Broadening narrow money: monetary policy with a central bank digital currency *

Jack Meaning † James Barker‡ Emily Clayton ‡ Ben Dyson ‡

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Abstract

The debate around central banks issuing a fiat digital currency has gathered pace in recent years. This paper offers a view of central bank digital currency (CBDC) that bases it in the existing frame of reference for economists, defining it as any form of electronic central bank ('narrow') money. Under such a definition many of the issues around a CBDC should be familiar to monetary economists. In fact such a CBDC already exists in the form of central bank reserves. From this point we then discuss how a universally accessible CBDC could be used as a monetary policy instrument and how it would impact on the monetary transmission mechanism (MTM). We conclude that monetary policy could operate in much the same manner as it does currently, by varying the interest rate paid on balances of electronic central bank money and/or by varying the aggregate quantity of electronic central bank money. There exists a large degree of uncertainty about the extent to which elements of the MTM would become stronger, weaker, faster or slower, which will depend ultimately on the precise design of a given CBDC, the objective it is intended to achieve and the reaction of other agents within the economy.

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†Bank of England. Corresponding author: jack.meaning@bankofengland.co.uk

‡Bank of England

1 Introduction

There is a burgeoning debate around the possibility and the desireability of central banks issuing their own fiat versions of digital currencies.[1] There are currently identified research programmes in this area at numerous central banks around the world, including the Bank of Canada (2017), the European Central Bank (Mersch, 2017), the Riksbank (2017) and the Bank of England (2017) as well as the Bank of Japan and the People's Bank of China.

The debate brings together a number of diverse elements. There are issues of technology, such as those discussed in Danezis and Meiklejohn (2015). Most commonly CBDC are associated with the distributed ledger technology (DLT) which lies behind Bitcoin and other private digital currencies. However, Scorer (2017) argues that this need not be the case. The impact of CBDC on the structure of the financial system is another important strand of the literature, with the potential impact of introducing CBDC on incumbent banks, their business models, and the financial system as whole discussed by BBVA (2017) and Foundery (2016) amongst others. A number of authors have considered the benefits of CBDC in terms of payments systems and similarly financial inclusion (Dyson & Hodgson, 2016). Barrdear and Kumhof (2016) is one of the first papers to begin to build a structured theoretical model of CBDC and try to quantify its macroeconomic impact. Crossing all of these various strands are questions of the optimal design of CBDC and how one may develop a framework to assess this, (Fung and Halburda, 2016).

In this paper we will focus on CBDC as an instrument of monetary policy. More specifically, we will look to assess the likely impact of CBDC on the ability of policymakers to achieve their monetary objectives. Mersch (2017), for instance, raises concerns that monetary policy may be made more difficult by the introduction of CBDC. Although by the untested nature of CBDC there remains a large degree of uncertainty around its ultimate impact, our analysis suggests that the introduction of CBDC is not likely to disrupt the ability of policy makers to pursue their monetary stability objectives. In fact, on balance we would suggest that there may be some benefits to the flexibility and efficacy of monetary policy.

A first step in understanding CBDC from a monetary policy perspective is to have a familiar frame of reference. To this end we offer a general definition of CBDC as any electronic, fiat claim on a central bank that can be used to settle payments or as a store of value. This should be recognisable to most economists with some background in monetary theory as simply electronic narrow money. Having such a relatable definition is a crucial part of demystifying CBDC and hopefully fostering debate among a broad range of economists.

The paper then traces the impact of a particular form of CBDC, a universally accessible, interest-bearing balance with the central bank, through the stages of the monetary transmission mechanism. This form of CBDC could be thought of conceptually as a widening of access to existing systems of reserve accounts at a central bank, which are currently only accessible to a limited subset of economic agents.

The large degree of uncertainty around the ultimate design of CBDC, the economic environment it will be realised into and the structural changes that may accompany it make it hard to arrive at definitive or quantitatively robust comments over what impact CBDC would have on the MTM. Rather, this paper aims to provide a framework for thinking about these issues and then begin to populate that framework with broad brush conclusions based on existing theory and reasonable assumptions. These issues will need to be continually monitored and revisited if and when CBDC were actively introduced. What is more, they will need to be balanced by considerations of the other dimensions of CBDC, such as its effect on payments systems and financial stability.

The rest of the paper is laid out as follows; we begin by elucidating on our general definition of CBDC and the various sub-characteristics it may exhibit; we then provide a balance sheet

[1] A digital currency is defined in Bordo & Levin (2017) as: "an asset stored in electronic form that can serve essentially the same function as physical currency, namely, facilitating payments transaction".

exposition of an economy with universally accessible CBDC and use it to work through some of the key CBDC transactions in the economy; in section 4 we discuss the likely impact of CBDC on the monetary transmission mechanism, building from the control of rates in the secondary market for CBDC to the channels by which this impacts the real economy; Lastly we highlight to alternative frameworks for CBDC before offering some concluding remarks.

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.[2] 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 a multitude of complex elements, covering 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 other-wordly to economists that are not so familiar with cryptocurrencies, blockchains, DLT (distributed ledger technology) and digital wallet providers. As a response, we offer a general definition that is both an accurate representation of CBDC, but that importantly couches it in terms that will be familiar to any economist who has 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 claim on 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.

