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# Retail Central Bank Digital Currencies: Implications for Banking and Financial Stability*

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**Abstract**

This paper reviews the literature examining how the introduction of a retail CBDC would affect the banking sector and financial stability. A CBDC has the potential to improve welfare by reducing financial frictions, countering market power in deposit markets and enhancing the payment system. However, a CBDC also entails noteworthy risks, including the possibility of bank disintermediation and associated contraction in bank credit, as well as potential adverse effects on financial stability. The recycling of the new CBDC liability through asset purchases or lending by the central bank plays an important role in determining the economic consequences of the introduction of a CBDC. A CBDC also raises important questions regarding the footprint of central banks in the financial system. Ultimately, the effects of a CBDC depend critically on its design features, of which remuneration is the one discussed most often in the literature.

*Keywords:* Central bank digital currency, bank disintermediation, financial stability, central bank balance sheet, payment system

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# 1 Introduction

The past decade has seen an explosion of interest in digital assets in general and central bank digital currencies (CBDCs) in particular. Propelled, in part, by the spread of private-sector digital asset ventures that have arisen out of distributed ledger technologies, the academic literature on CBDC is expanding rapidly but, to a large extent, is still in its infancy.[1]

This paper reviews the implications of the introduction of a retail CBDC in an advanced economy, focusing on the banking sector and associated ramifications for financial stability.[2] Broadly defined, a retail CBDC is a digital, general-purpose, central bank liability that can be used by households and nonfinancial businesses as a means of payment, or store of wealth, or both.[3]

Concerns have been expressed that the introduction of a CBDC could result in a sizeable outflow of bank deposits into CBDC holdings. If so, such a *bank disintermediation*—a contraction in bank balance sheets—could result in an associated reduction in the availability of bank credit. However, existing studies encompass a wide range of results on the degree of potential bank disintermediation and even its plausibility. While researchers usually view CBDC as an imperfect substitute for bank deposits that will likely affect banks' balance sheets and funding structure, the different assumptions they employ regarding the behavior of banks, or the economic environment within which banks operate, lead to a variety of, sometimes polar-opposite, predictions.

To clarify the factors underlying the range of effects of a retail CBDC on bank balance sheets, we introduce a simple framework of CBDC issuance, illustrating the financial positions of households, the banking sector, the central bank and the government. A point that becomes immediately clear is that the central bank plays a crucial role in determining outcomes. In particular, how the central bank *recycles* the new CBDC liability—that is, its balance sheet policy regarding which assets, if any, are purchased to match the CBDC liability—is revealed as important—an underappreciated topic in the literature in our view. The central role that

[1] Kosse and Mattei (2022) reports that 90 percent of the 81 central banks surveyed by the Bank for International Settlements (BIS) in the fall of 2021 had projects under way studying the desirability and viability of CBDC.

[2] Our focus on retail CBDC, combined with space restrictions, implies that many aspects of CBDC are either not discussed in this paper, or not given the attention they would otherwise deserve. For example, the payments and technological aspects of a CBDC are discussed only insofar as they relate to our topic. And many aspects of design choices are omitted. For example, a CBDC could be token-based or account-based. A CBDC could be held directly by households and nonfinancial firms, or it could also be intermediated through banks or nonbank financial institutions such as fintechs. Other design features might relate to how CBDCs interface with technology and governance, with tradeoffs between accountability and transparency versus privacy and anonymity. Our exclusion of these aspects of CBDC design should not be taken as a denial of their importance.

[3] This asset is in contrast to a wholesale CBDC which is mainly used by financial intermediaries for settling interbank transactions, international transactions, and other related transactions with the central bank.

recycling could play raises fundamental questions about the proper role of central banks: Many of the contributions to the literature envision an expanded footprint of central banks in the financial system, in some cases extending their activities beyond liquidity provision.

A CBDC might catalyze changes in financial holdings that could, in theory, materially affect financial stability. We distinguish the range of effects in *normal times*, owing to changes in banks' funding structure, from their effects in *stress times*, through changes in the likelihood and severity of bank runs. Here too, the central bank's recycling of CBDC plays an important role.

We identify several avenues through which the introduction of a CBDC could improve welfare. First, CBDC could ameliorate some of the financial frictions in deposit or loan markets, likely from more competitive pricing of deposits, loans, or both. Second, a CBDC could serve as a catalyst for private-sector technological innovations in banking and payments. Third, partly through induced technological change, it could enhance the efficiency of the domestic retail payments system, making transactions faster, safer, and less expensive.[4]

The weighing of the costs and benefits of a CBDC depends critically on its design features. A retail CBDC is usually taken to be an universally accessible asset held by a wide class of economic agents; nevertheless, holding CBDC could be restricted to subgroups such as citizens or households and small businesses.[5] CBDC could be elastically and continually supplied to eligible parties, or it could be limited by caps, transfer size, or transfer frequency restrictions. Arguably the most important design feature of a CBDC, however, is remuneration—that is, whether and how CBDC holdings would pay interest. Irrespective of remuneration, in order to garner the network externalities that would make it successful, a CBDC would presumably have to be widely adopted and used as a means of payment.[6] But the more remunerative it is to hold CBDC, the more viable it becomes as a store of value for households and firms, all else equal.[7]

[4]Indeed, it is sometimes argued, depending on the circumstances, that the advent of private digital assets might oblige the creation of a publicly issued digital asset to support the stability of new payment platforms. Carapella and Flemming (2020) reviews the potential implications of CBDC for payments systems. A companion paper to this article, Infante et al. (2023), discusses the likely effects of the introduction of a CBDC for the implementation and transmission on monetary policy in an advanced macroeconomy.

[5]Another design feature of a CBDC is whether it is token-based, like currency, or account-based, like bank deposits. Conceptually, a token-based system requires verifying the validity of the object used to pay, while an account-based system relies on verifying the identity of the payer. Garratt, Yu, and Zhu (2022) provides a useful discussion of these differences. See also Duffie (2019).

[6]Network externalities, in this context, refers to the fact that the convenience (and value) of a payment technology rises with the number of parties who use the same technology. This implies elements of natural monopoly that limit the number of competing digital currencies that can coexist in equilibrium.

[7]As we discuss below, the distinction between remunerative and nonremunerative CBDC, and the distinction between money as a means of payment and a store of value, declines as market interest rates approach the effective lower bound on nominal interest rates.

The remainder of this article proceeds as follows. Section 2 examines the implications of CBDC for the banking sector, introducing the simple framework for CBDC issuance. In section 3, we examine the likely impact on financial stability. Some concluding remarks follow.

## 2 Implications for the banking sector

One of the most frequently raised concerns in the CBDC debate is the risk of bank disintermediation—that is, a CBDC (especially a remunerated CBDC) could compete for funding with banks, which could increase banks' funding costs and adversely affect bank lending. Indeed, banks play a crucial role in today's financial system, in part due to their ability to create liquidity through *maturity transformation*—i.e., by financing long-maturity assets with short-term liabilities.[8] The economies of scope—or synergies—that arise from combining lending and deposit-taking activities give banks a natural advantage in providing liquidity (Acharya and Mora, 2015), protecting firms and households against idiosyncratic and systemic liquidity shocks (Gatev and Strahan, 2006, Kashyap, Rajan, and Stein, 2002), and thereby promoting economic growth (Bencivenga and Smith, 1991, Berger and Sedunov, 2017).[9]

To illustrate how issuing a retail CBDC could affect banks and the broader financial system, we start with a picture of the financial system as a chain of assets and liabilities. A CBDC would be a new type of liability issued by the central bank and held by the private sector.[10] In a typical case of issuance, depicted in Figure 1, households may send $1 of bank deposits to the central bank and receive $1 of CBDC in exchange—that is, households instruct banks to send $1 of reserves to the central bank.[11] The size of the central bank's balance

[8] By accepting deposits, banks create *inside money*, providing a safe and stable store of value and a means of payment. By extending loans, banks provide funding to a diverse set of economic agents, using their expertise to screen, monitor, and support borrowers.

[9] Egan, Lewellen, and Sunderam (2022) shows empirically that "deposit productivity"—that is, the ability to attract deposits without bearing substantial overhead costs such as bank branches—explains about two-thirds of the value of the median bank. They also find evidence of significant synergies between deposits and lending, suggesting that to the extent that CBDC can lure deposits away from banks, there could be negative spillover effects. Piazzesi and Schneider (2022) presents a theoretical model within which the introduction of CBDC prevents the exhaustion of economies of scale in the joint provision of deposit taking and credit lines; by "cream skimming" the deposit market, CBDC induces a reduction of welfare.

[10] We treat CBDC as a liability of the central bank directly held by the private sector. This includes cases in which CBDC is only operationally intermediated by private service providers for physical operations and customer service, an arrangement that appears to be preferred by many central banks (Auer, Cornelli, and Frost, 2020). A closely-related alternative, synthetic CBDC—discussed by Adrian and Mancini-Griffoli (2021)—would be a liability of private intermediaries. However, it would be backed fully by central bank reserves and thus its economic implications could be essentially identical to those of CBDC that is a direct liability of a central bank.

