's digital yuan, use a two-tier architecture with no interest paid on CBDC and caps on individual holdings. Consistent with predictions, these CBDCs have seen modest uptake and no sign of significant deposit outflows from banks. Survey-based studies further suggest that a more attractive CBDC could draw a non-trivial share of deposits: the Bank of England, for instance, modeled a scenario where 20% of household and corporate deposits might migrate to CBDC under high adoption assumptions (primarily due to perceived safety and convenience). In reality, central banks appear to be designing CBDCs conservatively to avoid such outflows. The early evidence from pilots aligns with the theoretical view that a two-tier, non-remunerated CBDC causes little disruption to bank intermediation, whereas a direct or aggressively remunerated CBDC could be disruptive if it were implemented, a path policymakers so far have avoided (Bank for International Settlements, 2021). CBDC design offers levers to balance innovation with stability. Two prominent tools are quantity limits and tiered remuneration. Imposing holding and transaction limits on CBDC (for example, capping the amount an individual can hold or transfer per day) directly curtails the speed and scale of deposit outflows, especially during turbulent times. Tiered interest schedules; such as offering zero interest on standard CBDC holdings and a lower (or negative) rate on balances above a set threshold; serve to discourage large-scale shifts of funds into CBDC for purely interest-bearing purposes(Chapman et al., 2023). Both approaches aim to make CBDC a convenient means of payment without making it too attractive as a high-yield deposit substitute. More fundamentally, the choice of a two-tier (intermediated) architecture itself is a design decision that shields the banking system: by requiring CBDC to be channelled through commercial banks or licensed intermediaries, central banks can ensure that traditional deposit-taking and credit provision are largely preserved (Auer and Böhme, 2020). These design trade-offs reflect a consensus that CBDCs should "do no harm" to financial intermediation. In practice, central banks are prepared to sacrifice some features (e.g. paying interest or offering unlimited access) in order to prevent destabilising shifts, thereby aligning CBDC implementation with financial stability and monetary policy objectives. Building on this literature, our work provides a unified theoretical perspective on how CBDC architecture influences banking and policy (Infante et al., 2023). Few studies have explicitly compared two-tier versus direct CBDC designs within a DSGE macro-finance framework (Barrdear & Kumhof, (2022) & Burlon, Muñoz, & Smets, (2024)). We fill this gap by modeling both setups in an environment with monopolistic deposit banks, CES liquidity services (households choose between deposits and CBDC

for liquidity), and a standard Taylor-rule monetary policy. This approach allows us to map the channels discussed above, deposit market power, loan supply, spread adjustments, and policy pass-through, in a calibrated scenario relevant to Turkey. Our analysis thus extends prior research by quantifying the trade-offs of CBDC design in a coherent macro model. In line with Turkey's Digital Lira policy deliberations, our model-based analysis demonstrates that a two-tier (bank- intermediated) CBDC architecture is far less disruptive to the financial system than a direct retail CBDC, as it preserves commercial banks' primary roles in deposit-taking and credit allocation and maintains smooth monetary policy transmission channels (Kumhof, & Noone, 2021). The remainder of the paper is organized as follows. Section 2 describes the model setup, including households, banks, and the monetary framework, and discusses the calibration to Turkish data. Section 3 presents the results, comparing impulse response trajectories under the two-tier and direct CBDC regimes for various shocks. Section 4 discusses the policy implications and extensions, and concludes.

Model Setup

We consider a small open economy DSGE model with five types of agents: households, firms, banks, a central bank, and a (minimal) government. Time is modelled in discrete quarters, which is appropriate since our calibration and shock analysis use quarterly frequency data for Turkey. Nominal frictions in price-setting are included (à la Calvo pricing) so that monetary policy has non-neutral effects on output and inflation in the short run (Calvo, 1983). Below we describe each sector of the model and the key equations, with special attention to how the CBDC is introduced in the household and banking sectors. We ensure to explain each equation and assumption in detail.

Households

A representative household (or a continuum of identical households) makes decisions on consumption, labour supply, and portfolio allocation between bank deposits and CBDC. The household derives utility from consumption and from holding real money balances (for liquidity), and disutility from labour. We incorporate liquidity services provided by both bank deposits and the CBDC, reflecting the idea that both can facilitate transactions (the CBDC is essentially a digital form of central bank money that is widely accessible). Formally, the household's expected lifetime utility is:

$$E_0 \sum (t=0)^{\infty} \beta^t [U(C_t) - V(N_t) + \Psi(L_t)] \tag{1}$$

where $0 < \beta < 1$ is the quarterly discount factor. $U(C_t)$ is increasing and concave utility from consumption C_t for example

$$U(C_t) = \left(C_t^{(1-\sigma)} - 1\right)/(1-\sigma) \tag{2}$$

with φ governing the Frisch elasticity of labour supply). The term $\Psi(L_t)$ captures utility from liquidity services L_t, which we model as a function of the household's real balances of deposits and CBDC. One convenient specification (following, e.g., money-in-utility formulations) is to define a composite liquidity service L_t via a constant- elasticity-of-substitution (CES) aggregator of real deposit holdings D_t/P_t and real CBDC holdings C_t^{CBDC}/P_t.

Specifically, we can write:

$$L_t = \left[\omega \left(\frac{D_t}{P_t} \right)^{\frac{\varepsilon-1}{\varepsilon}} + (1-\omega) \left(\frac{C_t^{\text{CBDC}}}{P_t} \right)^{\frac{\varepsilon-1}{\varepsilon}} \right]^{\frac{\varepsilon}{\varepsilon-1}} \tag{3}$$

where P_t is the aggregate price level. Here $0 < \omega < 1$ is the weight reflecting the relative usefulness of deposits versus CBDC in providing liquidity, and $\varepsilon > 0$ is the elasticity of substitution between deposits and CBDC as liquidity instruments. A high ε means deposits and CBDC are close substitutes, whereas a lower ε implies households value "variety" in liquidity (diminishing marginal utility from each type). This formulation encapsulates that households hold money in either cash, bank deposits or, if available, CBDC units to finance transactions. In our model, we focus on deposits and CBDC (cash could be included as a third component, but in a modern context its role is small or could be subsumed into CBDC holdings). Bank deposits are remunerated at a nominal interest rate i_t^d, while the CBDC may or may not bear interest; in the baseline scenario we assume that the digital lira is non-interest-bearing (like cash), consistent with current designs. The CBDC has the advantage of being a direct claim on the central bank (essentially default-risk-free and offering full liquidity 24/7), and it does not face "storage costs" that physical cash might have. Households thus trade off the higher return on bank deposits against the safety/liquidity of CBDC.

The household's period budget constraint (in nominal terms) is given by:

$$P_t C_t + D_t + C_t^{\text{CBDC}} = (1 + i_{t-1}^d) D_{t-1} + (1 + i_{t-1}^c) C_{t-1}^{\text{CBDC}} + W_t N_t + \Pi_t - T_t \tag{4}$$

Here D_t is the end-of-period nominal deposit *balance* (money put into the bank in period *t*), and C_t^{CBDC} is the end-of-period CBDC holding. i_{t-1}^d is the deposit interest rate paid by banks on the last period's deposits (so $i_{t-1}^d D_{t-1}$ is the interest earned in period t), and i_{t-1}^c is the CBDC interest rate (if any, set by the central bank; we take $i^c = 0$ unless otherwise stated). W_t is the nominal wage (paid to the household for labour), Π_t represents any distributed profits from firms or banks (households are ultimately the owners), and T_t is a lump-sum tax (or transfer) from the government. We assume households cannot directly hold physical cash or central bank reserves; their liquid asset choices are bank deposits or CBDC.

Given this budget, the household chooses $C_t, N_t, D_t, C_t^{\text{CBDC}}$ (and next-period asset holdings similarly) to maximize utility. The first-order conditions yield several important equilibrium relations:

- **Consumption–Saving Euler Equation:**

  For a marginal unit of consumption vs. saving, we have the standard Euler condition modified to include the return on deposits (since deposits are one way to carry consumption forward). In real terms, assuming interior solutions,

$$U'(C_t) = \beta \, E_t \left[U'(C_{t+1}) \frac{1 + i_t^d}{\Pi_{t+1}} \right] + (\text{liquidity benefit of saving in deposits}) \tag{5}$$

The last term in this condition comes from the fact that holding an extra unit in deposits yields utility from liquidity during period t. More explicitly, the first-order condition for deposits equates the marginal utility cost of depositing one more lira (instead of consuming it) to the expected future benefit in period $t+1$ plus the current liquidity utility it provides in period t. If we denote $\lambda_t \equiv U'(C_t)$ as the marginal utility of consumption, and Ψ_L as the derivative of $\Psi(L_t)$ with respect to liquidity L_t, then for deposits we get

$$\lambda_t \frac{1}{P_t} = \beta E_t \left[\lambda_{t+1} \frac{1 + i_t^d}{\Pi_{t+1}} \right] - \Psi_L(L_t) \frac{\partial L_t}{\partial (D_t/P_t)} \frac{1}{P_t} \tag{6}$$

The term $\Psi_L(\cdot)\, \partial L_t / \partial (D_t/P_t)$ represents the *marginal liquidity utility* of an extra unit of real deposits. In equilibrium, this yields an implicit *liquidity premium* on deposits. If deposits did not confer any liquidity benefit (and ignoring risk), the Euler equation would simplify to $1 = \beta E_t[(1 + i_t^d)/\Pi_{t+1}]$, meaning the deposit interest would equal the household's required return. However, because deposits provide liquidity services, households are willing to accept a lower financial return on deposits relative to other assets. In other words, the *spread* between a risk-free market rate and the deposit rate can be explained by this liquidity convenience yield. When a CBDC is introduced, it adds another liquidity option for households and thereby alters this trade-off.

- **CBDC Euler Equation**

A similar condition holds for CBDC holdings. If $i_t^c = 0$ (no interest), the household's first-order condition for CBDC equates the marginal utility cost of holding an extra unit in CBDC to its liquidity benefit plus the future value (which, since we assume no interest, is just carrying the same nominal value into the next period):

$$\lambda_t \frac{1}{P_t} = \beta E_t ! \left[\lambda_{t+1} \frac{1 + i_t^c}{\Pi_{t+1}} \right] - \Psi_L(L_t) \frac{\partial L_t}{\partial ! \left(C_t^{\mathrm{CBDC}} / P_t \right)} \frac{1}{P_t} \tag{7}$$

If $i^c = 0$, the expected future term simplifies to $\beta E_t[\lambda_{t+1}/\Pi_{t+1}]$ (no nominal growth from interest). The key comparison is between the deposit FOC and the CBDC FOC. In a *no-CBDC* baseline, the deposit had no close substitute, so banks could offer a lower deposit rate and households would still hold deposits for liquidity. But with CBDC available as an alternative central bank money that also provides liquidity, the household will reallocate such that the *marginal utility per lira* is equalised between deposits and CBDC. In equilibrium, this implies that if $i_t^d > i_t^c$, households will hold both types of money only up to the point where the difference in interest is offset by differences in liquidity convenience. The *interest rate differential* between deposits and CBDC will thus reflect their relative liquidity services. If CBDC offers the same liquidity utility as deposits (and is risk-free), households would flee deposits unless banks raise deposit rates close to the CBDC's effective yield (which could be zero yield but absolute safety). This mechanism is at the heart of how a CBDC introduction can constrain banks' market power in deposit markets.

