Broadening Narrow Money: Monetary Policy with a Central Bank Digital Currency*

Jack Meaning,[a] Ben Dyson,[b] James Barker,[a] and Emily Clayton[a]
[a]Bank of England
[b]Bank for International Settlements Innovation Hub

This paper discusses central bank digital currency (CBDC) and its potential impact on the monetary transmission mechanism. We first offer a general definition of CBDC which should make the concept accessible to a wide range of economists and policy practitioners. We then investigate how CBDC could affect the various stages of transmission, from markets for central bank money to the real economy. We conclude that monetary policy would be able to operate much as it does now, by varying the price or quantity of central bank money. Transmission may even be strengthened for a given change in policy instruments.

JEL Codes: E42, E52, E58.

1. Introduction

The feasibility and desirability of central banks issuing their own fiat versions of digital currencies has been the focus of a growing debate in recent years. Numerous central banks around the world are researching the topic, including the Bank of Canada (2017), the European Central Bank (Lagarde 2020), the People's Bank of China (2020), the Sveriges Riksbank (2021), and the Bank of England (2020). The policy community is being aided by the wider academic community—for instance, Bjerg (2018), Bordo and Levin (2019),

*We would like to thank John Barrdear, Andrew Hauser, Charles Kahn, Michael Kumhof, and Andrew Levin for a number of informative discussions. We also thank two anonymous referees for their helpful comments. The views here represent those of the authors only and should not be interpreted as an official position of the Bank of England in any way. Corresponding author e-mail: jack.meaning@bankofengland.co.uk.

Eichengreen (2019), and projects such as the Massachusetts Institute of Technology's Digital Currency Initiative. Despite this, the literature remains in relative infancy, with consensus around some fundamental issues only slowly beginning to form. What is more, the very concept of a central bank digital currency can appear inaccessible to economists who are not familiar with blockchain, distributed ledger technology, or similar terminology.

A first contribution of this paper is therefore to offer a general definition of central bank digital currency (CBDC) around which consensus can build and which, importantly, should feel familiar to anyone with a basic understanding of the monetary process. We define central bank digital currency as *any electronic, fiat liability of a central bank that can be used to settle payments, or as a store of value.*

By this definition, a CBDC must be both electronic and a central bank liability. But beyond this, there are important policy choices to be made around key design parameters which are under the control of the central bank. These include the range of counterparties that have access to CBDC; whether CBDC will be freely convertible for other kinds of central bank money and/or commercial bank deposits; and whether CBDC is interest bearing. We explore each of these parameters in more detail in this paper. The optimal setting of each will depend on what the policymaker is seeking to achieve with CBDC, and so is intrinsically linked to their policy objectives.

Under the general definition given above, CBDC already exists in the form of central bank reserves (which are electronic liabilities of the central bank). CBDC could therefore be viewed simply as electronic narrow money. But access to central bank reserves is usually granted to a limited range of counterparties, primarily banks. Introducing a universally accessible CBDC is conceptually equivalent to broadening access to central bank reserves to the widest possible range of domestic counterparties, including nonfinancial businesses and households.

This broadening of narrow money is not without potential complications. Banks are currently given privileged access to central bank money because they play a key role in both the payments system and the transmission of monetary policy. Importantly, central banks use access to central bank reserves, the interest paid on those reserves, and the creation of new reserves as fundamental tools of monetary policy. Consequently, it is important to analyze the effects of widening access to electronic central bank money on the implementation and transmission of monetary policy.

This paper explores the impact of introducing CBDC on monetary policy. After discussing a range of potential design parameters, we focus on a specific form of central bank digital currency which is universally accessible, interest bearing, and freely convertible for other forms of central bank money and commercial bank deposits. We explore how CBDC might affect the implementation of monetary policy decisions and the channels, speed, and strength with which those decisions are transmitted to the real economy, focusing on two key tools in the current monetary policy toolkit: (i) changes in policy rates and (ii) asset purchases (in the style of quantitative easing).

While it is difficult to make definitive, quantitative statements at this stage about the impact of CBDC, our analysis leads us to the broad conclusion that a universally accessible, interest-bearing, freely convertible CBDC could be used for monetary policy purposes in much the same way that central bank reserves are now. On the margin, there may even be reason to believe that the monetary transmission mechanism would be stronger for a given change in policy instruments.

The rest of the paper is laid out as follows. In section 2 we elaborate on our general definition of CBDC. In section 3 we discuss the various design choices that a central bank can make, and specify the benchmark model that will be the basis for our analysis in later sections. Sections 4 and 5 discuss the likely impact of CBDC on the monetary transmission mechanism, from the control of CBDC rates by the central bank to the channels through which this affects the real economy. Section 6 considers central bank asset purchases with CBDC. Section 7 briefly discusses some of the key financial stability risks introduced by CBDC, and section 8 concludes.

2. Defining Central Bank Digital Currency

The term *central bank digital currency* is currently used to refer to a wide range of potential designs and policy choices, with no single commonly agreed definition. This is, in part, due to the fact that the concept sits at the nexus of a number of different areas of research and brings together topics as diverse as computer science, cryptography, payments systems, banking, monetary policy, and financial stability. As a result, the debate around CBDC may at times appear opaque to economists who are not familiar with cryptocurrencies, blockchain, and distributed ledger technology (DLT).

As a response, we offer a general definition that is both an accurate representation of CBDC and stated in terms that will be familiar to any economist with a basic understanding of the monetary process. It is our hope that this will remove any perceived mystique around CBDC and promote wider discussion of CBDC among economists.

To that end, we define a central bank digital currency simply as *an electronic, fiat liability of a central bank that can be used to settle payments or as a store of value.* It is in essence electronic central bank—or "narrow"—money.

This definition sits within a number of wider definitions of money and digital assets. Bordo and Levin (2017) define a digital currency as "an asset stored in electronic form that can serve essentially the same function as physical currency, namely facilitating payments transactions." Our definition simply adds to this the condition that the asset in question is a fiat liability of the central bank. It can also be viewed within the framework of the "money flower" of Bech and Garratt (2017) that looks to define and classify a range of money-like assets according to four characteristics: electronic; central bank issued; peer-to-peer exchange; and universally accessible. Within the money flower representation, our definition of CBDC is depicted by the four core segments incorporating both retail and wholesale central bank cryptocurrencies, settlement or reserve accounts with the central bank, and deposited currency accounts.[1]

Beyond two inherent characteristics (i.e., that CBDC must be both electronic and a central bank liability), we leave our definition of CBDC deliberately general. This is because central banks must make a number of design choices which could give rise to different forms of CBDC (Bank for International Settlements 2018). While there remains considerable uncertainty around the optimal

[1]The analysis within Bech and Garratt (2017) goes on to focus on the subset of money that is based on cryptographic technology, and so discusses central bank *crypto*currencies—CBCC rather than CBDC.

setting of these design parameters, a general definition allows for a structured discussion without limiting the possibilities open to policymakers. Key policy choices that we will consider below include the range of counterparties that have access to CBDC; whether CBDC is freely convertible for other kinds of central bank money and/or commercial bank deposits; and whether CBDC is interest bearing.

This general definition also provides a framework by which any future research can define the subset of CBDC to which it refers and assess how its conclusions may vary were those parameters to be set differently. We therefore see this as an important contribution of our paper.

By this definition, one form of CBDC already exists and sits at the heart of the monetary system in most economies: central bank reserves are both electronic account balances and a fiat liability of the central bank. A number of studies, including He et al. (2017), implicitly assume the same in their analysis.

3. Design Characteristics of CBDC

The optimal design of a specific model of CBDC will depend on a central bank's motivation for introducing it. In central bank discussions to date, these motivations fall into four categories. First, CBDC could support monetary policy by strengthening existing tools or introducing new ones. Second, CBDC may have financial stability benefits, by serving as a risk-free asset for those who are not covered by deposit insurance, or by encouraging greater settlement in central bank money and eliminating settlement and credit risk from the payment system. Third, in economies where the use of cash is rapidly declining, such as Sweden, CBDC can be seen as a way of preserving public access to central bank money and safeguarding a critical national payments system. Finally, in countries where a higher proportion of the population is unbanked, CBDC may increase financial inclusion by providing universal access to electronic payments. The following parameters must be set according to these motivations and the central bank's wider objectives.

3.1 Access

One of the key parameters that policymakers would have to decide on is the range of counterparties that have access to CBDC. A CBDC may be universally accessible—in other words, it can be held by anyone for any purpose—or access may be restricted to a limited subset of economic agents, or for limited purposes.

Some authors—for instance, Fung and Halaburda (2016) and Bjerg (2017)—identify universal access as a fundamental characteristic of any CBDC. This view derives from a definition of *currency* as something that must be able to be held by anyone. However, it is possible that central banks may issue a CBDC that is available only to a subsector of the economy, such as a "retail CBDC" for households and nonfinancial businesses only, or a "wholesale CBDC" which can be used as a settlement asset in financial markets by firms that do not currently have access to central bank reserves (Bech and Garratt 2017). The question is then a semantic one about whether a CBDC that is *not* universally accessible could still be considered a central bank digital *currency*. In fact, the European Central Bank initially chose to use the broader term "digital base *money*" (Lagarde 2020), which we find to be more accurate, but for consistency we will stick with the more widely used term "CBDC."