[11] In this example and throughout the paper, we focus on CBDC that is designed to be a close substitute for deposits, rather than cash. Gust, Kim, and Ruprecht (2023) argues that a cash-like CBDC would have minimal effects on the banking sector. Agur, Ari, and Dell'Ariccia (2022) explores the optimal design of CBDC as a payment instrument with an intermediate degree of anonymity and security, located somewhere between

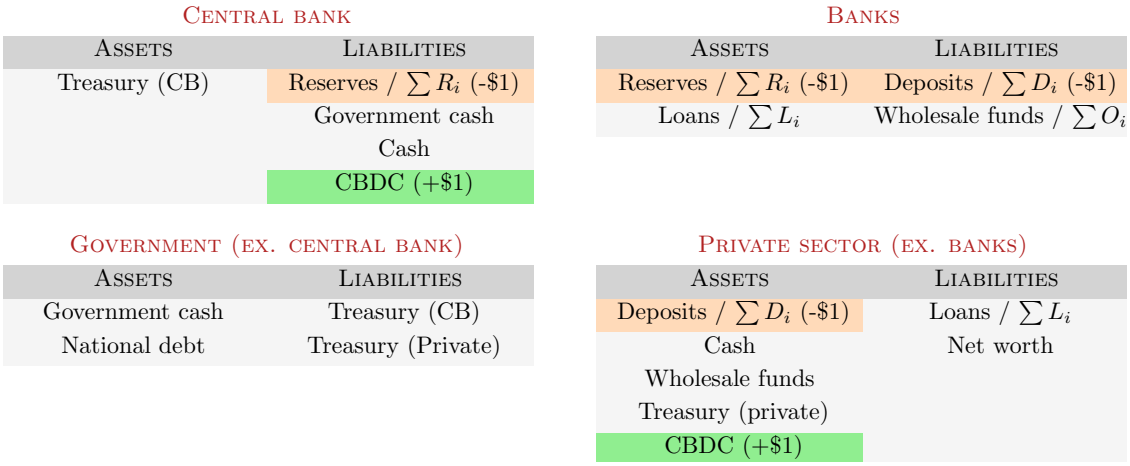


Figure 1: Impact of CBDC Issuance on Balance Sheets

Items colored in red decrease $1 in the example given, while items colored in green increase $1. Mathematical symbols for bank assets and liabilities—$\sum R_i, \sum L_i, \sum D_i$ and $\sum O_i$—are as in Equation 1, describing banks' balance sheet management. Each item on the balance sheet is an asset of a sector and a liability of a different sector, except for the private sector's net worth and national debt.

sheet remains fixed even as its liability composition changes, with a decrease of $1 in reserves, shown in red, offset by an increase of $1 in CBDC, shown in green. The banking sector's aggregate balance sheet shrinks, with a decline of $1 in reserves on the asset side matched by a $1 decrease in deposits on the liability side. In this simple example, which assumes no response by the central bank, banks are disintermediated—i.e., their balance sheet shrinks—but the supply of bank credit (loans) to the economy is unchanged because banks reduce only their reserve holdings.

The actual response of the financial system to the issuance of CBDC would likely not be as simple as shown in the figure—indeed, various agents in the economy would likely change their portfolios in response. More broadly, the demand for a CBDC is unclear and would depend on specific design choices, as would the corresponding effect on bank deposits and lending. While many types of CBDC could be benign in their implications, a new central bank liability could disrupt the current financial structure, much of which is built on the unique way in most jurisdictions in which banks have access to the central bank. The extent to which any such disintermediation would negatively affect lending depends on the viability

perfectly anonymous cash and perfectly secure deposits.

of alternative sources of funding for banks and on alternative sources of credit for households and firms. It would also depend, at least in part, on how CBDC are *recycled* through the economy—that is, on how the central bank responds to increases in CBDC on its balance sheet.[12]

Overall, while the growing theoretical literature on this subject is not yet conclusive, it suggests that the likely effects of CBDC on the banking sector depend on five main factors that are related to the banking sector's organization or design features of CBDC:[13]

1. *Competitiveness of the banking sector.* To the extent that banks have market power in the deposit market, the introduction of a CBDC that directly competes with bank deposits could lead to an increase in deposit rates but would not necessarily result in a contraction in the quantity of bank deposits and lending.

2. *Substitutability between bank deposits and CBDC.* The degree of substitutability between a CBDC and deposits or other liabilities depends on its attractiveness relative to other money-like assets, which in turn could influence how CBDC competes with traditional bank deposits.

3. *CBDC remuneration.* A CBDC can lead to bank disintermediation if its interest rate is high enough, but a non-interest-bearing CBDC, or a CBDC with a rate that is low, might have insignificant effects on bank intermediation. A rate paid on CBDC that lies in an intermediate range could even promote bank intermediation, depending on the competitive structure of the banking sector.

4. *Wholesale funding.* To the extent that banks can replace any lost retail deposits with wholesale funding, a CBDC would have a relatively small impact on lending. At present, such an offsetting effect is particularly relevant for larger banks.

[12] Adrian and Mancini-Griffoli (2021) uses the term "recycling" to represent an issuer of private digital money lending money back to banks through wholesale funding after receiving the digital money funded by liquidating bank deposits. We use the term more broadly to describe how the central bank may lend to various sectors in the economy, including the government (through purchases of Treasury securities), banks, households and businesses.

[13] Studying similar events from banking history may also provide guidance. Grodecka-Messi (2019) analyzes the response of the banking sector in Canada to the introduction in 1935 of the central bank note issuance monopoly by the Bank of Canada. Note issuance had been an important source of revenue for private banks, one that allowed them to smooth profits. Consequently, those banks that had been constrained by new issuance limits experienced higher volatility of equity returns in the short run and lower asset returns in the long run. The effect on lending was either insignificant or ambiguous. Put into perspective, these estimates likely represent a worst-case scenario of the effects on incumbent private banks of the introduction of a new form of central bank currency today because consumers already have access to several substitutes for central bank currency. Moreover, the 1935 law obliged a complete switch from commercial bank notes to central bank notes; any switch to a CBDC today would presumably be voluntary.

5. *CBDC account and transaction limits.* Restrictions on the quantity of CBDC that users can hold, transact, or earn interest on, or its transaction frequency, could limit bank disintermediation.[14]

In addition to these five factors, in section 2.4 we underscore the importance of the central bank's operating framework. How the central bank responds to CBDC inflows possibly by recycling funds to the rest of the economy is critical for understanding a CBDC's effects on the banking sector.

## 2.1 CBDC, deposits, and lending: a simple framework

Consider Figure 1 introduced before, which shows a bank (indexed by $i$), maximizing its profit, $\Pi_i$, by managing its balance sheet, consisting of two types of assets—loans ($L_i$) and reserves ($R_i$)—and two types of liabilities—deposits ($D_i$) and other liabilities ($O_i$) which include equity and wholesale funding. The bank's profit function is written as follows:

$$\Pi_i = r_{L,i}L_i + r_{IOR}R_i - R_{D,i}D_i - r_{O,i}O_i - c(L_i, R_i, D_i, O_i). \tag{1}$$

Specifically, the bank chooses the quantities subject to the balance sheet identity, $L_i + R_i = D_i + O_i$. The rates $r_{L,i}, r_{D,i}$, and $r_{O,i}$ denote interest paid on the assets and liabilities, which, to the extent the bank has some market power, it can influence.[15] The exception is the interest paid on reserves, $r_{IOR}$, which is set by the central bank. Market clearing imposes constraints on the relationship between quantities and interest rates; for example, $D_i$ may be an increasing function of $r_{D,i}$ to capture rate-dependent deposit demand of households. Finally, $c$ denotes the regulatory cost that the bank may face as a function of the size and composition of its balance sheet.

A reduction in deposit base due to outflows to CBDC is often thought as implying bank disintermediation, defined as a contraction in bank balance sheets, and it is assumed this portends a decrease in bank credit supply. The relationship arises from the balance sheet identity $L_i + R_i = D_i + O_i$: if a bank's deposit base ($D_i$) shrinks due to outflows to CBDC, then its loan ($L_i$) and balance sheet ($D_i + O_i$) will shrink unless other sources of funding can be found, or holdings of other assets (reserves in the equation or other liquid asset holdings in

[14] As we note later, such restrictions can be used to limit risks to financial stability, albeit at the cost of reducing the benefits that accrue from widespread usage of a CBDC.

[15] As suggested by our specifying that banks choose quantities and may influence interest rates, one might think of a (symmetric) Cournot-Nash equilibrium here, which is consistent with the depiction of the market structure of U.S. banks, as well as many other countries; see, VanHoose (2017) for a summary. However, at this level of abstraction, we need not dwell precisely here on the equilibrium concept. Gust, Kim, and Ruprecht (2023) derives an equilibrium using the same profit function in an environment with perfectly competitive banks.

practice) are reduced instead. The same argument applies to the banking system as a whole, as the balance sheet identity holds in the aggregate: $\sum L_i = \sum D_i + \sum O_i - \sum R_i$. In models where the stocks of reserves ($\sum R_i$) and non-deposit funding ($\sum O_i$) are nonexistent or do not meaningfully respond to the introduction of CBDC, contractions in bank balance sheets, deposit base and credit supply (by banks) are one and the same.

However, the same balance sheet identity shows that a decrease in deposit base need not lead to a contraction in the size of bank balance sheets or in credit supplied by banks. In the example noted above, there was no change to bank loans because both reserves and deposits declined by \$1. Credit supply $\sum L_i$ could also be held constant if other forms of bank funding, $\sum O_i$, offset reductions in deposits. Thus, the degree of contraction in credit supply or in banking sector balance sheet can be determined only if we know how to characterize households' portfolio decisions (including $\sum D_i$ and $\sum O_i$) and the central bank's balance sheet policy—which determines $\sum R_i$. And different assumptions about these factors underlie the wide range of possible outcomes regarding bank disintermediation and credit supply.

### 2.2 Banking-sector competition and CBDC remuneration

Andolfatto (2021) and Keister and Sanches (2022) consider polar cases of competition, focusing mostly on the market for deposits, and study the disruption caused by a CBDC. Andolfatto (2021) examines the case of a monopoly bank and shows that introducing an interest-bearing CBDC that competes in the market for deposits can lead to an *increase* in bank deposits and an *increase* in deposit rates. In the model, CBDC pays interest at a rate that is set independently from the policy rate. This allows the CBDC interest rate to act as a floor on deposit rates, forcing banks to offer more favorable terms to depositors.[16] As a result, introducing a CBDC reduces the monopoly distortion in the banking sector and expands the supply of deposits through both higher savings by existing depositors and the inclusion of unbanked individuals. Thus, contrary to conventional wisdom, a CBDC need not lead to a contraction in bank lending, depending on the competitive structure of the banking sector.

In contrast, Keister and Sanches (2022) examines the case of a perfectly competitive banking sector, embedded within a Lagos and Wright (2005) New Monetarist framework. In this setting, the effects of a CBDC depend on whether it facilitates transactions that would otherwise be realized with cash or with deposits, and bank disintermediation is unavoidable if the CBDC is highly competitive with bank deposits. A cash-like CBDC would have no direct impact on bank funding because it merely substitutes one form of money for another.

[16]The mechanism is much like that of a monopoly-fringe model where the introduction of a CBDC acts like a downward shift in the cost function of the fringe, shrinking the portion of the market that the monopolist can claim and improving outcomes for the ultimate consumers.