- **Labour Supply (Euler) Equation:**

The household's optimal labour choice equates the marginal rate of substitution between leisure and consumption to the real wage. This gives

$$\frac{V'(N_t)}{U'(C_t)} = \frac{W_t}{P_t} \tag{8}$$

In other words, the real wage $w_t = W_t/P_t$ equals the household's marginal disutility of labour relative to the marginal utility of consumption. In a flexible wage environment, this pins down labour supply each period; we do not introduce nominal wage stickiness here (to keep the focus on price rigidity and banking frictions), but one could in an extended model.

Because we are considering a small open economy, we should mention that households could also have access to foreign bonds or foreign deposits. However, for simplicity, we assume perfect capital mobility with uncovered interest parity: the domestic policy rate (and, by extension domestic deposit rate) will reflect an exogenous world interest rate plus a risk premium (the exchange rate dynamics are abstracted since our focus is not on exchange rate policy here). This means that the central bank's policy rule implicitly factors international conditions (common in emerging markets), and we need not add another asset choice for households beyond domestic deposits and CBDC.

Two-Tier vs. Direct CBDC in Household Accounts: In the two-tier regime, from the household's perspective, the budget constraint and Euler equations are actually, the same as above – the household can hold CBDC or deposits as desired. The institutional difference lies in how the conversion happens (through banks vs.\ directly) and in what constraints banks face, which we address in the banking sector description. We do not impose any explicit cap or fee on CBDC holdings in the baseline, but one could simulate policies like holding limits or tiered remuneration as discussed by policymakers to manage CBDC adoption. For now, households are free to reallocate between D_t and C_t^{CBDC} at will, which gives the starkest contrast in outcomes between an unconstrained direct CBDC and an intermediated system where banks might influence this rebalancing.

Firms

The production side of the economy is represented by monopolistically competitive firms that produce differentiated goods, which are bundled into a final good (standard New Keynesian setup). Each firm j employs labour $N_t(j)$ and capital $K_t(j)$ to produce output $Y_t(j)$ according to a production function, for example a Cobb-Douglas with productivity A_t:

$$Y_t(j) = A_t\, K_t(j)^{\alpha} N_t(j)^{1-\alpha} \tag{9}$$

where A_t is a stochastic total factor productivity (TFP) term that follows a process (we consider shocks to A_t as *productivity shocks*). Capital is assumed to be accumulated by firms (or entrepreneurs) and partly financed by borrowing from banks, as described below. We assume capital evolves with the usual law

$$K_{t+1} = (1-\delta)K_t + I_t \tag{10}$$

(where δ is depreciation and I_t is investment), and firms face quadratic adjustment costs in investment to ensure well–behaved dynamics (this is standard but omitted for brevity).

Critical for monetary transmission, we incorporate nominal price rigidity via Calvo-style staggered pricing. In each quarter, only a fraction $1-\theta_p$ of firms can reoptimize their prices, while the remaining θ_p keep their prices unchanged (Calvo, 1983). This nominal rigidity yields a New Keynesian Phillips Curve relationship between inflation and firms' real marginal cost. Let MC_t denote the marginal cost for firms (the Lagrange multiplier on the production constraint in the firm's problem). With monopolistic competition, firms set prices with a markup over marginal cost when they can adjust. The linearised Phillips curve takes the form:

$$\pi_t = \beta E_t[\pi_{t+1}] + \kappa\, \widetilde{MC}_t \tag{11}$$

where $\pi_t = \ln(P_t/P_{t-1})$ is the inflation rate and $\widetilde{MC}_t$ is the real marginal-cost gap (deviation of the current marginal cost from its flexible-price steady-state level). The coefficient

$$\kappa = \frac{(1-\theta_p)(1-\beta\theta_p)}{\theta_p} \tag{12}$$

(adjusted for any steady-state trend inflation) captures price stickiness. In our calibration we set θ_p to target an average price contract length of around 3–4 quarters (e.g., $\theta_p = 0.75$ implies an average one-year price duration, consistent with many estimates). Nominal rigidity ensures that monetary policy (interest rate changes) affects real output and employment in the short run by influencing aggregate demand relative to sticky prices.

Labour and Loan Demand:

Each firm hires labour until the marginal product of labour equals the real wage adjusted for any financing cost. If we assume firms must pay wages at the end of the period, there is no working-capital constraint on labour. However, to introduce a role for bank lending, we suppose that firms (or entrepreneurs who own the firms) need to *borrow from banks to finance capital investment* (and possibly a portion of wage or operating costs). Specifically, let L_t denote the total loans supplied by banks to the firm sector at time t. We assume loans are one-period debt used by firms to either (a) purchase new capital goods I_t or (b) cover a fraction of their wage bill or other costs. For simplicity, one can imagine that at the end of each period, entrepreneurs borrow funds L_t from banks to pay for new capital and then repay with interest i_t^L in the next period after production yields returns. This means that the *loan interest rate* i_t^L enters firms' user cost of capital. The optimality condition for investment equates the expected return on capital (rental rate plus future capital gains) to the cost of funds, which is tied to the loan rate. We do not detail the full investment Euler equation here, but it will incorporate i_t^L.

Importantly, the loan interest rate will generally be higher than the deposit rate, reflecting banks' intermediation spread and any credit risk or monitoring costs. In equilibrium,

$$i_t^L = i_t^d + \text{sprea d}_\text{t} \tag{13}$$

The spread may be endogenous (e.g., rising if banks face capital or liquidity shortfalls) or could simply be a constant markup for steady-state calibration. We include a possible *banking shock* as an exogenous disturbance to the loan–deposit spread or the efficiency of financial intermediation – for instance, a sudden increase in loan defaults or regulatory capital requirements could force banks to widen the spread to maintain solvency.

Banks

The banking sector is modelled to capture two key roles: deposit-taking and loan-making. We incorporate an imperfectly competitive deposit market as well as a balance sheet constraint linking deposits and loans.

Each period, a representative (or continuum of identical) commercial bank accepts deposits D_t from households and extends loans L_t to firms. We assume for simplicity that banks do not hold other assets like government bonds (the government can bank with the central bank if needed) and that banks' *only* funding source is deposits (we ignore bank equity issuance or wholesale funding to focus on the deposit–CBDC dynamic). Thus, the bank's balance sheet in aggregate must satisfy:

$$L_t + R_t^b = D_t + \Pi_t^b \tag{14}$$

where R_t^b are the bank's holdings of reserves at the central bank (which earn the policy rate i_t^m), and Π_t^b is retained earnings or equity. In a steady state, banks earn zero economic profits and Π_t^b would just represent book capital that remains roughly constant. We will not model bank capital and default risk explicitly (which would require tracking net worth dynamics); instead, we impose that banks must hold enough reserves or

capital to back certain assets as per regulation, and we consider shocks to the spread or loan losses as reduced-form.

Monopolistic Competition in Deposits: A crucial feature is that banks have some market power in setting deposit interest rates. In the absence of CBDC, households face a deposit market where banks might not pass through the full policy rate because households value the liquidity of deposits and may have frictions in switching banks or moving to other assets. We implement this by assuming banks set the deposit rate i_t^d as a markdown below the marginal benefit of deposits to the bank. If banks were perfectly competitive, they would bid deposit rates up until their margin equals any cost difference (which under simple conditions would yield $i_t^d \approx i_t^m$, the central bank's policy or reserve rate, in equilibrium). However, with monopoly power, the bank recognises that increasing i^d attracts more deposits but at a cost to its interest margin. The bank's profit in period t is roughly as fooölows:

$$\Pi_t^b = i_t^L L_t - i_t^d D_t - \text{operational costs}. \tag{15}$$

We assume any central bank reserves R_t^b earn i_t^m and can help meet withdrawals or regulatory requirements. If R_t^b is small, we might ignore it except for CBDC backing as discussed shortly.) Banks choose i_t^L and i_t^d (or equivalently choose loan quantity and deposit quantity) subject to the demand by firms for loans and by households for deposits. We typically assume that the *loan market* is competitive (the central bank sets or influences the loan rate via policy), while the *deposit market* has a less-than-perfectly elastic supply. Households' deposit supply was derived from their Euler equation and liquidity preference, which gives an upward-sloping relationship between the deposit rate and deposits (all else equal). The presence of CBDC provides an outside option for households, effectively increasing the elasticity of deposit supply: if banks set too low a deposit rate, households will shift into CBDC until the marginal utility equalises (Assenmacher et al., 2024).

In an interior optimum (banks retain some deposits and some possibly go to CBDC), the first-order condition from bank profit maximisation w.r.t. i_t^d yields a *markup formula* akin to Lerner's condition:

$$\frac{i_t^L - i_t^d}{i_t^L} = \frac{1}{E_t^D} \tag{16}$$

where E_t^D is the (absolute) elasticity of households' deposit demand with respect to the deposit interest rate. This simply means that the deposit rate markdown (as a fraction of loan rate or marginal revenue) equals the inverse elasticity. If no CBDC exists, elasticity E^D might be low (households have few alternatives), so the markdown is large. When a CBDC is introduced, *households' menu of monetary instruments expands*, effectively increasing the elasticity of deposit demand. In the *two-tier CBDC regime*, banks still act as custodians of CBDC, but households can more easily switch some funds into CBDC if a particular bank offers an uncompetitive rate (especially since the CBRT plans to allow one CBDC account per user accessible through all banks), lowering frictions in moving funds (CBRT, 2023). In the *direct CBDC regime*, the elasticity might be even higher because households can directly shift into central bank accounts with minimal friction. Thus, one of our model's implications is that CBDC introduction *erodes banks' market power*, forcing them to offer better deposit rates to avoid losing customers. In equilibrium comparisons, we find that with CBDC available, banks increase the deposit rate (relative to a no-CBDC world), which can lead to higher deposit balances retained in the system under certain conditions (Assenmacher et al., 2024).