Within our general definition there obviously exists a wide range of sub-characteristics and parameters that could be set or varied and would more precisely define any given CBDC. For instance, CBDC could also be a cryptocurrency based on a distributed ledger technology similar to that behind Bitcoin, Litecoin or Dash. Alternatively, it could be provided through a more mature and established technology such as that which powers the Bank of England's current Real Time Gross Settlement (RTGS) system. This would mean it were not a cryptocurrency, but it would remain a central bank digital currency. CBDC could pay a rate of interest, be that fixed or variable, but equally, it need not. In some cases CBDC may be restricted to a limited subset of the economy, while in others it may be universally accessible to all agents. An important dimension along which CBDC could vary within our general definition is in terms of their objective. CBDC could be used as an active tool for monetary policy. This case forms the large part of the discussion in the remainder of this paper. However, CBDC may conceivably have a number of other objectives; it may be intended to ensure a secure and efficient payments system across the central bank's balance sheet, or it may be an instrument of financial stability policy.[3] Which of these objectives lies behind a given CBDC will have fundamental implications for the optimal setting of the other parameters. Table 1 shows some common money-eque assets and the characteristics they each have. As shown by the first row, under our general definition, the first two characteristics are both necessary and sufficient to class an asset as CBDC, while the others may or may not hold.

Before any real-world CBDC could be launched, careful consideration would need to be given to the setting of these parameters. However, we feel it is helpful to have a general description of the essence of CBDC from which future research can build. It also provides a framework by which any future research can define the subset of CBDC to which it referring, and assess how its conclusions may vary were those parameters to be set in an alternative manner. We therefore see this an important first contribution of our paper.

[2] To some extent there is even a lack of consensus around the naming convention for such an asset. While we proceed with the terminology of central bank digital currency, it has also been referred to as electronic base money (EBM), digital base money (DBM) and e-money, among others.

[3] We will consider a CBDC designed for the payments objectives briefly from a monetary transmission perspective later in this paper.

Table 1: Characteristics of CBDC and other money-esque assets

	Liability of central bank	Electronic	Universally accessible	Cryptocurrency	Interest bearing	Trades at par	Mon.pol instrument
CBDC	✓	✓	?	?	?	?	?
Reserves	✓	✓	x	x	?	✓	✓
Bank notes	✓	x	✓	x	x	✓	x
Deposits	x	✓	✓	x	x	✓	x
Bitcoin	x	✓	✓	✓	x	x	x

To give a clear example, under our general definition, reserves are a form of central bank digital currency.[4] They are *not* a cryptocurrency as they are not based on distributed ledger or other cryptographic system of account. In many cases they pay a rate of return, either on the total balance held, or on those parts of the balance deemed *excess*. However, they are only accessible to a limited number of participants, predominantly select monetary financial institutions. Their primary objective is as an active instrument for monetary policy, however, for a small subset of the economy they also provide secure, efficient payments services, and in times of liquidity provision, they can become an instrument of liquidity of financial stability policy.

For the majority of this paper we will focus on a universally accessible, interest-bearing CBDC. For the main, we abstract from questions of the precise technology underpinning the CBDC, leaving this for authors with a comparative advantage in that field. Crucially, our primary concern is with CBDC as a monetary policy insturment, so we discuss payments and financial stability only in so far as they have consequences for the transmission of monetary policy.

Conceptually, another way to think about the CBDC discussed in this paper is as simply a widening of access to the existing system of reserve accounts offered by central banks. Both the Federal Reserve and the Bank of England have undertaken projects to broaden access to these markets in recent years, although access is still limited to a relatively small subset of the economy. The universally accessible CBDC discussed below takes that process to its extreme conclusion of access being granted to all agents within the economy.

3 CBDC: a balance sheet view

As a first step in considering how CBDC could affect monetary policy, figure 1 shows a series of stylised balance sheets for the main sectors of the economy both before and after the introduction of a CBDC of the type described above. The first panel should be familiar to many. Central bank money exists in two forms; reserves, which are electronic, and bank notes. As we have noted above, given our general definition, reserves are a form of central bank digital currency. These two liabilities are backed by asset holdings which in this simplified exposition are entirely government bonds.

Bank notes can be held by both banks and the non-bank private sector, while only banks can hold reserves. Banks make loans to the non-bank private sector and in turn generate deposits on the liability side of their balance sheet.[5] Non-banks hold these deposits as assets, alongside government securities, equity in the banking sector and physical central bank money, while their liabilities consist of loans taken from the banking sector and tax obligations.

The second panel in figure 1 shows how this picture changes with the existence of universally accessible CBDC. The two forms of central bank money remain, although to draw a distinction we rename universally accessible electronic central bank money "CBDC" rather than "reserves". The quantity of CBDC has increased compared to the upper panel. This is a likely consequence

[4] This assertion has been echoed by the IMF (Dong *et. al.* 2017).

[5] For a clear exposition of the mechanisms by which this occurs, see McLeay *et. al.* (2014)

of the increased number of economic agents who can now access CBDC and an assumption that their increased demand outweighs any aggregate reduction in demand stemming from a banking sector that can now divest itself more easily of CBDC should it wish to.[6] This divestment is likely to be limited due to increased demand for a CBDC-esque asset resulting from liquidity regulation, inter alia.