The optimal degree of access will depend on the policy objective of the central bank. For example, central banks that introduce CBDC for financial inclusion objectives would be best to extend access as widely as possible, especially among households. However, if the purpose of CBDC is to ensure a safe and efficient payments system, consistent with the objectives of many central banks, then it could be argued that a CBDC with narrow access, such as the reserves systems employed currently in many economies around the world, is sufficient, especially in economies with efficient and secure banking and financial infrastructure. Since the financial crisis of 2007–09 a number of central banks, including the Bank of England (Bank of England 2015), have undertaken projects to widen access to central bank money to broker-dealers, central counterparties, and others, in order to improve financial stability. This suggests that if financial stability were the motivation for introducing CBDC, then the optimal level of access would include a wider range of financial institutions than just the banking system, but would probably fall short of universal access.

3.2 Interest Bearing

A second important policy choice is whether CBDC is interest bearing. An interest-bearing CBDC might pay positive, zero, or even negative rates at various points in the economic cycle. The arguments in favor of paying interest on short-term central bank liabilities have their origins in Friedman (1960), who argued that they should pay a rate of interest equivalent to the risk-free rate to ensure that the opportunity cost of holding money is equal to the marginal cost of its production. A CBDC with a variable interest rate could be used as the main instrument of monetary policy, set in order to guide the macroeconomy and to stabilize inflation and output.

A central bank may want to pay different rates to different types of holders of CBDC. For instance, it may wish to pay different rates to banks and nonbanks (including households), because banks play a special role in the transmission of monetary policy and the economy more widely. Banks create money and purchasing power in the economy (McLeay, Radia, and Thomas 2014), and we would expect them to continue to create the marginal unit of money even with a universally accessible CBDC. Paying different rates to banks and nonbanks would allow monetary policy to influence banks—and therefore credit and money creation—differently to nonbanks. For instance, the spread between the rate paid to banks and nonbanks could be used as a monetary policy tool in itself, the implications of which will be briefly explored in section 4.1.

Determining the stance of monetary policy is not the only reason one might pay interest on CBDC. If CBDC is not being used as an instrument of monetary policy per se, policymakers may still want to pay a variable rate of interest in order to regulate demand for CBDC. In this context, CBDC would require two different rates. The interest rate paid on CBDC held by banks would be used to set the stance of monetary policy (just as the rate on reserves is used today), whilst the interest rate on CBDC held by nonbanks could be used to regulate demand for CBDC. Lowering the "nonbank rate" in times of financial stress may help to limit demand for

CBDC and mitigate risks to financial stability from a "digital bank run" (Barrdear and Kumhof 2016).

Some writers have proposed using a negative rate on CBDC, alongside the complete withdrawal of physical cash, as a way of circumventing the zero or effective lower bound on monetary policy. Kimball and Agarwal (2015), Goodfriend (2016), and Rogoff (2016) all suggest that replacing cash with a CBDC could make it easier to set a negative rate on central bank money and thus alleviate the lower bound on interest rates. However, as recognized by these authors, the removal of cash is not a necessary consequence of CBDC and while one may have a bearing on the other, the two policies should be assessed on their own merits. In this paper we do not assume, nor advocate, the removal of physical central bank money.

Were CBDC to be non-interest bearing, it would be closer in spirit to central bank notes. Fixing the rate on CBDC permanently at zero would mean that it could not be used as a monetary policy tool. But if the objectives of the policymaker were to improve payment efficiencies and financial inclusion, it is not essential that a CBDC pays interest. As noted by Armelius et al. (2018), though, a non-interest-bearing CBDC could actually raise the lower bound for interest rates, because it does not bear the storage costs that currently apply to bank notes. This would worsen the constraint on monetary policy, so any benefits to payments would need to be weighed against this cost.

3.3 Convertibility

A third policy choice concerns whether CBDC is freely convertible for (i) other forms of central bank money, namely reserves and cash, and (ii) commercial bank deposits. It is common practice for central banks to allow free convertibility at par (1:1) between their different types of liability (so that £10 of reserves can always be exchanged for £10 of cash). There are clear incentives for central banks to continue with this approach under a CBDC, in order to ensure monetary stability. In this setup the central bank can set the overall size of the monetary base (for example, through asset purchases), but it cannot directly set the composition of liabilities within it (as this is determined by the preferences of banks and nonbanks to hold different types of central bank liability).[2]

However, a number of authors have suggested breaking with this convention, particularly in the context of CBDC. For instance, Kimball and Agarwal (2015) and Assenmacher and Krogstrup (2018) outline a framework in which a flexible exchange rate can be operated between cash and electronic central bank money in order to impose an effective negative interest rate on cash and overcome the lower bound. But such a system would mean that the economy would be operating with two distinct fiat currencies simultaneously, albeit with a managed exchange rate. We doubt that this would be plausible in practice. For instance, it would raise significant questions around which of the two currencies—physical cash or CBDC—would be the unit of account in the economy. Establishing and securing the unit of account is one of the most fundamental roles of a central bank, and so this risk should not be lightly dismissed.

It is also convention that commercial bank deposits (in the form of demand deposits) and central bank money are freely convertible at par. Kumhof and Noone (2018) suggest that ending this convention, so that deposits could not be freely converted into CBDC at par, would help to eliminate the financial stability risks that CBDC may introduce. In our view, the ability of depositors to exchange commercial bank money for central bank money on demand is fundamental in maintaining the confidence in bank deposits, and many of the activities of the monetary authority (such as lender of last resort, liquidity regulations, and deposit insurance) are geared toward ensuring that this is always possible. In fact, we would consider it a necessary part of establishing a stable monetary framework in which CBDC and bank deposits coexisted and exchanged at parity (i.e., 1:1) (Bjerg 2018).

[2]This is a central feature of the par convertibility of central bank liabilities even now: the central bank can choose to inject reserves into the banking system, but if there is a surge in demand for central bank notes, then they must allow the stock of notes to increase while the stock of reserves falls, or else inject additional reserves, expanding the monetary base. The alternative is that the increased demand for notes goes unmet and the price of a note changes relative to the price of reserves, breaking parity between different types of central bank money and undermining monetary stability.

3.4 Technology

More practical design choices relate to the technology used to power a CBDC, in particular whether a CBDC should use distributed ledger technology or more established technologies, such as those currently used for existing central bank real-time gross settlement systems. Importantly, this highlights a distinction between a central bank digital currency, which can be based on a variety of technological options, and a central bank *crypto*currency, which by definition is based on cryptographic technology, such as distributed ledgers. While Danezis and Meiklejohn (2016) advocate the use of distributed ledger technology, Scorer (2017) argues that this would not be necessary, even though distributed ledgers may have advantages over centralized ledgers in specific areas—for example, around resilience.[3] However, the technology is still considered to be too immature to power a critical national payment system such as the Bank of England's Real-Time Gross Settlement system (Bank of England 2020).

3.5 Our Benchmark Model of CBDC

Our primary interest in this paper is a CBDC in the context of monetary policy. For most of the analysis that follows we will therefore focus on a particular design of CBDC intended to be used as part of the monetary policy toolkit. Setting the parameters discussed above with this in mind, we consider a CBDC that is universally accessible, interest bearing, and freely convertible to other forms of central bank money and to commercial bank deposits.

We assume free convertibility, at par, for the reasons discussed in section 3.3: without convertibility between its own liabilities, the central bank would be managing multiple distinct fiat currencies, and without convertibility between central bank money and deposits, the central bank risks undermining confidence in the value of those deposits. A consequence of free convertibility between CBDC and deposits is that the impact of a customer withdrawing CBDC on the banking sector's balance sheet is identical to that of a cash

[3]Benos, Garratt, and Gurrola-Perez (2017) evaluate distributed ledger technology in relation to securities settlement and suggest that it has the potential to improve efficiency and lower the costs of trading in these markets, but also highlight the current immaturity of the technology.

withdrawal. When the depositor requests to withdraw CBDC from their deposit account, the commercial bank would reduce the balance of the depositor's account and transfer CBDC across the central bank's balance sheet to the depositor's CBDC account. The banking sector's balance sheet shrinks by the amount of the withdrawal (since reserves/CBDC are removed from its assets while deposits are deducted from its liabilities), whilst the depositor has simply swapped one asset (deposits) for another (CBDC), with no overall change in the size of their balance sheet. Nonbanks are able to convert (freely and at par) between bank deposits and cash (via a cash withdrawal) or between bank deposits and CBDC (via a withdrawal to a CBDC account). Banks are able to convert freely between CBDC (fulfilling the role played by reserves) and cash.

Banks can also convert bonds and other eligible collateral into CBDC, either by selling those assets to the central bank (outright purchases) or using them as collateral to borrow CBDC (through repos). In theory the central bank could allow any economic agent to undertake such transactions and change the aggregate supply of CBDC. However, in practice, this would require central banks to deal with a much wider range of counterparties, with the risk and operational burden that that implies. We therefore assume that for practical reasons, only banks could trigger the creation of new CBDC (in aggregate) by exchanging assets with the central bank. Section 6 discusses the exception to this rule, considering the scenario in which nonbanks are allowed to sell assets directly to the central bank in exchange for newly issued CBDC through programs in the style of quantitative easing.[4]

We assume universal accessibility to take our position to its extreme. As stated already, a limited-access version of CBDC exists already in the form of reserves. Therefore, by comparing the current environment with one with universal access, we can get some sense of an upper bound to the various effects we will discuss below. It is worth being explicit here that we do not assume that reserves coexist alongside a new CBDC. Rather, we assume there is a single, universally accessible CBDC that is available to banks, households,

[4]Again, it should be noted that a number of central banks are currently reviewing who has access to their balance sheet.

and corporates equally, thus replacing reserves as an asset for banks and acting as a new asset for other sectors of the economy.[5]

As our focus is on monetary policy implementation, we assume the monetary authority wants to use CBDC to guide monetary conditions. Therefore, our benchmark CBDC is interest bearing. More specifically, we assume that the central bank uses the interest rate on CBDC as the primary instrument by which to influence other rates in the economy and fulfill its objective to stabilize the macroeconomy. This setup allows us to explore the monetary policy implications when all sectors of the economy can hold CBDC and can respond to changes in interest rates by switching from CBDC to deposits or vice versa. For the most part, we assume that a single rate is paid on all forms of CBDC (i.e., to both banks and nonbanks) and are explicit where we do not.