A deposit-like CBDC, on the other hand, would be a substitute for bank deposits, inducing banks to set higher deposit interest rates and accept lower levels of deposits and lending. Notwithstanding this crowding-out of bank intermediation, the introduction of a CBDC increases the aggregate stock of liquid assets, promoting more efficient exchange and ultimately improving social welfare.[17]

Andolfatto (2021) and Keister and Sanches (2022) reach starkly different conclusions on how the aggregate deposit base may change with the introduction of a CBDC, largely because of different assumptions regarding the competitiveness of the banking sector. We illustrate similarities and differences between these studies through the lens of the simple framework introduced with equation 1. In both studies, remuneration of CBDC is a critical design feature that affects disintermediation: an interest-bearing CBDC is a perfect substitute for savings deposits, and thus there is no demand for deposits if the deposit rate, $r_{D,i}$, is less than the interest rate on CBDC, $r_{CBDC}$. In Andolfatto (2021), the bank is a monopolist and faces deposit demand $D_i = f(r_{D,i})$ that is increasing in $r_{D,i}$ if $r_{D,i} \geq r_{CBDC}$ and $D_i = 0$ otherwise. If $r_{CBDC}$ is set at a level that is higher than $r_{D,i}$ that prevailed before the introduction of CBDC, then the monopolist bank optimally increases $r_{D,i}$ to $r_{CBDC}$, increasing $D_i$ as well. In Keister and Sanches (2022), the deposit market is competitive with a single rate $r_D$. As in Andolfatto (2021), perfect substitutability implies $r_D = r_{CBDC}$ if $r_{CBDC}$ is set higher than the equilibrium deposit rate without CBDC. However, with the higher funding cost implied by higher $r_D$, the banking sector maintains a smaller balance sheet and the equilibrium deposit base $\sum D_i$ shrinks even as the demand for savings $f(r_D)$ expands with the higher $r_D$; the increased demand for savings is met by deposits and CBDC together.

While the degree of competition in the banking sector is an empirical question, our reading of the available evidence suggests that competition in banking lies in between the two extreme cases. For example, Drechsler, Savov, and Schnabl (2017) shows that U.S. banks have market power in deposit markets, with an increase in the federal funds rate widening the spread between policy rates and deposits and reducing the quantity of deposits.[18]

Chiu et al. (2023) constructs a general equilibrium model that captures the complete spectrum of competition in the U.S. banking sector. Under the authors' calibration, an interest-

[17] Williamson (2022) also employs a model of competitive banking, similar to Keister and Sanches (2022), in which banks demand safe assets as collateral because they mitigate the incentive problem associated with asymmetric information. That paper shows that introducing a CBDC to compete with bank deposits can raise welfare by freeing up collateral—that is, by reducing the demand for safe assets that private banks require to back deposits.

[18] See VanHoose (2017) for a detailed survey. Banks raising deposits in concentrated markets have also been shown to pay lower rates and earn higher profits (Berger and Hannan, 1989, Hannan and Berger, 1991) as well as to have lower funding risk, thereby enabling them to extend longer-maturity loans (Li, Loutskina, and Strahan, 2021).

bearing CBDC could lead to higher deposit rates, more deposits and lending, and lower loan rates in the U.S. by ameliorating market-power distortions.[19] Nonetheless, improved intermediation arises only if remuneration on CBDC is in an intermediate range—in this case, as in Andolfatto (2021), a CBDC acts as a threat to capture bank deposits and incentivize banks to offer more favorable terms to their depositors. Too low a rate on CBDC does not affect the equilibrium—indeed, an unremunerated CBDC would not have a material effect on bank disintermediation irrespective of the level of competition in the banking sector. However, a rate that is too high results in disintermediation, because banks are forced to raise the lending rate to restore profitability, leading to a reduction in both deposits and lending.[20] Overall, for their favored calibration where the average three-month Treasury bill rate is 0.9 percent, the authors find that a CBDC could expand bank intermediation if its interest rate is between 0.3 and 1.5 percent and, at the maximum, could increase deposits and loans by 2 percent and the total output by 0.2 percent.

### 2.3 Alternative sources of funding and limits to deposit substitution

Andolfatto (2021), Keister and Sanches (2022), and Chiu et al. (2023) all examine the effects of CBDC using models in which bank lending is entirely funded by deposits and where reserves play a limited role. In such models, $\Delta \sum L_i \simeq \Delta \sum D_i - \Delta \sum R_i$, the change in deposits, $\Delta \sum D_i$, is similar to the change in bank loans, $\Delta \sum L_i$, and thus a contraction in bank deposits necessarily leads to a contraction in bank loans. However, banks—particularly the largest—can at least partially replace deposit shortfalls with wholesale funding, mitigating contraction in bank loans: $\Delta \sum L_i = \Delta \sum D_i - \Delta \sum R_i + \Delta \sum O_i$.[21]

Whited, Wu, and Xiao (2023) estimates an infinite-horizon dynamic model of the banking industry in which imperfectly competitive banks can fund themselves with either deposits or wholesale funding. Households have preferences for different instruments—such as cash, transaction deposits, and savings deposits—depending on the transactions they can facilitate, the interest rates they earn, and the levels of anonymity they provide. If the CBDC is regarded as embodying the same convenience as cash, a non-interest-bearing CBDC would capture 8 percent of the deposit market; a CBDC with remuneration set equal to the federal funds rate

[19] An interesting aspect of the set-up in Chiu et al. (2023) is that the provision of CBDC can affect economic outcomes even if the CBDC is not held in equilibrium because of its ability to shift the balance of power in lending. A broadly similar phenomenon occurs in Garratt, Yu, and Zhu (2022).

[20] As the interest rate paid on short-term, risk-free assets decline to their effective lower bound, the issue of CBDC remuneration diminishes in relevance and nonremunerative CBDC becomes viable as a store of value.

[21] Auer et al. (2022) notes the scarcity of papers exploring this issue and mentions equity funding and long-term bonds as alternative sources of financing. As we discuss in section 3, replacement of deposits and other forms of short-term funding by equity or long-term bonds may enhance financial stability. Replacement of deposits by less sticky wholesale funding may increase run risk.

would capture 32 percent.[22] Even so, less than a fourth of the impact on deposits would be passed through to lending because banks can replace a large fraction of lost deposits with wholesale funding.

The introduction of a CBDC could affect small and large banks differently. In this regard, Whited, Wu, and Xiao (2023) argues that large banks are better equipped than small banks to adapt to a financial system with CBDC because their superior access to wholesale funding makes them less reliant on retail deposits. Indeed, the authors estimate that the negative impact of CBDC on bank lending for small banks could be three times as large as that for large banks, even though the effects on deposits are similar. The associated deterioration in credit availability might be particularly severe for small nonfinancial firms, given that the empirical literature has established that small nonfinancial firms rely disproportionately on small banks for credit (Brainard, 2017). Auer et al. (2022) notes that such heterogeneous effects make it challenging to assess the efficiency gains from CBDC.

Finally, in their deliberations on CBDCs, many central banks have also been weighing the prospects of account restrictions to ameliorate any adverse effects of a CBDC on bank intermediation.[23] These restrictions include *stock-based limits*, such as ceilings on the quantity of CBDC that can be held in an account, and *flow-based limits* on the amount users can transact (European Central Bank, 2020, Bank for International Settlements, 2021). Using a model of a perfectly competitive banking sector, similar to Keister and Sanches (2022), Assenmacher et al. (2021) analyzes quantity restrictions on CBDC accounts to limit surges in demand that might undermine bank funding. The paper shows that while quantity constraints would reduce bank disintermediation, the gains would likely come at the expense of reduced welfare overall arising from increased matching frictions. Using a different framework, Bindseil (2020) examines an interest-bearing CBDC with tiered remuneration, meaning that interest payments per dollar decline as deposit balances increase. Overall, a downward-sloping remuneration rates schedule for CBDC would also temper any shift of large balances out of bank

[22] In related work, Li (2023) presents a model where households' preferences over cash, bank deposits, and CBDC are based on certain attributes of these payment instruments, such as anonymity and payment of interest rates. Estimating the model using survey data from Canada, the author estimated that in the case of unremunerated CBDC, the aggregate CBDC holdings out of households' liquid assets could range from 4 to 52 percent, depending on whether households perceive CBDC to be closer to cash or deposits.

[23] Various approaches have been used to project the potential demand for a CBDC using payments or balance sheet data and conditioning on alternative take-up scenarios. In this regard, Bank of England (2021) estimates that around 20 percent of household and non-financial corporate deposits would transfer to new forms of digital money. García et al. (2020) calculates a bank deposit outflow in Canada of 5 percent of bank assets—corresponding to 16 percent of bank deposits—assuming that all transaction deposits denominated in Canadian dollars would face competition from a CBDC. In the most stringent scenario where all transaction and savings deposits could move to a CBDC, the deposit outflow would be 10 percent of bank assets, corresponding to 33 percent of bank deposits. Finally, Adalid et al. (2022) concludes that deposit substitution would range between 0.5 to 18 percent of aggregate euro area bank liabilities.

deposits into CBDC.

### 2.4 Recycling of CBDC and its effect on bank balance sheets

Absent reactions by the central bank, an increase in CBDC holdings of bank depositors mechanically leads to a decrease in bank reserves. Reserves play a prominent role on banks' balance sheets and are the cornerstone of monetary policy implementation in many countries. Ultimately, the total supply of reserves is determined by the central bank and how its liabilities are split between those parties that have access. Central bank's offsetting of any reduction in reserve supply due to outflows to its new CBDC liability by purchasing assets or lending to the economy—that is, how much CBDC is recycled back into the economy—is a policy decision. And this recycling policy would affect the banking sector not just through its effect on reserve supply but also through the types of assets purchased for recycling.

In the simple case of bank disintermediation described at the beginning of section 2, both reserves and deposits decline by $1 with no impact on bank loans. But the central bank could choose to offset the decline in reserves by purchasing $1 of Treasury securities from investors. And if the investors elected to hold the proceeds as deposits, then the change in reserves and deposits would be zero on net and bank balance sheets would be unchanged.[24] Alternatively, if investors chose to lend some of the proceeds to banks in the form of wholesale funding, the resulting change in bank balance sheets would be similar to the prediction of Whited, Wu, and Xiao (2023).