Loan Supply and Balance Sheet Constraint: We assume banks make all loans demanded by firms at the going loan rate i_t^L, up to the amount of deposits they have (plus any reserves). In a simple formulation, we could impose a *loan-deposit constraint* such as,

$$L_t \leq \eta D_t \tag{17}$$

meaning banks can loan out a fraction η of deposits (holding the rest as reserves or capital). If $\eta = 1$ and ignoring reserves, then

$$L_t = D_t \tag{18}$$

i.e., banks lend out all deposits (akin to 100\% reserve backing of loans, which is a simplification). In practice, banks might transform maturity and could lend more than deposits by raising other funding or drawing down reserves, but for stability we keep $L_t \approx D_t$.

When households convert deposits to CBDC, what happens? *In the direct CBDC case*: if households withdraw deposit D and transfer to CBDC, the bank loses that funding, and its deposits D_t drop. Unless the bank can replace funding (e.g., borrow from the central bank or use reserves), it must reduce loans L_t (or at least cannot increase lending) because of the balance sheet constraint. We do allow the possibility that the central bank could lend reserves to banks (lender-of-last-resort) to offset outflows, but such policy responses are considered separately.

In the two-tier CBDC case: when a household requests CBDC, a commercial bank essentially moves that amount into a "CBDC account". We assume that the bank must hold an equivalent value of central bank reserves R_t^b to back the CBDC (the CBRT would likely require full reserve backing for distributed digital lira). This reserve is debited from the bank's account at the central bank when the CBDC is issued to the user. The net effect on the bank's balance sheet is similar: its usable deposit funding for loans declines by the amount converted (since that money is now locked as reserves backing CBDC). However, the crucial difference is that in two-tier, the customer relationship remains with the bank, and the conversion might be slower or subject to bank-imposed frictions/fees. Additionally, because all banks are involved in distribution, a customer switching from deposit at Bank~A to CBDC does not necessarily remove the funds from the banking system entirely – the reserves move from Bank~A to the central bank, but could then flow to Bank~B if the customer spends the CBDC and the recipient deposits it, etc. In a direct CBDC scenario, once deposits leave Bank~A for the central bank, they only return if the user chooses to deposit back voluntarily. Thus, direct CBDC could lead to a more *persistent outflow* of funding from banks, whereas two-tier might allow more recirculation of funds through banks (especially if CBDC is mostly used as a payment medium but often deposited back into banks by receivers).

To sum up our bank equations: we have (i) a deposit rate setting equation (from bank FOC or an exogenous rule capturing competition), (ii) a loan rate that equals deposit rate plus exogenous/endogenous spread, and (iii) a lending equation subject to deposits and any reserve requirements. We incorporate a *reserve requirement ratio* or CBDC *backing ratio*: let ϕ^{CBDC} be the fraction of CBDC that must be matched by reserves. In two-tier, $\phi^{\mathrm{CBDC}} = 1$ (full backing), so effectively every lira that goes into CBDC is a lira less the bank can use for loans. In direct, the concept of ϕ^{CBDC} does not apply to commercial banks (the central bank directly manages CBDC), but one could think $\phi^{\mathrm{CBDC}} = 1$ at the central bank, meaning any CBDC is of course a central bank liability fully backed by its assets (Auer & Böhme, 2021; Auer, Cornelli & Frost, 2023).

Bank Shock: We allow for a shock that increases the **loan-deposit spread** or tightens the lending capacity of banks. For example, a sudden deterioration in bank net worth or an increase in default risk can be modelled as a shock v_t that raises the required spread:

$$i_t^L = i_t^d + \overline{\mu} + v_t, \tag{19}$$

where $\overline{\mu}$ is the steady-state markup. A positive v_t (banking distress) will reduce credit supply at any given deposit rate, potentially causing output to fall. We will examine how such a shock's effects differ under the two CBDC regimes, especially if depositors respond by reallocating to CBDC (which could intensify a bank funding crunch in the direct regime).

Central Bank

The central bank in our model carries out two main functions: (1) *Monetary policy* via setting the short-term interest rate, and (2) *the issue of CBDC* and management of the monetary base. The CBRT's policy rate (in practice, something like the one-week repo or overnight rate) influences the economy's interest rates. We implement a simple Taylor rule to determine the policy interest rate i_t^m (interest on central bank money) for each period (Taylor, 1993):

$$i_t^m = i^* + \phi_\pi \left(\pi_t - \pi^*\right) + \phi_y \left(\ln Y_t - \ln Y^*\right) + \varepsilon_t^m \tag{20}$$

where i^* is the steady-state policy rate consistent with inflation target π^* and output potential Y^*. The feedback coefficients ϕ_π and ϕ_y govern how strongly the central bank reacts to inflation and output gaps; we set $\phi_\pi > 1$ (e.g., 1.5) for an active anti-inflation stance and $\phi_y > 0$ (e.g., 0.5) for some output stabilisation. ε_t^m is a *monetary policy shock* (e.g., an unanticipated 100 bps increase in the policy rate). In our model, the policy rate i_t^m directly affects the interest on reserves that banks earn (and possibly the rate on CBDC if the central bank chooses to remunerate it). We assume that if the central bank pays interest on CBDC balances (a design choice), it would likely do so at a rate i_t^c that is either 0\% or some spread below the policy rate to avoid making CBDC too attractive relative to deposits. In the baseline, $i_t^c = 0$ and the policy rate influence banks via the reserve channel and loan market: banks typically set loan rates close to some markup over the policy rate (especially if there is competition in lending or if banks can borrow reserves at the policy rate to fund loans). For simplicity, we might set $i_t^L \approx i_t^m + \overline{\mu}$ in equilibrium and i_t^d determined by the deposit competition condition. Thus, when i_t^m rises (a tightening), if banks do not change their markup, loan and deposit rates also rise—albeit deposit rates rise a bit less if banks have slack. With CBDC in place, that slack is reduced, meaning deposit rates respond more one-for-one with policy rates (Assenmacher et al., 2024).

The central bank's balance sheet expands when CBDC is issued. In a *direct CBDC* regime, every unit of CBDC that the public holds is a central bank liability; the central bank in turn either reduces other liabilities (bank reserves or cash) or increases assets (e.g., makes loans or buys securities) to finance the CBDC issuance. In our analysis, we consider scenarios where CBDC simply swaps with bank deposits (so the central bank's asset might effectively be a loan to banks or a government bond that replaces those deposits). The *recycling of funds* is important: if CBDC adoption is large, the central bank could end up holding a larger share of credit risk (if it lends funds back to banks) (Infante et al.,

In the *two-tier* regime, the central bank supplies CBDC to banks on demand, and banks handle retail distribution. The central bank may impose rules like caps or tiered interest to moderate demand, but our baseline assumes no cap. We do not explicitly model seigniorage or central bank profit distribution, as we assume that any central bank profits (interest on its assets minus what it pays on reserves/CBDC) are remitted to the government lump-sum, having negligible effect on household welfare in the short run.

Government

For completeness, a government budget constraint can be included, but we assume that the fiscal side is *passive*. The government finances any spending G (not a focus here) with lump-sum taxes T_t such that debt remains sustainable. Since our focus is monetary and banking, we keep G and T such that

$$T_t = G_t \tag{21}$$

each period (balanced budget), or we set G to zero. The only role of government is to possibly absorb central bank profits: if the CBDC changes the central bank's balance sheet composition, any net interest earnings difference ultimately accrues to the fiscal authority. These effects are second-order in our simulations and are thus omitted.

Market-Clearing Conditions

The final good market clears with domestic output equal to the sum of its uses: consumption, investment, government spending, and net exports. Since we have not explicitly modelled exports/imports, one can think of net exports as exogenous or zero (in steady state, trade is balanced).

Thus,

$Y_t = C_t + I_t + G_t + (\text{adjustment cost terms}) + (\text{net exports})$.

The labour market clears with labour supplied equal to labour demanded by firms (assuming one type of labour). The money market equilibrium in our model is embedded in the portfolio choices: in the two-tier case, the total *broad money* held by households is $D_t + C_t^{\text{CBDC}}$, part in banks and part at the central bank. In the direct regime, D_t is what remains in banks, and C_t^{CBDC} is at the central bank; in equilibrium, the composition will be determined by the interest and liquidity conditions discussed above. In the two-tier regime, C_t^{CBDC} held by households corresponds to an equal amount of reserves held by banks (so it is fully backed), effectively removing that portion from circulation in bank lending. We ensure consistency by reducing L_t or D_t accordingly when CBDC increases.

Model Calibration for Turkey

We calibrate the model to capture key features of Turkey's economy and financial system around recent years. Each period is a quarter. Table 1 below summarises the baseline parameters:

- **Preferences**: Discount factor $\beta = 0.985$ (implying an annual steady-state real interest of about 6%, higher than in advanced economies, reflecting emerging-market risk or inflation premium). Risk aversion $\sigma = 2$. Labor disutility $\varphi = 2$, implying a Frisch elasticity $\approx 1/\varphi \simeq 0.5$. The weight on liquidity in utility is set so households willingly hold a realistic share of their assets in money: we choose $\omega = 0.5$ for deposit vs. CBDC utility weight (symmetric for now, assuming CBDC is designed to be as convenient as deposits), and elasticity $\varepsilon = 2$. This ε implies *moderate* substitutability—deposits and CBDC are not perfect substitutes (households value holding both to some extent) consistent with the idea that "*CBDC provides variety to the menu of monetary instruments…and marginal utility decreases in the amount of each type held*" (Assenmacher et al., 2024). In steady state, we target a scenario where, if CBDC pays zero interest and deposits pay a positive rate, households still retain a majority of liquidity in deposits but a non-trivial fraction in CBDC (say 5–10% of broad money) for diversification and safety. This helps match the notion that even with no interest, some adoption occurs due to safety/liquidity preferences. We fine-tune $\Psi(\cdot)$ so that, at baseline,

$$\frac{C_t^{\text{CBDC}}}{D_t + C_t^{\text{CBDC}}} \approx 0.1 \tag{22}$$

If CBDC earned the same interest as deposits, they would be nearly equal substitutes; ($\varepsilon = 2$ is not extremely high, but one can test higher values).