Beyond assuming that CBDC is practically feasible, we have chosen to take a technology-agnostic approach for the model of CBDC used in this paper. However, even abstracting away from technological choices, some decisions on practical matters are necessary to understand whether CBDC would be widely used. In our benchmark model we assume that the central bank would provide the underlying payments platform for CBDC but would not deal directly with members of the public. Instead, it would allow private-sector firms, such as financial technology firms, payment institutions, or banks, to identify customers, register CBDC accounts on their behalf, and provide the customer interface and customer services related to CBDC accounts. These firms would be responsible for administering CBDC accounts but would not take custody of the CBDC itself, ensuring that CBDC remained a liability of the central bank to the end user, rather than to an intermediary. We assume that the payment services available to CBDC account holders would be comparable to those available to holders of bank deposits, and that the CBDC and deposit-based payment systems would be interoperable (so that any deposit account could make a payment to any CBDC account and vice versa). This means that CBDC would serve as a close—but not perfect—substitute for bank deposits. This point is crucial: as

[5]Making a CBDC universally accessible to nonresidents as well as residents could have implications on capital flows and the exchange rate. These are complex issues that we do not address in this paper.

discussed by Broadbent (2016), if CBDC only serves as a substitute for central bank notes, then the composition of central bank liabilities and private-sector assets changes, but beyond some minor implications for seigniorage, the monetary policy implications are negligible.[6] However, once CBDC starts to offer services similar to bank deposits, there will be an impact on the quantity and price of bank funding, with more interesting implications for monetary policy. Importantly, we assume that CBDC accounts would not offer credit facilities, such as overdrafts, to the vast majority of users, although the central bank would still be able to lend CBDC to certain financial institutions, as it does with reserves today.

4. Controlling the Interest Rate on Central Bank Money

The core of modern monetary policy is the ability to set and guide interest rates in the market(s) for central bank money. Traditionally this has been done in one of two ways, shown in figure 1. In a corridor (or channel) system the central bank sets the quantity of reserves such that the secondary (interbank) market for reserves clears at the target rate. Alternatively, in a floor system the central bank expands the supply of reserves to at least satiate demand. To pin down this demand, the central bank pays a rate of interest on balances, or at least a proportion of balances, held with it overnight (Goodfriend 2002).

Conceptually, very little would change to either of these frameworks if access to reserves were expanded to a universally accessible, interest-bearing CBDC (see figure 2). In a corridor system the central bank could still control the supply of central bank money such that the short-term unsecured borrowing rate for central bank money cleared at the target level. Equally, in a floor system the central bank could expand the quantity of CBDC such that demand was satiated, with CBDC balances being remunerated at a given rate.

One notable difference, however, would be that the market for electronic central bank money would now have a much wider range

[6] The impact on seigniorage could be positive or negative depending on (i) the interest rate paid on CBDC (if any) and (ii) the relative cost of producing CBDC versus the costs of producing the equivalent amount of cash (including fixed and marginal costs). We discuss this more in section 4.

Figure 1. Secondary Market for Central Bank Money without a CBDC

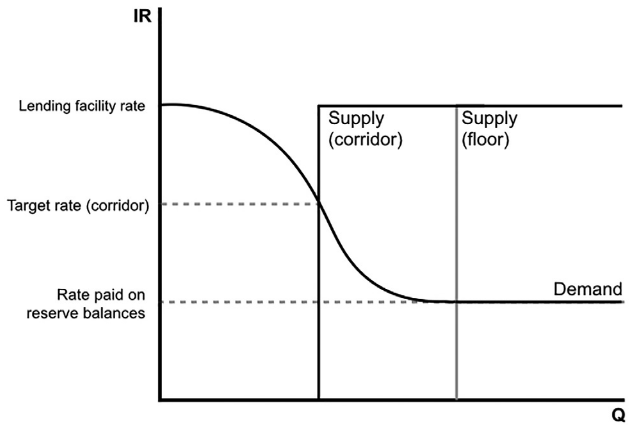
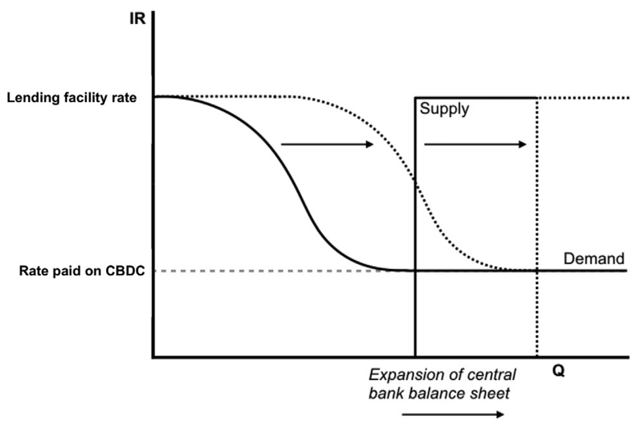


Figure 2. Secondary Market for Central Bank Money with a CBDC



of potential participants, since CBDC would allow electronic central bank money to be held by all agents rather than just commercial banks. These participants may also have a much wider range of motivations for holding, lending, and borrowing CBDC.

A first consequence of this is that the demand curve for electronic central bank money would shift to the right. How far it would shift would depend on the setting of the parameters discussed in section 3 and the extent to which CBDC is a substitute for bank deposits. Assuming that CBDC is freely convertible for deposits, and is integrated into the existing deposit-based payment systems, significant demand for CBDC could come from those who currently hold deposits. This demand could be limited, in the case of households, by the fact that their deposits are covered by deposit insurance, so that there is no significant difference in credit risk between deposits and CBDC. In contrast, for private-sector and nonbank financial corporations, which are not covered by deposit insurance, CBDC offers an asset that has the same payment characteristics as deposits but without any credit risk, and so may be more attractive. Both of these sources of demand for CBDC are likely to be sensitive to the spread between rates paid on CBDC and rates paid on deposits.

Under a corridor system, any change in demand for central bank money would need to be accommodated to ensure that the secondary market continued to clear at the market rate. All else equal, this would imply that the size of the central bank balance sheet would be larger in light of increased demand.

Under a floor system, to maintain the interest rate on CBDC as the relevant policy rate, the central bank would only need to expand supply to the point where aggregate demand continued to be satiated. However, in economies that have implemented large quantitative easing programs, the total expansion in the balance sheet may be less than the total new demand for CBDC from the nonbank sector. QE often results in the banking sector (in aggregate) holding more reserves that it desires, because—prior to the introduction of CBDC—there is no other sector which can hold reserves, and so no way for the banking sector to reduce its aggregate holdings. The introduction of CBDC, which can be held by both banks and nonbanks, would enable banks to divest themselves of unwanted CBDC balances—for example, by buying assets from the nonbank sector in exchange for CBDC. This would allow banks to reduce their holdings of CBDC to the point of inflection in the original demand curve, in the process meeting some of the new demand for CBDC from the nonbank sector. The total increase in the central bank's balance sheet will therefore be equivalent to the new demand for CBDC from the nonbank sector, minus any undesired reserves/CBDC that the banking sector chooses to sell to the nonbank sector (and minus any substitution by the nonbank sector from physical cash into CBDC).

A second consequence of a universally accessible CBDC is that the demand curve would now be subject to a wider range of shocks. The factors that would drive demand for CBDC from corporates, nonbank financial institutions, and households may be different than those that affect the demand of banks. If these new factors and the shocks moving them were positively correlated with those that already affect the traditional market participants, then this, combined with larger absolute balances, would make the demand curve for CBDC less stable than the current demand curve for reserves. In turn, this would mean that a corridor system would require more active management and monitoring by central banks and could potentially lead to a more volatile balance sheet size. Conversely, if the shocks affecting new market participants were negatively correlated with those of existing participants, the demand curve could actually become more stable, as there would now be a deeper market that could smooth the idiosyncratic deviations of different participants. What is more, even if the demand from new participants was volatile, that would not necessarily mean it was less predictable than currently. Demand for cash is subject to large seasonal swings in demand, but central banks are able to manage these relatively easily, as they are often predictable and based around weekends, holidays, or similar shifts in spending. Whether the demand curve for CBDC would be more or less difficult to manage is ultimately an empirical question, though one that is hard to answer ex ante. Its practical importance, however, makes it a high priority for future research.

Universal-access CBDC would also have implications for the extent to which the interest rate paid on central bank money could act as an effective floor to other interest rates. A number of central banks employing floor systems have observed market rates falling below the interest rate paid on overnight balances at the central bank. One of the main causes of this is the tiered access to the central bank's balance sheet in these economies. In a floor system, when only a limited number of agents have access to the central bank's balance sheet and are paid interest on their balances held there, those agents who do not have access or do not receive interest are willing to lend funds overnight for less than the rate paid by the central bank, making the floor less effective (Keating and Machiavelli 2018). Giving everyone access to the central bank's balance sheet via a universally accessible CBDC and paying all market participants a rate of interest would better ensure that no one is willing to lend for a rate lower than the floor, making the floor a more effective constraint.