In yet another scenario, the private sector could redeem $1 of bank loans, rather than holding the proceeds from the sale of Treasuries as deposits. In this case, banks would be disintermediated, with $1 reduction in both loans and deposits, similar to the outcomes described in Andolfatto (2021) and Keister and Sanches (2022); see Figure 2 for illustration. In response, the central bank might decide to lend to banks directly rather than to buy Treasuries to prevent bank disintermediation or, hypothetically, even lend to households and businesses directly.[25]

Interestingly, early papers on this topic, such as Brunnermeier and Niepelt (2019) and Fernández-Villaverde et al. (2021), did not leave much room for considerations of this sort.

[24] In practice, banks hold Treasury securities and the central bank may buy Treasuries from banks directly, replacing Treasuries with reserves among banks' assets. In that case, banks' net holdings of liquid or safe assets (reserves plus Treasuries) decline: reserves are unchanged and Treasuries decline by $1. This would have further consequences if banks attempted to return their liquid assets to their original level. In particular, if they were to buy Treasuries from households, financed by deposits, the net effect on the balance sheets of the different sectors would be the same as in the example described in the text.

[25] In the U.S., central bank lending could be implemented through, for example, the primary credit facility. The extent to which central banks can provide direct lending depends on each jurisdiction's operating framework as well as applicable law.

They show that, under certain conditions, society is indifferent between banks obtaining funding via private agents, such as depositors, or from the central bank; thus, there ends up being no allocative or macroeconomic consequences of CBDC, despite disintermediation. Ironically, some of the papers that have challenged this Modigiani-Miller-like result ended up defining the specific conditions under which the equivalence result could be restored—even in the presence of market imperfections. For example, in a model where banks face borrowing limits, Abad, Nuno, and Thomas (2023) shows that an expansion of the central bank's balance sheet in response to imperfect substitutability across the monetary instruments, can nevertheless be neutral for bank intermediation and for the economy as a whole.

In one of the most complete and ambitious studies on bank reserves, CBDC and its recycling, Niepelt (2023) constructs a DSGE model to compare a two-tiered payment system with reserves in an economy where banks have market power in deposit markets, versus a single-tiered CBDC-based system where the central bank engages directly with depositors, but those transactions are costly. Under the model's calibration, CBDC has the potential to overcome banks' market power and increase the efficiency of liquidity provision. However, in contrast to Brunnermeier and Niepelt (2019), which characterizes how the central bank can "sterilize" the surge in CBDC in a frictionless setting, in the distorted economy of Niepelt (2023), the benefits of having the central bank resolve the negative externalities stemming from liquidity provision have to be balanced against any political or agency costs associated with central bank recycling of funds via direct lending to the banking sector.

These examples and references show how the policy implementation framework that underlies the central bank's balance sheet management—that is, the microstructure through which monetary policy is carried out, day to day—is important for determining the effect of CBDC on banks. Any such implementation framework presumably reflects preferences for the supply of reserves to the banking system and the types of assets held on the central bank's balance sheet. Those preferences could be state-dependent and, to cite one example, could be quite different in periods of quantitative tightening as opposed to easing. Moreover, in some jurisdictions, central banks' normal operating frameworks allow purchases of government securities exclusively, and lending to the broader economy only via emergency facilities, which limits the scope of central bank recycling of funds back to the economy. We elaborate on these issues in our companion paper, Infante et al. (2023). It seems clear that the interactions of CBDC issuance with central bank operational policy is a fruitful area for future research.

Central bank

| Assets | Liabilities |
|---|---|
| Treasury (CB) (+$1) | Reserves / $\sum R_i$ |
| | Government cash |
| | Cash |
| | CBDC (+$1) |

Banks

| Assets | Liabilities |
|---|---|
| Reserves / $\sum R_i$ | Deposits / $\sum D_i$ (-$1) |
| Loans / $\sum L_i$ (-$1) | Wholesale funds / $\sum O_i$ |

Government (ex. central bank)

| Assets | Liabilities |
|---|---|
| Government cash | Treasury (CB) (+$1) |
| National debt | Treasury (Private) (-$1) |

Private sector (ex. banks)

| Assets | Liabilities |
|---|---|
| Deposits / $\sum D_i$ (-$1) | Loans / $\sum L_i$ (-$1) |
| Cash | Net worth |
| Wholesale funds | |
| Treasury (private) (-$1) | |
| CBDC (+$1) | |

Figure 2: Central Bank and Household Responses Leading to Bank Disintermediation

Items colored in red decrease $1 in the example given, while items colored in green increase $1. Mathematical symbols for bank assets and liabilities—$\sum R_i, \sum L_i, \sum D_i$ and $\sum O_i$—are as in Equation 1, describing banks' balance sheet management. Each item on the balance sheet is an asset of a sector and a liability of a different sector, except for the private sector's net worth and national debt.

# 3 Financial stability implications

As noted previously, the introduction of a CBDC could impinge on the banking sector's deposit base, which in turn could represent an increase in costs for banks. However, quite apart from mere costs, a CBDC could also adversely affect the stability of the banking sector by expanding direct access to central bank liabilities, by creating a public alternative to bank deposits, and by changing the business models of banks. More generally, competition for bank liabilities from CBDC could change the architecture of the financial system by either crowding out deposits and forcing banks to rely on alternative sources of funding, or crowding out banks' other sources of short-term private debt. The overall implications for financial stability depend on how banks replace the shortfall in liabilities, and their safety relative to those liabilities they replace.

The introduction of a CBDC may also increase run risks for the banking system in times of stress if the cost of shifting funds between bank liabilities and CBDC is low enough and if the CBDC is an attractive vehicle for the safe storage of funds. Moreover, the systemic risks are not limited to banks: A CBDC could be an attractive place to quickly move funds from nonbank financial intermediaries, such as money market funds (MMFs).[26]

Looking beyond the composition of financial firms' liabilities, a CBDC could also have a beneficial effect via new technologies designed to enhance payments systems, potentially augmenting their resilience. Specifically, by promoting interoperability between electronic payments systems, a CBDC could create incentives to reduce barriers between systems and enhance the stability of digital private payment networks, including the nascent stablecoin industry, effectively increasing the network externalities of these new payment systems.[27]

## 3.1 Financial stability in normal times: implications for banks' funding structure

In this subsection, we focus on how the introduction of CBDC can affect the resilience of bank funding structures, in "normal times," by which we mean when financial markets are not in stress. Specifically, consider a stylized bank with the profit function expressed in equation 1. The introduction of a CBDC could attract funds from banks' original claimants: from depositors, $D_i$, or even from other liabilities, $O_i$. The financial stability implications for banks in normal times depend on how banks adjust their funding structures after the introduction of CBDC, and in particular the riskiness of $D_i$ and $O_i$ relative to banks' new

[26]The possible effect of CBDC on the resilience of the banking system during normal and stressed times is described in policy papers such as Mancini-Griffoli et al. (2018) and Bank for International Settlements (2021).

[27]Chapman et al. (2023) includes a general discussion of what the business model of CBDC might be and its connection to stablecoins.

forms of funding, and their associated costs.

A financial stability concern arises in the bank disintermediation case when the contraction in bank deposits induced by the introduction of CBDC increases reliance on sources of funding that are more vulnerable to runs.[28] To the extent that banks lose a safe and "sticky" source of funding in form of deposits, they may seek less sticky and less safe wholesale funding, as discussed in section 2.[29] The 2008–09 financial crisis is a cautionary tale in this regard in that undue liquidity mismatch led to bank runs, a breakdown of wholesale markets, and distressed asset sales that threatened the solvency of individual banks and the viability of the financial system as a whole (Brunnermeier, 2009, Tirole, 2011).

An alternative view suggests that CBDC can increase the resilience of the financial system by reducing the convenience yield associated with holding safe assets, thereby limiting financial firms' incentive to issue short-term debt.[30] Specifically, recent literature has identified a potential role for short-term government debt, possibly including CBDC, to crowd out excessive private money, such as private MMFs, which are inherently risky (Stein, 2012, Greenwood, Hanson, and Stein, 2015, Krishnamurthy and Vissing-Jorgensen, 2015). In the same vein, the introduction of CBDC remunerated at a competitive rate might decrease the supply of short-term wholesale funding—$O_i$ in our notation—discouraging banks from relying on such short-term, run-susceptible debt. The role of the central bank's balance sheet to improve financial resilience is further discussed in Carlson et al. (2016) and Greenwood, Hanson, and Stein (2016). While these works are not uniquely concerned with CBDC, they are consistent with the notion that the introduction of a competitive, interest-bearing CBDC could be an important policy tool for enhancing financial stability, all else equal, by incentivizing banks and other financial intermediaries to rely on more stable funding sources. This prospect is not well captured by any of the banking-sector models discussed in section 2 and thus the subject deserves further attention. In any event, these insights suggest that the overall effect of a CBDC on financial stability during normal times, operating through the possible crowding-out of deposits and other money-like private liabilities, is ambiguous.

[28]The failure of Silicon Valley Bank and Signature Bank in the U.S. in March 2023 underscored the fact that not all bank deposits are safe. Even so, the observations of this subsection still hold if the funding used to replace the shortfall in deposits is riskier than the existing deposit base.

[29]In the U.S. case, the risk associated with reliance on wholesale funding would be mitigated, at least in principle, by the liquidity coverage ratio, net stable funding ratio, and high-quality liquid asset requirements that were enacted in 2014. Of note, these liquidity regulations only apply to the largest banks, and their calibration may not fully capture banks' vulnerability from systemwide increases in the share of wholesale funding. However, it is important to recognize that the introduction of a CBDC could change the runoff rate of some liabilities, and that would need to be captured by the regulation.

[30]While the safe asset convenience yield is often ascribed to U.S. Treasuries (Krishnamurthy and Vissing-Jorgensen, 2012, for example), a growing literature has documented that private short-term debt could also enjoy a safe asset convenience yield.

### 3.2 Financial stability in times of market stress

Quite apart from its effects on bank funding in normal times, the creation of a widely available CBDC could increase the risk of a systemwide run by providing a safe and liquid alternative for depositors to run in times of financial distress.

