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The Macroeconomic Implications of CBDC: A Review of the Literature

Sebastian Infante, Kyungmin Kim, Anna Orlik, André F. Silva, and Robert J. Tetlow*

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This paper provides an overview of the literature examining how the introduction of a CBDC would affect the banking sector, financial stability, and the implementation and transmission of monetary policy in a developed economy such as the United States. A CBDC has the potential to improve welfare by reducing financial frictions in deposit markets, by boosting financial inclusion, and by improving the transmission of monetary policy. However, a CBDC also entails considerable risks, including the possibility of bank disintermediation and associated contraction in bank credit, as well as potential adverse effects on financial stability. A CBDC also raise important questions regarding monetary policy implementation and the footprint of central banks in the financial system. Ultimately, the effects of a CBDC depend critically on its design features, particularly remuneration.

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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 evaluates the range of macroeconomic implications of the introduction of a CBDC in a modern economy like the United States, as gleaned from the academic literature. Our intention is for this paper to serve as a resource for senior staff or central bankers, providing them with the latest thinking to address questions regarding the general advisability of CBDC, and how the design features of any prospective CBDC affect their efficacy as digital assets in the 21st century macroeconomy. To this end, we begin by laying out a conceptual framework for what follows, starting with a high-level description of the present situation in the absence of a CBDC. This provides a foundation for assessing how the design features of CBDC would affect economic functioning in general. As noted, our analysis is macroeconomic in nature. Even so, the macroeconomy as it pertains to CBDC cannot be divorced from critical aspects of the banking sector, to which we devote much attention. This, in turn, means we address implications for financial stability and for the implementation and transmission of monetary policy. But we only touch on the payments system because it and other topics such as bank regulation and supervision are not a focus of our review.[2] Our analysis is also on what the literature contributes to our understanding of the economics of CBDC, unconstrained by political or legal features or by restrictions.[3]

In general, we view the initial equilibrium as one of a large open economy with financial frictions that inhibit savers—those with wealth but without marketable projects or opportunities

[1] Kosse and Mattei (2022) report 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. Help in this area has come from outside collaborators such as MIT's Digital Currency Initiative.

[2] See Carapella and Flemming (2020) for information on the potential implications of CBDC for payments systems. Waller (2021) and Andolfatto (2021b) argue that ongoing developments in payments systems in the public sector (such as FedNow) and the private sector (such as the Automated Clearing House network) weaken the case based on payments system grounds for the adoption of a CBDC in the United States.

[3] Among other things, this means we do not adopt the restrictions embedded in the Federal Reserve Board's white paper (Federal Reserve Board, 2022), which, among other things, would rule out a non-intermediated CBDC.

for investment—from contracting directly with entrepreneurs—those with projects but insufficient wealth of their own to bring those projects to market. Similarly, households face a life-cycle pattern of income that mostly rises over time, along with an objective to smooth consumption, which spurs borrowing early in life and saving later on. Finally, households and most firms have needs for conducting transactions safely and efficiently. Taken together, these conditions imply a role for money as a medium of exchange, as a store of value, and as a unit of account. They also furnish a business case for the American financial structure that includes banks (and nonbank financial institutions) as well as capital markets. Banks play a crucial role in creating liquidity through maturity transformation, accepting short-term deposits and lending in the long term in the form of risky illiquid loans to businesses and households.[4] Credit markets are beset with asymmetric information and incomplete markets, which in turn means that as a part of the extension of loans, banks also screen and monitor risks. These risks have implications for financial stability. It is the expertise of banks in assessing the riskiness of borrowers in the presence of asymmetric information, along with their role in facilitating maturity transformation, that is perhaps the key distinction between the roles of banking and capital markets in the financial system.

The set of pre-existing monies is important for what we outline below. The economy we consider already has currency, both token (that is, cash) and account-based (reserves). The banking sector relies on retail and wholesale deposits; however, remunerated reserves at the central bank are held exclusively by the banking sector.[5] Except where otherwise noted, we assume that the banking sector is imperfectly competitive and that economic rents accrue in the

[4] This description of what banks do is, by necessity, a simplification. Banks obtain funding from risky wholesale funding markets, as well as riskless retail deposits that are protected by government insurance, and under certain conditions, borrow from central banks. They also invest in more than just household and commercial loans. That said, none of these details is important for the points we make in this paper except insofar as the availability of funding obtained from central banks may differ depending on whether conditions in financial markets are normal or stressed.

[5] To be precise, in the U.S. case there are entities other than banks that hold reserves, such as federal agencies, although these entities do not receive remuneration on their reserve balances.

supply of banking services.[6] In most instances, we will take for granted that the central bank implements monetary policy using a floor system with ample reserves.[7]

Into this world a CBDC is introduced. Our reading of the literature has identified 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. Part of this improvement would likely come from more competitive pricing of deposits, loans, or both. Second, it could enhance the efficiency of retail payments systems, making transactions faster, safer, and less expensive. Third, a CBDC could facilitate international transactions and improve financial inclusion among the unbanked. Fourth, in the face of the declining use of cash, a CBDC could help ensure the existence of a widely accepted means of payment that, if it were directly issued and administered by the central bank, need not depend on private intermediaries (Nicolaisen, 2017; Engert and Fung, 2017). Fifth, a CBDC could serve as a catalyst for private-sector technological innovations in banking and payments. Indeed, it is sometimes argued that, depending on the circumstances, the advent of private digital assets might oblige the creation of a publicly issued digital asset to support the stability of new payment platforms. And sixth and finally, it has at least the potential to improve the transmission of monetary policy.

But CBDCs also carry risks. The risks that the literature has outlined differ depending on design features, but an oft-cited concern is the possibility of bank disintermediation. Disintermediation, and the associated ease with which a CBDC could facilitate rapid changes in financial holdings, could affect the availability of bank credit or endanger financial stability. And CBDCs raise fundamental questions of the proper role of central banks. For example, many of the contributions to the literature envision an expanded footprint of central banks in the financial system, in some cases extending their role in liquidity provision, among other areas.

These possibilities notwithstanding, as we discuss in varying detail below, what should be expected of CBDC depends critically on its design features, of which there are many. A

[6] With a handful of very large banks and thousands of small ones, the best description of the structure of U.S. banking depends on which market one is referencing, but it can be fairly described as imperfectly competitive and in some respects as an oligopoly with a competitive fringe. See Pilloff and Rhoades (2002) and VanHoose (2017) on the structure of the banking industry.

[7] That said, we will have something to say about the relationship between central bank reserve management tools, such as the overnight reverse repo facility or the standing repo facility and CBDC.

CBDC could be token-based or account-based.[8] A CBDC could be held directly by households and nonfinancial firms ("retail" CBDC) or intermediated through banks or nonbank financial institutions such as fintechs ("intermediated" CBDC). Holding CBDC could be open to everyone or restricted to subgroups such as U.S. nationals or households and small businesses. CBDC could be elastically and continually supplied to eligible parties, or it could be limited by caps, transfer size, or transfer frequency restrictions. Finally, perhaps the most important design feature of a CBDC is remuneration—that is, whether CBDC holdings would pay interest and whether any such interest would be proportional or tiered as a function of the size of a holding.[9]

The design features affect the likely competitiveness of a CBDC in certain markets and the role that a CBDC might fulfill. For example, if a CBDC pays no interest, its use as a store of value is circumscribed, at least during times when market interest rates are significantly above the *effective lower bound* (ELB) on nominal interest rates. In such circumstances, CBDC is much like cash, and its usage would be determined by how much convenience it provides, relative to its money-like rivals. And, indeed, the *convenience yield* of CBDC—that is, the nonpecuniary benefit provided, which can differ with the application—is a recurrent theme in the literature.[10] More generally, the connection between the design features of a CBDC and take-up by stakeholders is a complex one, with the prospects for a CBDC inextricably intertwined with competing payments mechanisms and technologies in markets with network externalities.[11]

The remainder of this literature review is divided into five sections, plus two appendixes, and proceeds as follows. In section 2, we examine the implications of CBDC for the banking

[8] An example of a token-based system is physical currencies while bank deposits exemplify an account-based system. 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 *et al.* (2020) provides a useful discussion of these differences. See also Duffie (2019).

[9] This list of design features is not exhaustive. Several others relate to how CBDCs interface with technology, interoperability, and governance, with tradeoffs between accountability and transparency versus privacy and anonymity. Our exclusion of these aspects of CBDC design reflects our focus and is not intended to deny the importance of these questions.

[10] This notion of convenience yield applies more broadly than just to CBDC and is often associated with the additional benefit from holding a financial asset that is safe or money-like or both, such as U.S. Treasury bills or very short-term private liabilities. It is often measured as the difference between the risk-free cost of capital and the yield on money-like assets. This spread captures investors' willingness to forfeit higher returns to reap the benefits of holding safe, money-like assets.

[11] 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.

sector. Building on what changes could be expected in banking, section 3 discusses the likely impact on financial stability. We then pivot to monetary policy, first looking at how the implementation of monetary policy might differ, in section 4, and then turning to how the introduction and design of a CBDC could affect the transmission of monetary policy, in section 5. Some concluding remarks follow. The first of the appendixes provides a brief comparison of CBDC to the Federal Reserve's overnight reverse repurchase agreement (ON RRP) facility and assesses the lessons that can be gleaned from that experience. Appendix B discusses the international experience with CBDCs.

2. Implications for the banking sector

Banks play a crucial role in today's financial system, in part due to their ability to create liquidity through *maturity transformation*—that is, by financing illiquid, long-maturity assets funded by liquid, short-term liabilities (Diamond and Dybvig, 1983). 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. The economies of scope—or synergies—that arise from combining lending and deposit-taking activities gives banks a natural advantage over other financial institutions in providing liquidity (Acharya and Mora, 2015), protecting firms and households against idiosyncratic and systemic liquidity shocks (Gatev and Strahan, 2006; Kashyap *et al.*, 2002), and promoting economic growth (Bencivenga and Smith, 1991; Berger and Sedunov, 2017).[12]

One of the most frequently raised concerns in the CBDC debate is the risk of bank disintermediation. Indeed, a CBDC could represent a source of competition for funding with banks, especially if remunerated, which could increase banks' funding costs and adversely affect bank 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

[12] Egan *et al.* (2022) show 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 there may be negative spillover effects to the extent that CBDC can lure deposits away from banks.

way in which banks have access to the central bank in most jurisdictions.[13] The extent to which any such disintermediation would negatively affect lending depends on the viability of 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. In any event, the growing theoretical literature examining the potential effects of a CBDC on deposit and lending markets is not yet conclusive, with considerable uncertainty regarding the precise effects.[14]

Overall, the literature has shown that the likely effects of CBDC on the banking sector depends on four main factors:

1. *Competitiveness of the banking sector.* To the extent that banks have market power in the deposits 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.[15]
2. *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.

[13] In the United States, there are multiple ways economic agents have direct access to the central bank. At one extreme, there is physical cash, which is available to everyone. At the other extreme, there are remunerated central bank reserves, which can only be accessed by depository institutions. To the extent that CBDC provides an intermediate level of access to other economic agents, it can affect the financial structure—see section 4 for more details on CBDC implementation.

[14] 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 of the central bank note issuance monopoly, by the Bank of Canada, established in 1935. Note issuance was an important source of revenue for private banks and allowed them to smooth profits. Consequently, the banks constrained by new issuance limits experienced higher volatility of return on equity in the short run and lower returns on assets 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 the incumbent private banks of introduction of a new form of central bank currency. Indeed, consumers nowadays have access to several substitutes for central bank currency, which were unavailable then. The public in Canada was mandated by law, at that time, to entirely switch from commercial bank notes to central bank notes. Today, if a CBDC were to be introduced such a shift would be voluntary.