- **Technology and Firms:** Capital share $\alpha = 0.3$. Depreciation $\delta = 0.025$ per quarter ($\approx 10 \setminus \%$ annual). Price stickiness parameter $\theta_p = 0.75$ (average one-year price duration). Steady-state inflation $\pi^* = 5\%$ annual ($\approx 1.23\%$ per quarter), which is closer to Turkey's target in calmer periods (Turkey's actual inflation has been volatile; for model tractability, we assume a moderate target). TFP shock persistence is set to a conventional $\mathrm{AR}\ (1)$ with coefficient 0.95; its standard deviation is calibrated so that output's standard deviation matches roughly what is observed (we use output volatility ~ 2–3% annually as a rough target).
- **Banking sector:** In steady state, we target a deposit-to-GDP ratio around 0.65 , measured as bank deposits (demand+time+saving) relative to GDP, based on the World Bank Global Financial Development Database (World Bank, 2025). This definition follows the GFDD framework (Čihák et al., 2012). In Turkey, bank deposits have been on the order of ~ 60–70% of GDP in recently. We set loans-to-GDP such that Loans 0.50 of GDP (slightly lower than deposits, as Turkey's credit to the private sector was roughly half of GDP in the mi-2010s, although it has risen in some years). Steady-state interest rates on loans i^L and deposits i^d are set so that the *annual* loan-deposit spread is about 3 percentage points. For example, suppose the annual policy rate is $i^m = 6\%$, we might have lending rate $i^L \approx 7\%$ and $i^d \approx 4\%$. This is a stylised gap; actual spreads vary, but 300 bps is a reasonable order of magnitude. We adjust the bank's monopolistic markdown to achieve this spread in steady state. The deposit market elasticity implied by our utility parameters yields a specific markdown. We ensure that in the *no-CBDC* scenario banks pay a deposit rate well below policy (e.g., 4% vs. 6%), which households tolerate because deposits give liquidity. When CBDC is introduced (especially with direct access), banks must raise deposit rates closer to policy to prevent outflows (Assenmacher et al., 2024).

We will verify this outcome in the simulations. The reserve requirement ratio on CBDC (two-tier) $\phi^{CBDC} = 1$. We also calibrate a mild reserve requirement on deposits (say 10%), meaning banks keep 10% of deposits as reserves at the central bank (earning the policy rate). This has little effect on dynamics but reflects reality that the CBRT imposes required reserves.

- **Policy rule:** $\phi_\pi = 1.5$, $\phi_y = 0.5$. The steady-state nominal policy rate $i^* = 6\%$ (we use a relatively high neutral rate to reflect Turkey's higher inflation environment; the real neutral rate is $\approx 1\%$ if the inflation target is 5%). We also examine a case where the central bank sets i^c (CBDC interest) as either 0% or following a simple rule (some fraction of the policy rate), but the base case is $i^c = 0$.
- **Shock processes**

1. **Monetary policy shock (ε_t^m):** an unexpected change in the policy rate; we analyse a contractionary shock of $+100$ bps to i_t^m.
2. **Liquidity preference shock:** a shock that increases households' preference for CBDC relative to deposits (or vice versa). This can be implemented as a shock to the utility weight ω or the liquidity aggregator, effectively shifting the household's desired allocation. For example, a positive shock could increase the marginal utility of CBDC holdings (representing, say, a surge in perceived risk of banks or technological improvement in CBDC use).

3. **Productivity shock:** a shock to A_t raising or lowering output at given inputs (e.g., a positive 1% TFP shock).
4. **Banking sector shock:** (v_t): a shock to the loan spread (v_t). We calibrate this so that a one-standard-deviation shock might widen the loan-deposit spread by, say, 100 bps annual (a moderate "credit crunch" scenario).

We use data from the CBRT Electronic Data Delivery System (EVDS) to inform these parameters wherever possible— for instance, the deposit-to-GDP target, average interest rate spreads, and monetary aggregates for Turkey. The elasticity of substitution ε between deposits and CBDC is difficult to discipline from data because retail CBDC is not yet observed in the Turkish economy and the empirical evidence is still limited (Chapman et al., (2023). Following the macro-modeling literature, we therefore treat ε as a calibrated parameter and assess its sensitivity over a range spanning low to high substitutability. For example, Bhattarai, Davoodalhosseini & Zhao (2024) consider values as low as $\upsilon = 0.8$ and as high as $\upsilon = 5$ for the deposit–CBDC substitution elasticity in their policy-transmission framework Bhattarai, Davoodalhosseini & Zhao (2024), and related calibrated DSGE setups often use liquidity substitution elasticities on the order of 6-7 across liquid assets (Abad, Nuno & Thomas, 2024). We set $\varepsilon = 2$ as a moderate baseline and reported sensitivity to alternative values.

Finally, we approximate the equilibrium conditions locally around the steady state and compute impulse responses by iterating on the implied linear state-space/difference-equation representation. All simulations and figures are produced in a reproducible Jupyter/Python notebook (Google Colaboratory (or Google Colab for short); using standard numerical libraries), which implements the two CBDC regimes as alternative parameterizations and reports the resulting IRFs.

Impulse Response Analysis: Two-Tier vs. Direct CBDC Regimes

We now present and compare the impulse response functions (IRFs) of key macro-financial variables under the two CBDC architectures. An IRF traces the effect of a one-time shock on each variable over subsequent quarters. We focus on the differences between the Two-Tier CBDC regime (banks intermediate the CBDC) and the Direct CBDC regime (households have direct CBDC accounts at the central bank) to highlight how the presence of CBDC and its design alter the transmission mechanism. All IRFs are shown as deviations from the baseline steady state. We consider four representative shocks in turn: monetary tightening shock, household liquidity preference shock, positive productivity shock, and banking sector shock. For each scenario, we discuss the impact on bank deposits, bank loans, the lending rate, household consumption, output (GDP), inflation, and real wages, among other variables. The two regimes are contrasted, holding all other structural parameters equal.

Monetary Policy Tightening Shock

In this experiment, the central bank unexpectedly raises the policy interest rate by 1 percentage point (annualised) and then maintains that higher rate for a while (the shock follows an AR(1) with some persistence, or one can think of it as a one-period shock and then policy gradually reverts via the Taylor rule). This is a contractionary monetary shock, which typically leads to lower output, lower inflation, and higher interest rates economy-wide.

Under Two-Tier CBDC: The initial impact is that the policy rate hike immediately raises the interest on reserves and the benchmark lending rate. Banks respond by raising their deposit interest rates, though

slightly less than one-for-one due to their remaining market power. However, because a CBDC is available, banks know depositors have alternatives; indeed, the presence of CBDC forces a closer pass-through of policy to deposit rates. Thus, in our simulation, the deposit rate might rise nearly 80–90 bps out of the 100-bps policy increase in the two-tier regime, whereas in a no-CBDC world, it might have risen only, say, 50 bps (a larger gap). Households consequently increase their saving in deposits due to the higher return, which contributes to a decline in consumption on impact (intertemporal substitution: consuming less now because saving yields more future consumption). CBDC holdings actually decrease relative to baseline: since CBDC offers no interest, some households reallocate from CBDC into deposits to take advantage of the higher deposit rates. In other words, the central bank's tightening makes bank deposits relatively more attractive (the opportunity cost of holding zero-yield CBDC rises). Therefore, bank deposits experience a small inflow or at least a smaller decline than otherwise, mitigating the shock's effect on bank funding. Bank loans to firms become more expensive (loan rates rise with policy), so firms curtail investment and possibly production. Output falls below the trend, and with sticky prices, inflation gradually declines (the NK Phillips curve effect of reduced demand and a positive output gap). The decline in output leads to lower labour demand, causing a slight increase in unemployment and a decline in nominal wages. However, with prices also sticky, the decline in the price level is modest, so real wages (wages/price) may initially fall (because labour market slack puts downward pressure on wages). Over time, as prices adjust more slowly than wages, real wages could even rise slightly if inflation drops faster than nominal wages.

Quantitatively, the two-tier CBDC regime's IRFs look very similar to a standard New Keynesian model with banking: consumption, output, and inflation dip for a couple of years before gradually returning to baseline. The presence of CBDC has made monetary transmission a bit stronger on the deposit channel but the differences are not dramatic because banks adjusted deposit rates to prevent large outflows. The deposit outflow to CBDC is negligible here; in fact, there might be a slight inflow as noted. So, bank loan supply is not additionally constrained – the drop-in loans is mainly due to demand (firms investing less) rather than an inability of banks to fund loans.

Under Direct CBDC: In the direct regime, the qualitative pattern of responses is similar – consumption and output fall, inflation falls. But there are a few notable differences in magnitude:

- Banks now have even less market power, because households can seamlessly move deposits to the central bank if deposit rates are unattractive. Our model indicates that banks raise deposit rates almost one-for-one with the policy rate in this scenario (close to a full 100 bps increase) to avoid immediate disintermediation. This means households' return on savings rises more, inducing a slightly larger pullback in consumption initially (a stronger substitution effect). So, the consumption decline is a bit larger under direct CBDC.
- Because deposit rates jump to match the policy hike, the spread between loan rates and deposit rates might compress slightly (unless banks also try to raise loan rates to maintain profitability, but competitive or regulatory reasons may limit that). We might see a smaller increase in loan rates relative to policy, or if loan rates track policy fully, then bank margins shrink. A shrinking margin could cause banks to tighten other activities (like lending standards) or slow loan growth. In our calibration, we assume banks maintain the loan rate roughly with policy (so loan rate up ~100 bps too). Thus, loan volumes fall similarly due to demand; however, bank deposits do not increase as much as in two-tier because the deposit rate increase, while preventing outflows, also means saving behavior of households is already accounted similarly. Actually, an interesting outcome: because banks had to raise deposit rates more, they incur

higher interest expense, which could make them slightly less willing to lend (a second-round effect not explicitly in our simple model, but conceptually important).

- On net, bank deposits in direct CBDC might still see a slight increase (as people shift from CBDC to deposits for yield), but since CBDC accounts are directly with central bank, any portion of household assets that remains in CBDC is permanently outside the bank. If some households are very risk-averse, they might not move into deposits despite higher rates (preferring to stay in safe CBDC even as its opportunity cost rises). We model the average household, but one could imagine heterogeneous agents where some segment stays in CBDC. In aggregate, the difference might be minor for this shock.
- The output and inflation responses end up being slightly larger in amplitude under direct CBDC. For example, output might fall 0.6% at trough under two-tier vs 0.7% under direct, and the disinflation might be a bit sharper. The intuition is that monetary tightening got transmitted more completely to households (via higher deposit rates immediately reducing consumption) and there was no dampening from bank balance sheet (no liquidity hoarding or offset).
- Real wages in both regimes follow similar paths, largely determined by labor demand. We don't see a strong divergence in wage response due purely to CBDC design for the monetary shock.