It is worth noting here that we do not assume, nor advocate, the removal of cash. Such an innovation is often a feature of debates around central bank digital currencies, and in some cases is even used to motivate their introduction. Goodfriend (2015), Agarwal and Kimball (2015) and Rogoff (2016) all suggest that a central bank digital currency could make it easier to set a negative rate on central bank money and thus alleviate the lower bound on interest rates. However, as recognised 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 topics should be recognised as distinct.

In contrast to the existing paradigm CBDC can now be held by non-banks as well as banks, giving non-banks three assets by which they can effect transaction; banknotes, CBDC and commercial bank deposits. To the extent that non-banks hold CBDC on the asset side of their balance sheet, all else equal, they will draw down on other assets. Exactly which assets they draw down will depend on their motivation for demanding CBDC. It may be a reduction in their holdings of banknotes, of government securities and similar financial assets, or of bank deposits. In practice it is likely to be some combination of all three. The reduction in demand for commercial bank deposits has the effect of shrinking the aggregate size of the banking sector's balance sheet. The magnitude and second-round effects of such a development are highly uncertain, but it is an important structural change that would require further analysis prior to a CBDC of the type discussed here being issued.

In terms of assets available to them, commercial banks are relatively unaffected, although they can now obtain CBDC, should they need to, from non-banks as well as from other banks and the central bank.

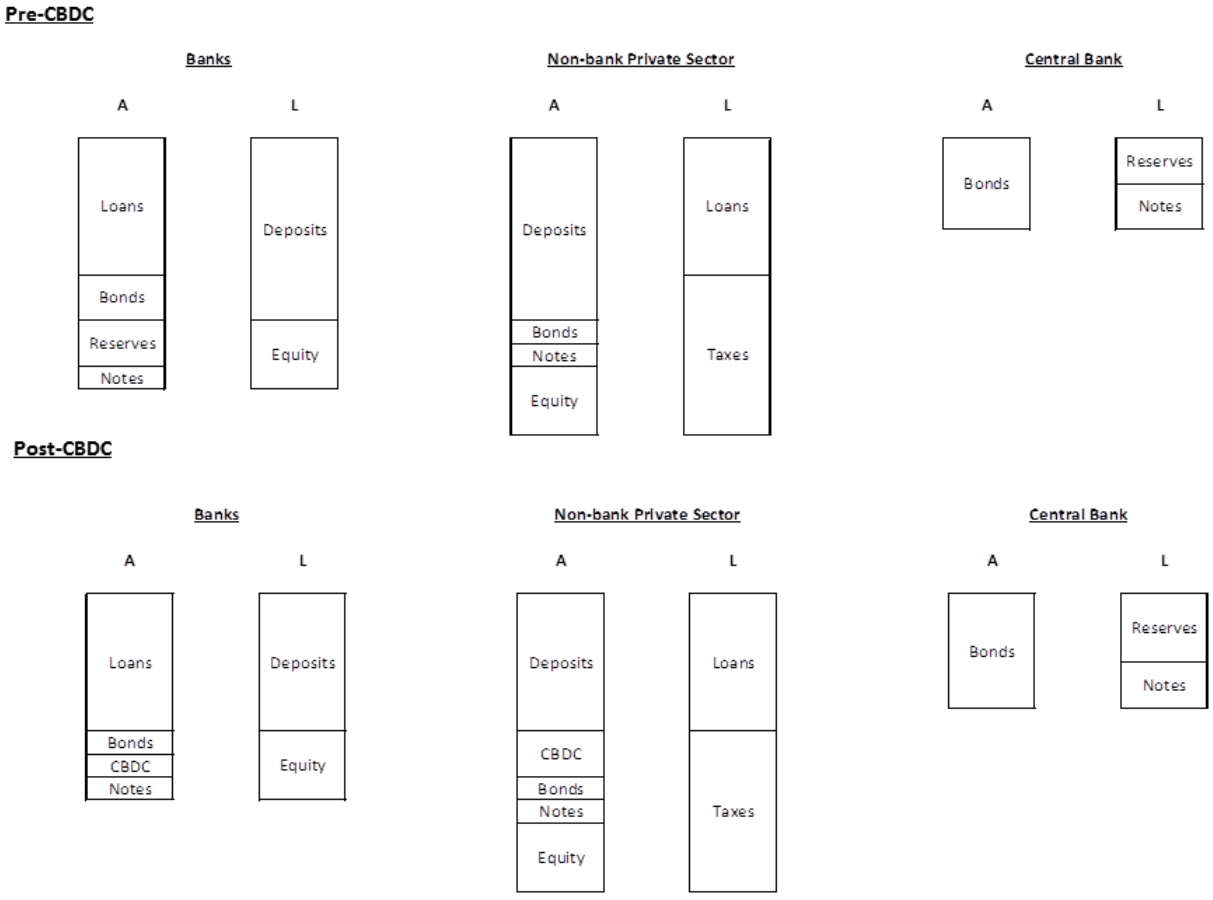
This balance sheet exposition is helpful for framing how a number of key transactions may occur under our model of CBDC. The first transaction concerns how non-banks get access to CBDC. In this model, depositors are able to withdraw CBDC on demand in the same way that they can currently withdraw bank notes. In practical terms, this means that the commercial bank would make a transfer from its CBDC account to the CBDC account of the depositor, and would reduce the depositors account balance by the same amount. The banking sector's balance sheet shrinks by the amount of the withdrawal, whilst the (now former-) depositor has simply swapped one asset (deposits) for another (CBDC). [7]