The mechanism is simple: the more attractive the alternative to bank deposits is in terms of liquidity and safety, and the more easily depositors can shift out of deposits and into the alternative asset, the more run-susceptible deposits become.[31] However, if the central bank recycled its CBDC liabilities back to the economy through banks or directly to borrowers, it might mitigate the increase in run risk or even decrease it, enhancing financial stability. Fernández-Villaverde et al. (2021) adopts a variant of the classic three-period bank run model of Diamond and Dybvig (1983), introducing a CBDC that allows consumers to store their endowments as deposits at the central bank. In this environment, CBDC directly competes with commercial banks *ex ante* to attract depositors in the first period, and a strategic depositor must decide whether to withdraw and consume their endowments in the second period. Instead of lending directly to the economy the central bank recycles funds indirectly to the broader economy through investment banks, which limits the amount of risk sharing the central bank can offer. Despite its technological disadvantage in terms of lending, the central bank can still compete with commercial banks for deposits because the central bank's investments are not callable and, thus, are protected from early liquidation; and because the central bank can renege on depositor withdrawals without defaulting. This means that central bank depositors do not have an incentive to run, while commercial banks are still susceptible to them because of their traditional fragility, resulting in the central bank assuming the role of the monopoly provider of deposits in the economy. Relatedly, in Kim and Kwon (2023), the central bank coexists with banks and can recycle CBDC liabilities to provide funding to banks, which increases overall credit supply and decreases run risk.

Schilling, Fernández-Villaverde, and Uhlig (2020) posit the *CBDC trilemma*, according to which a central bank that operates a CBDC can deliver, at most, two of three goals: financial stability, efficiency, or price stability.[32] As in Fernández-Villaverde et al. (2021), the authors

[31] Auer et al. (2022) notes that the potential increase in run risk due to CBDC may be exaggerated, because investors already have the option of purchasing government securities. While we agree that CBDC is not entirely unique in its implications for financial stability (see section 3.2.1 for a discussion of ON RRP), we note that by holding the proceeds of the sale in the form of CBDC the seller of government securities can avoid the banking system.

[32] See Schilling, Fernández-Villaverde, and Uhlig (2021) for a concise, accessible summary of the CBDC trilemma. We note that the concept of financial stability in Schilling, Fernández-Villaverde, and Uhlig (2020) refers to avoiding runs ("spending runs") *on the central bank*; that is, situations where the public has an incentive to spend nominal liabilities, including CBDC, quickly and in large amounts before inflation erodes the purchasing power of nominal liabilities. This differs from the definition considered in most of this section.

start with a Diamond and Dybvig (1983) bank-runs model, with two important differences: first, the central bank is the sole "deposit taker" that invests in long-term illiquid assets; second, all contracts are denominated in nominal terms.[33] These two features imply that the central bank can, in principle, internalize the impact of its sale of illiquid assets by choosing how much of them to sell to early consumers before the asset matures. This choice affects the quantity of goods that are available to consume in an intermediate period, which in turn affects the nominal price level: by selling more of the illiquid asset, there are more goods available to early consumers, which puts downward pressure on the price level—the price-stability part. The knowledge that the central bank can limit the quantity of sales, pushing up the price level, serves as a threat to would-be strategic withdrawers, eliminating the run equilibrium—the financial stability part. The central bank can also choose the optimal amount of *ex ante* risk sharing, in the sense of Diamond and Dybvig (1983)—the efficiency part. But in this model, the central bank cannot achieve these three goals simultaneously—hence, the trilemma. For example, by offering optimal consumption paths and consigning liquidity management to rule out the run equilibrium, the central bank surrenders price stability. It is important to keep in mind that, as in Fernández-Villaverde et al. (2021), the mechanism at work here relies on a central bank that has considerable market power in an illiquid market—that is, the central bank is the marginal lender in the economy.

In one way or another, Fernández-Villaverde et al. (2021), Schilling, Fernández-Villaverde, and Uhlig (2020), and many others assume that households and businesses can steer additional funds away from bank deposits into CBDC, leading to still more bank disintermediation. Moreover, the ability of depositors to switch from traditional banks to a CBDC in times of stress further underscores the idea that how the central bank recycles the incoming flow into CBDC plays an important role in determining whether CBDC is destabilizing. Building on the stylized representation of the balance sheets of different sectors in the economy introduced earlier, Figure 3 illustrates the problem a central bank faces from a surge in the demand for CBDC from depositors, which forces it to lend directly to private agents.

The figure shows that in order to maintain the size of the banking sector facing a $1 outflow of deposits to CBDC, the central bank could decide to lend directly to banks to alleviate funding strains. While not in the context of regular open market operations, this recycling is akin to what occurred during the banking stress following the closure of the Silicon Valley Bank in March 2023, where the take-up at the Fed's discount window replenished ailing banks' liquidity position.[34]

[33] The assumption of the central bank as a monopoly deposit taker is relaxed in an extension that incorporates a mass of private banks. The authors show that their results continue to hold if the central bank controls a sufficiently large share of the deposit market.

[34] Following the closure of the Silicon Valley Bank, the Federal Reserve increased reserves as its liability—

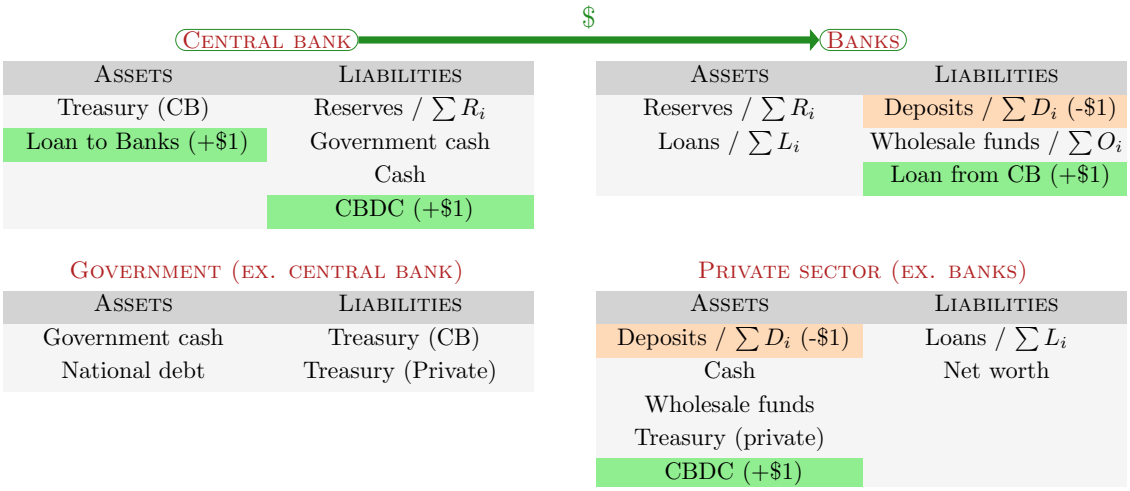


Figure 3: Central Bank Recycling Runs

See Figures 1 and 2 for a description of notation.

Fundamentally, the run risk problem in a bank-run model with CBDC is that deposits and CBDC are near-perfect substitutes. Accordingly, the proposed solutions to this problem tend to involve either reducing the substitutability of these assets for some or all financial agents or limiting the range over which substitution can occur. Thus, the instability caused by a systemwide run into CBDC can be mitigated with some of the design features of CBDC.[35] Some proposals for a cash-like CBDC involve creating an intentionally inferior means of payments; for example, Keister and Sanches (2022) speculates that a CBDC might be designed with low transfer limits, making it impractical for use in large-value payments, an example of the flow- or stock-based limits discussed in the previous section. Similarly, a CBDC with tiered remuneration would discourage a systemic run into CBDC by reducing the return on shifting large balances out of bank deposits and into CBDC while maintaining the attractiveness of CBDC for small account holders (Bindseil, 2020). A downward sloping remuneration curve on individual take-up tempers the problem of having to meet all demands for CBDC at a fixed (administered) rate and, as such, shares some of the dynamic price elasticity features

assets for the banking sector—and the private sector increased its holdings of deposits at banks that were viewed as healthy—liabilities for the banking sector.

[35] See Infante et al. (2023) for a discussion of the mechanics behind monetary policy implementation with CBDC.

of other market-based safe-haven assets such as U.S. Treasury bills.[36] In practice, however, the specific design of a declining interest payment schedule for CBDC to discourage runs could be difficult to calibrate and might have to evolve over time with market conditions and technology. That said, establishing individual or aggregate caps on the permitted holdings of CDBC could, on their own or in addition to tiered remuneration, provide a similar safeguard against run risk.

As an alternative to tiered remuneration, Kumhof and Noone (2021) proposes a set of principles that, if implemented as policies, would eliminate runs from deposits into CBDC. The more novel of these are that the central bank would not guarantee that banks have direct convertibility between CBDC and other central bank liabilities (such as reserves), and that banks would not guarantee that depositors will have direct convertibility between bank deposits into CBDC.[37] Together, these principles would introduce a friction that would render CBDC somewhat independent from reserves so that excess demand in one type of liability would not necessarily spill over to another. In their model, the absence of direct convertibility implies that differences in prices between central bank liabilities can emerge at times, with an arbitrageur operating to ensure prices do not get too far out of line. However, in practice, one cannot be assured that arbitrageurs will fulfill their role in times of financial stress. More broadly, it is difficult to imagine that the lack of direct convertibility between CBDC and reserves would be deemed an acceptable price to pay—or even incentive compatible—for most central banks in exchange for enhanced financial stability.

These considerations indicate that if central banks were to introduce a remunerated CBDC, consideration should be given to incorporating features that introduce price sensitivity to curb run risk such as tiered remuneration, individual or aggregate caps on usage, or limited convertibility.

### 3.2.1 Some lessons from the Federal Reserve's ON RRP facility

The financial stability concerns over CBDC are similar to those raised by the introduction of the Federal Reserve's Overnight Reverse Repurchase Facility (ON RRP) in the U.S. in 2013. The ON RRP facility provides nonbank financial institutions with direct access to the central bank in the form of Treasury-backed repos.[38] The financial stability risks of

[36] By "dynamic price elasticity features" we mean the tendency of spikes in demand for Treasury securities and other safe-haven assets to increase their prices, thereby curbing the quantity demanded in real time. By definition, this does not happen with administered rates.