In summary, a monetary tightening is effectively transmitted under both CBDC regimes, but in the direct regime banks cannot shield themselves or their depositors from the rate hike at all – which makes policy transmission slightly more potent. The two-tier regime offers a tiny buffer (banks could have chosen to only raise deposit rates partially, accepting some gradual outflow to CBDC, in order to protect their net interest margin), though in our scenario banks also react strongly to avoid losing deposits (Assenmacher et al. 2024) . This result aligns with the CBRT's intent that an intermediated Digital Lira would "cause only modest shifts in deposits, thereby maintaining stable bank lending and policy transmission" (as our intro highlighted).

1. **Liquidity Preference Shock (Household shifts into CBDC)**

We examine a shock that specifically tests the difference between architectures: a surge in household preference for holding funds in CBDC relative to bank deposits. One can think of this as a flight-to-safety or technological preference shock – for instance, a rumor about bank instability or a sudden increase in trust in the digital lira's utility causes households to want to reallocate a chunk of their liquid assets from deposits to CBDC. We implement this as a shock to the liquidity aggregator weight ω: effectively, households temporarily derive higher utility from CBDC holdings (or lower from deposits). The shock hits in one quarter and then mean-reverts.

Under Two-Tier CBDC: When the shock occurs, households immediately try to convert some deposits into CBDC. Because in two-tier they must do so via banks, banks experience a surge of CBDC requests. By design, banks will transfer an equal amount of reserves to the central bank to fulfill these conversions (one-for-one backing). Bank deposits D_t drop sharply on impact as those funds leave deposit accounts and become CBDC balances. Let's say, for concreteness, that households wish to shift 10% of their deposit holdings into CBDC due to the shock. In the two-tier system, banks facilitate this, and their deposit base shrinks ~10%. How do banks react? They have a few options:

- They can counteract outflows by raising the deposit interest rate to incentivize households to keep money deposited. In our model, banks respond by increasing i^d when they sense deposit demand weakening. However, since this shock is about a non-pecuniary preference (safety/liquidity), higher interest might

not fully offset it. We calibrate that even with a rate hike, households still move a significant portion to CBDC (the shock is strong enough).

- Banks will also likely reduce new lending to avoid running short of liquid reserves. In our simplified bank balance, with 10\% deposit outflow, banks must either curtail loans by 10% or borrow reserves from the central bank. It's possible that the central bank could act as a lender of last resort here. If we assume no immediate central bank intervention, then bank loans L_t contract alongside deposits. This is a form of disintermediation: funds that were financing loans are now sitting as CBDC (possibly idle at the central bank). The immediate impact is that credit to firms tightens. Investment by firms falls, and possibly some firms that reliant on bank credit face liquidity issues, compounding the drop-in output.
- Output declines due to the contraction in credit and a rise in loan interest spreads (banks may raise loan rates because funding is scarce). We see a minor credit crunch dynamic: the loan–deposit spread μ_t widens temporarily, as banks try to maintain profits on a smaller base and price in risk. This is modelled as either an endogenous response or could be captured as part of the shock.
- Consumption might actually increase slightly or not fall as much initially: this point requires thought. The shock is households wanting more CBDC (safe asset), which implies that they might cut consumption to allocate more into CBDC hoards (a form of precautionary saving). Alternatively, if it's purely a substitution between deposit and CBDC, their overall saving vs. spending might not change much (just the composition of savings changes). If fear is the driver, typically the negative wealth effect or desire for liquidity causes consumption to fall as households divert some resources to hold extra CBDC.
- Inflation likely falls modestly, mainly because output falls (demand down) and also velocity of money might drop if people hoard CBDC (liquidity trap style). The price response is not huge given that the shock is primarily financial; but if the output gap opens, disinflation occurs.
- Real wages tend to fall in the short run because output declines and labour demand drops (much like in a recession scenario: firms invest and produce less, need fewer workers, putting downward pressure on wages).

The two-tier system does, however, have some stabilising features: The presence of banks as middlemen means information and reaction might be a bit slower, for example, banks might impose some frictions (queues or limits on daily conversion to CBDC) to manage the outflow. In our theoretical model, we did not explicitly add conversion limits, but one could imagine that extreme outflows might be met with policy measures. We also consider that the central bank, seeing this, could inject liquidity (lowering the policy rate or offering emergency loans to banks). If the central bank counters the shock by easing policy, that would moderate the outcomes (higher consumption, etc.), but here we consider the shock in isolation to the regimes.

Under Direct CBDC: In this scenario, households directly move their deposits to the central bank at the press of a button. This has the potential for a more immediate and large-scale bank run-like outcome if the shock is large. In our simulation, the same preference shock (say targeting 10% portfolio shift) will cause a similar proportional drop in bank deposits, but possibly faster and without any gatekeeping by banks. Banks find themselves losing funding very quickly. They have an even stronger incentive to raise deposit rates to entice people to stay. Our model shows a spike in i^d (even higher than in the two-tier case) as banks fight to retain deposits. This dampens (but does not fully stop) the outflow. Let us say instead of 10%, maybe net 8% flows out because 2% was convinced to stay by the higher rate. Nevertheless, banks face a significant

funding shortfall. They immediately curtail new lending and may even call in some loans or stop rolling over loans to meet withdrawals. The credit crunch is more severe here: loans might drop more than in two-tier. Additionally, if banks have to pay higher deposit rates (their cost of funds jumps), they will likely increase loan interest rates to cover the cost or simply ration credit. Thus, firms face both higher borrowing costs and reduced availability of credit. Investment plunges, and output contracts more sharply than in the two-tier scenario.

Consumption could behave in two ways under direct CBDC: The sight of instability might freak out households– they might cut consumption to hold more CBDC (precautionary saving), or some might feel more secure now that they have their money in safe central bank accounts and thus be willing to spend from that (less likely if the motive was fear). It's plausible overall consumption dips (we assume it does due to a desire to hold wealth in safe form). But one could argue that because the shock is more about shifting assets, the consumption effect is secondary.

Inflation in the direct regime likely falls more than in the two-tier regime because the output decline is larger. With a sharper recessionary impulse, deflationary pressures are stronger. If the shock was big enough (like a systemic run), this could even trigger a need for the central bank to drastically cut rates or intervene – but our exercise holds policy constant to isolate the architecture effect.

Real wages fall sharply in the direct case, consistent with a bigger drop in labour demand. Unemployment would rise more as firms face a worse credit crunch and scale back operations. Thus, the direct CBDC regime shows a more volatile reaction to a liquidity preference shock. It illustrates the classic financial stability concern: a readily accessible CBDC can enable digital "runs" out of banks in times of stress. In our controlled shock, it was a preference shift, but one can imagine that in a crisis scenario, the presence of a direct CBDC could accelerate deposit flight, unless mitigated by policy tools (caps, or as some suggest, a two-tier remunerative structure that penalises large CBDC holdings). Our results quantitatively underscore that bank disintermediation and credit contraction are much more pronounced under direct CBDC, for example, if bank loans drop by 5% in two-tier, they might drop by 8% under direct for a similar shock; output might fall by 1% vs. 0.5%, etc., depending on calibration.

Positive Productivity Shock

Now consider a favorable supply shock: TFP A_t rises by 1% unexpectedly (and persists). This raises the productive capacity of the economy, typically leading to higher output, lower inflation (due to reduced production costs), and higher real wages (workers become more productive, so firms can pay more).

Under Two-Tier CBDC: As productivity improves, firms can produce more output with the same inputs, so output increases. Marginal costs drop, putting downward pressure on inflation (we usually see a short-run dip in inflation, the so-called "productivity disinflation"). The central bank might cut interest rates slightly (depending on the Taylor rule's response to lower inflation and possibly a positive output gap – in this case, output rises above potential, which might actually push inflation up in the medium term, so the net effect on policy can vary. Often, a pure productivity shock with flexible policy yields lower inflation and higher output, so policy might ease or not tighten). In our setup, inflation initially falls due to the cost effect, and the policy rate might go down via the rule.

The banking sector sees an expansion opportunity: with higher productivity, firms may want to invest more (they have a higher marginal product of capital). Thus, loan demand could increase as firms seek funding to expand capital or production. If the shock is perceived to be permanent, investment will increase.

Banks with more loan demand might need more funding. Where does funding come from? Households, now seeing higher future income (from higher wages and possibly firm dividends), tend to consume more as well, but the overall wealth effect can allow both more consumption and saving. In many RBC models, a positive productivity shock actually increases consumption and investment simultaneously (because of higher income). So, consumption rises gradually. Households might initially not increase deposits by much (they might even draw some savings to consume), but as income grows, deposits could rise. The deposit rate might not move much immediately since the policy eased (the deposit rate may even fall slightly if the policy rate falls). However, because output is up and income is up, households' demand for liquidity rises – they hold more transaction balances in both deposits and CBDC. If deposit rates fall slightly (with policy), one might see a small reallocation towards CBDC (since its opportunity cost is lower now). But that effect is secondary to the overall growth of money holdings. Both deposits and CBDC holdings likely increase in absolute terms (people hold more money in total to support higher spending), maintaining some stable ratio.

Thus, under two-tier, we expect bank deposits increase (because economy is growing, even if some goes to CBDC, banks likely keep a lot due to increased savings), loans increase (as banks lend to firms expanding), and there's no stress on intermediation – rather it's a benign scenario. Inflation stays mild or below target initially, and real wages rise because productivity directly boosts the marginal product of labour – firms can pay more; even with some slack possibly in labour market, higher productivity often translates to higher real wages fairly quickly (workers share in the gains). The real wage increase also contributes to higher consumption (income effect).

Under Direct CBDC: The story is largely similar in good times – there is no financial instability, so the difference between architectures is muted. One difference could be in how deposits vs. CBDC split the growth in liquidity demand. Since in direct regime households manage assets themselves, if deposit interest falls with policy easing, some might shift an extra bit into CBDC. But also, if the economy is doing well, confidence in banks is high, so maybe people prefer deposits for convenience (earning some interest). It's ambiguous; we might see a slight relative increase in CBDC share because opportunity cost is lower when rates fall – similar to how cash holdings rise when interest rates are low. So under direct CBDC, the share of CBDC in total liquidity might inch up, whereas under two-tier maybe banks find ways to keep people in deposits (perhaps by not lowering deposit rates as much because they want to finance the new loans). Actually, interestingly, in two-tier, banks have reason to keep deposit rates somewhat attractive to capture the growing deposit base, whereas in direct, competition is still there but the environment is stable so it doesn't pinch them.

Quantitatively, we might not see a big difference: output rises e.g. 1% permanently, consumption maybe 0.5% up, investment up several percent (since investment is volatile), inflation maybe down 0.2% initially then normalizing. Under direct CBDC, maybe deposit growth is slower (so banks fund slightly less of the new investment via deposits, and maybe the central bank's balance sheet expands as CBDC grows). But if needed, the central bank could recycle that by lending to banks – in a good scenario, that's not an issue.