A second transaction highlights how a central bank could increase the aggregate supply of CBDC in the economy, by purchasing assets from either banks or the non-bank private sector and paying for these assets with newly created CBDC. This new liability of the central bank would be matched on the asset side by the acquired assets, and would appear on the balance sheet of the bank or non-bank seller as a change in composition of assets, rather than a change in the total quantity of assets. In this simplified framework, the central bank only holds government bonds on the asset side of its balance sheet. However, there is no reason though that CBDC cannot be exchanged by the central bank for other assets in the economy. The decision on which

[6] This argument in turn is based on the assumption that the aggregate banking sector is currently holding reserves in excess of its desired level as a result of quantitative easing programmes.

[7] This ability of depositors to exchange commercial bank money for central bank money on demand is key to maintaining the confidence in bank deposits, and much of the activities of the monetary authority (such as lender of last resort, capital and leverage regulations, and deposit insurance) are geared towards ensuring that this is always possible. Of course, allowing depositors to withdraw CBDC on demand has implications for bank funding and liquidity, and could create financial stability risks, as in a financial crisis depositors would find it easier to run to CBDC than to run to cash. Those financial stability risks clearly require careful management. However, under the alternative approach of disallowing depositors from withdrawing CBDC on demand, it may become much more complicated to maintain parity between central bank money and commercial bank deposits, particularly when the demand for deposits or CBDC shifts significantly. These issues require further analysis but are outside the scope of this paper.

Figure 1: Stylised balance sheets before and after the introduction of CBDC



This is a stylised representation and the sizes of boxes, relative or absolute, are not intended to be indicative of a real world balance sheet for any given sector.

assets would be eligible for asset purchases to control the CBDC supply would depend on a range of factors including the risk tolerance of the policymaker, the central bank's other balance sheet objectives, and the objectives of the monetary expansion itself.[8]

4 The monetary transmission mechanism

We next look at how the introduction of a CBDC could affect the transmission of monetary policy decisions, that is to say, how a change in the policy instrument leads to a change in the path of the real economy, most notably inflation, output or employment. There are many taxonomies by which this complex and ever-changing set of processes can be characterised, but in the analysis that follows we will discuss three broad stages. The first is the setting of the policy instrument; either the interest rate on, or quantity of, electronic central bank money in the secondary market. Second is the pass-through of changes in the price and interest rate on CBDC to the interest rates and prices of other assets in the economy. Lastly there is the pass-through from these financial market movements to the real economy. This final stage can itself be subdivided into a range of transmission channels including the real interest rate channel, the bank lending channel and the expectations/signaling channel, among others.

For the most part we will focus on the marginal impact of a change in a given policy instrument. CBDC would likely bring with it a host of changes to the steady state structure of the economy, such as changes to the equilibrium interest rate or steady state credit spreads but we discuss these only briefly when laying out the arbitrage conditions that follow. For a fuller analysis of such issues, we refer the reader to Barrdear and Kumhof (2016). We will also focus on the most common existing instruments of policy, namely (1) the short-term nominal interest rate and (2) quantitative easing. This provides a clearer lens through which to view the marginal change to the policy transmission mechanism that is a pure consequence of a universally accessible CBDC, rather than a discussion of less conventional policy options which would in of themselves represent an innovation to the monetary framework.

4.1 MTM stage 1: the secondary market for CBDC

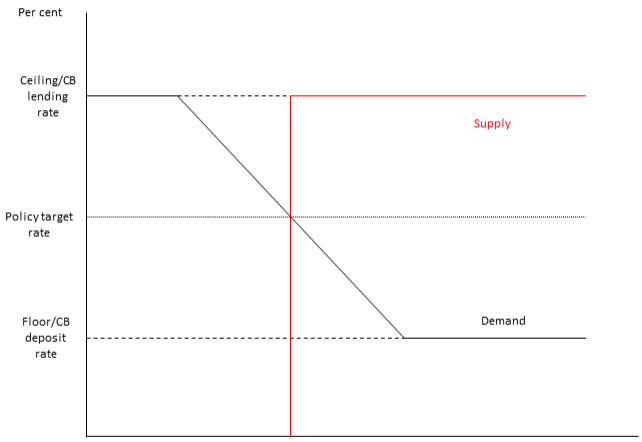
The starting point for practical monetary policy is the ability of a central bank to guide the prevailing interest rate in the secondary market for central bank money. Prior to 2008 this was primarily achieved through setting the aggregate supply of electronic central bank money such that on any given day not everyone in the market had sufficient central bank money to meet their desired/required holdings. Some banks must therefore borrow to fill this deficit and pay a price to do so. For a given demand, increasing the supply of central bank money meant fewer market participants would be short of central bank money relative to their preferred holdings and a greater number would be holding balances in excess of where they wanted to be, and so the price of borrowing on the secondary market would fall.