[15] The degree of substitutability between a CBDC and deposits or other bank liabilities is also important for banks. For example, the design features of a CBDC may affect its attractiveness across different money-like assets (*e.g.*, shares in money market funds), which in turn would influence how directly the CBDC could compete with traditional bank deposits.

3. *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. Such an offsetting effect is particularly relevant for larger banks.
4. *CBDC account limits.* Restrictions on the quantity of CBDC that users can hold, transact, or earn interest on could limit the extent of bank disintermediation.[16]

2.1. CBDC and bank disintermediation

2.1.1. Banking-sector competition and CBDC remuneration

Andolfatto (2021a) and Keister and Sanches (2022) consider polar cases of competition in the banking sector when examining the implications of CBDC on bank disintermediation. Andolfatto (2021a) examines the monopoly case, showing that introducing an interest-bearing CBDC can lead to an increase in bank deposits and an increase in deposit rates by serving as competition in the market for deposits. In his 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.[17] As a result, introducing a CBDC reduces the monopoly distortion in the banking sector and expands the supply of deposits through both higher savings of existing depositors and the inclusion of unbanked individuals. Thus, a CBDC need not lead to a contraction in bank lending—indeed, it may even induce an expansion in lending for banks with a binding regulatory liquidity constraint.

In contrast, Keister and Sanches (2022) examine the case of a perfectly competitive banking sector, embedded within a Lagos and Wright (2005) New Monetarist framework.[18] In this setting, bank disintermediation is unavoidable if the CBDC is highly competitive with bank

[16] As we note later, such restrictions can be used to contain take-up and limit risks to financial stability, but at the potential cost of reducing the positive benefits of CBDC introduction.

[17] 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.

[18] The New Monetarist framework seeks a fundamental role for money in a world where interest-bearing assets would otherwise dominate the holding of cash-like money as a store of value. Money introduced into an environment of costly search alleviates the famous "double coincidence of wants" problem in exchange. See Williamson (2017) for a summary.

deposits. The effects of a CBDC depend on whether it facilitates transactions that would otherwise be realized with cash or with deposits. A cash-like CBDC would have no direct impact on bank funding because it would merely substitute one form of money for another. 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. The crowding out of bank intermediation notwithstanding, the authors find that the introduction of a CBDC increases the aggregate stock of liquid assets, which promotes more efficient exchange and ultimately improves social welfare.[19]

Andolfatto (2021a) 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 their different assumptions regarding the competitiveness of the banking sector. While this is an empirical question, our reading of the literature is that the degree of competition in the banking sector likely lies in between the two extreme cases these authors assume. For example, Drechsler *et al.* (2017) show 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.[20]

Chiu *et al*. (2022) construct a general equilibrium model that captures the complete spectrum of banking-sector competition, calibrated to U.S. data. In the calibration, the United States has an imperfectly competitive banking sector, implying that an interest-bearing CBDC could promote bank intermediation, leading to higher deposit rates, more deposits and lending, and lower loan rates.[21] Nonetheless, improved intermediation arises only if remuneration on CBDC is in an intermediate range— in this case, as in Andolfatto (2021a), a CBDC would act as a threat to capture bank deposits and incentivize banks to offer more favorable terms to their

[19] Williamson (2021) also employs a model of competitive banking, similar to Keister and Sanches (2022), in which safe assets are in demand by banks to serve as collateral owing to the incentive problem associated with asymmetric information. The 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.

[20] 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 *et al*., 2021).

[21] An interesting aspect of the set-up in Chiu *et al.* (2022) 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 *et al.* (2022).

depositors. Too low a rate on CBDC would not affect the equilibrium, while a rate that is too high results in disintermediation, because banks would be forced to raise the lending rate to restore profitability, leading to a reduction in both deposits and lending. Of course, in the event that the rate of return on a short-term, risk-free asset declines to its ELB, the issue of CBDC remuneration loses its relevance. Overall, the authors find, for their favored calibration where the average three-month Treasury bill rate is 0.9 percent, 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.

2.1.2. Alternative sources of funding and limits to deposit substitution

Andolfatto (2021a), Keister and Sanches (2022), and Chiu *et al.* (2022) all examine the effects of CBDC using models in which bank lending is entirely funded by deposits. However, banks—particularly the largest banks—can at least partially replace deposit shortfalls with wholesale funding. This feature comes into play in Whited *et al.* (2022), who consider economies of scope in the joint production of deposit and lending services by banks.[22] If these economies of scope are sufficiently large, disintermediation in deposits can undermine bank lending; however, if they are not sufficiently large, the wholesale market provides an alternative source of funding that can at least partially offset the negative effect on lending. Based on the estimation of their infinite-horizon dynamic banking model, the authors conclude that CBDC could lead to a significant decrease of bank deposits, particularly if the CBDC is remunerated. However, they also show that a CBDC would likely have only a small impact on bank lending to the extent that banks can replace a large fraction of any lost deposits with wholesale funding.

In contemplating CBDCs, many central banks have also been weighing the prospects for account restrictions to ameliorate the potential adverse effects of a CBDC on bank intermediation. 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

[22] *Economies of scope* are technological factors that make the joint production of two or more goods (or services) more cost efficient than manufacturing them individually. According to some economists, bank lending is subject to economies of scope, in part because the proceeds of a loan automatically create a corresponding deposit when they are deposited in a client's account. The term *synergies* is sometimes used to capture roughly the same idea; the term *bundling* often refers to products that are sold together because of economies of scope.

(see, for example, European Central Bank, 2020; Bank for International Settlements, 2021).[23] Using a model of a perfectly competitive banking sector, similar to Keister and Sanches (2022), Assenmacher *et al.* (2021) analyze quantity restrictions on CBDC accounts to limit surges in demand that might undermine bank funding. They show that while quantity constraints would restrict bank disintermediation, those gains would likely come at the expense of reduced welfare overall. Using a different framework, Bindseil (2020) examines an interest-bearing CBDC with tiered remuneration; that is, where interest paid is nonlinear in the deposit balance. Overall, a downward-sloping remuneration schedule of CBDC rates would also discourage the shift of large balances out of bank deposits into CBDC.

2.1.3. Bank size, heterogeneity and synergies between assets and liabilities

A strand of the literature studies whether the introduction of a CBDC could affect small and large banks differently. Because the empirical literature has established that small nonfinancial firms rely disproportionately on small banks for credit (*e.g.*, Berger *et al.*, 2017), these potential asymmetries could have implications for credit availability that also vary with the size of nonfinancial firms.

Garratt *et al.* (2022) construct a stylized model where banks with a large deposit base compete with smaller ones to show that the introduction of CBDC could indeed have differential effects across large and small banks. The authors assume that depositors at large banks enjoy a nonpecuniary benefit—a convenience yield—that they do not receive from small banks, a modelling construct intended to capture the ancillary service benefits of account holdings.[24] They further assume that this convenience yield could be replicated by a bank-distributed CBDC, one that policymakers can set independently of the CBDC interest rate. Holding constant the interest rate paid on CBDC and on reserve balances, the introduction of an interest-bearing CBDC in their setting weakens the market power of large banks by narrowing the convenience

[23] Such limits are also under consideration for limiting the consequences of CBDC on monetary policy implementation and financial stability, as we discuss later in this paper.

[24] Differences in nonpecuniary benefits across banks are motivated by differences in network branches, better mobile apps, or a wider range of other services that are more readily available at large banks.

gap between small and large banks.[25] This result differs markedly from Whited *et al.* (2022), who argue that large banks are better equipped than small banks to adapt to a financial system with CBDC because their access to wholesale funding makes them less reliant on retail deposits. The authors estimate that the negative impact of CBDC on bank lending can be three times the size for small banks as for large banks, even though the effects on deposits are similar.

The introduction of a CBDC could also curtail the synergies between banks' assets and liabilities. In Piazzesi and Schneider (2022), for example, both bank deposits and credit lines are used to facilitate payments, and banks face costs that are proportionate to their balance sheet asset holdings. Credit lines play a critical role: by unilaterally drawing on a credit line, a borrower instantly creates a bank asset—a loan—that is matched by a liability—a deposit. The use of credit lines economizes bank balance sheet costs for two reasons. First, in the absence of credit lines, banks require asset holdings to support existing deposits before and after transactions take place. Instead, the synchronization of the creation of loans and deposits that arises from credit lines economizes on the assets needed to back deposits. Second, in an economy with credit lines, agents do not need to hold deposits for expected transactions, but only for realized transactions.[26] Thus the tight connection between credit lines and deposits reduces the amount of deposit holdings and, consequently, the quantity of costly assets held by banks to back deposits.[27] It follows that the introduction of a CBDC into a financial system that would otherwise rely exclusively on deposits for all transactions is beneficial, all else being equal, because it reduces banks' balance sheet costs. But in a financial system built on credit lines, a CBDC elicits deposit outflows, undermining the synergies between credit line provision and deposit taking, forcing banks to hold larger volumes of costly assets than they would otherwise.

[25] As in many contributions to this literature, CBDCs in Garratt *et al.* (2022) benefit depositors at the expense of banks and, for that reason, depositors usually favor a higher CBDC rate than do banks. However, there are calibrations in which the large bank deposit rate is equal to the CBDC rate and where both banks and depositors favor a higher convenience yield of CBDC.

[26] Note that agents handling transactions themselves does not imply a net outflow or inflow into the banking system.

[27] This mechanism is in the spirit of Kashyap *et al.* (2002), who argue that the synergies between lending and deposit-taking reduce the quantity of liquid assets necessary to provide both services, all else being equal.

2.2. CBDC and financial inclusion

Households with access to financial services can smooth consumption over time, withstand transitory financial shocks, and build wealth, ultimately improving economic outcomes (*e.g.*, Brainard, 2017). However, an estimated 5.4 percent (7.1 million) of U.S. households are unbanked (Federal Deposit Insurance Corporation, 2020). This aggregate figure elides considerable heterogeneity, with unbanked rates being considerably higher among households that are lower income (up to 23.3 percent), less educated (up to 21.4 percent), Black (13.8 percent), Hispanic (12.2 percent), American Indian or Alaska Native (16.3 percent), and working-age disabled (16.2 percent). Moreover, the process of disbursing CARES Act payments to help combat the financial effects of the COVID-19 pandemic revealed the challenges for the U.S. payments system to reach all citizens, particularly low-income households who needed the funds the most (George, 2020). Ameliorating the financial inclusion gap is therefore a priority for the Fed (Federal Reserve Board, 2022) and an important motivation for considering issuing a CBDC (Barr *et al.*, 2020; Bank for International Settlements, 2022; Bank for International Settlements and World Bank, 2022; Federal Reserve Board, 2022).

While a CBDC has the potential to improve financial inclusion, it may not be enough to fully meet the goal of including people in the formal financial system, because the reasons for financial exclusion vary considerably across individuals. Overall, costs are listed as the most important factor for individuals to remain unbanked. Indeed, in the latest FDIC survey, the motive that was cited the most was "don't have enough money to meet minimum balance requirements," but also included was "bank account fees are too high" and "bank account fees are too unpredictable" (Federal Deposit Insurance Corporation, 2020). Thus, a CBDC with low or zero usage fees could help improve financial inclusion. However, lack of trust in banks and privacy concerns were also commonly reported in the survey as reasons for being excluded, which suggests that even if banks addressed all the cost-related motives for not having a bank account, some unbanked households would remain so. In addition, unbanked households are also significantly more likely to be digitally excluded—that is, they are less likely to have access to internet or own a smartphone—than are banked households. This issue is particularly important in today's financial system, with internet access potentially being a bigger factor

determining financial inclusion than physical access to a bank branch (Boel and Zimmerman, 2022).