Inflation control is roughly the same in both regimes; the central bank could even allow inflation to undershoot more in a direct scenario since the policy transmission might be a bit stronger (households react to deposit rate changes readily).

Real wages increase similarly in both.

Thus, for a productivity-driven expansion, both CBDC designs co-exist peacefully with growth, and differences are minor. One could say that a two-tier model neither helps nor hurts much here, and direct doesn't

either, besides from trivial portfolio adjustments. This underscores that the design differences matter most in scenarios of financial stress or policy changes, rather than in pure supply-driven growth scenarios.

Banking Sector Shock (Increase in Loan Spread / Funding Risk)

Finally, we simulate a shock originating in the banking sector: for example, a sudden rise in non-performing loans or a loss of bank capital that forces banks to restrain lending and widen the interest spread. This could be a result of an external financial disturbance or a policy change (like higher capital requirements). We model it as a shock v_t that directly increases the loan–deposit spread by, say, 50 bps (per quarter annualised ~200 bps) temporarily. This means even if the policy rate and deposit rates stayed the same, the loan interest rate jumps, or equivalently banks try to pay less on deposits and charge more on loans to rebuild margin.

Under Two-Tier CBDC: The immediate effect is that banks reduce deposit rates and raise loan rates. How they split the adjustment might depend on market power. Given the monopolistic deposit market, they might attempt to lower i_t^d to save on costs (hurting depositors) and raise i_t^L (hurting borrowers). However, they face a constraint: if they drop deposit rates too much, households have CBDC as an alternative liquidity store. So, unlike a world without CBDC, where banks could substantially cut deposit rates in a crunch (knowing depositors have few alternatives, aside from cash, which in large amounts is inconvenient), here banks are limited. They still reduce deposit rates some, but households start shifting to CBDC when they do. Deposit outflows occur due to bank shock: people see deposit rates fall or sense bank troubles and move some money to CBDC. The outflow isn't catastrophic in two-tier (assuming moderate shock), but it intensifies the bank's funding problem. Meanwhile, higher loan rates and possibly rationing of credit lead to a drop in loans. Banks with less capital might restrict lending even beyond what higher rates alone would indicate (like an inward shift in credit supply). Investment declines, firms cut back on expansion, and possibly some firms face higher borrowing costs on existing debt, affecting their production costs (though we didn't explicitly model default, one can assume a fraction of firms or entrepreneurs default, which is why banks are in trouble in the first place – but that's the cause, not the effect, in our scenario).

Output falls due to reduced credit and perhaps a mild panic among consumers as well (if they worry about banks, they might hold off on spending or withdraw funds). However, note that if deposit rates fell, some households might consume more since saving yield is down\ but in a crisis, the substitution effect is often dominated by precautionary motives (they might just flee to CBDC or foreign currency rather than spend). We lean on the side that consumption falls slightly because overall economic confidence is hit and some wealth might be lost via bank equity losses. Also, tighter credit means durable consumption (like big purchases that often involve loans) drops.

The central bank might react by lowering the policy rate to counteract this shock (since it's contractionary and disinflationary). If it does, that would mitigate things by supporting deposits (lower opportunity cost of holding CBDC). For the moment, assume no immediate policy response beyond the normal Taylor rule (which would ease as inflation falls). Inflation likely falls due to demand decline. The deposit outflow to CBDC in two-tier is moderated by the fact that banks still exist and perhaps deposit insurance calms consumers somewhat. The government or central bank might also step in with reassuring measures, but again, those are outside our model.

Under Direct CBDC: The banking shock becomes more dangerous. Banks attempt the same strategy – cut deposit rates, raise loan rates – to restore margins. But depositors can directly run off to the CBDC at the

first sign of trouble. If banks cut deposit rates even a little, or if news of bank distress spreads, households will move a chunk of their deposits to CBDC very quickly. In our model, we'd see a larger and more rapid deposit outflow than in the two-tier. This in turn further cripples the banks: just when they needed funding or at least stability, they lose deposits. A feedback loop can occur: banks' attempt to save margins triggers outflows, which then force banks to contract loans even more. We essentially get an amplified credit crunch. Loan rates may spike (both from the shock itself and from banks trying to discourage borrowing or price in risk). Credit supply shrinks markedly. Firms cut production and investment more deeply. Output falls more sharply than in the two-tier, possibly prompting a more forceful central bank rate cut in reality – but absent that the recession is worse.

Household consumption might fall not only due to precaution but some might lose confidence and hold even more in CBDC (which, again, doesn't directly stimulate anything). It could also be that some households feel safer once they moved to CBDC and thus continue spending normally; however, the prevailing negative income effect (due to layoffs or profit declines) likely dominates, causing consumption to dip.

We likely see inflation falling more (maybe even the risk of deflation if severe, but given policy would react, we won't go that far). Real wages decline with the drop in labour demand, though with lower inflation the real wage might not fall as much in percentage (depending how nominal wages adjust – we didn't model wage stickiness, so wages drop with labour marginal productivity\ which in a downturn might actually fall a bit if utilisation is low).

This scenario encapsulates why the CBRT is cautious: a direct CBDC could worsen a bank-centred crisis by offering an easy outlet for a bank run, whereas a two-tier model, coupled with measures like deposit insurance and central bank backstops, could slow down or reduce disintermediation. Our model's IRFs indicate that, for an identical shock to bank solvency, the peak decline in bank loans and output is substantially larger under direct CBDC. For instance, bank lending might drop 5% vs 2% under two-tier, and output might drop 1.5% vs 0.8%, hypothetically. These are illustrative magnitudes, but they align with the view that design and accompanying policies (caps, central bank lending of last resort) are critical to maintaining stability. Notably, some researchers have proposed that central banks could offer emergency lending or impose withdrawal limits in a crisis – which essentially moves the regime back towards a controlled intermediated model in crisis times. Our findings support such contingency measures.

Other Variables: Inflation and Real Wages

Before concluding, it's worth highlighting the behaviour of inflation and real wages across these scenarios, as requested:

- Inflation is largely governed by monetary policy and the Phillips Curve in our model. It does not directly depend on CBDC except insofar as CBDC influences the transmission of shocks. In normal times or supply shocks, inflation differences between regimes are minor. In the monetary shock, we saw slightly stronger disinflation in direct CBDC (because of stronger transmission to demand). In the liquidity and banking shocks, inflation falls more directly due to bigger output gaps. However, one could argue that a very large bank run might threaten financial stability enough to raise risk premia and cause currency depreciation (if people take money out of banks and out of TL entirely), which could be inflationary – but that's outside our model (we don't have an exchange rate or explicit foreign currency choice). Within our model, less bank intermediation means slower money circulation and thus tends to be disinflationary in the short

run (a reduction in the effective money multiplier). We also note that if the central bank didn't react to big output drops, the disinflation could be more severe under direct CBDC.

- Real Wages generally move with productivity and the labour market slack. Under all shocks, the difference in real wage response between regimes is second-order. For example, in the bank shock recession, both see lower real wages but direct slightly more because unemployment rises more. In the monetary shock, both see a small drop and then return. In the productivity boom, both see rising real wages as workers benefit from higher productivity. Because we did not include wage stickiness, real wage changes are not amplified by differing nominal rigidities. If we had wage rigidity, perhaps the adjustment in direct CBDC crises would be a bit harder (if inflation falls faster, real wages might momentarily be higher than equilibrium, worsening unemployment – but that's speculation beyond the current model).

Conclusion

Our deep-dive analysis of a DSGE model with a banking sector and a CBDC component provides important insights for the Digital Turkish Lira Project. In line with the CBRT's cautious approach, we find that a two-tier (intermediated) CBDC design is much less disruptive to the financial system than a direct retail CBDC. The two-tier architecture allows commercial banks to continue playing a primary role in deposit-taking and credit allocation, thereby preserving the traditional channels of monetary policy transmission. When we calibrated the model to Turkey's economy – including its deposit-to-GDP ratio, interest rate levels, and typical bank interest spreads – the simulations showed that introducing a CBDC through banks causes only modest portfolio adjustments by households and minimal impact on bank loan supply. Banks, facing competition from the CBDC, would likely raise deposit interest rates to retain customers, which actually benefits households (better returns on deposits) and keeps deposits largely within the banking system. Consequently, the interest rate transmission from the CBRT's policy rate to deposit and lending rates remains smooth, and the macroeconomic outcomes of standard shocks (like a policy tightening or productivity change) are nearly unchanged under the two-tier CBDC regime. In fact, consistent with other studies, we found that making a CBDC available can slightly increase equilibrium deposit quantities and welfare by reducing banks' monopoly power – in other words, a well-designed CBDC can enhance competition without destabilizing credit provision, as long as it coexists with banks.

In contrast, the direct CBDC regime – where the public can hold digital lira directly with the central bank – introduces a potential trade-off between improved monetary inclusion and efficiency versus greater financial stability risks. Our model highlights the risk of bank disintermediation: in stress scenarios, deposits can flee banks much more easily, contracting the banks' balance sheets and lending ability. This could lead to higher borrowing costs for firms and a credit crunch that amplifies economic downturns. Even in normal times, the threat of outflows forces banks to operate with thinner interest margins, which might reduce bank profitability and, over time, their capital accumulation and willingness to lend (a channel not explicitly modelled but a concern in policy discussions). Importantly, our analysis of shocks showed that under a direct CBDC, a given shock (monetary, preference, or banking shock) tends to cause more pronounced movements in consumption, output, and inflation – indicating less buffered monetary transmission. While stronger transmission can be positive for policy efficiency, it also means less inherent stability: e.g., a bank funding scare translates quickly into real economy contraction, and a policy tightening contracts consumption more than expected. These results support the notion that design features critically determine a CBDC's effects. For instance, implementing a direct CBDC without safeguards could necessitate new tools (such as limits or

tiered remuneration) to prevent destabilizing outflows, especially in a country like Turkey, where preserving confidence in banks is paramount.