The Federal Reserve's Overnight Reverse Repo Program (ONRRP) provides a useful test case for the potential benefits of a universally accessible CBDC. In 2013 the Federal Reserve widened access to central bank liabilities by allowing a range of nonbank money market investors to participate in the ONRRP. Prior to this, short-term rates in money markets had fallen below the interest on excess reserves (IOER) paid to bank counterparties. Since the introduction of the ONRRP, the Federal Reserve has been able to impose a firm floor on short-term interest rates. Although it represents a more limited expansion of counterparties than the case of universal access that we explore in this paper, the Fed's experience with ONRRP highlights many of the design tradeoffs required to balance the monetary policy and financial stability objectives that are relevant to our analysis, including the potential to alleviate some of these with differentiated rates, as discussed by Frost et al. (2015).

One question that widening access to electronic central bank money raises is: under a corridor system, which rate in the secondary market should the central bank target? Currently, participants in the market for reserves lend to one another on relatively short terms—almost exclusively less than 12 months—as their main motivation is to smooth temporary liquidity shocks. However, assuming that nonbanks engage directly in the market, a more diverse set of market participants may lead to CBDC being lent for a wider range of reasons and over a wider set of terms. It is conceivable that a corporate looking to borrow for capital expenditure may take out a CBDC-denominated loan over a number of years, or that a household may borrow CBDC to buy a house, in which case the terms could be measured in years rather than days or months. However, as long as the sellers of goods, services, or assets are able to substitute freely between deposits and CBDC (which we assume they can), then they should be neutral between receiving payments in CBDC or deposits, and should not offer any incentive for buyers to pay by one medium over the other. This means borrowers themselves should be neutral between borrowing CBDC and borrowing deposits—they will borrow from whichever lender offers them the best borrowing rate.

This would create a term structure of central bank money in a way that does not currently exist. The shape of this term structure would depend on expectations of the overnight rate for CBDC. The interest rate on a given loan would then be a function of this expected path and a series of premiums based on factors including the length of the term and the risk of default.

Even with a larger term structure of rates for central bank money, it makes sense for policymakers to continue to target very short-term rates, as they largely do now. In part this is because these rates contain fewer premiums. By effectively controlling short rates, and giving clear forward guidance about the future path these rates will take, policymakers can also guide longer rates. However, an additional reason is that in the case of a universal CBDC, it is likely that the participants in the short-term segment of the market would not change very much. Households and nonfinancial businesses rarely manage their liquidity at the overnight frequency and so would not likely borrow at such a short term. Conversely, if they were willing to lend to a bank overnight, then they would likely already be holding their funds in the form of demand deposits. Some nonbank financial corporates may be more willing to be involved in the overnight market, but this is likely to be skewed toward those firms that already have a working knowledge of markets that are very similar to that for overnight central bank money. To the extent that this happens, it should make the overnight market both more competitive and more liquid. Crucially though, the large majority of overnight lending will still be undertaken by the banking system and firms who already have access to electronic central bank money, allowing central bankers to guide the market much as they do today.

On balance, none of the above would appear to restrict the central bank's ability to control the short-term interest rate on central bank money, although a more volatile demand curve might make a floor system more attractive as an operational framework than a corridor. Widening access to central bank money could even afford policymakers tighter control of rates when operating under a floor system, because the risk-free rate on central bank money is available to all agents rather than only the banking sector.

4.1 Paying Different Rates to Banks and Nonbanks

Although many central banks opt to pay a single rate of interest on balances deposited with them, this need not be the case. A number of central banks now pay different rates of interest on balances based on the amount held, so as to influence the interest on the marginal unit differently to that on the entire balance (see, for instance, Basten and Mariathasan 2018 for a discussion of the Swiss case). This would be perfectly viable with a universally accessible CBDC, and could allow the central bank to influence those agents who use large holdings of CBDC as a store of wealth differently than agents who hold small balances purely for transactional purposes. This could be useful if policymakers wanted to impose negative rates on large, idle holdings of CBDC without penalizing smaller transactional accounts.

Similarly, a central bank could pay different interest rates depending on who holds the CBDC.[7] Perhaps the most logical way to differentiate CBDC holdings with a universally accessible CBDC would be between balances held by banks and those held by the nonbank private sector. This could be motivated by the special role that banks play in the monetary transmission mechanism and the economy more widely. Banks create money and purchasing power in the economy (McLeay, Radia, and Thomas 2014) and we would expect them to continue to create the marginal unit of money even with a universally accessible CBDC (see section 5.3). Paying differentiated rates of interest would allow monetary policy to influence banks—and therefore credit and money creation—differently to nonbanks.

The spread between the rates paid to banks and nonbanks could be set as a positive, but fixed, level with the two rates moving together. In this case there would be a steady-state impact on banks' balance sheets, but the consequences for monetary policy beyond our benchmark case would be limited. Alternatively, the spread itself could be varied through time, which would have implications for monetary policy. An increase in the spread could lower the cost of holding a given level of liquidity for a bank, which in turn would improve its balance sheet position. There would therefore be a

[7]For instance, not all participants in the federal funds market currently receive interest on their balances held with the Federal Reserve.

monetary stimulus through the bank balance sheet channel, or through the bank lending channel. Even if banks passed some or all of the increase in the return on their assets to depositors in the form of higher deposit rates, this would be stimulative through a cash flow channel.[8] The spread between the banking-sector CBDC rate and the nonbank CBDC rate would therefore provide an extra dimension to the stance of monetary policy. Such a design feature may also be attractive to a policymaker introducing CBDC for financial stability motives, as it would allow them to incentivize the holding of liquidity in specific sectors of the economy.

Although paying different rates to banks and nonbanks may assist in implementing monetary policy, a system that explicitly pays more to banks than to the public at large could be politically contentious; these debates may be especially acute in times of financial crisis.

4.2 Seigniorage

In section 3.5 we highlight that the impact of a universally accessible CBDC would have an ambiguous impact on seigniorage. While the net impact on the extent of seigniorage would be uncertain, it may also be relatively small in terms of overall monetary transmission. However, a more fundamental issue would be if the changes were such that seigniorage actually became negative, with an increasingly quasi-fiscal dimension to monetary policy.[9] While theoretically possible, the conditions required for such an eventuality are limited and seem unlikely. For instance, positive seigniorage is practically guaranteed if the central bank were to control the aggregate supply of CBDC through outright purchases. With the rate paid on CBDC as the floor of rates in the economy, the assets held on the central bank's balance sheet would always imply a greater return and positive seigniorage.[10]

[8] Banks may choose to pass on the higher return in order to strategically gain market share, or because if they didn't, another bank would.

[9] We thank an anonymous referee for highlighting this point for us.

[10] Obviously the central bank would be subject to interest rate risk and could ultimately make losses if it failed to manage the risk on its balance sheet correctly, but this is an issue with which central banks are familiar, and on which they have significant expertise.

Were the central bank to supply CBDC via repo transactions, then both the rate of return paid on CBDC balances and the rate with which it conducted repos would be decision variables of the policymaker. For negative seigniorage to occur, the central bank would have to pay a higher rate of interest on balances than it charged to issue new CBDC through repos. This seems unlikely, as it would amount to providing CBDC at below cost. It would also undermine the use of the interest rate paid on CBDC as the policy rate, as it would open up a risk-free arbitrage opportunity to borrow CBDC from the central bank via a repo and then simply store it in a CBDC account. This would lead to the floor on market interest rates being bounded on the downside by the repo rate, not the rate of interest paid on CBDC. Were the central bank to pay differentiated rates on CBDC and pay nonbanks a higher rate on balances than it paid banks, or charged banks to borrow through repos, then there could potentially be negative seigniorage across the entire balance of CBDC. However, as argued above, the repo rate and interest on CBDC rates are both decision variables of policymakers and it is more likely that differentiated rates would be used to pay higher interest rates to banks than to nonbanks, if at all.

4.3 Issuing CBDC Alongside Existing Reserves

An alternative to paying different interest rates on a single form of electronic central bank liability would be for the central bank to issue CBDC as a distinct asset alongside existing reserves. The rate of interest paid would depend on the asset held and not the counterparty holding the asset. This is similar to the situation today: physical cash is distinct from reserves, and pays zero interest regardless of whether it is held by a bank or a nonbank. Nonbanks can only hold cash, whereas banks can hold both cash and reserves, meaning that they have access to a preferential rate of interest (i.e., the policy rate paid on reserves). This arrangement has parallels to the model assumed in Barrdear and Kumhof (2016): banks would be able to hold both reserves and CBDC as distinct assets bearing different interest rates, whilst nonbanks would only be able to hold CBDC. The primary rate of monetary policy would be the rate paid on reserves, while the rate paid on CBDC would be used to control demand for CBDC relative to bank deposits.

At first glance this scenario seems to offer extra possibilities for monetary policy under a CBDC. However, under some sensible assumptions, we believe the outcome would be practically identical to the scenario above in which different rates are paid to banks and nonbanks on a single liability in the form of CBDC. As we show in Meaning et al. (2018), if different forms of central bank liabilities are freely convertible, and reserves and CBDC are equivalent in a technological, transactional, and regulatory sense, banks will choose to hold only reserves as long as they pay a higher rate than CBDC. The end result is that banks are paid the reserves rate and nonbanks earn the CBDC rate, equivalent to the one-asset framework outlined above.

For the rest of the analysis we assume that there is only one form of CBDC paying one rate regardless of whether it is held by banks or nonbanks.