Maniff (2020) proposes several design features for a CBDC to improve financial inclusion, including: (i) a CBDC should have no minimum balance requirements and transactions should incur little to no cost; (ii) a CBDC should balance transaction privacy for consumers while complying with the Bank Secrecy Act and anti-money laundering regulations; (iii) because some unbanked households do not trust banks, banks should not be the only entities to support a CBDC; and (iv) because unbanked households are less likely to have a smartphone or internet access, endpoint access for a CBDC should not rely solely on a digital wallet via a smartphone app or a webpage; alternative endpoint solutions, such as brick-and-mortar locations and stored-value cards, should also be adopted.

Similarly, Bank for International Settlements and World Bank (2022) argue that while CBDCs could offer an opportunity for governments and central banks to promote universal access of financial services, they should be complemented with public policies to address other key reasons for financial exclusion. For instance, wide-reaching financial and digital literacy activities might be necessary to afford a CBDC the same level of trust enjoyed by other forms of central bank money. Another key element could be the development of a system allowing for the seamless exchange between digital and physical forms of currency.

Finally, to the extent that a goal of a CBDC is to promote financial and digital inclusion by making the payment system more competitive, there are alternative technologies that can be considered. For example, Brazil launched Pix in November 2020—an instant payment platform developed, managed, operated, and owned by the country's central bank. Similar to Zelle, the largest P2P transfer network in the United States, Pix works through smartphone apps from banks and other digital wallet services. However, a key aspect for Pix's success is that it is mandatory for all the licensed financial and payment institutions in the country to accept and transact on the platform, with Pix including not only free payments between individuals, but also low charges for merchants. Despite the similarities between a retail CBDC and a common payment platform such as Pix, a CBDC would be a claim on a central bank rather than on private intermediaries, allowing for more direct settlement. Nonetheless, Pix's standardized and inclusive payment system supporting interoperability, competition, and lower costs has seen

remarkable growth in terms of rates of adoption. In just over one year after launch, 67 percent of the Brazilian adult population were Pix users, and 60 percent of firms had signed up (Duarte *et al.*, 2022). Moreover, Pix transactions have reached volumes comparable to credit and debit cards, and partly substitute for other digital payment instruments such as bank transfers. Overall, the total level of digital transactions rose considerably—indeed, Pix transfers were carried out by 30 percent of the adult population who had not made any transfers in the year prior to Pix's launch (Duarte *et al.*, 2022). However, despite its success in making payments more efficient and expanding the number of digital payment users, Pix alone may not be sufficient to fully close the financial inclusion gap because individuals still need a bank account or a payment service to use the platform. Ultimately, digital forms of payment still tend to be either not fully accessible or prohibitively costly for unbanked consumers, creating a "last-mile" problem for the unbanked (Shy, 2021).

3. Financial stability implications

Anything that significantly affects the structure of the banking sector might also affect the stability of the financial sector—a CBDC is no exception. As we noted previously, the introduction of a CBDC could impinge on the banking sector's deposit base, which 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 deposits from CBDC could change the architecture of the financial system by crowding out a class of private debt, forcing banks to rely on alternative sources of funding, and potentially making the banking sector more fragile.[28]

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 and execution is rapid. 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

[28] Of note, the mechanism predicting an increase in risk-taking is often cited in policy papers, rather than in the academic literature. One exception is Chiu *et al.* (2002), who extend their baseline model to show that the introduction of a CBDC can either increase or decrease bank risk-taking depending on the relative bargaining power of banks and borrowers.

(MMFs).[29] However, a CBDC could have a beneficial effect via new technologies designed to enhance payments systems, potentially augmenting their resilience. Specifically, by promoting interoperability between electronic payment systems, a CBDC could create incentives to reduce barriers between systems. And a properly designed CBDC could either support the development of a robust stablecoin sector used in decentralized financial (DeFi) networks or crowd out fragile stablecoins altogether. These innovations, among others, would likely promote financial inclusion and augment the resilience of the payment system.

3.1. CBDC in normal times

As noted above, a CBDC would represent an alternative safe asset that competes with traditional short-term financial assets, which could lead to bank disintermediation. The extent of any disintermediation depends on a variety of factors. In this subsection, we focus on just one: the viability of alternative sources of funding for banks.

Most papers examining the likely influence of CBDC on bank intermediation implicitly assume that deposits are the only source of bank funding, which could lead to a reduction in lending and economic activity. A financial stability concern, however, arises when that *does not* happen and instead the potential contraction in bank deposits increases reliance on other sources of funding. The overall effect on the resilience of the banking sector depends in large part on precisely how banks replace any reduction in funding in those cases where CBDC does, in fact, crowd out deposits in aggregate. To the extent that banks lose a safe and "sticky" source of funding in deposits, they may seek less-sticky and less-safe wholesale funding.[30] 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).

[29] The possible effect of CBDC on the resiliency 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).

[30] 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.

A large body of literature has argued that banks' reliance on deposits is beneficial from a financial stability perspective, partly because of the economies of scope (or synergies) that accrue to the joint production of deposits and lending.[31] While the introduction of CBDC would not necessarily directly curtail synergies between deposit-taking and bank lending, a CBDC that crowds out deposits and forces banks to rely on alternative sources of funding could limit the scope for these synergies, which in turn would make them riskier, all else being equal.

An alternative view suggests that CBDC can increase the resilience of the financial system by reducing the convenience yield associated with holding safe assets. Specifically, some 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 *et al.*, 2015; Krishnamurthy and Vissing-Jorgensen, 2015). The mechanism is that by increasing the supply of public safe assets, an interest-bearing CBDC compresses the safe asset convenience yield, resulting in short-term funding rates that are closer to intermediaries' true borrowing costs. This, in turn, reduces intermediaries' incentives to rely excessively on short-term, runnable debt. The role of the central bank's balance sheet to improve financial resilience is further discussed in Carlson *et al.* (2016) and Greenwood *et al.* (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 by incentivizing banks and other financial intermediaries to rely on more stable funding sources. Taken together, these insights suggest that the overall financial stability effects of a CBDC in crowding out deposits, and other money-like private liabilities, is a complicated one.

3.2. CBDC in times of market stress

The creation of a widely available CBDC could increase the risk of a systemwide run, either by attracting a surfeit of depositors initially or by providing a safe and liquid alternative for depositors to run in times of financial distress. Fernandez-Villaverde *et al.* (2021) adopt a variant of the classic three-period bank runs model of Diamond and Dybvig (1983), introducing a CBDC that allows consumers to store their endowments as deposits at the central bank. In this

[31] Brunnermeier and Payne (2021) provide an overview of the benefits from "bundling" bank deposits and lending.

environment, CBDC directly competes with commercial banks to attract depositors in the first period, and strategic bank and central bank depositors must decide whether to withdraw and consume their endowments in the second period.[32,33] The authors assume that the central bank cannot directly invest in long-term technologies that allow commercial banks to offer risk sharing to depositors, thus leaving the central bank at a disadvantage. Instead, the central bank is able to lend indirectly to the broader economy through investment banks, allowing the central bank to recycle funds to the broader economy—an equivalence result similar to that of Brunnermeier and Niepelt (2019), except focused in this case on banks' role in maturity transformation.[34] Despite its technological disadvantage, the central bank can still compete with commercial banks for deposits because of two key assumptions: first, the central bank's investments are not callable and, thus, are protected from early liquidation; and second, the central bank can renege on depositor withdrawals without defaulting. This means that the central depositors do not have an incentive to run on the central bank, while commercial banks are still susceptible to runs because of their traditional fragility. Under these conditions, the central bank deposit contract is attractive to depositors, resulting in the central bank assuming the role of the monopoly provider of deposits in the economy.

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-Wright 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

[32] Diamond and Dybvig (1983) is considered by many as perhaps the canonical model of bank runs. In that model, the risks that households face regarding when they may need to liquidate deposits at banks gives rise to a demand for liquidity, but the fact those risks are private information means that insurance contracts against this risk are not feasible. The deposit contracts banks do offer, while not optimal, provide smoother consumption over time than do illiquid assets. But they give rise to multiple equilibria, including one that is subject to *run risk*. If enough depositors panic, banks must liquidate their assets at substantial private and social cost. Thus the illiquidity of assets is both the rationale for banks and the source of their fragility. Much of the voluminous literature that has sprung out of the Diamond and Dybvig model has dwelt on refinements that could rule out, or at least mitigate, the runs equilibrium.

[33] Modelling CBDC as a deposit contract at the central bank implies that, in principle, CBDC can be remunerated, which distinguishes it from cash.

[34] Brunnermeier and Niepelt (2019) usefully draw attention to the question of how CBDC would be recycled in the broader economy, an underappreciated topic in this literature. However, as discussed in section 4.4.1, their equivalence assumption is unrealistic, at least for the U.S. economy. In that same section, we observe that a surge in CBDC take-up may force central banks to expand their balance sheet, which could influence central bankers' choice of their preferred operating framework.

currency; the remaining share uses bank deposits that become worthless if the bank becomes insolvent, which introduces run risk. In this set-up, the likelihood of a systemwide banking panic is a function of the spread between prevailing interest rates and the return on depositors' outside option—cash—which in this case is zero. Consequently, runs are more likely when interest rates are low. An interest-bearing CBDC that is accepted for both cash and deposit transactions is then introduced. Given its greater flexibility as a means of payment and its remuneration, CBDC takes over the role of the outside option for depositors, compressing the spread between prevailing rates and that outside option. Accordingly, the CBDC makes withdrawals from commercial 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—which ignores the complications of a more interconnected financial system—usefully 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.

Schilling *et al.* (2020) posit the now-famous *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.[35] As in Fernandez-Villaverde *et al.* (2021), the authors 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.[36] 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

[35] See Schilling *et al.* (2021) for a concise, accessible summary of the CBDC trilemma. We note that the concept of financial stability in Schilling *et al.* (2020) refers to avoiding runs ("spending runs") *on the central bank*, that is situations where the public has incentives to spend nominal liabilities quickly and in large amounts (including CBDC) before inflation (or merely an expectation of inflation) erodes the rate of exchange between nominal liabilities and real goods. This differs from the definition considered in most of this section.

[36] 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.

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—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. By choosing to maintain stable prices and promote efficient risk sharing, the central bank must accept the risk of destabilizing runs. And, finally, the central bank could maintain stable prices and eliminate run risk, but only at the cost of foregoing efficient risk sharing. Even so, it is important to keep in mind that, as in Fernandez-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 section 4.4, we discuss why this may be a strong assumption). While derived for a stylized framework, the notion of a CBDC trilemma is likely more broadly applicable, including to environments where benevolent central bankers assiduously pursue their mandated goals—financial stability, efficiency and price stability—but face inescapable trade-offs. As such, the trilemma is arguably indicative of the ways in which CDBC could influence the political economy of central banking, including central bank independence—issues that have been largely neglected in the literature to date.

Fundamentally, the run risk problem in bank runs models 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.[37] Some proposals for a cash-like CBDC involve creating an intentionally inferior means of payments; for example, Keister and Sanches (2022) speculate that a CBDC might be designed with low transfer limits, making it impractical for use in large-value payments, as with the flow- or stock-based limits discussed in the previous section. Similarly, as noted in section 2, a CBDC with *tiered*

[37] See section 4 for a discussion of the mechanics behind monetary policy implementation with CBDC.

remuneration—meaning that interest payments per dollar decline as deposit balances increase—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). This approach 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 of other market-based safe-haven assets such as U.S. Treasury bills.[38] In practice, however, the specific design of CBDC's declining interest payments to discourage runs could be difficult to calibrate and might have to evolve over time with market conditions and technology. 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, in line with some of the design features of the Federal Reserve's overnight repurchase agreement facility.[39]

As an alternative to tiered remuneration, Kumhof and Noone (2021) propose 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.[40] Together, these principles would introduce a friction that would render CBDC somewhat independent from reserves so that excess flows 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, the experience with the Treasury market in March 2020, among others, has revealed that one cannot be assured that market makers 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

[38] 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.