For added stability, and to insulate the market interest rate from large, unanticipated swings in demand, central banks bound their target rate on both sides. To bind on the downside they set a rate at which they would remunerate balances of central bank money held on account with them. This imposed a floor, as no-one would be willing to lend in the secondary market, which inherently involved exposure to some risk, for less than they could store the funds risk free overnight at the central bank. On the upside, rates were bounded by policymakers setting a rate at which they would lend additional central bank money on a collateralised basis. This acted as a ceiling, as no-one would be willing to pay significantly more to borrow in the secondary market than they would be charged by the central bank to borrow the same funds. [9] This floor and ceiling approach

[8] In theory CBDC could be gifted to the economy without the need to withdraw an asset from the private sector. Such helicopter drops are discussed in Turner (2015).

[9] There are a number of reasons as to why some secondary market rates may be above this ceiling in practice. For instance, borrowing from the central bank may come with a stigma, or be seen as a signal of fragility by markets. Similarly, the central bank may only lend against high-quality liquid assets, whilst it may be possible to borrow uncollateralised in the secondary market, but at a higher cost.

Figure 2: Secondary market for central bank money under a corridor system



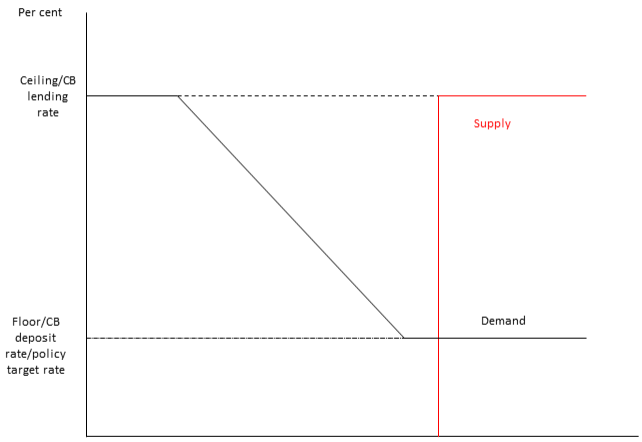
is known as the corridor system.

More recently, central banks have expanded the quantity of central bank money as part of their large-scale asset purchase programmes. This has had the effect of pushing the prevailing market rates to the floor of the corridor as central bank money is so plentiful that very few, if any, participants find themselves short of their desired holdings and in need of credit from the secondary market. This has reduced activity in the secondary market and has led to the key interest rate of concern to policy makers being that paid on reserve balances. As shown by Goodfriend (2002), under such a system it is possible for the policymaker vary both the price and the quantity of reserves independently of one another.

How could this initial crucial stage of the monetary transmission change were CBDC to become universally accessible? A complete assessment and design of the optimal operational framework of a system with CBDC is beyond the scope of this paper. It would depend on multiple factors, among them the central bank's motivation for introducing CBDC, the balance of other objectives for the central bank's balance sheet management, the liquidity and depth of the markets in which the central bank acts and the reaction of markets to the introduction of a universally-accessible CBDC. Many of these things will vary between central banks and over time, requiring bespoke assessment and regular reviews, as is the case for operational frameworks in central banks currently. However, what we can offer is a higher level assessment, conditioned on plausible assumptions and existing theory, that should be sufficient to build policy relevant conclusions and support the analysis that follows.

First, the very concept of the secondary market would change. At the moment the secondary market consists of a small, relatively homogeneous group of participants (banks) lending to one another over a relatively narrow set of terms for relatively similar purposes (smoothing liquidity/payments shocks). Even then, there is not a single prevailing interest rate as one might infer from Figure 2 above. Rather there exists a myriad of rates, each set in a bespoke manner and based on the specific nature of the given loan. These can be affected by term, risk, the col-

Figure 3: Secondary market for central bank money under a floor system



lateral provided, or not, and the strength or otherwise of the relationship between the two parties.

A universally accessible CBDC would mean that the secondary market for CBDC would become a much broader concept than it is currently. CBDC could be lent between a much wider range of agents and on much more diverse terms. It could be interbank, as is currently the case, but it may also be from a hedge fund to a bank, or a household or business to a bank. It could be to smooth a payments shock, or it could be to fund purchases of goods and services from the real economy. The introduction of a wider range of borrowing motives could potentially give rise to a wider range of terms as well. While borrowing to smooth payments shocks is by its nature short-term, borrowing central bank money to fund a house purchase would likely require a longer term. In fact, the secondary market for CBDC could conceptually cover the entire credit market as we think of it today. Given this, central banks would have to be clear about exactly which parts of the market they were targeting, or possibly take a more holistic approach to assessing policy.

With this broader concept of a secondary market, could a central bank continue to guide rates? The answer is yes, in much the same way as it does now.

The interest rate paid on CBDC balances by the central bank would set the floor to the wider spectrum of rates in the secondary market. This is because, since holding CBDC balances overnight with the central bank is the most risk-free and liquid way of transferring value from one period to another, no-one is going to lend CBDC for any kind of risk or term without charging some premium over the CBDC deposit rate to compensate them for the increased risk/illiquidity of lending. The CBDC rate would be approximate to a risk-free rate.[10] All other rates would then be above this floor, with their precise spreads determined by the size and nature of the relative premia arising from, among other things, term, risk or illiquidity.