5. Further Transmission of Monetary Policy

5.1 Transmission to the Wider Universe of Interest Rates

As is currently the case, the process of arbitrage would mean that changes in the rates on CBDC would pass through to rates on other assets in the economy. In the appendix we present a stylized model that provides an intuitive formalization of this process under a universally accessible CBDC. In essence what one would expect to see is that the interest rate that clears the market for CBDC would be the theoretical risk-free rate, minus a premium derived from the nonpecuniary transactional utility (or convenience yield) provided by CBDC:[11]

$$R^C = R - \phi^C. \tag{1}$$

This transactional utility can be motivated in a number of ways and need not be constant, but it could vary through time and, as posited by Friedman (1960), it could be a function of the stock of CBDC

[11]The market rate may also be a positive function of the cost of administering accounts, or the underlying payments system. ϕ^C could therefore be thought of as a more complex composite premium of factors that drive a wedge between the risk-free rate and the rate on CBDC.

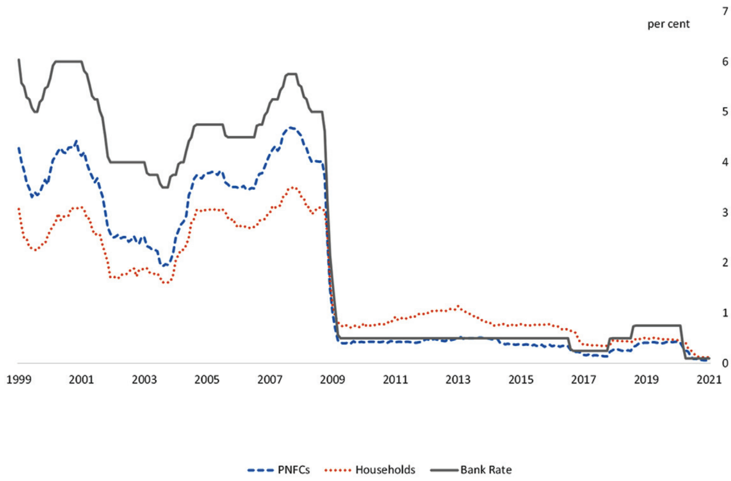
itself. Bordo and Levin (2017) develop the ideas of Friedman in the context of CBDC. They suggest that if $\phi^c = f(Q^c)$ and the creation of CBDC is costless, then the supply of CBDC should be expanded to the point where $\phi^c = 0$ and the rate of return on CBDC equals the risk-free rate, $R = R^c$. The rates of interest on other assets in the economy can then be written in the general form by

$$R^x = R^c + \phi^x, \tag{2}$$

where ϕ^x is a premium specific to asset x that could be a function of a wide range of factors. These factors could include the relative probability of default compared with CBDC, the relative transactional utility provided by the asset, and the relative utility provided by the asset for liquidity-management or regulatory purposes. For instance, government bonds would have little to no default risk, so that element of the premium would be low, but they also provide little to no transactional utility, which would cause a positive spread against the CBDC rate to occur. Deposits with commercial banks could provide transactional services similar to CBDC, and so would see an equivalent premium along that dimension, but inherently contain some risk of default, and so would see a positive spread over the CBDC rate.

An initial consequence of a universally accessible CBDC is likely to be that deposit rates offered by commercial banks would most likely need to be higher than the interest rate paid on CBDC. Prior to the 2008 financial crisis, deposit rates were consistently below the policy rate (figure 3). This could be explained by two phenomena. First, banks had a monopoly on the creation of *electronic* money that could be used to make transactions in the wider economy and nonbanks had no outside alternative. Banks could make use of this monopoly to lower the rate that they paid on deposits. In terms of equation (2) this meant that the transactional utility for nonbanks of reserves was zero, while the transactional utility of commercial bank deposits was high, so the latter rate naturally fell below the former. What is more, state backstops, implicit or otherwise, gave the perception that bank deposits were essentially risk free, so there was no default premium built into deposit rates. Second, banks offered a bundling of services, such as overdrafts and preferential mortgage or lending rates, which provided a utility to holding deposits with

Figure 3. Sight Deposit Rates vs. Policy Rates in the United Kingdom



Source: Bank of England.

the banking sector and which were reflected in a negative premium, lowering the rate at which the deposit market cleared.

With a universally accessible CBDC, central banks would be making available to nonbanks an outside, competitive option for the provision of a means of payment (although unlike some bank deposits, this would not be bundled with other services such as overdrafts). With such an outside option, depositors who are offered less than the current CBDC rate have the option of withdrawing CBDC (in exchange for a reduction in their deposit balances). This would, as a minimum, lower the spread between the policy rate and deposit rates. If the additional services offered by deposits held with a commercial bank, such as overdraft facilities, were not sufficient to outweigh the additional risk they represented, then the spread would, in fact, change sign and deposit rates would need to be higher than the CBDC rate. This would constitute a large structural change for the banking sector which could have consequences for credit provision and banks' funding models. Some of these effects, such as pressures on net interest margins, could be largely if not completely mitigated by the paying of differentiated rates of interest on CBDC balances, as discussed in section 4.1.

As well as potentially changing the structure of interest rates in the economy in a levels sense, there are a number of features of the model of CBDC outlined earlier that could affect the speed and extent of pass-through between changes in the policy rate and other rates. Most notably, the existence of a competitive money alternative to bank deposits is likely to mean that if the interest rate on that alternative changes, but deposit rates do not move by an equal amount, then people will reallocate their portfolio to take advantage of the relatively higher return that has opened up. This would create flows between the two assets. If the policy rate which is paid on CBDC is increased, then this could result in a fall in demand for bank deposits, while if the policy rate is cut, this could drive demand from CBDC into bank deposits. This will be particularly acute when it is easier to convert between CBDC and deposits. To the extent that pass-through from policy rates to deposit and wholesale rates has been estimated to be currently less than one, CBDC is likely to strengthen this stage of transmission.

We agree with Bordo and Levin (2017) that deposit-taking institutions that engage in customer-focused relationship banking are likely to be less vulnerable to the outflows of deposits than the areas of the market that compete purely on price terms. We also acknowledge that evidence for the United Kingdom shows that deposits are sticky—depositors do not often switch banks—and so have low price elasticity (Chiu and Hill 2015). However, deposits may become less sticky once the central bank offers an outside option, and as a result of regulatory changes that will make it easier to switch accounts (such as the European Union's Second Payment Services Directive). Ultimately, whether there is a change in the speed of pass-through from changes in the policy rate to changes in deposit rates will depend on how banks react. We could assume that technology is likely to mean that depositors can more easily and costlessly move between deposits and CBDC, so banks would have to respond quickly to stem deposit flows. However, banks may react to the increased flightiness of deposits by changing their funding models to rely more on term funding, to "lock in" deposits. This would mean that pass-through to rates paid on deposits would ultimately be slower.

Larger changes in deposits and wholesale rates for a given change in the policy rate would also mean a larger impact on banks' funding costs, all else equal. For a given markup on these funding costs, this would have a larger impact on loan rates. This increased sensitivity of both funding costs and lending rates to changes in the policy rate could act to strengthen the bank *lending* channel, which we will discuss further in the next section.

5.2 Transmission to the Real Economy

The ability to influence interest rates is only an intermediate step in the monetary transmission mechanism. We now consider the implications of a universally accessible CBDC for the transmission of policy changes to the real economy.

Given that our previous analysis suggests that universally accessible CBDC is likely to make interest rates more sensitive to changes in the policy rate, all else equal, this will serve to amplify the strength of a number of channels for a given change in the policy rate. Most obviously, the real interest rate channel would strengthen as interest rates on savings and credit would shift more for the same change in the policy rate and so would the incentives for intertemporal substitution by economic agents. For similar reasons, the cash flow channel would also be strengthened.

The impact on the bank lending channel of transmission is less clear. To the extent that bank funding costs would become more sensitive to changes in the policy rate for the reasons described above, this would strengthen the bank lending channel. What is more, the additional competition in credit provision may make pass-through to lending rates more complete. However, there are a number of factors that would most likely weigh in the other direction. First, were deposit rates to be above policy rates, this could squeeze the net interest margins of the banking sector, which could result in lower profits. This would mean bank capital grows at a slower rate, constraining banks' ability to lend and therefore weakening the bank lending channel.

Perhaps more fundamentally, if a CBDC were to disintermediate the banking sector and significantly reduce the size of its aggregate balance sheet, this would reduce the importance and traction of the bank lending channel. This disintermediation is more likely when a

CBDC is a close substitute for bank deposits and fully or partially dominates them in some aspects. This would be precisely when the benefits to the monetary transmission mechanism discussed above would be at their greatest. This serves to highlight an important tradeoff in the setting of the design parameters of CBDC: making CBDC too attractive relative to bank deposits will strengthen the real interest rate channel by providing a more competitive outside option, but weaken the bank lending channel by disintermediating banks. Conversely, making CBDC very unattractive relative to deposits means that it would not represent a true outside option to deposits, so very little would change. How to manage this tradeoff will depend on many factors, including the importance of the banking sector in the economy, the viability of nonbank finance to provide credit to the economy in lieu of a diminishing banking sector, and the central bank's ultimate motivation for introducing CBDC. It would seem likely that if the motivation for CBDC is purely to provide a secure digital payment system with no need to affect monetary policy, then it is unnecessary to make CBDC an attractive substitute for *interest-bearing* deposits, especially when weighed against the risk of disintermediating the banking sector.

5.3 CBDC and Money Creation by Banks

The transmission mechanism may also change if the introduction of CBDC affects the way that banks choose to issue loans. Banks are crucially involved in money creation in the economy, because they lend by issuing new deposits, in effect creating new money and purchasing power (McLeay, Radia, and Thomas 2014; Jakab and Kumhof 2015). In contrast, nonbank lenders transfer existing purchasing power (either deposits or CBDC) from savers to borrowers, but do not create any new purchasing power in the process. With the introduction of CBDC, banks could still continue to lend by issuing new deposits, but they would now have the option to lend CBDC (by transferring CBDC to the borrower's CBDC account).This would make them more like nonbank lenders, and reduce the sensitivity of money creation to a change in monetary policy.