[39] Appendix A explores the parallels between a possible Federal Reserve CBDC and the existing ON RRP facility.

[40] 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.

acceptable price to pay—or even incentive compatible—for most central banks in exchange for enhanced financial stability.

In a somewhat different vein, Keister and Monnet (2022) argue 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 deposits outflows into other liquid investments that stem from the perceived 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. The argument that operating a CBDC and macroprudential policy are complementary is an intriguing one. And, certainly, the opacity of financial markets was an important factor during the lead-up to the Global Financial Crisis. This argument can also be thought of as the counterpoint to the worry that at least some classes of CBDC would unduly increase the footprint of central banks in the (private) financial system.

Overall, the literature suggests that there could be significant financial stability issues associated with an elastically supplied, widely available CBDC that can serve as an attractive safe-haven asset in times of market stress. These considerations indicate that if the Federal Reserve 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, or individual or aggregate caps on usage (Bindseil, 2020).

3.3. CBDC, payments, and financial stability

The introduction of CBDC can also affect the soundness of the payments system. A successful launch would likely increase the interoperability between new emergent digital payment systems and enhance the soundness of decentralized finance (DeFi) networks by establishing and

promulgating universal standards for interoperability.[41] 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, sacrificing payment efficiency to raise customer switching costs and limiting interoperability between systems. The creation of an intermediated (or hybrid) CBDC, where private actors create 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 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 (2021) emphasizes the importance of interoperability across different jurisdictions and draws parallels with the National Banking Era.[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. All of this suggests that issuing an all-purpose CBDC may incentivize technological innovations in payment systems and may be one way for participants to coalesce on a common architecture, facilitating transactions across systems and eliciting the efficiency gains that would come from coordinating payments.

Relatedly, a CBDC also has the potential to support the development of stablecoins, or perhaps become the default stablecoin itself. As highlighted by the report on stablecoins published by the President's Working Group *et al.* (2021), stablecoins play an important role in DeFi networks by allowing participants to exchange their "tokens" for a more widely accepted

[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).

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

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. Even so, if the main purpose of a CBDC is to facilitate greater competition between existing payment systems and new payment technologies, such as stablecoins or DeFi networks, there may be more direct and less costly options to consider. For example, the introduction of Pix in Brazil has increased the convenience of making payments, promoting lower financial costs and higher financial inclusion, as discussed previously in section 2.2.

Along the same lines, Gorton and Zhang (2022) argue that governments should be wary of giving up their monopoly over issuing circulating money by allowing privately issued digital monies such as stablecoins to coexist. Their argument, based on a mixture of economic theory and historical experience, is that the fundamental characteristic of any currency is that it circulates at par with no questions asked (NQA). That is, the value of money should be "informationally insensitive," a condition that private issuance cannot satisfy.[44] Drawing on the historical experience of Scotland, England, and the United States, among others, Gorton and Zhang (2022) show that privately issued monies never really satisfied the NQA property, because their value depended on the solvency of the issuer, which often triggered bank runs. This meant that the use of privately produced money was either effectively restricted to the geographical area where users could be confident of the solvency of the issuer or was backed by unlimited liability, as in the case of Scotland. The authors argue that the inherent instability of a

[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.

[44] The argument is that as soon as an asset is no longer informationally insensitive (equivalently, no longer NQA), adverse selection could sow uncertainty and thus hinder transactions. Questions regarding the solvency of an issuer could then arise, which promotes 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 NQA property.

private medium of exchange was a driving force for the emergence of the sovereign's money monopoly through the creation of central banks.[45]

In quite a different setting, Fernandez-Villaverde and Sanches (2019) end up with similar conclusions as Gorton and Zhang in terms of conclusions. They argue that in a world of competing privately issued monies such as stablecoins and cryptocurrencies, a publicly issued money is essential for establishing price stability and achieving efficient allocations. In their model, competition among rival currencies induces the government to follow a policy rule that pegs the real value of government money. This, in turn, drives private money out of the economy and allows the government to implement the efficient solution.

4. Monetary policy implementation

To this point, we have discussed the likely implications of the introduction of a CBDC for the banking sector and financial stability. We now begin the transition toward monetary policy. To this end, this section provides a discussion of how monetary policy would be implemented in our semi-hypothetical economy after the introduction of a CBDC. To set the stage for that discussion, however, we begin with a modest digression on how CBDC could affect the balance sheets of banks, the central bank, the government, and households. We show how balance sheet outcomes depend on the characteristics of the banking sector and the broader financial system. Furthermore, we illustrate the prominent role played by a central bank's balance sheet management policy and its decisions about recycling CBDC—that is, whether and how to expand its balance sheet following CBDC issuance. This is the bridge from the partial equilibrium or sectoral depictions of how CBDC affects the economy to monetary policy implementation and, ultimately, to the general equilibrium characterizations of section 5.

For present purposes, we assume that reserves, CBDC and physical currency are denominated in the same unit of account and can be exchanged without discount from (market) value. This means we abstract from the complexities that floating exchange valuations between CBDC and reserves or physical currency would create for the management of a central bank's balance sheet.

[45] Other drivers were to have an elastic supply of the currency and fiscal concerns.

4.1 Central Bank's balance sheet mechanics

We begin this section by discussing five scenarios that characterize possible changes to the balance sheets of the central bank and its counterparties. These scenarios are based on a simple conceptual framework, whose starting point is a central bank that issues reserves held by the banking sector, and CBDC and physical currency—that is, cash—which are held by households.[46] The central bank is assumed to back its liabilities by holding government debt only, which is also held by households; banks extend loans and issue deposits and non-deposit liabilities to households.

The first two scenarios are straightforward transactions involving just two parties, households and the central bank; their simplicity allows us to discuss them without illustration. The other three scenarios are complex enough that figures illustrating the implications of the transactions for the various agents' balance sheets will be helpful. The direction and magnitude of changes in agents' balance sheets will depend on how households finance their purchases of CBDC, which differs across scenarios.

In the first scenario, which we call *cash-CBDC reallocation*, households directly exchange cash for an equivalent value of CBDC, a transaction that keeps fixed the overall size of the central bank's balance sheet. The balance sheets of all other parties—the government (excluding the central bank) and commercial banks—are unchanged. In the second scenario, dubbed *CBDC injection*, households exchange Treasury securities directly with the central bank for CBDC. As in the first scenario, no other parties are affected, but in this instance there is an increase in the size of the central bank's balance sheet.

To illustrate the remaining three scenarios, we employ a framework to visualize the balance sheet effects of CBDC issuance. More importantly, this framework will also help us synthesize the literature from the viewpoint of monetary policy implementation; we pinpoint the different assumptions that underlie the differences in balance sheet outcomes across the scenarios, with a particular emphasis on how the central bank manages its balance sheet. Figure 1 illustrates the balance sheet positions of the central bank, banks, households, and the

[46] In this simple framework, households represent the aggregate economy, including nonbank financial firms. As such, this framework is not suited to study specific effects on the nonbank financial sector or the implications of purely technological or operational choices in CBDC design.

government when households decide to hold CBDC that is a direct liability of the central bank. The changes noted in the figure are for our third scenario, which we call the *bank disintermediation* scenario, in which households exchange deposits held with banks for CBDC. In this case, reserves and bank deposits both decrease, while the size of the central bank's balance sheet is unchanged.

Central Bank	
Assets	Liabilities
Treasury (CB)	Reserves -$1
	Government cash
	Cash
	CBDC +$1

Households	
Assets	Liabilities
Deposits -$1	Loans
Cash	Net worth
Non-deposit bank funding	
Treasury (household)	
CBDC +$1	

Banks	
Assets	Liabilities
Reserves -$1	Deposits -$1
Loans	Non-deposit bank funding

Government (not including CB)	
Assets	Liabilities
Government cash	Treasury (CB)
National debt	Treasury (household)

Note: In the illustrated scenario, entries increasing by $1 are marked green, while those decreasing by $1 are marked red. "Net worth" for households and "National debt" for government represent residuals, not tradable securities. For the Federal Reserve, "Government cash" represents the Treasury General Account (TGA). CB is central bank.

Figure 1: Stylized balance sheets and a *bank disintermediation* scenario

As pointed out by Bindseil (2019), the *bank disintermediation* scenario is particularly important, because, as the name suggests, it implies a reduction in the deposit base of the banking sector, which could affect banks' cost of funding depending on the competitive structure of the sector. In addition, as discussed by Malloy *et al.* (2022), the corresponding reduction in the quantity of reserves could elicit a response from the central bank, depending on its operating framework and policy objectives. For example, the central bank could choose to offset the reduction in reserves under the *bank intermediation* scenario by buying Treasury securities from households through banks by increasing reserves, while households are credited for the sale of Treasuries through a commensurate increase in deposits. In this case, the net change in household deposits is zero, and the overall net change in all agents' balance sheets is as if households simply sold $1 of Treasuries directly to the central bank to acquire $1 of CBDC—identical to the *CBDC injection* scenario.

Once household deposits are replenished, households may allocate the proceeds from the sale of Treasuries differently rather than retain them as deposits. For example, households may choose to hold fixed the sum of their asset holdings of cash, deposits and CBDC, and use the proceeds to pay down bank loans instead. The net impact in this instance would be that the central bank's balance sheet expands by an additional $1 of Treasury holdings funded by CBDC, banks are disintermediated by a $1 decrease in both loans *and* deposits, and household balance sheets shrink—deleveraging—by a $1 reduction in loans matched by a net $1 decrease in assets: a $1 increase in CBDC and $1 decreases in Treasuries and deposits. We call this scenario *banking contraction*, which is illustrated by the left panel of figure 2.

Banking contraction

Central Bank	
Assets	Liabilities
Treasury (CB) +$1	Reserves
	Government cash
	Cash
	CBDC +$1

Banks	
Assets	Liabilities
Reserves	Deposits -$1
Loans -$1	Non-deposit fund

Households	
Assets	Liabilities
Deposits -$1	Loans -$1
Cash	Net worth
Non-deposit fund	
Treasury (household) -$1	
CBDC +$1	

Government (not including CB)	
Assets	Liabilities
Government cash	Treasury (CB) +$1
National debt	Treasury (household) -$1

Bank funding reallocation

Central Bank	
Assets	Liabilities
Treasury (CB) +$1	Reserves
	Government cash
	Cash
	CBDC +$1

Banks	
Assets	Liabilities
Reserves	Deposits -$1
Loans	Non-deposit fund +$1

Households	
Assets	Liabilities
Deposits -$1	Loans
Cash	Net worth
Non-deposit fund +$1	
Treasury (household) -$1	
CBDC +$1	

Government (not including CB)	
Assets	Liabilities
Government cash	Treasury (CB) +$1
National debt	Treasury (household) -$1

Note: Entries increasing by $1 are marked green, while those decreasing by $1 are marked red. CB is central bank.

Figure 2: Illustration of two scenarios

An alternative way to allocate the proceeds from the sale of Treasuries would be for households to increase non-deposit bank funding.[47] In this scenario, named *bank funding reallocation*, banks are not disintermediated, as illustrated by the right panel of figure 2. The net impact is such that the central bank's balance sheet expands with the additional dollar of Treasury holdings and a similar increase of CBDC; bank asset holdings are unchanged, while deposits decrease and non-deposit bank funding increases; and the size of household balance sheets is unchanged, with the $1 reduction in both Treasuries and deposits being offset by increases in non-deposit bank funding and in CBDC holdings.

The breadth of outcomes in these scenarios illuminates the debate concerning the effect of CBDC issuance on the banking sector. Banks may or may not incur disintermediation depending on how banks, households, and the central bank manage their balance sheets. Even the direction of the change of bank deposits is ambiguous. And the efficacy of replacement of deposits by non-deposit funding is determined by how households purchase CBDC from the central bank and how agents respond to central bank operations. Most importantly for this section, these scenarios differ in how the central bank's balance sheet changes, highlighting differences in embedded assumptions about central bank policy. Table 1 summarizes these outcomes of interest for each of the scenarios.