[37] While not addressed in the model, it is important to note that these features may reduce the purported benefits of introducing a CBDC in the first place.

[38] The ON RRP allows eligible money market funds (MMFs) to deposit funds overnight with the Fed at an administered rate. The main purpose behind the ON RRP's introduction was not to create an alternative means of transactions, but rather to support interest rate control by the Fed.

an interest-bearing and intermediated retail CBDC would be much like the ON RRP by allowing nonbank counterparties to directly hold Fed liabilities in digital form. Frost et al. (2015) discusses the financial stability implications of the ON RRP facility and highlights two important design features that limit the scope of disintermediation and reduce the risk of runs to the facility during times of market stress. The first is that the ON RRP rate is set below the monetary policy rate, which limits its attractiveness relative to very safe funding instruments that offer interest near the policy rate. This is consistent with much of the CBDC literature which argues that low rates of remuneration reduce a CBDC's ability to crowd out financial firms' liabilities.[39] The second is that the ON RRP facility imposes caps on take-up at both the individual counterparty and aggregate level, which tempers the risks of a surge in times of market stress and thereby limits lenders' reliance on the facility as a stop gap. These insights are useful when considering specific design features aimed at attenuating the negative financial stability effects of CBDC on bank funding.

### 3.3 CBDC, payments, and financial stability

Outside of its impact on banks' or the central bank's balance sheet, CBDC can also affect financial stability through its effect on the payment system. CBDC is a means of payment directly controlled by the central bank, without relying on the soundness of the banking system. At the same time, it would likely alter private payment systems through competition. These characteristics can have various stabilizing influences on the financial system and may improve welfare.

For example, Williamson (2021) shows circumstances where the introduction of CBDC could increase the probability of a bank run—and yet still improve welfare. Working in a Lagos and Wright (2005) framework, Williamson emphasizes the payments aspect of central banking. In the baseline model without CBDC, a fraction of transactions is assumed to require the use of physical currency; the remaining share uses bank deposits that become worthless if the bank becomes insolvent, which introduces run risk. In this set-up, runs are more likely when interest rates are low because depositors' outside option is cash, which pays zero interest rate. An interest-bearing CBDC provides greater flexibility as a means of payment and, because of its remuneration, usurps the role of the outside option for depositors, compressing the spread between prevailing rates and that outside option, similar to the crowding-out effect described in section 3.1. Accordingly, the CBDC makes withdrawals from commercial

[39] While research has shown that take-up in the ON RRP can crowd out private repo (Anderson and Kandrac, 2017) and that the demand for safe assets can increase ON RRP take-up at the expense of private repo (Infante, 2020), the overall impact on the banking sector has not resulted in a significant contraction in bank deposits or bank lending to date.

banks more attractive, increases the propensity for withdrawals from bank deposits, and thus increases the likelihood of a bank run. But the same features of the CBDC that increase the likelihood of a run also mitigate the damage incurred, because they allow agents to carry out transactions even in the event a bank run materializes. This stylized model highlights the broader point that while CBDC may be destabilizing in a partial equilibrium sense, it also could furnish the means to reduce the economy's reliance on banks and the associated consequences of bank runs.[40]

In a somewhat different vein, Keister and Monnet (2022) argues that the introduction of a CBDC could enhance central bank monitoring of the financial system by enabling direct observation of unusual changes in financial flows in the broader economy, arguably extending their capacity for monitoring beyond what is typical for central banks. Specifically, in an environment without CBDC, regulators would be unable to observe bank deposit outflows into other liquid investments that stem from the suspected insolvency of a bank. In contrast, with a public, liquid investment opportunity such as CBDC, policymakers could observe inflows and outflows, giving them a real-time window on broader financial market conditions that would allow timely response. From this perspective, a CBDC may have been a useful source of real-time information during the banking stress of March 2023, where bank runs materialized at an accelerated pace (Rose, 2023).

### 3.3.1 CBDC and the soundness of emerging payment systems

The introduction of CBDC can also affect the soundness of prospective new payment systems. A successful launch would likely increase the interoperability between any new emergent digital payment systems and enhance the soundness of decentralized finance (DeFi) networks by establishing and promulgating universal standards for interoperability.[41] In other words, the introduction of CBDC could increase the network externalities of emerging private payment systems in general. Indeed, this is an oft-cited goal of CBDCs.

Duffie (2020) discusses the importance of interoperability between payment systems. Innovative electronic payment system providers may have incentives to fence off their services,

[40] Relatedly, Ahnert et al. (2022) observes that CBDC will diminish banks' essential role in the payment system and thus has the potential to reduce the inefficiencies associated with implicit support for the banking sector.

[41] Interoperability is the ability of systems to interact with one another quickly, seamlessly, and at a low cost. Interoperability can be broken into categories including *functional interoperability*, meaning the ability to share data, assets, contracts and applications; *vertical interoperability*, referring to end-to-end integration of, for example, point-of-sale devices with user wallets and payment rails; *horizontal interoperability*, meaning the interface between systems at the same level, such as a distributed ledger with a bank-based business network; *legal and regulatory interoperability*, often centering on difficulties in coordinating anti-money-laundering and know-your-customer responsibilities; and *technical interoperability*. See Central Bank Digital Currency Research Center (2021).

sacrificing payment efficiency, raising customer switching costs, and limiting interoperability between systems, in order to preserve monopoly rents. The creation of payment services supported by digital currencies issued by the central bank could mitigate these incentives. Specifically, if these new digital payment services make and receive payments in a common, safe, and public digital currency, interoperability is more easily achieved. This system is akin to the current reserve system where banks issue private money in the form of deposits while holding a fraction of their assets as public money—that is, reserves. Similarly, in the international and historical context, Gorton and Zhang (2021) emphasizes the importance of interoperability across different jurisdictions, drawing parallels with the National Banking Era in the U.S.[42] Prior to the National Banking Act of 1863, interstate trade was expensive and inefficient because of the use of private bank notes as a means of payment. The Act introduced a uniform currency, and the ensuing developments in banking increased efficiency in transferring funds. In brief, these innovations increased interoperability.

Relatedly, a CBDC also has the potential to support the development of stablecoins or discourage it by perhaps becoming the default stablecoin itself. As highlighted by the report on stablecoins published by President's Working Group on Financial Markets et al. (2021), stablecoins play an important role in DeFi networks by allowing participants to exchange their "tokens" for a more widely accepted asset. To the extent that unregulated stablecoins are themselves a source of risk to financial stability, the introduction of a CBDC can enhance overall stability by crowding out stablecoins, thereby allowing DeFi networks to rely on the soundness and stability of holding central bank liabilities directly or through a CBDC intermediary.[43] Alternatively, depending on the design, a CBDC could support the stablecoin industry by providing a safe and efficient reserve asset to store value and process payments across platforms, rather than crowd out stablecoins.

Along the same lines, Gorton and Zhang (2022) argues that governments should be wary of giving up their monopoly over issuing circulating money by allowing the coexistence of privately-issued digital monies such as stablecoins. For those authors, the fundamental characteristic of any currency is that it circulates at par with "no questions asked" (NQA). That is, incremental information should have no bearing on the value of money, a condition that private issuance cannot satisfy.[44] Drawing on the historical experience of Scotland, England,

[42] While the focus of Gorton and Zhang (2021) is on the international context, these same insights also apply to the promotion of interoperability across digital payments systems within a country.

[43] These issues became particularly salient following the disruptions in the stablecoin industry in May 2022. See Brainard (2022) for a discussion of how a CBDC might play a complementary role alongside stablecoins and DeFi in the U.S. financial system. See Catalini, de Gortari, and Shah (2022) for a discussion about the design of stablecoins, including the choice of assets to back their value.

[44] Gorton and Zhang has called the NQA property of an asset "informationally insensitive." The argument is that as soon as the value of an asset becomes sensitive to information (equivalently, no longer NQA), adverse

and the U.S., among others, Gorton and Zhang (2022) shows that privately-issued monies never satisfied the NQA property because their value depended on the perceived solvency of the issuer, which often triggered bank runs. The authors argue that the inherent instability of a private medium of exchange was a driving force for the emergence of the sovereign's money monopoly through the creation of central banks. They argue that the creation of a well-designed CBDC would discourage the adoption of stablecoins, which woudl improve the financial stability of the digital economy.

# 4 Conclusion

This paper has reviewed the potential implications of the introduction of a Central Bank Digital Currency to an advanced economy, according to the academic literature on the subject, concentrating on the effects on the banking sector and the associated issue of the stability of the financial sector. We considered the benefits that proponents of a CBDC argue could be realized, including reduction of financial frictions in deposit or loan markets, enhanced efficiency of payments, and the elicitation of private-sector technological innovations in banking and payments including decentralized finance and stablecoins. We also outlined the risks that the literature has identified, most notably the possibility of disintermediation of the banking sector and, by extension in some renderings, the reduction in the availability of credit.

We traced some of the mechanisms through which a CBDC might work, including via changes in the structure of banking and by way of modifications in the incentives to bear or respond to risks. The short answer is a familiar one: it depends. It depends on the structure of the banking sector, because a CBDC has the prospect of inducing more competitive behavior in bank lending and especially deposit-taking. If designed and implemented well, a CBDC could improve terms for depositors probably without large-scale disintermediation of credit overall. It depends on central bank operating procedures, because to the extent a CBDC does result in disintermediation among banks, whether and how the central bank might respond to accumulations of CBDC on its balance sheet with open market operations or asset purchases becomes an important factor. It depends on alternative sources of funding for banks, and for the economy more generally, because such sources can mitigate the effects of disintermediation and reduce banks' reliance on short-term funding, on the one hand, and increase the likelihood of bank runs, on the other. It depends on how households and nonfinancial businesses respond to the initiation of a new medium of exchange and store of value, because widespread adoption

selection could sow uncertainty and thus hinder transactions. Questions regarding the solvency of an issuer could then arise, which would promote defection from the good Nash equilibrium—that is, a run. The authors characterize the meltdown of algorithmic stablecoins in 2022 as an example of the breakdown of the NQA property.

is necessary to capture the gains from the network externalities that a CBDC can provide, but too much popularity can promote instability. It depends on how large and how active a role the central bank is prepared to play in the financial sector. And it depends on how a CBDC might catalyze, or hinder, the development of complementary technologies such as those championed by the fintech sector. Each of these possibilities is cloaked in uncertainty. As might be expected of a young, rapidly expanding literature, definitive answers to important questions are scarce. And while CBDC pilot projects are now legion, to date the data required to evaluate models are in short supply.