[10]Although actually in practice it would be lower than the theoretical risk-free store of value rate, as it would also contain a negative premium relecting the transactional/liquidity services that CBDC provided as money. For more on this see the discussion of arbitrage conditions in Section 4.2.1

The ceiling of a corridor system could also be complicated. In the extreme, were a policy maker to agree to lend CBDC to any agent across the full range of lending types (collateralised/uncollateralised, for short- or long-term purposes, for consumer credit or mortgages) then they would essentially be capping rates in the entire credit market. When combined with the floor, this would imply that the central bank is imposing a very tight control on interest rates in the economy, confining the whole spectrum of rates to within their designated corridor. In reality, central banks are unlikely to be willing to lend against such a wide range of risk-bearing assets. Instead, they would likely only lend CBDC to a limited subset of the economy, against a limited range of eligible assets, and at a limited range of terms. For instance, were they only to lend to institutions that are already covered by the existing reserve markets, and only in exchange for high quality collateral and for a relatively short term, then the corridor would in practice cap just rates in that subset of the market (short-term, collateralised, interbank lending). Other rates such as those on uncollateralised lending, term lending, or lending to non-banks could fluctuate outside of the corridor.

The terms on which it would grant access to lending facilities could become a policy variable in themselves. For instance, should the central bank need to provide liquidity assistance to a non-bank for monetary, financial or payments system stability reasons, it could allow access to the lending facility for a wider range of firms, or perhaps on easier terms such as lower requirements for collateral quality.

4.2 MTM stage 2: pass-through to other interest rates

The next step in the monetary transmission mechanism is the pass-through from interest rates on central bank money to those on other assets. This occurs through a process of arbitrage whereby agents trade off interest rate differentials until they are willing to hold the existing supply of assets at the prevailing market returns. Before we begin to think about how this process might change as a result of a universally accessible CBDC in terms of the speed and strength of transmission, it is helpful to sketch out a broad view of what these arbitrage conditions may look like. We do this through the lens of a stylised model that is most certainly partial rather than general equilibrium. It does however still serve as a helpful expositional tool and offers some initial intuitive insights into the structure of interest rates in an economy with a universally accessible CBDC.

4.2.1 Arbitrage conditions

Our arbitrage analysis begins from a theoretical risk-free interest rate, R, that represents the return on a pure store of value asset with no associated premia. 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 money, for instance, lowering transaction costs, ϕ^C. The total expected return from a unit of CBDC is therefore[11]

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

and no-arbitrage would imply

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

meaning that

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

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. We can now build from here to a wider array of assets. We do so by looking at each sector of the economy in turn and working through the no-arbitrage conditions that their balance sheets would imply.

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

Beginning with the non-bank private sector, consistent with our stylised balance sheets they can hold their wealth as a combination of 3 assets; CBDC (denoted by C), bank deposits (D) and government bonds (B).[12] 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 non-pecuniary 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 non-pecuniary return emanating from its role as money, 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 non-pecuniary 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 non-bank's end of period wealth equals

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

And so is maximised where

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

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

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

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

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

and

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

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 positive function of the transactional service of CBDC money, and a negative 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.[13]

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 non-banks, the banking sector receives both a pecuniary return on its CBDC holdings, R^C, and a non-pecuniary benefit from CBDC's transactional services, ϕ^B. Unlike non-banks, they receive an additional non-pecuniary 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. Government bonds also provide a benefit as HQLAs, but provide

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

[13] 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 premia, such as term, which would mean that the bond rate clears at a spread above the risk-free rate.

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 with monitoring cost of this type, see Goodfriend and McCallum (2007). We further assume 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 non-bank sector.

Taken together we can write the bank's problem as

$$R^C C + \phi^B C + \eta C + (1-\delta)[R^B + \epsilon]B + (1-\mu)R^L L - ML - R^D[C+B+L](1-\gamma) \tag{10}$$

the first order conditions of which give

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

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

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

and which optimises to give

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

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

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, of the default risk in bonds, and the relative benefits of CBDC as a HQLA when compared with bonds. When combined with the non-bank condition for bonds, this implies that the relative transactional services received by banks compared with non-banks must equal the additional benefit that banks receive from holding bonds as HQLA. The loan rate spread is a positive function of the cost of producing a loan and the probability of default.

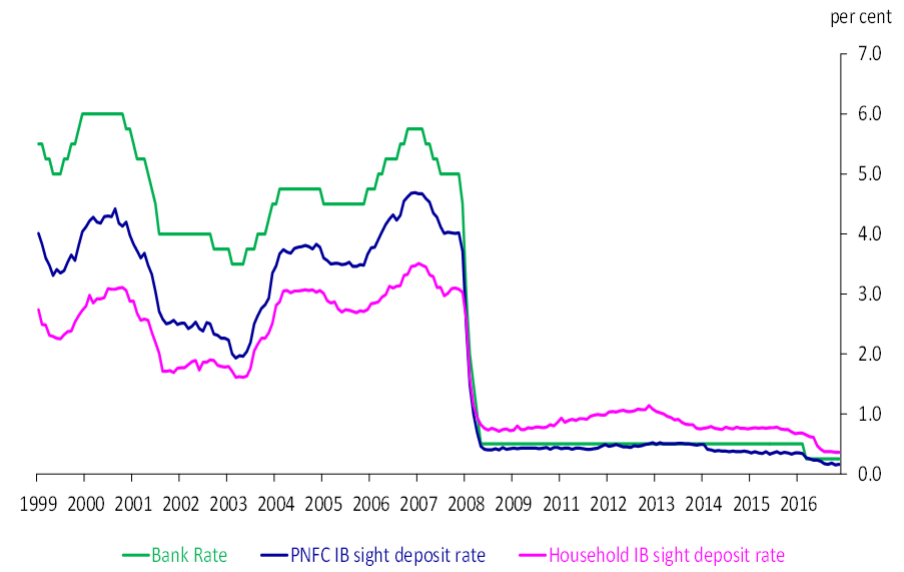
What does this show us?