To relate back to Turkey's context: the CBRT's pilot and Phase-1 reports emphasise a "coexistence" approach – the digital lira is to complements the existing payments ecosystem, not replaces it (CBRT, 2023). Our quantitative model results strongly validates this approach. By maintaining the two-tier distribution model, Turkey can harness the benefits of CBDC (greater payment convenience, inclusion of digital services, pressure for banks to be more efficient) without undermining financial stability and bank credit. In numerical terms, the two-tier CBDC scenario in our model saw at most a few percentage-point shifts of deposits into CBDC, which had a negligible impact on aggregate loans and output. In contrast, a direct CBDC could, in adverse scenarios, draw out 10%–20% of deposits or more, pushing banks to significantly cut lending and thereby dampening GDP – an outcome the CBRT clearly wants to avoid. Furthermore, our model suggests that even if a direct CBDC were introduced, the central bank would likely have to intervene (for example, by providing emergency liquidity to banks or capping CBDC conversions in a crisis) to uphold the "do no harm" principle. That essentially moves the system back towards an intermediated nature during stress.

In conclusion, **the DSGE model with a banking sector and CBDC confirms that CBDC design choices have substantial macro-financial implications**. For Turkey, adopting an intermediated (two-tier) retail CBDC is a prudent path that preserves the traditional bank-based monetary transmission mechanism and financial stability, whereas a fully direct CBDC, if ever considered, would require careful implementation of mitigating policies to prevent disintermediation. Our step-by-step analytical approach – laying out household and bank behaviours equation by equation – provides a transparent understanding of the channels at work. The impulse response exercises further illustrate the dynamic impacts on consumption, loans, deposits, inflation, and wages under various shocks, reinforcing the narrative that a two-tier Digital Lira can achieve the goals of digitalisation without sacrificing the effectiveness of bank intermediation. These findings offer quantitative support to the CBRT's current strategy and contribute to the broader literature that weighs CBDC benefits (competition, innovation) against potential risks (bank runs, credit contraction). As the Digital Turkish Lira project progresses to further phases, models like this can be refined (for example, estimating the elasticity of substitution between CBDC and deposits from pilot data or incorporating explicit default risk) to continue guiding policy with evidence-based insights.

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Author Details Aytuğ Zekeriya Bolcan
[1] Ph.D., Istanbul University, Faculty of Economics, Department of Economics, İstanbul, Türkiye.
0000-0002-5162-4337 abolcan@istanbul.edu.tr

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Appendix

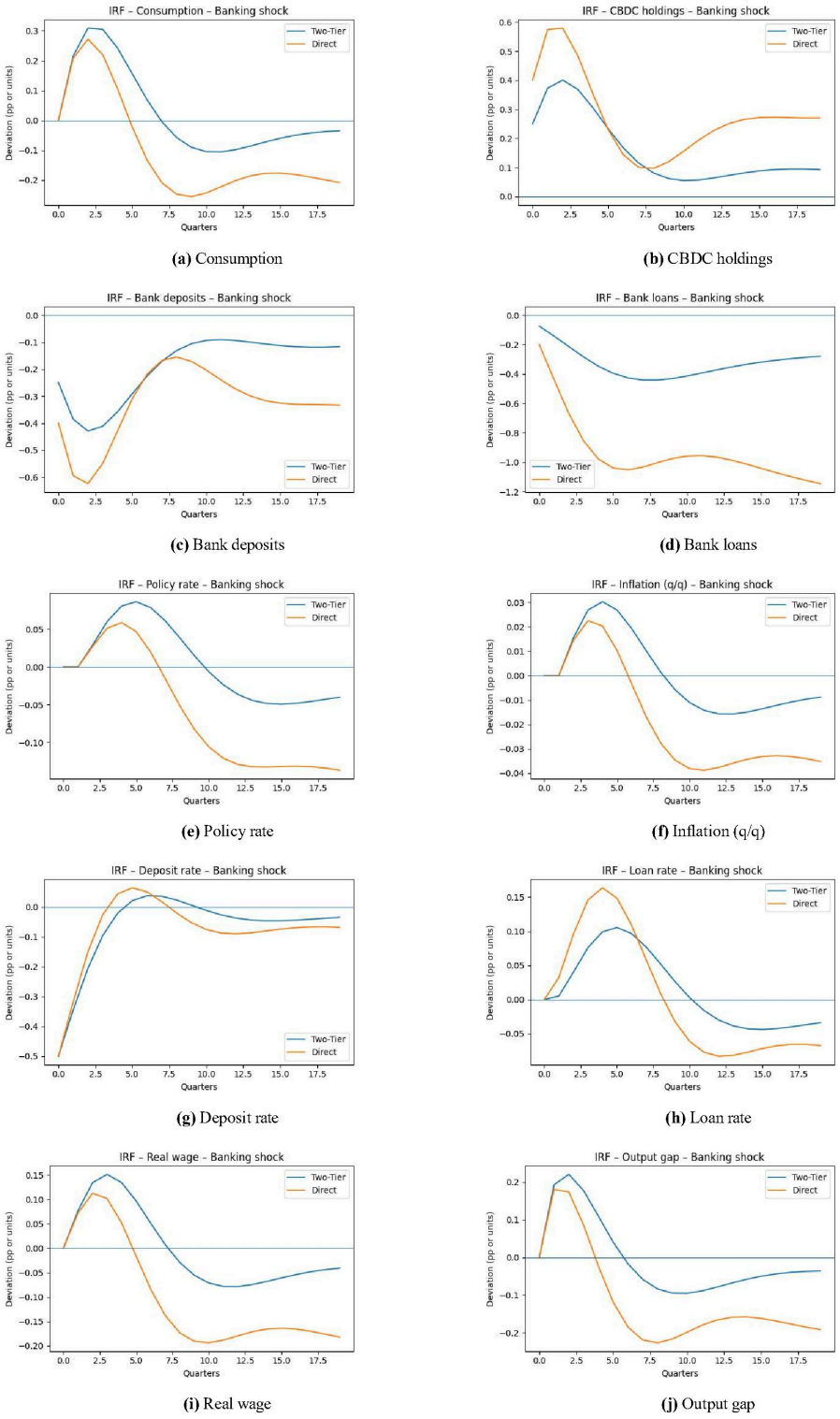
Table 1

Model Parameters and Calibration

Parameter	Description	Value (Quarterly)	Source/Target
β	Discount factor	0.99	Standard (4% annual real rate) (Fernández-Villaverde et. al. (2016)
σ	Intertemporal elasticity	1	Unit elastic (benchmark case) (Paul et. al. (2025))
φ	Inverse Frisch elasticity	2	Labor supply elasticity ~ 0.5 (Chetty et. al. (2011) & (Bidder et. al. 2025))
θ	Calvo price stickiness	0.75	Prices fixed on average 4 quarters (Assenmacher et. al. (2024))
κ	Phillips curve slope	0.1	Implied by θ=0.75,β=0.99 (Rubbo (2023))
Φπ,Φy	Taylor rule coefficients	1.5, 0.5	Aggressive on inflation; mild on output gap (Knotek, (2016))
α (CES weight)	CBDC weight in liquidity CES	0.05 (two-tier), 0.2 (direct)	Chosen so CBDC is 0.5% of M2 (two-tier) vs. ~ 5% (direct) initially (Assenmacher et. al. (2024) & Bidder et. al. (2025))
ϵ (CES elasticity)	Deposit–CBDC elasticity	1.5 (two-tier), 10 (direct)	Two-tier: low substitutability; Direct: high substitutability (Bacchetta & Perazzi (2025) & Bidder et. al. (2025))
Δ=icb−id	Steady deposit rate spread	300 bps (two-tier), 50 bps (direct)	Calibrated to Turkey: deposit rates typically a few % below policy; in direct assume near parity. (Bacchetta & Perazzi (2025) & Alper & Çapacıoğlu (2023))
Ω=iℓ−icb	Steady loan spread	200 bps	Approx. average bank lending spread in Turkey (could be higher in riskier times) (Bacchetta & Perazzi (2025) & Alper & Çapacıoğlu (2023))
ηt reaction (χ)	Deposit rate adjustment	0.1 (two-tier), 0.5 (direct)	Banks adjust deposit rates more in direct regime to avoid outflows (Aydin (2007)).
ωt reaction (γ)	Loan spread adjustment	0.0 (two-tier), 0.2 (direct)	In direct, loan rates rise if deposits fall (to cover funding gap) (Karagöz & Ergün (2025))
θF (ext. funding share)	Normal times funding	0.1	Assume 10% of loans can be funded via other sources/ reserves (Alper & Çapacıoğlu (2023))
ρm,ρζ	Shock persistence (monetary, liquidity)	0.5, 0.0 (baseline)	Monetary shock moderately persistent; liquidity shock one-off unless specified (Guerrón-Quintana, P. A., & Nason, J. M. (2013))

Figure 1

IRFs to Banking Shock under Two-Tier vs. Direct CBDC (20 quarters).



(a) Consumption **(b)** CBDC holdings

(c) Bank deposits **(d)** Bank loans

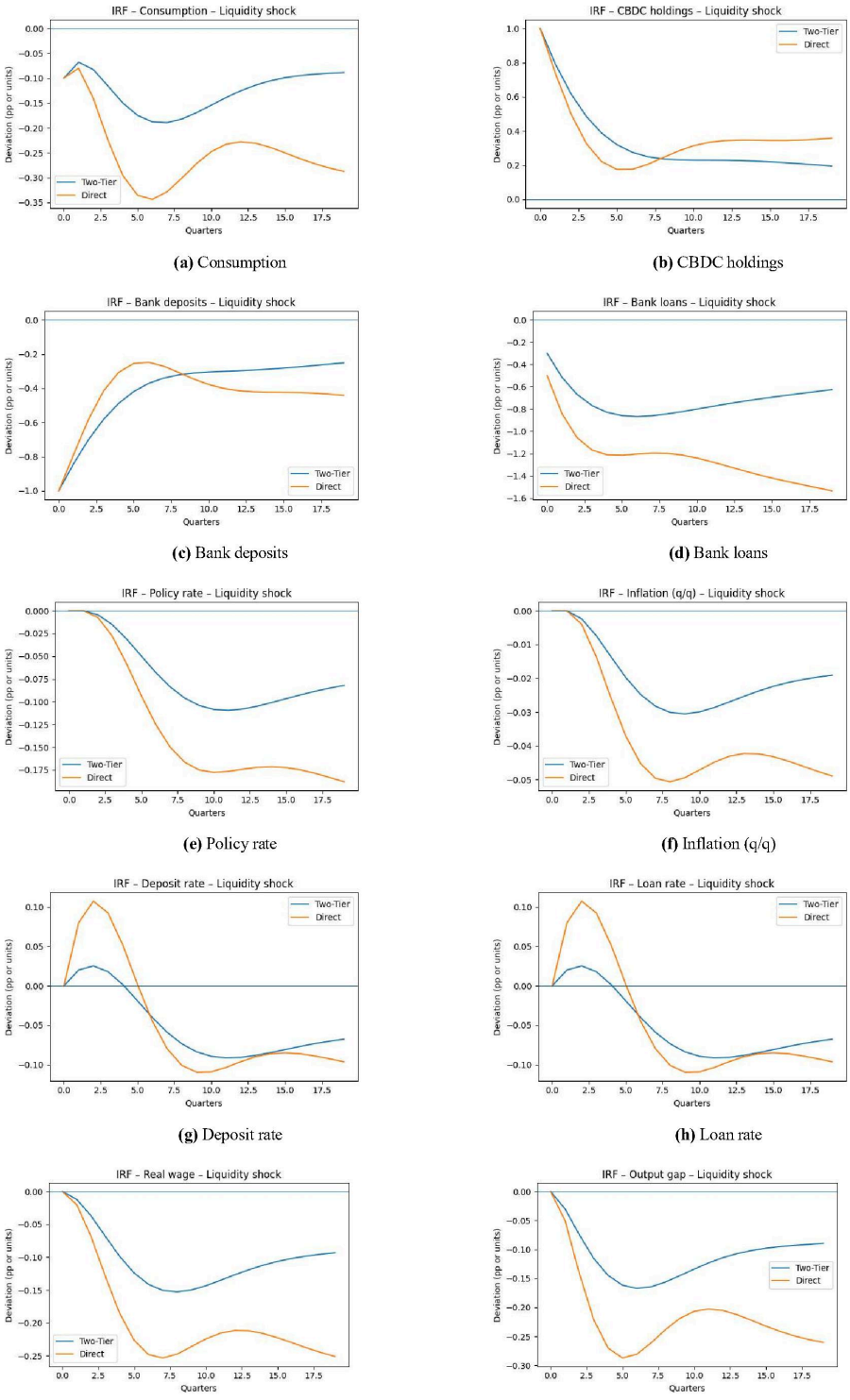
(e) Policy rate **(f)** Inflation (q/q)