In practice, however, there are a number of reasons why banks would continue to prefer to lend by issuing new deposits. Firstly, as discussed previously, there is unlikely to be demand for borrowing in CBDC specifically, implying that the interest rate on loans for a given level of risk and term should be the same whether it is CBDC or deposits that are borrowed. Secondly, for a bank, lending CBDC will have a more negative impact on current regulatory ratios (specifically the liquidity coverage ratio) than lending via issuing deposits. Lending CBDC ensures that the bank will lose £100 of liquidity for every £100 lent. In contrast, while lending by issuing deposits could still lead to some outflow of CBDC, it is likely to be less, on average, than 100 percent of the amount lent. Given this, credit creation by the banking system would continue as now even with the existence of a universally accessible CBDC, with new loans initially matched by newly issued bank deposits, and money creation would continue to be sensitive to changes in monetary policy. Of course, once those new deposits are created, though, it would remain the optimal portfolio choice of nonbanks as to how much of the newly created bank deposits were converted to CBDC, as is now the case with regards to the substitution between deposits and central bank notes.

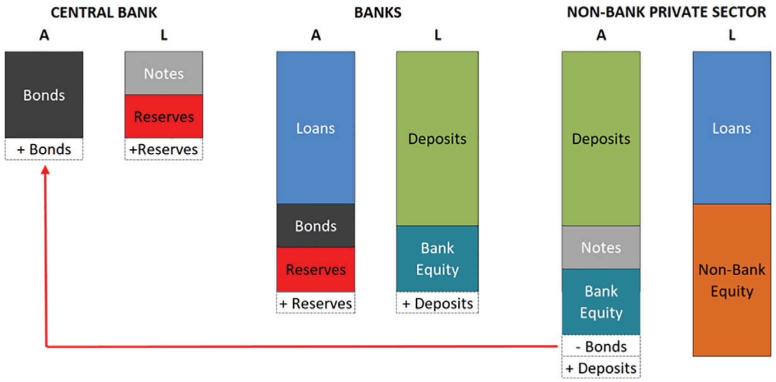
5.4 Overall Impact on Transmission

Overall the analysis above suggests that a universally accessible CBDC would most likely strengthen the impact of changes in the policy rate on the real economy, predominantly through increased pass-through from policy rates to other interest rates in the economy. Importantly, to the extent that this were true in practice, a CBDC would imply that policy rates needed to vary by less over the cycle to stabilize the economy, conditioned on the same shocks afflicting the economy. This could have benefits to policymakers, especially in the context of the lower bound as, for a given steady-state level of policy rates and set of shocks hitting the economy, the probability of the policy rate becoming constrained would be reduced.

6. Asset Purchases with CBDC

In recent years central banks have used newly issued money to purchase financial assets from the private sector, a policy known as quantitative easing (QE). This policy aimed to manipulate the relative supplies of assets in the economy and to lower longer-term interest rates, given that short-term rates were constrained by their

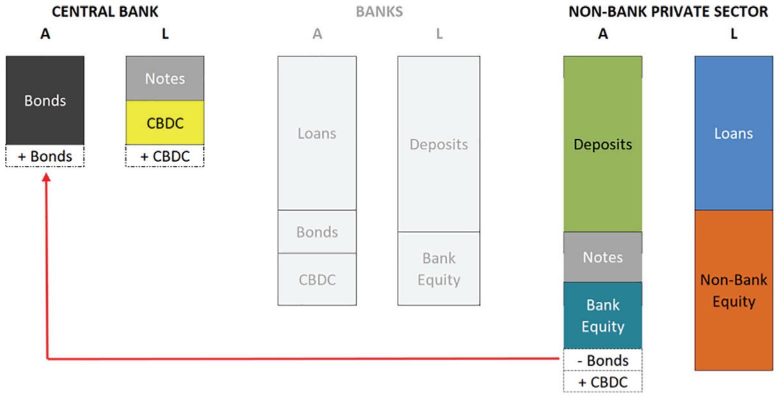
Figure 4. Central Bank Asset Purchase without a CBDC



effective lower bounds. However, since most nonbanks cannot currently hold accounts at the central bank, and it is impractical to pay for these assets by printing central bank notes, central banks had to use commercial banks as intermediaries between them and the ultimate (nonbank) sellers of the assets. In this process, the nonbank holds a deposit account at the commercial bank, which in turn holds a reserves account at the central bank, as shown in figure 4. (For color versions of figures 4 and 5, see the online version of the paper at http://www.ijcb.org.) The commercial bank sells the asset to the central bank on behalf of the ultimate seller (the nonbank). The central bank pays for this asset by crediting the commercial bank's account with newly issued reserves. Simultaneously, the commercial bank credits the nonbank's account with a new deposit. In this way, asset purchases through QE expand both narrow money (directly) and broad money (indirectly) by the same amount, through the simultaneous creation of new reserves and deposits.

If CBDC is introduced, the central bank would no longer need to use commercial banks as intermediaries to *indirectly* purchase assets from the private sector. Instead, the central bank could purchase financial assets *directly* from the nonbanks, paying for these assets by crediting the nonbank's CBDC accounts with newly issued CBDC, as shown in figure 5. This process does not alter the balance sheets of commercial banks and has no impact on the amount of central bank money held by the banking sector. This means that

Figure 5. Central Bank Asset Purchase with a CBDC



the effect of the policy would not be dependent on the reaction of the banking sector to holding increased quantities of reserves.

When asset purchases are conducted *indirectly* (i.e., through the banking system, prior to the introduction of CBDC), this reaction can take two forms: there is a mechanism through which QE may expand bank lending, making QE more effective, and an opposing mechanism through which banks' reactions may directly offset some of the desired effect of QE on interest rates.

With regards to the first mechanism, the impact of QE on the bank lending channel is presented in a theoretical model by Christensen and Krogstrup (2019). This states that the exogenous increase in reserves held by banks changes the characteristics of banks' balance sheets, lowering the degree of maturity mismatch and relaxing liquidity constraints away from their pre-QE preferred state. Banks respond by rebalancing their portfolios. In particular, they may increase bank lending, amplifying other channels of QE that work outside of the banking system.

If QE is undertaken directly with the nonbank sector using CBDC, there will be no impact on bank balance sheets, and so no need for banks to rebalance in this way. This would weaken any effects of QE through the bank lending channel. However, empirical work by Butt, Churm, and McMahon (2015) suggests that the impact of QE on the bank lending channel is already small, at least in the context of QE in the United Kingdom, and so the importance of this change in effect may be limited.

The opposing mechanism, by which banks may offset some of the desired effect of QE, depends on the extent to which banks meet their regulatory requirements for high-quality liquid assets (HQLA) by holding both government bonds and central bank money. Assuming that banks hold their preferred mix of government bonds and central bank money prior to QE, the effect of QE is to leave banks holding more HQLA than they desired and a greater-than-desired proportion of that HQLA in the form of reserves rather than bonds. The banking sector has no choice, in aggregate, but to hold this larger stock of reserves. If the sector wants to reduce its stock of HQLA to its pre-QE level, then it must sell off an amount of bonds to the nonbank sector. Simple rolling correlations on U.K. data suggest that as QE increased the quantity of reserves in the system, banks reduced their holdings of government securities in a manner consistent with them substituting from bonds to reserves. This sale of government bonds by the banking sector would push down prices and push up yields at exactly the time that the central bank is aiming to lower bond yields by buying them in large quantities, acting as an offset to the desired effect of QE.

This is different from the situation in which a universally accessible CBDC enables central banks to conduct purchases directly with nonbanks. To see clearly why, consider the balance sheet and decisions of the nonbank seller in the previous example. From their perspective, they have exchanged a government bond for a digital form of money. In a world of universally accessible CBDC, the exchange is largely the same. Given this, one could reasonably expect them to rebalance their portfolio in a broadly similar way and drive similar price responses, all else equal.[12] The difference between the two examples is therefore centered on the banking-sector portfolio and banks' demand for government bonds and reserves compared with one another and other assets. Following the arguments above, banks' demand for government bonds following a QE operation would be greater in the case of a universally accessible CBDC. This would result in lower rates on government bonds following asset

[12]To the extent that CBDC is more risk free than a bank deposit, exchanging it for a risky asset may actually represent a larger change in portfolio characteristics and so induce more rebalancing or larger price movements.

purchases.[13] Put another way, the current structure of QE programs creates additional money both on the nonbank and banking-sector balance sheets. QE with a universally accessible CBDC would only create additional money in one of those places.

Other key elements of QE would remain unchanged. For instance, in aggregate, the system would be unable to rid itself of CBDC. The closed system would now be extended to include more than just banks, so banks could shift demand to nonbanks, and vice versa, but importantly, an increase in quantity would have to be absorbed somewhere, and thus prices of other assets would have to adjust to allow portfolios and markets to clear.

Consequently, QE conducted directly with the nonbank sector through the use of a universally accessible CBDC would be stronger insofar as it would not directly affect banks' demand for government bonds as HQLA, but this would come at the cost of weakening the bank lending channel of QE. The net result is unclear. On balance, the fact that the central bank is able to directly engage with a larger pool of direct counterparts and can avoid distortions to the banking sector's aggregate balance sheet leads us to believe the benefits would outweigh the negatives, increasing the overall efficacy of QE. It should also be noted that a universal CBDC does not preclude the central bank conducting asset purchases directly with the banking sector, should it choose to.