Table 1

Illustration of changes in the composition of the central bank balance sheet

Scenario	CB balance sheet	Reserve supply	Bank balance sheet	Bank loans	Household holdings	
					Deposits	Cash & CBDC
Cash-CBDC reallocation	0	0	0	0	0	0
CBDC injection	+$1	0	0	0	0	+$1
Bank disintermediation	0	-$1	-$1	0	-$1	+$1
Banking contraction	+$1	0	-$1	-$1	-$1	+$1
Bank funding reallocation	+$1	0	0	0	-$1	+$1

Notes: Columns show the change in dollar values. CB is central bank.

Table 1 makes clear that the five scenarios outlined above imply different outcomes for variables of interest such as household money holdings, central bank and commercial bank

[47] In practice, non-deposit bank funding may be interpreted as wholesale funding, with the households representing the complete nonbank private sector.

balance sheet sizes, and reserve supply. It should also be clear that any combinations of these scenarios are also descriptions of possible outcomes; conversely, any balance sheet adjustments following the issuance of CBDC are also combinations of these same five scenarios—provided we assume no change in household net worth, national debt, or "government cash".[48]

As discussed elsewhere in this paper, assumptions about the central bank's balance sheet management policy, as well as economic theory and empirical analysis, would narrow the range of possibilities. For example, if there were reason to believe money-like holdings for households were highly substitutable, so that they might not be expected to change much in aggregate, then the *CBDC injection* scenario would be an unlikely outcome. Similarly, if the central bank were to maintain a constant level of reserves as a policy objective, the *bank disintermediation* scenario would be ruled out.

4.2 Implications for monetary policy implementation

We now turn to the implications of the range of balance sheet outcomes just discussed for monetary policy implementation. Wherever applicable, we highlight how these outcomes depend on central bank policy and how the central bank policy in turn may be determined by consideration of its potential effect on those outcomes.

In principle, the introduction of a CBDC need not fundamentally change the way a central bank controls its policy rate. Many central banks, including the Federal Reserve, already have substantial liabilities outside of reserve balances and are obliged to manage large and frequent transfers between these liabilities and reserves. That said, the magnitude of changes in balance sheet composition driven by CBDC would depend on the design features and could be sizable for some designs.

In a scarce-reserves regime, the central bank must actively monitor and forecast flows between reserves, CBDC, and other liabilities and offset changes in reserve balances with open market operations to maintain interest rate control. In an ample-reserves regime, the central bank may simply elect to increase the supply of reserves to minimize the potential impact of large

[48] The sum of coefficients of the linear combination will be the quantity of CBDC issued; alternatively, one can restrict the sum of coefficients to unity to normalize responses to an issuance of CBDC of one dollar. This results from having a finite number of distinct items in sectoral balance sheets.

flows between reserves and CBDC on money market rates. Central bankers might concur with Afonso *et al.* (2021), who argue that the advent of a new type of liability—such as CBDC—whose usage could be volatile and hard to predict reinforces the argument for preferring policy implementation with ample reserves.

The proper calibration of implementation parameters may not be a trivial task. With the introduction of a CBDC in an ample-reserves regime, a central bank need not routinely forecast the direction and magnitude of conversions between reserves and CBDC. Rather, the central bank might choose to expand its reserve supply, with the size of the required expansion depending on the degree of uncertainty in conversions between reserves and CBDC, which would be partly determined by the design of CBDC and the characteristics of the banking system.

4.3 Implications for the magnitude of central bank balance sheet expansion

The magnitude of balance sheet expansion in response to the introduction of a CBDC would depend on many factors. One factor is the demand for CBDC: If a central bank were to simply maintain a fixed supply of reserves with households substituting from deposits to CBDC, it would have to expand its balance sheet by the amount of substitution, as in the *banking contraction* and *bank funding reallocation* scenarios in figure 2 and table 1, in section 4.1. In such an environment, design choices that make CBDC more attractive—such as remuneration, greater versatility, or enhanced convenience as a means of payment—would presumably increase the demand for CBDC and expand the balance sheet by more than otherwise.[49] In contrast, design choices like those intended to limit risks to financial stability, including individual and aggregate caps and frictions in conversions, would work in the opposite direction.

The degree of expansion would also critically depend on the central bank's balance sheet management policy. As previously noted, a central bank could mitigate the reduction in reserves by engaging in open market operations or purchasing assets to expand the size of its balance sheet. In an ample-reserves regime, there could be considerable latitude in this choice if the

[49] In the literature, account-based CBDC—as opposed to non-account-based, often dubbed token-based or value-based—is often associated with reasonably convenient payment functionalities comparable to bank accounts, while a non-account-based CBDC is often associated with more limited functionality. However, this does not need to be the case in principle.

supply of reserves were a policy parameter chosen to provide a buffer against upward pressure on the policy rate, with a larger buffer generally leading to a larger central bank balance sheet.

The central bank's policy regarding its liquidity facilities—such as the discount window or the standing repo facility in the United States—would also affect the change in reserve supply and, correspondingly, the magnitude of balance sheet expansion. Tied up in all this is the question of how active a role the central bank would choose to play in the provision of liquidity and under what terms and conditions. On the one hand, the central bank could decide to expand reserve supply such that the usage of such facilities would be rare even in the presence of frequent sizable significant conversions from household deposits to CBDC. On the other hand, the central bank might choose a lower level of reserve supply and, correspondingly, a smaller balance sheet while encouraging more frequent use of liquidity facilities.

Of related interest, the ongoing level of usage in central bank facilities might damp the effect of CBDC conversions that would otherwise result in changes in reserve supply, allowing the central bank to let reserve supply fall rather than reverse the decline in supply. This might be the case in the United States, for example, if the level of ON RRP facility usage were high; conversions to CBDC that would otherwise decrease reserve supply might materialize instead as a decline in ON RRP take-up.[50]

4.4 Implications for central bank portfolio composition and net interest income

In our discussions to this point, we have implicitly assumed that the central bank can readily increase the quantity of reserves by purchasing government bonds.[51] This assumption caps the total expansion of the central bank balance sheet to the total amount of government securities in circulation, which may be difficult to accommodate in jurisdictions in which government assets are scarce. That is, if the central bank's balance sheet were to expand by a very large amount to accommodate CBDC issuance, it could run out of assets to hold, depending on what applicable laws allow in terms of eligible assets for purchase (Bank for International Settlements, 2018). This could be especially problematic if there were a run into CBDC, because the demand for the

[50] For example, investors might shift funds from ON RRP to other borrowers to arbitrage funding rate pressures associated with a decrease in reserve supply.

[51] In the United States, in normal circumstances, the Federal Reserve by law is restricted in what it can purchase to government securities, agency mortgage-backed securities, agency debt, and a few other minor categories.

sort of safe assets that the central bank traditionally holds could increase substantially in such a state (Meaning *et al.*, 2021).

In the United States, given the recent expansion of the stock of U.S. government debt outstanding and recent experiences with successful purchase programs of large volumes of securities over brief intervals of time in response to the coronavirus pandemic, concerns about the scarcity of government assets do not appear to be immediately relevant. However, there may be considerable political-economy issues related to a large central bank balance sheet, such as its implications for central bank independence or remittances.

If the Federal Reserve's balance sheet were to expand due to the introduction of a CBDC as a liability and a commensurate increase in its holdings of Treasury securities, remittances to the U.S. Treasury would be expected to increase so long as the yield of the purchased Treasury securities were higher than the expected rate of remuneration on CBDC or, equivalently, if the sum of the term premium in Treasury securities and the spread of expected short-term rates over expected CBDC remuneration rate were positive. However, a larger balance sheet comes with the risk of higher potential losses if interest rates were to rise unexpectedly. In addition, if the CBDC paid positive interest, any substitution of CBDC for currency would decrease net interest income.

All else being equal, a wider spread between short-term rates and the CBDC remuneration rate implies lower interest expenses and higher remittances, conditional on the size and composition of the Fed's balance sheet. However, a wider spread could also mean lower CBDC holdings, which might also have important consequences for the transmission of monetary policy; see the discussion on banking, in section 2, and on monetary policy transmission, in section 5.

4.4.1 Purchase of Nongovernment Assets

Our working assumption is that the central bank can only purchase government securities, as is the case, more or less, in the United States. However, much of the theoretical literature assumes

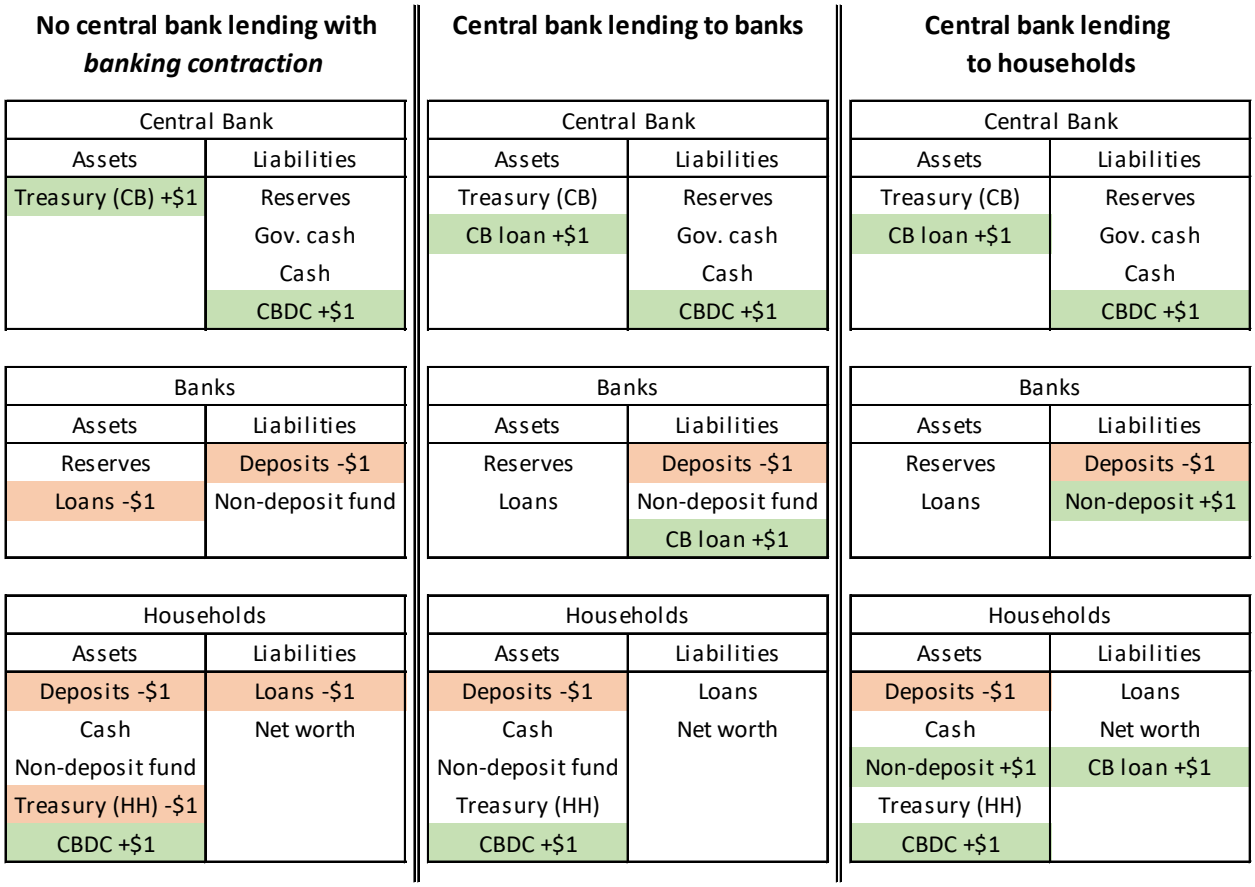
that the central bank can lend directly to households or banks on an ongoing basis.[52] This can be consequential: The irrelevance result described in Brunnermeier and Niepelt (2019) relies on the central bank's willingness and ability to undo actions by the private sector by effectively lending directly to households and businesses in response to a contraction in bank deposits. This is also the case of Fernandez-Villaverde *et al.* (2021), where the central bank lends to "investment banks," which then allocate funds to other economic agents. And so, too, in Schilling *et al.* (2020), where the central bank's sizable direct lending to economic agents affects the price level, and also in Burlon *et al.* (2022), where the central bank's assets consist entirely of loans to the banking sector.