First, under the seemingly sensible assumption that there is at least some notionally positive default risk in bank deposits and that deposits are no more useful in terms of providing transactional services than a CBDC, the deposit rate will be above the rate on CBDC. This is important as until the 2008 financial crisis, deposit rates were systematically below their equivalent policy rates, figure 4. The logic for this is clear; banks had monopoly power of the creation of money that could be used to make transactions in the wider economy and non-banks had no outside alternative. Banks could make use of this monopoly to lower the rate that they paid on deposits. In terms of our framework above, this made phi^C as very low, if not zero non-banks could not even hold CBDC, and ϕ^D very high. What is more, state backstops, implicit or otherwise, essentially rendered γ zero. With the outside option a CBDC would provide, were a commercial bank to try and pay less than the policy rate on funds, the non-bank depositor could withdraw CBDC in return for a reduction in their deposit balances.

It may be posited that with deposit guarantee schemes bank deposits are essentially risk-free. However, coverage of deposit guarantee schemes is far from exhaustive, especially for business account holders and accounts with large balances. What is more, even those that are covered face the risk of their money being frozen or tied up while the process of unwinding a failing bank

is undertaken and the deposit guarantee scheme enacted. Lastly, it might be argued that there is an implicit state guarantee, even when there isn't explicit deposit guarantee scheme coverage. We would argue that a CBDC would remove this guarantee of the banking sector and instead make it an explicit offer of the state to provide a functioning and risk-free payments and savings alternative. This would likely increase the perception of risk within deposits held with the banking sector, all else equal.

Figure 4: Sight deposit rates vs policy rates in the UK



Source: Bank of England.

4.2.2 The impact of CBDC on the second stage of monetary transmission

As well as potentially changing the structure of interest rates in the economy, there are a number of features of CBDC as we have envisioned it that could affect the speed and extent of pass-through between changes in the policy rate and other rates. Most notably, the central bank is now offering an outside option to those who want to hold electronic money balances and who previously could only do so via deposits with a commercial bank. Abstracting from the steady state shift that might occur as a result of this outside option, and also from the transitional period as any new steady state is achieved, the fact that there is a competitive money alternative to bank deposits is likely to mean that if the interest rate on that alternative changes, but deposit rates don't move one-for-one then there will be flows between the two assets as people reallocate their portfolio between the two assets to take advantage of the relatively higher return that has opened up. If the policy rate 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, which could in turn result from technological advances associated with a CBDC. To the extent that pass-through from policy rates to deposit and wholesale rates has been estimated to be less than one, CBDC is likely to strengthen this stage of transmission. We agree with Bordo and Levin (2017) that depositary institutions that engage in customer-focussed relationship banking are likely to be less

vulnerable to this than the areas of the market that compete purely on price terms. We also acknowledge that the current weight of evidence is that deposits are sticky within the banking system and so have a low price elasticity within banks (Chiu and Hill, 2015). The extent to which this remains the case once the central bank offers an outside option, and in the face of structural changes that will make it easier to switch accounts, such as PSD2 in Europe, remains to be seen and should be prioritised as an area for empirical work into CBDC.

Whether or not the speed of pass-through to deposit rates changes will depend on how banks react. The immediate assumption may be that as technology is likely to mean that depositors can more easily and costlessly move between deposits and CBDC, banks would have to respond quickly to stem deposit flows. However, if banks were to react to the increased flightiness of deposits by changing their funding models to rely more on term funding, it may be that pass-through to rates received by depositors is ultimately slower.

The strength of pass-through to lending rates for commercial bank money would likely be affected along two avenues. First, 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 mark-up on these funding costs, this would have a larger impact on loan rates. However, a universally accessible CBDC is also likely to foster more competition in the provision of credit. CBDC could allow non-banks to make loans more easily. For instance, peer-to-peer lenders would no longer have to clear settlements through their competitors in the banking sector, as they are currently forced to do in the existing system of tiered access to central bank money. This process incurs a cost which CBDC could alleviate, putting non-bank credit providers on a more equal footing with their banking sector counterparts. 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.

4.3 MTM stage 3: to the real economy

Being able to influence interest rates is only an intermediary step in the monetary transmission mechanism. The ultimate goal of changes in policy is to guide the real economy, spurring it on when growth or inflation are too low, and cooling it down when they are too high. This is achieved through a number of channels, for which there is a wide range of taxonomies.

A number of the channels by which the MTM leads to the real economy begin with the change in interest rates we have discussed previously. The most obvious of these is the real interest rate channel, but the cash-flow channel and bank lending channel are among those also dependent on changes in either nominal or real interest rates. Given that our previous analysis suggests that CBDC is likely to increase the extent of changes in interest rates for a given change in the policy rate, all else equal, this will serve to amplify the strength of all of these channels, for a given change in the policy rate. Beyond this however, it is hard to pin down any structural reason why a CBDC would influence the strength of, for example, the real interest rate channel. At its heart, this channel is based on the deep parameters determining the intertemporal preferences and decision making of economic agents. These are unlikely to be influenced by whether or not agents are fulfilling their intertemporal allocation through a CBDC, bank deposits, or some other asset.[14] Similarly, the cash-flow channel is based on the marginal propensities to consume of various agents, which there is little reason to believe would change as a result of CBDC becoming universally accessible.