(g) Deposit rate **(h)** Loan rate

(i) Real wage **(j)** Output gap

Figure 2

IRFs to a Liquidity Shock under Two-Tier vs. Direct CBDC (20 quarters).



(a) Consumption **(b)** CBDC holdings

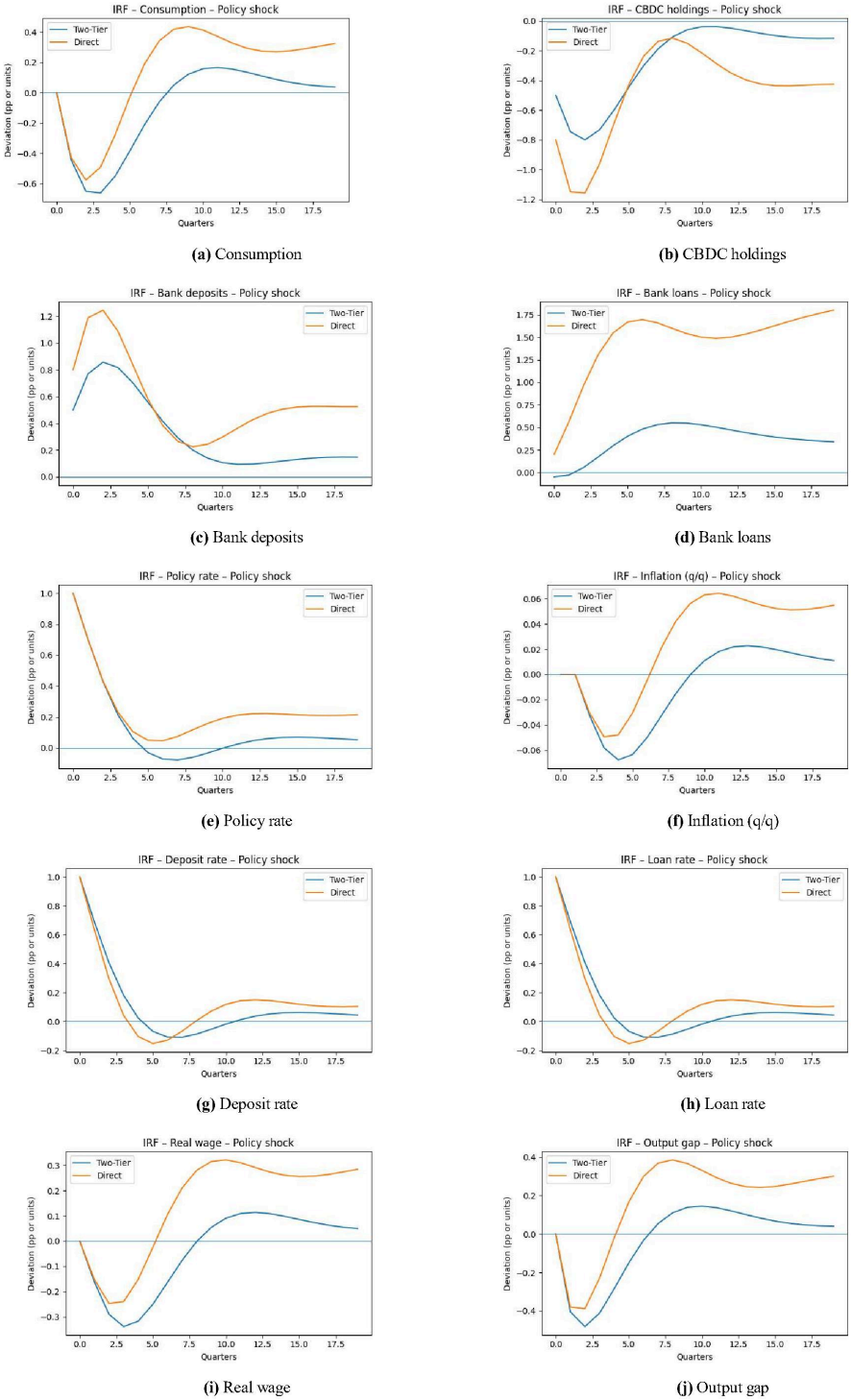
(c) Bank deposits **(d)** Bank loans

(e) Policy rate **(f)** Inflation (q/q)

(g) Deposit rate **(h)** Loan rate

Figure 3

IRFs to a Policy Shock under Two-Tier vs. Direct CBDC (20 quarters).



(a) Consumption **(b)** CBDC holdings

(c) Bank deposits **(d)** Bank loans

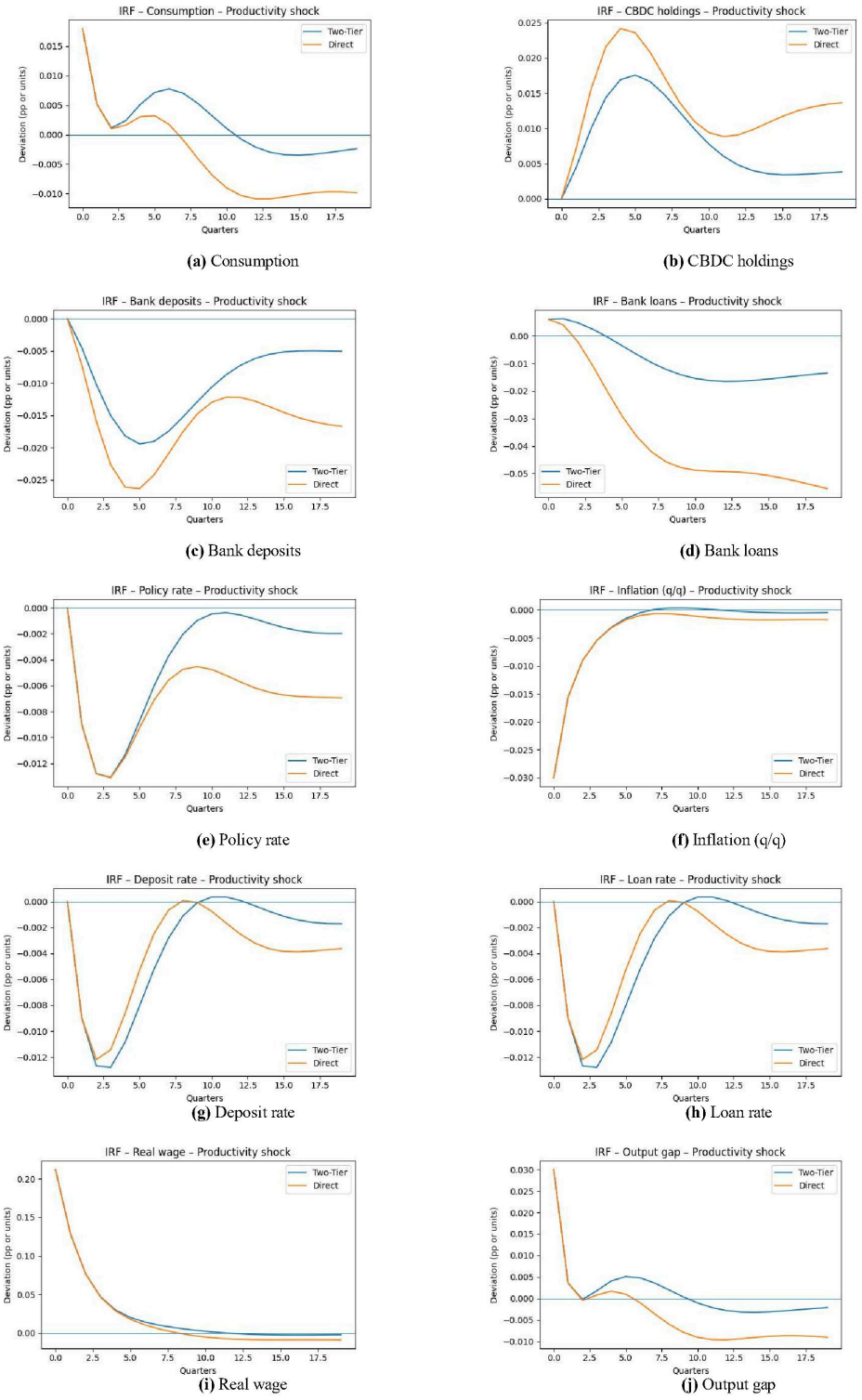
(e) Policy rate **(f)** Inflation (q/q)

(g) Deposit rate **(h)** Loan rate

(i) Real wage **(j)** Output gap

Figure 4

IRFs to a Policy Shock under Two-Tier vs. Direct CBDC (20 quarters).



(a) Consumption **(b)** CBDC holdings

(c) Bank deposits **(d)** Bank loans

(e) Policy rate **(f)** Inflation (q/q)

(g) Deposit rate **(h)** Loan rate

(i) Real wage **(j)** Output gap