The insights from these papers need to be put into perspective with each central bank's policy environment and implementation framework. In the United States, where recent experience with direct lending is limited to Section 13(3) facilities, these occurrences are rare and typically in response to severe market stress. Still, studying these contributions to the literature is arguably useful for emphasizing the alternative margins upon which various governmental authorities can act, should the need arise. Practicalities aside, we discuss how such lending would affect the balance sheets of different sectors of the economy.

Figure 3 shows how the balance sheets of various sectors might evolve with a central bank lending directly to banks or households. The left panel illustrates a bank disintermediation outcome with deposits and bank loans decreasing, as in the *banking contraction* scenario discussed above. In the middle panel, the central bank lends to banks to replace their lost deposits, similar to an example in Brunnermeier and Niepelt (2019). In the right panel, the central bank directly lends to households without expanding its holdings of Treasuries, and households use the borrowed money to fund banks.[53]

[52] This type of lending is distinct from lending from facilities like the discount window in the United States which is intended to support the liquidity positions of *individual* banks. Longer-term loans offered for a wider range of collateral such as those made under the Term Auction Facility of the Federal Reserve might be a better example.

[53] That central banks, or their surrogates, are assumed to be efficient in allocating credit among alternative borrowers is a separate, unaddressed issue in these papers. Some of the critiques of the pandemic-era lending programs give credence to the notion that this assumption is a strong one.



Notes: Entries increasing by $1 are marked green, while those decreasing by $1 are marked red. The government's balance sheet is not shown. CB is central bank and HH is households.

Figure 3: Impact of CB lending directly to banks or households

4.5 Other topics

4.5.1 CBDC and quantitative easing

CBDC might change the effect of quantitative easing (QE) on commercial bank balance sheets. In the absence of CBDC, the initial effect of QE, generally speaking, is to expand commercial bank balance sheets, because the central bank pays money to the seller of securities by issuing reserves to the bank of the seller, with the bank then crediting the account of the seller.[54] With the advent of CBDC, the central bank could pay the seller directly in CBDC without involving a

[54] Unless, that is, commercial banks are selling their own holdings of Treasury securities to the central bank. It follows that only those securities that are sold by nonbank holders would contribute to the expansion of commercial bank balance sheets.

commercial bank; alternatively, the central bank could pay the seller in deposits (by crediting the reserve account of the seller's bank) as per usual, though the seller might transfer the proceeds to the seller's CBDC account (for a similar example, see Meaning *et al.*, 2021). This case is described by the scenario of *CBDC injection* discussed earlier.

Beyond this initial step, the seller of the securities could transfer the proceeds to a commercial bank account, repay a bank loan, or use the funds for other purposes. To the extent that deposits and CBDC are close substitutes, the net effect of introducing CBDC would be to moderate the expansion of deposit base and thus that of reserve supply following QE, with CBDC functioning as an alternative destination of liquidity injected by the central bank. To take the U.S. case as an example, this is analogous with the experience of the Federal Reserve following the coronavirus pandemic, during which much of the proceeds of asset purchases ended up in increases in ON RRP take-up, rather than in reserve supply.[55]

4.5.2. Alternative approaches to accounting for CBDC on a central bank's balance sheet

The most common approach to issuing CBDC is to keep reserves and CBDC as distinct liabilities on the central bank's balance sheet, despite their many common features. Alternative approaches have been discussed in the literature, but they are essentially identical to the common approach in how they affect the balance sheets of the central bank and its counterparties.

Meaning *et al*. (2021) consider a scenario where reserves are replaced by CBDC, which are also held directly by households. If the central bank is willing to discriminate between different holders of CBDC—for example, between accounts held by banks and those held by households, as might be the case if policymakers were to selectively limit convertibility from one type of liability to another, based on the type of account holder in order to enhance financial stability—this alternative approach becomes equivalent to the common approach.[56] Also, CBDC held by commercial banks could be equivalent to reserves, in which case the central bank might base its policy rate on CBDC borrowing by commercial banks instead of reserve borrowing, which is currently the case in many jurisdictions.

[55] To be precise, the relevant similarity between ON RRP and CBDC is that both serve as alternative destinations of liquidity to reserves. We provide more details on these similarities and differences in Appendix A.

[56] The financial stability section of this paper, section 3, discusses caps on individual or aggregate account holdings and limits on convertibility as devices for avoiding, or mitigating, a surge in CBDC in times of market stress.

Bordo and Levin (2019) propose an approach akin to narrow banking, where supervised commercial banks would offer CBDC accounts to households and businesses, which are backed one-for-one by reserve holdings held at the central bank in segregated reserve accounts.

5. Monetary policy transmission

Central banks around the world have published discussion papers, or opinion pieces, on how CBDC might affect the transmission of monetary policy.[57] The academic literature on this subject, in contrast, is only beginning to emerge.

The implications of the introduction of a CBDC for the transmission of monetary policy can be usefully divided into three categories. As an intermediate step, the first category covers the effects on the configuration of rates paid on various instruments, and the spreads between rates on those instruments and CBDC. These could be called the relative-price effects that a CBDC may induce. The second category is changes to the dynamic propagation of changes in the (standard) policy rate to changes in financial conditions operating through the financial system and the economy more broadly.[58] Pass-through is said to be stronger (weaker) if a given change in the policy rate has larger (smaller) effects on macroeconomic variables in an economy with a CBDC than one without one, all else being equal. Finally, the third category is increments to the pass-through of monetary policy arising from the potential addition of a new policy instrument: the interest rate on CBDC.

Regarding relative-price effects, to the extent that CBDC is designed to be a close substitute for bank deposits, its issuance could help saturate the demand for short-duration safe assets, including Treasury securities, all else being equal.[59] Doing so could be expected to reduce the convenience yield of such assets, which in turn could raise the neutral rate of interest, otherwise known as r^*.[60] A higher r^*, in turn, could reduce the incidence and severity of zero-

[57] See, for example, Bank for International Settlements (2018, 2021, 2022), Bank of England (2020), Engert and Fung (2017), European Central Bank (2020), Sveriges Riksbank (2017, 2018, 2021, 2022).

[58] For present purposes, we take the propagation of policy rate changes here as a separate consideration from the implementation questions discussed in section 4 above.

[59] For material on the economics of safe assets, see Gorton (2017) and Gorton and Ordoñez (2022).

[60] Conventional theory suggests that real interest rates in the United States have been shown to be low at least in part because the premium for safety and liquidity has increased since the late 1990s; see Del Negro *et al.* (2017) and references therein for a discussion. Del Negro *et al.* (2019) study a broader set of advanced economies and similarly attribute the decline in interest rates primarily to the increase in demand for safe and liquid assets.

lower-bound episodes. In addition, a strand of the existing literature emphasizes that different levels of safety are associated with assets of different maturities (see, for example, Krishnamurthy and Vissing-Jorgensen, 2012). This suggests that the effect of CBDC on the average level of interest rates would be mostly felt at the short end, pointing to a flattening of the yield curve in steady-state equilibrium.

The effects of the changes in the levels of rates engendered by CBDC has garnered scant attention in the literature. Our tentative reading is that provided that CBDC is appropriately recycled through the economy and is designed to limit implications for bank disintermediation, the magnitude of these effects is likely to be small—less significant than the effects of technical change on the infrastructure of the payments system, for example.

The effects of CBDC on the dynamics of transmission, on the other hand, could be more consequential. Much of the CBDC literature deals with pass-through of policy rate changes into the broader spectrum of market rates and asset prices more generally; relatively little of it dwells on transmission to the nonfinancial sectors of the economy. Both the extent to which policy rate changes are passed through and the speed with which transmission occurs are relevant. We discuss these issues in the first subsection. Then, we take the next step and ask how CBDC might affect the design of monetary policy, whether through optimal policies or simple rules, including in the international context.

5.1. Interest-bearing CBDC as a policy instrument: Effects on pass-through

Meaning *et al.* (2021) argue that an interest-bearing CBDC could strengthen monetary policy transmission through several channels.[61] The ease with which households and businesses could shift resources to and from CBDC—which depends, in part, on the degree of substitutability between CBDC and other money-like assets—seems likely to make market interest rates more sensitive to changes in the (non-CBDC) policy rate, all else being equal. Thus, the interest rate channel would be strengthened, as interest rates on savings and credit would either shift by more,

[61] Traditionally, several channels of monetary policy transmission have been discussed in the literature, including the following: the *interest rate channel* (Mishkin, 1995), the *credit channel* (Bernanke and Blinder, 1988; Bernanke and Gertler, 1995; Gilchrist and Zakrajšek, 2012), the *bank lending channel* (Kashyap and Stein, 1995, 2000; Stein, 1998), the *bank balance sheet channel* (Van den Huevel, 2002; Lenel *et al.*, 2019), and the *deposits channel* (Drechsler *et al.*, 2017). How the introduction of CBDC would alter channels through which monetary policy is transmitted is a very much understudied topic thus far.

or more rapidly, for a given change in the policy rate.[62] The impact through the bank lending channel of transmission is less clear. To the extent that bank funding costs became more sensitive to changes in the policy rate, all else being equal, this would have a larger impact on loan rates, strengthening the bank lending channel.

There are, however, possible countervailing effects associated with an interest-bearing CBDC that could *weaken* traditional monetary policy transmission. In this regard, Piazzesi *et al.* (2022) note that the traditional effects of policy tightening could be weakened, because any incipient decline in spending stemming from a policy tightening would lower the convenience value of CBDC. This added cyclicality in the convenience yield would lead CBDC holders to shift back into bank deposits and bonds, putting downward pressure on the rate for those instruments and undoing, in part, the effects of original policy tightening.[63] More fundamentally, if a CBDC were to disintermediate the banking sector and significantly reduce the size of its aggregate balance sheet, this could reduce the traction of the bank lending channel.

The transmission mechanism may also change if the introduction of CBDC affects the way that banks choose to issue loans, as at least in principle they would have the option to lend in CBDC; that is, lend by transferring CBDC to the borrower's CBDC account. Setting aside how lending in CBDC might affect regulatory ratios, to the extent that borrowers might wish to fund in CBDC, this could make banks more like nonbank lenders and reduce the sensitivity of money creation by banks to a given change in policy rate. In practice, however, many factors would play a role in banks' decision whether to continue to lend and increase the quantity of deposits in the system. In addition, in the U.S. case, it is not clear how lending in CBDC would affect current regulatory ratios, such as liquidity coverage ratios, and whether CBDC would be considered a high-quality liquid asset for purposes of the calculation of these ratios. Moreover, it

[62] CBDC would likely shrink the average spread between lending and borrowing rates and transfer rents from the banking sector to firms and households; the dynamics of these spreads would also be affected. Both would induce (positive) wealth effects, for households in particular. For a recent study on disintermediation, independent of CBDC, and its effects on monetary policy transmission, see Crouzet (2021).