Going further, some authors suggest that a universally accessible CBDC would make quantitative easing as a policy instrument entirely obsolete. Bordo and Levin (2019) argue that abolishing physical cash and replacing it with an interest-bearing CBDC would remove the lower bound on nominal interest rates and allow central banks to conduct policy solely through altering the interest rate on CBDC. In a theoretical economy where cash does not exist, this is certainly true. However, although usage of cash is declining in Sweden and a few other developed economies, it remains

[13]Of course, the relative price changes between bonds and other assets that result from QE would likely lead to a second-round endogenous response from the banking sector. This could also reduce demand for government bonds, because the higher price and lower return would make them relatively less attractive compared with central bank money or other assets that could contribute to their HQLA. However, this mechanism would exist whether QE was conducted via issuance of traditional reserves or a universal CBDC.

significant in the majority of countries, including in the United Kingdom, Germany, and Japan. Therefore it is likely that, in most countries, CBDC would coexist alongside physical cash at least for the foreseeable future and would be a useful tool to enhance the effectiveness of QE.

7. Risks to Financial Stability and the Central Bank

Beyond its implications for monetary policy, CBDC could have implications for financial stability. Broadbent (2016) and Carney (2018) among others have highlighted the potential risks of large-scale "digital bank runs." A detailed analysis of these issues is a topic for another paper, but it is worth noting that measures to prevent this kind of risk may have consequences for the monetary policy impacts of CBDC. For example, introducing frictions that discourage large-scale runs to cash, such as daily transfer limits, notice periods for large CBDC withdrawals, or imposing fees on unusually large balances that could approximate the storage costs of cash, would affect the attractiveness of CBDC. This would reduce the extent to which it was a substitute for bank deposits and in turn limit the potential benefits from CBDC acting as an outside competitive option.

CBDC could also impose risks on the central bank, as a result of the need to hold assets to back a larger central bank balance sheet. Were the central bank to look to back these with incredibly safe assets, such as government bonds, then high demand for CBDC could lead to the central bank holding a significant fraction of domestic government debt. This could be especially acute in moments of financial stress when demand for safe assets increases; demand for both government bonds and CBDC could increase simultaneously. Alternatively, the central bank could back CBDC with a wider range of assets, but this would imply a riskier balance sheet than many hold now. Central banks would need to both manage these risks and be aware of the impact they would be having on any new asset markets in which they were to engage.

Further work is therefore needed to investigate the interactions between the impacts of CBDC on monetary policy, financial stability, and the central bank balance sheet. This work should draw on the growing literature on the interactions of current monetary-macroprudential policies (Nier and Kang 2016).

8. Concluding Remarks

At its simplest, a central bank digital currency can be thought of as electronic narrow money, and so in many ways it should feel familiar to economists and policymakers. Within this general definition there are important policy choices to be made, including around access, convertibility, and whether CBDC is interest bearing. Careful consideration will need to be given to these policy choices in future research and in order for any central bank to effectively introduce CBDC.

The main conclusion of this paper is that under a universally accessible, freely convertible, and interest-bearing CBDC, monetary policy could operate in much the same way as it currently does, guiding the economy through varying the rate of interest on electronic central bank money and the aggregate quantity of that money. The untested nature of such a CBDC means that the impact on the monetary transmission mechanism is uncertain, but we believe the most likely consequence is that CBDC would strengthen the monetary transmission mechanism, for a given change in policy instruments.

As well as enhancing the functioning of the existing monetary toolkit, CBDC also has the potential to enable more significant change in the toolkit itself. This paper has only considered the impact of CBDC on widely used monetary policy, namely changes in the central bank's policy rate, and asset purchases (quantitative easing). However, CBDC has also been discussed in the context of less conventional monetary policy, such as the use of negative rates (Kimball and Agarwal 2015) or direct distributions of newly issued CBDC to citizens—so-called helicopter money (Turner 2015; Hampl and Havranek 2018). These policies do not necessarily require a CBDC to be implemented, but the existence of CBDC may affect their feasibility and impact. It may even be that CBDC and future technological progress give rise to monetary policy instruments that have not yet been considered. This is a promising area for future research.

This paper is intended as an early step in the development of the literature on central bank digital currencies, and many fundamental questions remain unanswered. These relate to, among other things, the impact on the wider financial sector, the implications for financial stability, steady-state changes in the economy resulting from CBDC, and how CBDC would affect the balance sheet management of central banks. Significant work, both theoretical and empirical, will be required to inform any policy decision to introduce CBDC.

Appendix. The Structure of Interest Rates and Arbitrage Conditions

To aid thinking about the structure of interest rates in an economy with a universally accessible CBDC, we present a stylized model of the key arbitrage conditions that might prevail. While this model is partial rather than general equilibrium, and appeals to sensible assumptions rather than strict microfoundations to motivate the range of premiums, it still serves as a useful expositional tool and offers some initial, intuitive insights.

We begin from a theoretical risk-free interest rate, R, that represents the return on a pure store-of-value asset with no associated premiums. There is no risk of default, no illiquidity, and no term. CBDC is assumed to be risk free in the same way, but alongside its store of value function it also provides an additional service as a means of exchange, for instance, lowering transaction costs, ϕ^C. The total expected return from a unit of CBDC is therefore[14]

$$R^C + \phi^C \tag{A.1}$$

and no arbitrage would imply

$$R = R^C + \phi^C, \tag{A.2}$$

meaning that

$$R^C = R - \phi^C. \tag{A.3}$$

[14]With no default yet in the model, the expected returns are equal to the agreed returns.

This means that CBDC would clear at a rate below the theoretical risk-free rate by a spread determined by the transactional utility supplied by CBDC. In the exposition here we assume this transactional utility is fixed per unit of CBDC, independent of the quantity of CBDC. This is purely for clarity of presentation, and a credible alternative assumption is that the degree of transactional utility is a function of the quantity of CBDC held. Were transactional utility to be a negative function of quantity, but to a decreasing extent (the implied function has a negative first derivative and positive second derivative), then Friedman (1960) argues that, as the creation of central bank money is costless, the supply should be expanded to the point where ϕ^C is zero and $R^C = R$. This would imply that the rate paid on CBDC could be considered a reflection of the true risk-free rate.

Building from CBDC to a wider array of assets, we look at each sector of the economy in turn and work through the no-arbitrage conditions that their balance sheets would imply.

Beginning with the nonbank private sector, consistent with our stylized balance sheets (see figures 4 and 5 in main text), they can hold their wealth as a combination of three assets: CBDC (denoted by C), bank deposits (D), and government bonds (B).[15] For simplicity of exposition we assume that each of these assets is one period in term but can be differentiated by other characteristics. As discussed above, each unit of CBDC held provides a nonpecuniary benefit to the holder, ϕ^C—for instance, as a result of lowering transactional costs. Similarly, the interest rate paid on bank deposits is R^D, and bank deposits offer a similar but not necessarily equivalent nonpecuniary return emanating from its role as a means of exchange, ϕ^D. However, unlike CBDC, there is a probability, γ, that banks will default on their deposits, in which case the depositor gets neither the pecuniary return nor the nonpecuniary benefit. Lastly, government bonds offer an interest rate R^B. They are assumed to offer no transactional services but are defaultable with probability δ. Taken all together, this means that the nonbank's end-of-period objective function can be written as

[15] We abstract from equity without any loss of insight for the themes with which we are concerned.

$$R^C C + \phi^C C + (1-\gamma)[R^D + \phi^D]D + (1-\delta)R^B B, \tag{A.4}$$

and so is maximized where

$$\frac{dU}{dC} = R^C + \phi^C = 0 \tag{A.5}$$

$$\frac{dU}{dD} = (1-\gamma)[R^D + \phi^D] = 0 \tag{A.6}$$

$$\frac{dU}{dB} = (1-\delta)R^B = 0. \tag{A.7}$$

For the nonbank sector then, assuming that the rate on CBDC is set by the central bank,

$$R^D = \frac{R^C + \phi^C - (1-\gamma)\phi^D}{(1-\gamma)} \tag{A.8}$$

and

$$R^B = \frac{R^C + \phi^C}{(1-\delta)}. \tag{A.9}$$

This gives rise to two spreads. The spread of the deposit rate over the CBDC rate is a positive function of the relative transactional services of CBDC compared with deposits, and a positive function of the default rate. The spread of bond rates over the CBDC rate is a negative function of the transactional service of CBDC money, and a positive function of the default risk in the government bond. This all occurs in a one-period setting. In practice there is likely to be another significant premium driving a wedge between the two rates, which is the term premium. This could be derived in a multi-period model by the additional risk of locking funds away when you are subject to unknown payments or liquidity shocks, and would appear as a positive function of the term of the bond.[16] As discussed previously, were we to assume that the transactional utility of CBDC were a

[16] As another point of reference, bond rates will differ from the theoretical risk-free rate discussed above to the extent of inherent default risk only. In practice, there would also be other premiums, such as term, which would mean that the bond rate clears at a spread above the risk-free rate.

decreasing and concave function of the quantity of CBDC, then the supply can, and arguably should, be expanded to the point at which $\phi^C = 0$. This would mean that the only differences between government bonds and CBDC were the default risk in government bonds and the term. For short-term government bonds in stable economies, both of these elements could be expected to be negligible, and so we would expect the short-term government bond rate to be extremely close to the interest rate on CBDC. As noted by Bordo and Levin (2017), were the central bank to engage in open market operations between Treasury bills and CBDC, they could ensure that this would be the case in practice.

We follow the same process for the banking sector. Banks can hold assets in the form of CBDC (C), loans (L), or government bonds (B). Again, this is consistent with our balance sheet diagram. As with nonbanks, the banking sector receives both a pecuniary return on its CBDC holdings, R^C, and a nonpecuniary benefit from CBDC's transactional services, ϕ^B. Unlike nonbanks, they receive an additional nonpecuniary benefit, η, from CBDC through its role as a high-quality liquid asset (HQLA). This could be due to a regulatory need to hold HQLA, or a portfolio preference of the bank itself. In a system of mandated reserve requirements, this benefit could be very significant. Government bonds also provide a benefit as HQLAs, ϵ, but provide no transactional services, and default with probability δ.