We noted the critical role of CBDC design features in determining the outcomes that might be expected. A CBDC could be token-based or account-based; it could be held directly by households and firms or intermediated through banks or nonbank financial institutions such as fintechs; holding CBDC could be open to everyone or restricted to subgroups such as U.S. nationals, or households and small businesses; and CBDC could be elastically and continually supplied to eligible parties, or limited by caps, or by transfer size or transfer frequency restrictions. In most instances, these design features are proposed either to reduce the substitutability of CBDC with bank deposits and other liquid assets, or to restrict the speed or volume of substitution given high substitutability. This fact highlights a tradeoff in CBDC implementation, reducing the extent of potential benefits of a CBDC in exchange for reduced disruption to the business models of banks, a smaller presence of the central bank in the financial sector, or reduced risks to financial stability.

Remuneration is arguably the key design feature that any central bank would want to contemplate. A CBDC that pays no interest is consigned to the role of a medium of exchange; its value would be determined almost entirely by the convenience it would render. Or at least that would be the case when market interest rates are above the effective lower bound on nominal interest rates; different considerations come into play when a panoply of interest rates are clustered around zero. A remunerated CBDC, on the other hand, would be more attractive as a store of value. Our reading of the literature suggests that a remunerated, intermediated, widely available CBDC has the prospect of accruing network externalities for the public—as opposed to allowing banks and fintechs appropriate rents—as well as limiting disruptions to the financial system stemming from the shifting fortunes of various competing private monies. If a CBDC were contemplated, adding some combination of ceilings on CBDC holdings, limits on the amount users can transact, or tiered remuneration might be helpful to combat any financial instability issues. All that said, the plethora of models in the literature and the myriad of conclusions that fall out of those models argue for humility.

## References


Jorge Abad, Galo Nuno, and Carlos Thomas. CBDC and the operational framework of monetary policy. Working paper, 2023. URL https://www.galonuno.com/uploads/1/3/4/6/134687692/cbdc_mon_pol_ant_sep_2023.pdf.

Viral V. Acharya and Nada Mora. A crisis of banks as liquidity providers. *Journal of Finance*, 70(1):1–43, 2015. URL https://onlinelibrary.wiley.com/doi/10.1111/jofi.12182.

Ramón Adalid, Álvaro Álvarez-Blázquez, Katrin Assenmacher, Lorenzo Burlon, Maria Dimou, Carolina López-Quiles, Natalia Martín-Fuentes, Barbara Meller, Manuel A. Muñoz, Petya Radulova, Costanza Rodriguez d'Acri, Tamarah Shakir, Gabriela Šilová, Oscar Soons, and Alexia Ventula Veghazy. Central bank digital currency and bank intermediation. Technical Report 2022/293, European Central Bank, 2022. URL https://dx.doi.org/10.2139/ssrn.4108346.

Tobias Adrian and Tommaso Mancini-Griffoli. The rise of digital money. *Annual Review of Financial Economics*, 13:57–77, 2021. URL https://www.annualreviews.org/doi/abs/10.1146/annurev-financial-101620-063859.

Itai Agur, Anil Ari, and Giovanni Dell'Ariccia. Designing central bank digital currencies. *Journal of Monetary Economics*, 125:62–79, 2022. URL https://www.sciencedirect.com/science/article/pii/S0304393221000520.

Toni Ahnert, Katrin Assenmacher, Peter Hoffmann, Agnese Leonello, Cyril Monnet, and Davide Porcellacchia. The economics of central bank digital currency. Working Paper 2713, ECB Working Paper, 2022. URL https://www.ecb.europa.eu/pub/pdf/scpwps/ecb.wp2713~91ddff9e7c.en.pdf.

Alyssa G. Anderson and John Kandrac. Monetary policy implementation and financial vulnerability: Evidence from the overnight repurchase facility. *Review of Financial Studies*, 31(9):3643–3686, 2017. URL https://academic.oup.com/rfs/article/31/9/3643/4756472.

David Andolfatto. Assessing the impact of central bank digital currency on private banks. *Economic Journal*, 131(634):525–540, 2021. URL https://academic.oup.com/ej/article/131/634/525/5900973.

Katrin Assenmacher, Aleksander Berentsen, Claus Brand, and Nora Lamersdorf. A unified framework for CBDC design: Remuneration, collateral haircuts and quantity constraints. Working Paper 2578, European Central Bank, 2021. URL https://www.ecb.europa.eu/pub/pdf/scpwps/ecb.wp2578~bd5e2c4fdf.en.pdf.

Raphael Auer, Giulio Cornelli, and Jon Frost. Rise of the central bank digital currencies: Drivers, approaches and technologies. Working Paper 8655, Center for Economic Studies & Ifo Institute, 2020. URL https://www.cesifo.org/en/publications/2020/working-paper/rise-central-bank-digital-currencies-drivers-approaches-and.

Raphael Auer, Jon Frost, Leonardo Gambacorta, Cyril Monnet, Tara Rice, and Hyun Song Shin. Central bank digital currencies: Motives, economic implications, and the research frontier. *Annual Review of Economics*, 14:697–721, 2022. URL https:/doi.org/10.1146/annurev-economics-051420-020324.

Bank for International Settlements. Central bank digital currencies: Financial stability implications. Report, Bank for International Settlements, 2021. URL https://www.bis.org/publ/othp42_fin_stab.pdf.

Bank of England. New forms of digital money. Discussion paper, Bank of England, June 2021. URL https://www.bankofengland.co.uk/paper/2021/new-forms-of-digital-money.

Valerie R. Bencivenga and Bruce D. Smith. Financial intermediation and endogenous growth. *Review of Economic Studies*, 58(2):195–209, 1991. URL https://academic.oup.com/restud/article-abstract/58/2/195/1563335?redirectedFrom=fulltext.

Allen N. Berger and Timothy H. Hannan. The price-concentration relationship in banking. *Review of Economics and Statistics*, 71(2):291–299, 1989. URL https://www.jstor.org/stable/1926975?origin=crossref#metadata_info_tab_contents.

Allen N. Berger and John Sedunov. Bank liquidity creation and real economic output. *Journal of Banking & Finance*, 81:1–19, Aug. 2017. URL https://www.sciencedirect.com/science/article/pii/S0378426617300833?via.

Ulrich Bindseil. Tiered CBDC and the financial system. Working Paper 2351, European Central Bank, Jan. 2020. URL https://www.ecb.europa.eu/pub/pdf/scpwps/ecb.wp2351~c8c18bbd60.en.pdf.

Lael Brainard. Why opportunity and inclusion matter to america's economic strength, 5 2017. URL https://www.federalreserve.gov/newsevents/speech/brainard20170522a.htm. Speech delivered to the Opportunity and Inclusive Growth Institute Conference, Federal Reserve Bank of Minneapolis.

Lael Brainard. Preparing for the financial system of the future, 2 2022. URL https://www.federalreserve.gov/newsevents/speech/brainard20220218a.htm. Speech delivered to the US. Monetary Policy Forum, New York, NY.

Markus K. Brunnermeier. Deciphering the liquidity and credit crunch 2007-2008. *Journal of Economic Perspectives*, 23(1):77–100, 2009. URL https://www.aeaweb.org/articles?id=10.1257/jep.23.1.77.

Markus K. Brunnermeier and Dirk Niepelt. On the equivalence of private and public money. *Journal of Monetary Economics*, 106:27–41, Oct. 2019. URL https://www.sciencedirect.com/science/article/pii/S0304393219301229?via.

Francesca Carapella and Jean Flemming. Central bank digital currency: A literature review. FEDS Notes 2020-11-09, Board of Governors of the Federal Reserve System, 2020. URL https://www.federalreserve.gov/econres/notes/feds-notes/central-bank-digital-currency-a-literature-review-20201109.html.

Mark Carlson, Burcu Duygan-Bump, Fabio Natalucci, Bill Nelson, Marcelo Ochoa, Jeremy Stein, and Skander Van den Heuvel. The demand for short-term safe assets and financial stability: Some evidence and implications for central bank policies. *International Journal of Central Banking*, 12(4):307–333, 2016. URL https://www.ijcb.org/journal/ijcb16q4a8.htm.

Christian Catalini, Alonso de Gortari, and Nihar Shah. Some simple economics of stablecoins. *Annual Review of Financial Economics*, 14:117–135, 2022. URL https://www.annualreviews.org/doi/pdf/10.1146/annurev-financial-111621-101151.

Central Bank Digital Currency Research Center. CBDC taxonomy and design choices. Report, Central Bank Digital Currency Research Center, Mar. 2021. URL https://cbdcbrasil.com/wp-content/uploads/2021/06/CBDC_Taxonomy_Design_Choices_Research_2021_R3.pdf.

James Chapman, Jonathan Chiu, Mohammad Davoodalhosseini, Janet Jiang, Francisco Rivadeneyra, and Yu Zhu. Central bank digital currencies and banking: literature review and new questions. Discussion Paper 2023-4, Bank of Canada, February 2023. URL https://www.bankofcanada.ca/wp-content/uploads/2023/02/sdp2023-4.pdf.

Jonathan Chiu, Sayed Mohammad Davoodalhosseini, Janet Hua Jiang, and Yu Zhu. Bank market power and central bank digital currency: Theory and quantitative assessment. *Journal of Political Economy*, 131:1213–1248, 2023. URL https://www.journals.uchicago.edu/doi/full/10.1086/722517.

Douglas W. Diamond and Philip H. Dybvig. Bank runs, deposit insurance and liquidity. *Journal of Political Economy*, 91(3):401–419, 1983. URL https://www.jstor.org/stable/1837095#metadata_info_tab_contents.

Itamar Drechsler, Alexi Savov, and Philipp Schnabl. The deposits channel of monetary policy. *Quarterly Journal of Economics*, 132(4):1819–1876, 2017. URL https://academic.oup.com/qje/article/132/4/1819/3857743.

Darrell Duffie. Digital currencies and fast payment systems: Disruption is coming. Unpublished manuscript prepared for presentation to the Asian Monetary Policy Forum, May 2019. URL https://www.darrellduffie.com/uploads/policy/duffiedigitalpaymentsmay2019.pdf.