[63] In Piazzesi *et al.* (2022) the decisions of households and firms solve the same problems as in textbook treatments of the New Keynesian model. The only difference is that the central bank sets the quantity, as well as the interest rate, on money (that is, CBDC), instead of the short rate of the representative agent's stochastic discount factor. Unlike in the standard New Keynesian model, the response of the convenience yield to spending dampens the impact of policy on output and inflation, all else being equal. The endogenous adjustment of the convenience yield substitutes for policy as a stabilizing force in the sense that in the model, interest rate rules that do not aggressively respond to inflation need not make the economy susceptible to self-fulfilling recessions.

is unclear how much demand there would be for borrowing in CBDC and whether the interest rate on CBDC loans for a given level of risk would be the same whether it is delivered in CBDC or deposits. More broadly, the prospects for CBDC to fundamentally change the role of the banking sector in the transmission of monetary policy is an understudied area in the literature.

Setting aside the direct impact on the transmission of monetary policy through the channels described above, interest-bearing CBDC may also alter the pass-through of changes in interest rates on existing policy instruments, such as the rate of interest on reserve balances (IORB). The question arises of how the different instruments should be coordinated. The answer depends intrinsically on the substitutability of CBDC and bank deposits, as well as the structure of the deposit market. Jiang and Zhu (2021) present an analytical framework based on the polar case of a deposit-like CBDC—that is, a perfect substitute for bank deposits in their payments function—where the IORB and interest on CBDC affect the economy through different channels: The interest on reserves influences deposit balances and lending by affecting the cost of funding, or by affecting the relative attractiveness of loans versus reserves. Because CBDC is a perfect substitute for bank deposits, the CBDC rate fully dictates the deposit rate, thus eliminating the pass-through from the IORB to the deposit rate. In the interesting case where reserves are scarce, if the only policy rate is the IORB, then changes in the IORB pass through to both loan and deposit rates. Once an interest-bearing CBDC is introduced, the effect of IORB on deposit rates disappears, but the effect of IORB over lending rates is strengthened. Intuitively, this is because changes in IORB do not affect deposit rates, allowing the IORB to have a direct effect on bank profitability and thus on lending rates. However, the effect of the CBDC rate on the volume of deposits, or loan rates and quantities, is more complex. Ultimately, the passthrough of CBDC rate changes into the IROB weakens as competitiveness in deposit markets is reduced.[64]

The literature cited above focuses mainly on a central bank's ability to influence rates in financial markets and, hence, its effects on the availability of funds for businesses. Other recent work, such as Marsh (2022), points to a role for ubiquitous interest-bearing CBDC savings

[64] Drechsler *et al.* (2017), for instance, provide empirical evidence consistent with the fact that U.S. banks have market power over depositors. In the arguably less plausible case of a perfectly competitive deposit market, a CBDC tends to strengthen the effect of a change in the IORB on loan volumes because, with the deposit rate fixed at the CBDC rate, the effect of a change in the IORB passes solely through to the loan rate.

accounts as useful part of the infrastructure of monetary and especially fiscal policy. Provided that legislation was to allow it, widespread uptake of such accounts could furnish the means for targeted *fiscal* transfers as well as facilitate the implementation of helicopter drops, albeit at the cost of a noteworthy expansion of the central bank's footprint in the economy.

To evaluate the relative strengths of the above considerations, a rich model is needed. Below we survey some early attempts at evaluating the effects of different monetary policy arrangements in the presence of CBDC.

5.2. CBDC in various monetary policy frameworks

Only a handful of papers study the design of monetary policy and evaluate the efficacy of macroeconomic policies when CBDC effectively serves as a policy instrument, either on its own or in addition to the standard policy rate. In one such contribution, Barrdear and Kumhof (2022) embed a CBDC governed by one of three simple policy rules within a richly specified New Keynesian DSGE model with a CBDC that is an imperfect substitute for bank deposits.[65] One of the policy rules is a standard Taylor-type rule expressing a law of motion for the IORB; the other two are CBDC policy rules.[66] The authors note that policymakers might find it difficult, initially, to estimate the spread between the policy rate and the rate paid on CBDC that would obtain their preferred steady-state quantity of CBDC. It might therefore be preferable to initially issue a CBDC-quantity rule to let the market establish a reasonable range for CBDC interest rates and then subsequently switch to a CBDC interest rate rule.

Niepelt (2020) employs a business cycle model in the spirit of Sidrauski (1967) and studies optimal policy design in the presence of CBDC. Niepelt emphasizes the role of money as a means of payment and store of value rather than unit of account. Equilibrium in this economy ends up looking a lot like that of a real business cycle (RBC) model, with "pseudo-wedges" that capture liquidity premiums, monopsony power in deposits, and in some cases externalities in

[65] The initial exercise in the paper traces the transition of the economy from a steady state without CBDC, calibrated to match the U.S. economy prior to 2008, to one that includes CBDC. CBDC issuance amounting to 30 percent of GDP in their model could permanently raise GDP by 3 percent, because of lower real interest rates, lower distortionary tax rates, and lower costs of managing liquidity. This effect is arguably implausible in magnitude.

[66] In interpreting the CBDC rules, a key insight is that an increased supply of CBDC must be associated with a higher interest rate on CBDC. The return on a monetary asset consists of both a nonpecuniary convenience yield and a financial return that, by arbitrage, has to equal the policy rate. Additional supply of CBDC liquidity lowers the convenience yield of CBDC, which implies that the financial return on CBDC must rise.

reserve holdings. A social planner would satiate households with liquidity, choosing the social-cost-minimizing combination of deposits and CBDC up to the point where liquidity benefits equal the social costs of managing liquidity, à la Friedman (1969). This may involve the central bank absorbing some liquidity management costs that would otherwise have been borne by banks, particularly in the case where the choice of reserves of an individual bank fails to consider the external benefits of higher reserves.[67] How close could a Ramsey planner, who has to respect agents' optimality conditions, come to achieving this outcome? The irrelevance of the CBDC result of Brunnermeier and Niepelt (2019) reemerges: in Niepelt's stylized model with CBDC, and one without, identical (and optimal) outcomes can be achieved provided that the government chooses the right mixture of taxes and targeted subsidies.[68] A CBDC-based system does have the advantage that deposits can be replaced by CBDC without changing the allocation, in which case optimal monetary policy implements a version of the Friedman rule for money and the central bank balances its budget in present-value terms.

A still different class of model, the Lagos-Wright model, is the foundation for Davoodalhosseini (2022), who focuses on the policy mix between cash and CBDC in a stylized model. Observing that policymakers cannot observe household cash balances, the central bank is assumed to be able to conduct transfers to households based on their CBDC balances but not on their cash balances. The only policy that the central bank can implement with cash is to distribute the newly created cash evenly across all agents via an open market operation that exchanges CBDC for cash. While CBDC is more flexible as a policy instrument than cash, if it is assumed to be more costly to carry, the central bank faces a tradeoff. But if the cost of holding CBDC is not too high, better outcomes are achievable with CBDC than with cash.[69] Whether the

[67] The author allows for both an internal and external benefit of bank holdings of reserves, relative to deposit levels, with the latter standing in for possible systemic financial stability or market functioning benefits of reserves. The central bank absorbs liquidity management costs of banks through a subsidy on deposits.

[68] The paper generalizes the irrelevance result of Brunnermeier and Niepelt (2019) discussed above in section 4. As long as the private and public sectors are equally efficient in operating payment systems, and the central bank and the government have enough policy instruments at their disposal, a change in the composition of real balances in the household sector need not affect the equilibrium allocations (and portfolio shifts out of deposits and into CBDC do not endanger bank funding nor do they undermine bank intermediation).

[69] To better understand the results of Davoodalhosseini (2022), consider two schemes: a cash-only economy and a CBDC-only one. In the cash-only scheme, a negative inflation rate *would* be optimal, but such an equilibrium is not implementable because the central bank cannot force the agents to pay taxes on their cash balances, so zero inflation is the best outcome policymakers can achieve. (A positive inflation rate would lead agents to hold too little money, which is distortionary.) In contrast, in the CBDC-only economy balance-contingent transfers are

coexistence of cash and CBDC delivers higher welfare than the cash-only or CBDC-only schemes depends on the steepness of the tradeoff between them. In the author's calibration, if the cost of holding CBDC, relative to cash, is 0.25 percent of the transaction value, introducing CBDC can lead to a steady-state increase in consumption of 0.04 to 0.07 percent for Canada and 0.12 to 0.21 percent for the United States.

Finally, Minesso *et al*. (2022) develop a two-country DSGE model to examine the open-economy implications of CBDC for the transmission of shocks, optimal monetary policy, and welfare. In their model, CBDC amplifies the international spillover of shocks, because the introduction of tradeable CBDCs creates a new arbitrage condition that links interest rates, the exchange rate, and the remuneration of the CBDC adjusted for exchange rate risk. For the same remuneration, households would prefer holding CBDC relative to bonds because of the liquidity services that a CBDC provides that bonds do not. All else being equal, this strengthens the response of exchange rates to shocks, with foreign agents rebalancing more into CBDC than they would have into bonds, absent CBDC. In essence, the characteristics of CBDC—scalability, liquidity, safety, remuneration—sharpen the exchange rate channel of monetary policy through the uncovered interest parity condition by increasing the propensity of capital to flow internationally in response to shocks. The upshot is that the addition of CBDC could have significant effects on optimal monetary policy in the two economies and would enhance any asymmetries in the international monetary system: Issuance of CBDC by the domestic economy could hinder monetary policy autonomy in the foreign economy to some extent, depending on design features. It could also induce the foreign central bank to alter its monetary policy response to mitigate the stronger international spillovers created by the CBDC.[70]

feasible, which expands the set of implementable policies, rendering achievable the first-best outcome of negative inflation.

[70] The magnitude of these effects depends on the design of CBDC. Specifically, restricting the quantity of CBDC available to foreigners, limiting holdings, or reducing the appeal of the CBDC's remuneration with a tiered interest rate schedule, as proposed by Bindseil and Penetta (2020), would damp international spillovers, all else being equal.

5.3. CBDC and negative interest rates

Academics and policymakers alike have promoted *negative interest rate policy* (NIRP) as a means of creating more "policy space" for accommodation (Altavilla *et al.*, 2022; Bottero *et al.*, 2022; Heider *et al.*, 2019). Many of the effects of NIRP in standard macro models are similar to those typically associated with lowering the policy rate, including intertemporal substitution, portfolio reallocation into riskier assets, freeing up spending capacity through refinancing, increases in asset prices and wealth, and exchange rate depreciation (Campbell *et al.*, 2020).

Breaking through the ELB on nominal interest rates requires suppressing arbitrage between cash, which earns a zero nominal interest rate, and money in the bank, which *could* earn a negative interest rate, in principle. In the presence of cash, or a cash-like central bank liability earning zero return and no holding constraints, no other financial asset could yield a negative interest rate, because the holders could always arbitrage using a CBDC. Therefore, an unremunerated, elastically supplied CBDC would merely entrench the ELB (Panetta, 2022). Indeed, if the CBDC were non-interest-bearing, its introduction could *raise* the ELB, because CBDC does not bear the storage costs that currently apply to bank notes and that act as a tax on arbitrage with physical currency (Armelius *et al.*, 2018). This would exacerbate the ELB constraint on monetary policy.

Agarwal and Kimball (2015, 2019) present new options and review existing ones on how to eliminate the ELB, including employing a remunerated CBDC. In particular, the ELB on nominal interest rates can be overcome through a combination of, first, adopting or strengthening an electronic money standard in which electronic money, like CBDC, is the unit of account and, second, allowing the rate of return on paper currency to vary over time. Such an economy would be operating with two distinct fiat currencies simultaneously, albeit with a managed exchange rate. Then, as the interest rate on cash moves in line with the official policy rate, there is no arbitrage opportunity between cash and money. If the introduction of CBDC were to make a NIRP operational, it would add to the arsenal of policies that can enlarge the policy space in periods of low interest rates.[71]

[71] If the CBDC were non-interest-bearing, however, its introduction could actually *raise* the lower bound for interest rates, because it would not have to bear the storage costs that apply to currency, as noted by Armelius *et al.* (2018). This would exacerbate the ELB constraint on monetary policy.