The last asset that banks can hold on their balance sheet is loans. The pecuniary return is R^L with a default probability of μ. We assume a cost of producing and monitoring each loan, M. For a more developed model which includes monitoring costs of this type, see Goodfriend and McCallum (2007). We further assume that loans offer no transactional services, nor liquidity services. Lastly, banks must finance the asset side of their balance sheet with liabilities, meaning that they must pay R^D on all deposits owed to the nonbank sector.

Taken together, we can write the bank's optimization problem as

$$\begin{aligned} &R^C C + \phi^B C + \eta C + (1-\delta)[R^B + \epsilon]B \\ &\quad + (1-\mu)R^L L - ML - R^D[C+B+L](1-\gamma), \end{aligned} \tag{A.10}$$

the first-order conditions of which give

$$\frac{dU}{dC} = R^C + \phi^B + \eta - (1-\gamma)R^D = 0 \tag{A.11}$$

$$\frac{dU}{dB} = (1-\delta)R^B + (1-\delta)\epsilon - (1-\gamma)R^D = 0 \tag{A.12}$$

$$\frac{dU}{dL} = (1-\mu)R^L - M - (1-\gamma)R^D = 0 \tag{A.13}$$

and which optimizes to give

$$R^B = \frac{R^C + \phi^B + \eta - (1-\delta)\epsilon}{(1-\delta)} \tag{A.14}$$

$$R^L = \frac{R^C + \phi^B + \eta + M}{(1-\mu)}. \tag{A.15}$$

This shows that from the viewpoint of the banking sector, the spread of bond rates over the CBDC rate is a positive function of the transactional benefit of CBDC, the default risk in bonds, and the relative benefits of CBDC as a HQLA when compared with bonds. When combined with the nonbank condition for bonds, this implies that the relative transactional services received by banks compared with nonbanks must equal the additional benefit that banks receive from holding bonds relative to CBDC as HQLA. The loan rate spread is a positive function of the cost of producing a loan and the probability of default.

References

Armelius, H., P. Boel, C. Claussen, and M. Nessen. 2018. "The e-krona and the Macroeconomy." *Economic Review* (Sveriges Riksbank) 2018 (3): 43–62.

Assenmacher, K., and S. Krogstrup. 2018. "Monetary Policy with Negative Interest Rates: Decoupling Cash from Electronic Money." IMF Working Paper No. 18/191.

Bank for International Settlements. 2018. "Central Bank Digital Currencies."

Bank of Canada. 2017. "Digital Currencies and Fintech." Retrieved from https://www.bankofcanada.ca/research/digital-currencies-and-fintech/.

Bank of England. 2015. "Sterling Monetary Framework Annual Report 2014-15." Retrieved from https://www.bankofengland.co.uk/-/media/boe/files/sterling-monetary-framework/annual-report-2014-15.pdf.

———. 2020. "Central Bank Digital Currency: Opportunities, Challenges and Design." Discussion Paper, Bank of England.

Barrdear, J., and M. Kumhof. 2016. "The Macroeconomics of Central Bank Issued Digital Currencies." Staff Working Paper No. 605, Bank of England.

Basten, C., and M. Mariathasan. 2018. "How Banks Respond to Negative Interest Rates: Evidence from the Swiss Exemption Threshold." CESifo Working Paper No. 6901.

Bech, M. L., and R. Garratt. 2017. "Central Bank Cryptocurrencies." *BIS Quarterly Review* (September): 55–70.

Benos, E., R. Garratt, and P. Gurrola-Perez. 2017. "The Economics of Distributed Ledger Technology for Securities Settlement." Working Paper No. 670, Bank of England.

Bjerg, O. 2017. "Designing New Money: The Policy Trilemma of Central Bank Digital Currency." Working Paper, Copenhagen Business School.

———. 2018. "Breaking the Gilt Standard — The Problem of Parity in Kumhof and Noone's Design Principles for Central Bank Digital Currencies." Working Paper, Copenhagen Business School.

Bordo, M., and A. Levin. 2017. "Central Bank Digital Currency and the Future of Monetary Policy." NBER Working Paper No. 23711.

———. 2019. "Digital Cash: Principles and Practical Steps." NBER Working Paper No. 25455.

Broadbent, B. 2016. "Central Banks and Digital Currencies." Speech given at the London School of Economics, March 2.

Butt, N., R. Churm, and M. McMahon. 2015. "Did Quantitative Easing Boost Bank Lending?" Blog Entry, Bank Underground, July 17. Retrieved from https://bankunderground.co.uk/2015/07/17/did-quantitative-easing-boost-bank-lending/.

Carney, M. 2018. "The Future of Money." Speech to the Inaugural Scottish Economics Conference, Edinburgh University, March 2.

Chiu, J., and J. Hill. 2015. "The Rate Elasticity of Retail Deposits in the United Kingdom: A Macroeconomic Investigation." Staff Working Paper No. 540, Bank of England.

Christensen, J., and S. Krogstrup. 2019. "Transmission of Quantitative Easing: The Role of Central Bank Reserves." *Economic Journal* 129 (617): 249–72.

Danezis, G., and S. Meiklejohn. 2016. "Centrally Banked Cryptocurrencies." University College London.

Eichengreen, B. 2019. "From Commodity to Fiat and Now to Crypto: What Does History Tell Us?" NBER Working Paper No. 25426.

Friedman, M. 1960. *A Program for Monetary Stability.* Fordham University Press.

Frost, J., L. Logan, A. Martin, P. McCabe, F. Natalucci, and J. Remache. 2015. "Overnight RRP Operations as a Monetary Policy Tool: Some Design Considerations." Finance and Economics Discussion Series No. 2015-010, Board of Governors of the Federal Reserve System.

Fung, B. S., and H. Halaburda. 2016. "Central Bank Digital Currencies: A Framework for Assessing Why and How." Staff Discussion Paper No. 2016-22, Bank of Canada.

Goodfriend, M. 2002. "Interest on Reserves and Monetary Policy." *Economic Policy Review* (Federal Reserve Bank of New York) 8 (1): 77–84.

———. 2016. "The Case for Unencumbering Interest Rate Policy at the Zero Bound." In *Designing Resilient Monetary Policy Frameworks for the Future.* Proceedings of the 2016 Economic Policy Symposium sponsored by the Federal Reserve Bank of Kansas City, held in Jackson Hole, Wyoming, August 25–27.

Goodfriend, M., and B. T. McCallum. 2007. "Banking and Interest Rates in Monetary Policy Analysis: A Quantitative Exploration." *Journal of Monetary Economics* 54 (5): 1480–1507.

Hampl, M., and T. Havranek. 2018. "Central Bank Capital as an Instrument of Monetary Policy." Econstor.

He, D., R. Leckow, V. Haksar, T. Mancini-Griffoli, N. Jenkinson, M. Kashima, T. Khiaonarong, C. Rochon, and H. Tourpe. 2017. "Fintech and Financial Services: Initial Considerations." IMF Staff Discussion Note No. 17/05.

Jakab, Z., and M. Kumhof. 2015. "Banks are Not Intermediaries of Loanable Funds — and Why This Matters." Staff Working Paper No. 529, Bank of England.

Keating, T., and M. Machiavelli. 2018. "Interest on Reserves and Arbitrage in Post-Crisis Money Markets." FEDS Notes, March 1.

Kimball, M., and R. Agarwal. 2015. "Breaking Through the Zero Lower Bound." IMF Working Paper No. 15/224.

Kumhof, M., and C. Noone. 2018. "Central Bank Digital Currencies — Design Principles and Balance Sheet Implications." Working Paper No. 725, Bank of England.

Lagarde, C. 2020. "The Future of Money — Innovating While Retaining Trust." Retrieved from https://www.ecb.europa.eu/press/inter/date/2020/html/ecb.in201130~ce64cb35a3.en.html.

McLeay, M., A. Radia, and R. Thomas. 2014. "Money Creation in the Modern Economy." *Quarterly Bulletin* (Bank of England) (Q1): 14–27.

Meaning, J., B. Dyson, J. Barker, and E. Clayton. 2018. "Broadening Narrow Money: Monetary Policy with a Central Bank Digital Currency." Staff Working Paper No. 724, Bank of England.

Nier, E., and H. Kang. 2016. "Monetary and Macroprudential Policies — Exploring Interactions." In *Macroprudential Policy,* Vol. 86, ed. Bank for International Settlements, 27–38. Bank for International Settlements.

People's Bank of China. 2020. "Central Bank: Digital RMB Closed Test Will Not Affect RMB Issuance and Circulation." Retrieved from http://www.gov.cn/xinwen/2020-04/17/content_5503711.htm.

Rogoff, K. 2016. *The Curse of Cash.* Princeton University Press.

Scorer, S. 2017. "Central Bank Digital Currency: DLT, or Not DLT? That is the Question." Blog Entry, Bank Underground, June 5. Retrieved from https://bankunderground.co.uk/2017/06/05/central-bank-digital-currency-dlt-or-not-dlt-that-is-the-question/.

Sveriges Riksbank. 2021. "E-krona." Retrieved from https://www.riksbank.se/en-gb/payments--cash/e-krona.

Turner, A. 2015. "The Case for Monetary Finance — An Essentially Political Issue." Paper presented at the IMF 16th Jacques Polak Annual Research Conference, Washington, DC, November 5–6.