Darrell Duffie. Interoperable payment systems and the role of central bank digital currencies. Working Paper 3867, Stanford Graduate School of Business, May 2020. URL https://www.darrellduffie.com/uploads/policy/DuffiePaymentInteropMay2020.pdf.

Mark Egan, Stefan Lewellen, and Arvind Sunderam. The cross-section of bank value. *Review of Financial Studies*, 35(5):2101–2143, 2022. URL https://academic.oup.com/rfs/article/35/5/2101/6345359.

European Central Bank. Report on a digital euro. Report, European Central Bank, 2020. URL https://www.ecb.europa.eu/pub/pdf/other/Report_on_a_digital_euro.

Jesús Fernández-Villaverde, Daniel Sanches, Linda Schilling, and Harald Uhlig. Central bank digital currency: Central banking for all? *Review of Economic Dynamics*, 41:225–242, July 2021. URL https://www.sciencedirect.com/science/article/pii/S1094202520301150?via.

Josh Frost, Lorie Logan, Antoine Martin, Patrick McCabe, Fabio Natalucci, and Julie Remache. Overnight RRP Operations as a monetary policy tool: Some design considerations. Finance and economics discussion series (FEDS), Federal Reserve Board of Governors, 2015. URL http://dx.doi.org/10.17016/FEDS.2015.010.

Alejandro García, Bena Lands, Xuezhi Liu, and Joshua Slive. The potential effect of a central bank digital currency on deposit funding in Canada. Staff Analytical Note 2020-15, Bank of Canada, 2020. URL https://doi.org/10.34989/san-2020-15.

Rodney Garratt, Jiaheng Yu, and Haoxiang Zhu. How central bank digital currency design choices impact monetary policy pass-through and market composition. Unpublished manuscript, Jan. 2022. URL https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4004341.

Evan Gatev and Philip E. Strahan. Banks' advantage in hedging liquidity risk: Theory and evidence from the commercial paper market. *Journal of Finance*, 61(2):867–892, 2006. URL https://onlinelibrary.wiley.com/doi/10.1111/j.1540-6261.2006.00857.x.

Gary Gorton and Jeffery Zhang. Protecting the sovereign's money monopoly. Research Paper 22-031, University of Michigan Law Econ, 2022. URL https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4162884.

Gary Gorton and Jeffrey Zhang. The Orkney Slew and central bank digital currencies. Unpublished manuscript, 2021. URL https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3937323.

Robin Greenwood, Samuel G. Hanson, and Jeremy C. Stein. A comparative-advantage approach to government debt maturity. *Journal of Finance*, 70(4):1683–1722, 2015. URL https://onlinelibrary.wiley.com/doi/10.1111/jofi.12253.

Robin Greenwood, Samuel G. Hanson, and Jeremy C. Stein. The Federal Reserve's balance sheet as a financial-stability tool. *Jackson Hole Economic Symposium Conference Proceedings*, pages 335–397, 2016. URL https://www.hbs.edu/faculty/Pages/item.aspx?num=52330.

Anna Grodecka-Messi. Private bank money vs central bank money: A historical lesson for CBDC introduction. Working Paper 2019:21, Lund University, 2019. URL https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3992359.

Christopher Gust, Kyungmin Kim, and Romina Ruprecht. The effects of CBDC on the federal reserve's balance sheet. Working paper, 2023.

Timothy H. Hannan and Allen N Berger. The rigidity of prices: Evidence from the banking industry. *American Economic Review*, 81(4):938–945, 1991. URL https://www.jstor.org/stable/2006653#metadata_info_tab_contents.

Sebastian Infante. Private money creation with safe assets and term premia. *Journal of Financial Economics*, 136(3):828–856, 2020. URL https://www.sciencedirect.com/science/article/pii/S0304405X19302867.

Sebastian Infante, Kyungmin Kim, Anna Orlik, André F. Silva, and Robert Tetlow. The macroeconomic implications of CBDC: a review of the literature. Finance and economics discussion series (FEDS), Federal Reserve Board of Governors, November 2022. URL https://doi.org/10.17016/FEDS.2022.076.

Sebastian Infante, Kyungmin Kim, Anna Orlik, André F. Silva, and Robert Tetlow. Implications of CBDC for the implementation and transmission of monetary policy. unpublished manuscript, in progress, July 2023.

Anil K. Kashyap, Raghuram Rajan, and Jeremy C. Stein. Banks as liquidity providers: An explanation for the coexistence of lending and deposit-taking. *Journal of Finance*, 57(1): 33–73, 2002. URL https://onlinelibrary.wiley.com/doi/10.1111/1540-6261.00415.

Todd Keister and Cyril Monnet. Central bank digital currency: Stability and information. *Journal of Economic Dynamics and Control*, 142:1–20, Sept. 2022. URL https://www.sciencedirect.com/science/article/pii/S0165188922002056?via.

Todd Keister and Daniel R. Sanches. Should central banks issue digital currency? *Review of Economic Studies*, 2022. URL https://www.restud.com/paper/should-central-banks-issue-digital-currency/. forthcoming.

Young Sik Kim and Ohik Kwon. Central bank digital currency, credit supply, and financial stability. *Journal of Money, Credit and Banking*, 55(1):297–321, 2023. URL https://onlinelibrary.wiley.com/doi/full/10.1111/jmcb.12913.

Anneke Kosse and Ilaria Mattei. Gaining momentum–results of the 2021 BIS survey on central bank digital currencies. Discussion Paper 125, Bank for International Settlements, May 2022. URL https://www.bis.org/publ/bppdf/bispap125.pdf.

Arvind Krishnamurthy and Annette Vissing-Jorgensen. The aggregate demand for treasury debt. *Journal of Political Economy*, 120(2):233–267, 2012. URL https://www.journals.uchicago.edu/doi/epdf/10.1086/666526.

Arvind Krishnamurthy and Annette Vissing-Jorgensen. The impact of treasury supply on financial sector lending and stability. *Journal of Financial Economics*, 118 (3):571–600, 2015. URL https://www.sciencedirect.com/science/article/pii/S0304405X15001518?via.

Michael Kumhof and Clare Noone. Central bank digital currencies—design principles for financial stability. *Economic Analysis and Policy*, 71:553–572, Sept. 2021. URL https://www.sciencedirect.com/science/article/pii/S0313592621000898?via.

Richard Lagos and Randall Wright. A unified framework for monetary theory and policy analysis. *Journal of Political Economy*, 113(3):463–484, 2005. URL https://www.journals.uchicago.edu/doi/10.1086/429804.

Jiaqi Li. Predicting the demand for central bank digital currency: A structural analysis with survey data. *Journal of Monetary Economics*, 134:73–85, 2023. URL https://www.sciencedirect.com/science/article/pii/S0304393222001398.

Lei Li, Elena Loutskina, and Philip E. Strahan. Deposit market power, funding stability and long-term credit. Working Paper 26163, National Bureau of Economic Research, 2021. URL https://www.nber.org/papers/w26163.

Tommaso Mancini-Griffoli, Maria Soledad Martinez Peria, Itai Agur, Anil Ari, John Kiff, Adina Popescu, and Celine Rochon. Casting light on central bank digital currency. Staff Discussion Notes 2018/008, International Monetary Fund, 2018. URL https://www.imf.org/en/Publications/Staff-Discussion-Notes/Issues/2018/11/13/Casting-Light-on-Central-Bank-Digital-Currencies-46233.

Dirk Niepelt. Money and banking with reserves and CBDC. *Journal of Finance*, 2023. URL https://www.niepelt.ch/files/cepr18444.pdf. forthcoming.

Monika Piazzesi and Martin Schneider. "Credit lines, bank deposits or CBDC?: Competition and efficiency in modern payment systems.". Unpublished manuscript, 2022. URL https://web.stanford.edu/~piazzesi/CBDC.pdf.

President's Working Group on Financial Markets, the Federal Deposit Insurance Corporation, and the Office of the Comptroller of Currency. Report on stable coins. Technical report, President's Working Group on Financial Markets, 2021. URL https://home.treasury.gov/system/files/136/StableCoinReport_Nov1_508.pdf.

Jonathan Rose. Understanding the speed and size of bank runs in historical comparison. Economic synopses, Federal Reserve Bank of Saint Louis, 2023. URL https://files.stlouisfed.org/files/htdocs/publications/economic-synopses/2023/05/26/understanding-the-speed-and-size-of-bank-runs-in-historical-comparison.pdf.

Linda Schilling, Jesús Fernández-Villaverde, and Harald Uhlig. Central bank digital currency: When price and bank stability collide. Working Paper 28237, National Bureau of Economic Research, 2020. URL https://www.nber.org/papers/w28237.

Linda Schilling, Jesús Fernández-Villaverde, and Harald Uhlig. Facing the central bank currency digital trilemma. In D. Niepelt, editor, *Central bank digital currency: Considerations and projects, outlook*, pages 45–50. CEPR Press, London, 2021. URL https://www.sas.upenn.edu/.

Jeremy C. Stein. Monetary policy as financial stability regulation. *Quarterly Journal of Economics*, 127(1):57–95, 2012. URL https://scholar.harvard.edu/stein/publications/monetary-policy-financial-stability-regulation.

Jean Tirole. Illiquidity and all its friends. *Journal of Economic Literature*, 49(2):287–325, 2011. URL https://www.jstor.org/stable/23071618#metadata_info_tab_contents.

David VanHoose. *The industrial organization of banking: bank behavior market structure and regulation.* Springer, Berlin, 2 edition, 2017. URL https://doi.org/10.1007/978-3-662-54326-9.

Toni M. Whited, Yufeng Wu, and Kairong Xiao. Will central bank digital currency disintermediate banks? Unpublished manuscript, Jun. 2023. URL https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4112644.

Stephen D. Williamson. Central bank digital currency and flight to safety. *Journal of Economic Dynamics and Control*, 142, Sept. 2021. URL https://www.sciencedirect.com/science/article/pii/S0165188921000816?via.

Stephen D. Williamson. Central bank digital currency: Welfare and policy implications. *Journal of Political Economy*, 139:2829–2861, November 2022. URL https://www.journals.uchicago.edu/doi/10.1086/720457.