There are, however, several legal, communication, and political challenges to overcome in order to implement an electronic money standard, as Agarwal and Kimball (2019) duly note. Moreover, such a regime would raise questions regarding which of the two currencies—physical cash or CBDC—would be the unit of account in the economy. Ultimately, the issue of whether all cash should be eliminated might need to be addressed, a step that could have implications for financial inclusion. Goodfriend (2016) and Rogoff (2016) both suggest that replacing cash altogether with a CBDC could make it easier to set a negative rate on central bank money. Perhaps so, but Americans have demonstrated a fondness for currency. For example, the United States has not eliminated the penny, as other countries such as Canada have done, despite the fact that it costs well over one cent to mint each penny. And even the suggestion of eliminating the dollar bill to promote the use of a dollar coin has been greeted with hostility.

6. Concluding remarks

This paper has reviewed the potential macroeconomic implications of the introduction of a central bank digital currency (CBDC), according to the academic literature on the subject. We considered the list of benefits that proponents argue a CBDC could render, including reduction of some of the financial frictions in deposit or loan markets; enhanced efficiency of payments; improved financial inclusion of the unbanked; elicitation of private-sector technological innovations in banking and payments; and improved transmission of monetary policy. In broad terms, our tentative conclusion is that the prospects for improvements along these lines in many cases are significant, although there are uncertainties and tradeoffs to be weighed.

We traced the mechanisms through which a CBDC might work: via changes in the structure of banking; by altering the implementation of monetary policy; by way of modifications in the incentives to bear or respond to risks; and ultimately on the transmission of monetary policy through the economy. 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 sales 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 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.

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, and its rate of remuneration could serve as an additional policy tool. Our reading of the literature suggests that a remunerated, intermediated, widely available CBDC has the prospect of garnering 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. There are enough uncertainties and contingencies that it seems likely that there will always be an element of a leap of faith in any decision to move forward.

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Appendix A: CBDC and the lessons from ON RRP

If a CBDC were account-based, interest-bearing, and intermediated, it would be much like the current reserve system in the United States, except that a CBDC would presumably allow nonbank counterparties to directly hold Fed liabilities in digital form.

The existing Overnight Reverse Repurchase Agreement (ON RRP) facility already provides nonbank financial firms direct access to the central bank in the form of Treasury-backed repos. Introduced in 2013, the ON RRP facility allows money market funds (MMFs) to deposit funds overnight with the Fed at an administered rate, which is below the rate on balances held at the Federal Reserve Banks (IORB).[72] Operationally, take-up in the ON RRP facility transforms reserves held by the banking sector into Treasury reverse repos held by ON RRP counterparties, keeping the overall size of the System Open Market Account portfolio unchanged. By offering those institutions that are ineligible to earn IORB—a highly liquid risk-free investment—access to the ON RRP facility, the Fed provides a floor on money market rates in an environment of ample reserves, thereby supporting the implementation of monetary policy.

The main purpose behind the ON RRP's introduction was not to create an alternative CBDC, but rather to support interest rate control. Even so, the similarities between the ON RRP facility and an account-based, interest-bearing, intermediated CBDC can help us understand how the introduction of a CBDC might affect the banking sector, the implementation and transmission of monetary policy, and financial stability. In this appendix we discuss how the design features of the ON RRP might relate to a theoretical CBDC, along with the main differences between the ON RRP and a CBDC.

Design features of the ON RRP and their implications

As with CBDCs, one concern with the ON RRP facility has been its potential to crowd out financial firms' liabilities such as deposits. Two important design features of the ON RRP limit the scope of disintermediation and are thought to be stabilizing during times of market stress: an ON RRP rate that is below the monetary policy rate, and individual and aggregate caps on take-up.

In the current operating framework, the ON RRP rate is at (or just above) the bottom of the target range for the federal funds rate, while IORB is at (or just below) the top of the target range. Setting a relatively low ON RRP rate 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, limiting its direct effect to very safe funding instruments that offer interest near or below the floor of the target range for the federal funds rate. The ON RRP directly competes with private overnight repo backed by Treasuries and provides cash investors with an outside

[72] Eligible ON RRP counterparties include banks, government-sponsored enterprises, and sufficiently large SEC-registered 2a-7 funds (that is, registered MMFs).

option that sets a lower bound on money market rates. And while research has shown that take-up in the ON RRP can crowd out private repo, and that the demand for safe assets can increase ON RRP take-up at the expense of private repo, the overall impact on the banking sector so far has not led to a significant contraction in bank deposits or bank lending.[73] That said, the effect on the banking sector could change as short-term interest rates increase and the Federal Reserve's balance sheet contracts.

The ON RRP facility also imposes individual counterparty and aggregate caps on take-up. While the specifics have changed since inception, the caps were designed, in part, to temper any surge in take-up in times of market stress and thereby limit individual firms' reliance on the facility as a stop gap.[74]

Differences between ON RRP and CBDC

The similarities between CBDC and ON RRP notwithstanding, there are potential differences between how the ON RRP facility operates relative to a hypothetical CBDC that are important for drawing lessons from the ON RRP experience.

First, the ON RRP facility is not intended for counterparties to make payments. Even if the use of MMF shares for payments was commonplace, these payments would still rely on the banking-sector's existing payments system, in part because of the lack of direct convertibility between MMF, ON RRP take-up and reserves. Thus, the ON RRP facility does not provide the direct transaction services that are among the purported benefits of the introduction of a CBDC.

Second, MMFs that participate in the ON RRP facility hold other assets, and thus the take-up of ON RRP is an equilibrium choice by MMFs that depends on market rates and alternative investments. MMFs' broad set of investment opportunities allows for arbitrage between rates, contributing to the facility's role as an effective floor for short-term funding rates. It is not clear whether an account-based intermediated CBDC, similar to the ON RRP, would allow its intermediaries the same dynamic flexibility. Specifically, an intermediated CBDC that requires intermediaries to only hold central bank liabilities—that is, a "narrow CBDC," akin to a narrow banking system—implies a tighter link between intermediaries' activities and the central bank's balance sheet, reducing overall flexibility. In addition, a narrow CBDC could make it harder to stabilize the price of reserves relative to CBDC, as it would depend either on CBDC holders' ability to convert CBDC into cash or reserves (*i.e.*, direct convertibility) or on arbitrage between reserves and CBDC intermediaries' liabilities. In contrast, a CBDC intermediary that is allowed to hold other classes of assets would be more flexible and could directly engage in arbitrage

[73] See Anderson and Kandrac (2017) for evidence on how the ON RRP facility crowds out private repo liabilities and Infante (2020) on how take-up at the ON RRP facility increases, and private repo decreases, as the demand for short-term money-like assets increases, which is also suggestive of substitutability between the two.

[74] The aggregate cap on the ON RRP was removed in December 2015 to support the increase in the target range of the federal funds rate. The individual counterparty cap has increased since the facility's inception and now stands at $160 billion. To date, significant flight-to-quality concerns have not materialized.

between CBDC and those other assets, much in the same way MMFs invest in the ON RRP and other asset classes such as private repo, making the ON RRP rate an effective lower bound on money market rates. However, tight regulations may be required to reduce the maturity or credit transformation that would otherwise occur in CBDC intermediaries' asset holdings.

Appendix B: On the international experience with CBDC

The advent of distributed ledger technologies, and their potential to fundamentally change payments systems, has spurred worldwide interest among central banks on the subject of CBDCs. According to a 2021 BIS survey of 81 central banks, 86 percent were actively researching the potential for CBDCs, 60 percent were experimenting with the technology, and 14 percent were deploying pilot projects.[75] In addition, to date there are four CBDC programs in 11 jurisdictions—all in emerging market economies—that are currently active, and two jurisdictions that have attempted to implement a CBDC but cancelled their plans.[76] While the motivations behind the creation of a CBDC differ across jurisdictions, studying how a range of central banks have considered CBDCs can give insights into their potential and pitfalls. At the same time, these insights should be taken with caution, as each jurisdiction faces a unique set of challenges and economic realities, making it difficult to draw general conclusions.

In this appendix, we first discuss some of the different reasons behind the introduction of a CBDC. We then dig a little deeper, exploring the cautionary tale of the Ecuadorian CBDC initiative that was launched in 2014 and subsequently failed in 2018.

Motivations behind CBDC

Countries that have explored the implementation of CBDC have expressed various reasons for doing so. The BIS has conducted four surveys across a growing list of central banks in advanced and emerging economies regarding their motivations, current expectations, and the legal authority to implement CBDC.[77] In general, these surveys have found that central banks are particularly interested in weighing the potential for retail CBDCs, either distributed directly or via intermediaries. The surveys show that emerging market economies were motivated by the potential for CBDC to improve payments efficiency and safety, as well as to promote more financial inclusion; advanced economies indicated their main motivation was the safety of their payments system. More recently, there has been a growing impetus toward understanding the prospects for CBDC to improve cross-border payments.

Some jurisdictions have expressed interest in CBDC for more defensive reasons. For example, the Sveriges Riksbank has been assessing how their CBDC, known as the e-krona, might be able to address the secular decline in the use of cash, which may be contributing to the exclusion of some of the Swedish population—a so-called "digital exclusion." Similarly, the People's Bank of China is developing a publicly provided electronic payment system (e-CNY) to mitigate the risks from the public's reliance on private-sector digital platforms such as Alipay

[75] See Kosse and Mattei (2022) and https://www.bis.org/about/bisih/topics/cbdc.htm.

[76] An interactive map tracking CBDC initiatives across the world can be found at https://www.atlanticcouncil.org/cbdctracker/.

[77] Summaries of previous survey results can be found in Barontini and Holden (2019), Boar *et al.* (2020), and Boar and Wehrli (2021).

and WeChat Pay, which have proliferated in China. These efforts have been in conjunction with other regulatory oversight measures on these platforms to reduce the risk of bank disintermediation.[78]

The case of Ecuador's "dinero electronico"

Arauz *et al.* (2021) detail the experience of Ecuador, a dollarized economy that operated a CBDC program between 2014 and 2018, called "dinero electronico" (DE). DE was a voluntary mobile payment system developed by the Banco Central del Ecuador (BCE) to allow citizens to transfer money in real time from person to person. Before its introduction, it was estimated that 82 percent of payments in Ecuador were settled in cash and only 10 percent in bank transfers. Policymakers sought to extend the country's domestic electronic payment system to improve financial inclusion. With just an identity card and a cell phone (not necessarily a smartphone), citizens could access the network via cell phone lines through one of the nationwide carriers. Accounts were denominated in USD, the country's official currency, and were backed by dollar-denominated assets held by the BCE.

DE was launched in 2015, with citizens being allowed to add money to their accounts much in the same way they would make deposits at a bank to enable the use of checks or debit cards. Transactions were made in a real-time gross settlement system with associated fees that were competitive. Between 2016 and 2017, the number of users increased sevenfold, from approximately 50,000 to 400,000 users.

Despite its rapid growth, DE was terminated at the end of 2017. Several criticisms of DE contributed to its demise. Among these were that DE was not able to facilitate cross-border payments, that it facilitated criminal activity, that it could be used as a surveillance program, and that it might incentivize the government to force payments in DE. It also did not help that private banks were opposed to the program. While some of these criticisms were contested, the list does highlight that the BCE wrestled with many of the same issues that other jurisdictions currently face. From this experience, Arauz *et al.* (2021) conclude that the presence of network externalities from a superior technology does not ensure widespread adoption. Success of a CBDC will necessarily be judged on a multifaceted basis, one that includes elements of political economy and trust in government.

[78] See Auer *et al.* (2020) for more details on foreign central banks' motivations to implement a CBDC.