The process by which agents form expectations would also appear to be largely independent of the introduction or otherwise of a universally accessible CBDC. Therefore one may only expect the expectations/signalling channel to be affected insofar as CBDC adds or detracts from the clarity and credibility of central bank communications of the policy stance. This seems unlikely

[14]The caveat to this may be that if CBDC is a truly risk-free asset then this may lower the risk of transferring wealth between periods and increase the amount of intertemporal allocation that occurs, but this would predominantly be a level change rather than a change in the extent of transmission.

to be large, but if the pass-through from policy rates to wider rates were to become fuller then the potential for policy becoming constrained would be reduced, all else equal. [15]

The exchange rate channel could become more sensitive to a change in the policy rate, as international differentials in market interest rates would widen by more. For the logical argument behind this, think of an uncovered interest rate parity (UIP) condition in which the two rates of interest that matter are the bond rate in each currency. If a given change in the domestic policy rate leads to a greater change in the bond rate, then the exchange rate will have to move by more to clear the market consistent with UIP.

Perhaps the channel of transmission that would be most affected by the introduction of a universally accessible CBDC would be the bank lending channel. As discussed previously, the funding costs of banks would likely become more sensitive to changes in policy rates. This should strengthen the bank lending channel. What is more, the additional competition in credit provision may make pass-through to lending rates more complete. However, this picture has the potential to be complicated by a number of features of an economy with universally accessible CBDC. First, the fact that deposit rates are now above policy rates could squeeze the net interest margins of the banking sector and thus could result in less lending occuring.[16].

Banks are also crucially involved in money creation, a key part of the impact of the bank lending channel. Currently banks lend by issuing new deposits, in effect creating new money and purchasing power, McLeay et al. (2014). In contrast, non-bank 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 can continue to lend by issuing deposits, but they could alternatively choose to lend CBDC'. In practical terms, this would require that they ask the borrower to nominate a CBDC account into which the lent funds could be transferred. If banks shifted to lending CBDC (and therefore acting like a non-bank lender) rather than lending by issuing deposits, this could disrupt the bank lending channel and weaken the transmission of monetary policy. In practice, there are a number of reasons why banks would normally prefer to lend by issuing new deposits. Firstly, there is unlikely to be demand for borrowing in CBDC specifically: as long as the sellers of goods, services or assets are able to substitute freely between deposits and CBDC, 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 interest rate. Consequently, the interest rate for lending for a given level of risk and term should be the same whether it is CBDC or deposits that are borrowed. For this reason, banks are unlikely to receive requests to borrow in CBDC specifically. Secondly, lending CBDC will have a much more negative impact on current regulatory ratios (specifically the Liquidity Coverage Ratio and Net Stable Funding Ratio) than lending via issuing deposits, because lending CBDC ensures that the bank will lose 100 of liquidity for every 100 lent.

All taken together,this analysis 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. The size (and even the sign) of this change in the strength of transmission is incredibly uncertain and the unprecedented nature of a CBDC of this kind complicates, if not precludes, any informative empirical work.

4.4 QE with CBDC

In recent years central banks have purchased assets from the private sector and funded these with newly created central bank money, a policy known as quantitative easing. However, because of

[15] See point on the effectiveness of QE under market stress.

[16] We suggest a partial solution to this in section 5.1 based on paying differentiated rates of interest on CBDC held by banks to that held by other agents.

the existing financial system, the story is slightly more complicated than this. A more accurate description of the operation is as a three-way agreement between the central bank, commercial banks and the private sector. As non-banks cannot currently hold electronic central bank money, and purchasing assets by printing physical notes is neither practical, nor desirable, non-banks must use commercial banks as intermediaries to sell assets to the central bank. The commercial bank sells the asset to the central bank on behalf of the non-bank and receives an increased balance of electronic central bank money in its account with the central bank. It simultaneously generates a new commercial bank deposit on the liability side of its own balance sheet, which it credits to the ultimate seller of the asset, the non-bank. A consequence of this system is that a a quantitative expansion of central bank money necessarily involves an increase in the aggregate liquidity of the banking sector.

Conducting asset purchases with CBDC would remove this necessity to increase banking sector liquidity. By paying non-banks directly with CBDC, the operation can completely by-pass the banking system should the central bank wish to do so. There is theoretically the possibility that as non-banks rebalance their portfolios, some of the newly created CBDC may find its way into the banking sector in exchange for deposits. In practice, this is likely to be limited as CBDC and bank deposits will be relatively close substitutes, and the theory behind portfolio rebalancing would suggest that agents are more likely to rebalance into assets that are closer in nature to the asset they sold, rather than that which they received.

4.4.1 The portfolio rebalancing channel

One of the main theoretical transmission mechanisms of asset purchases is the portfolio rebalancing channel. This has its theoretical basis in work by Tobin (1969) and others, who show that if assets are imperfect substitutes for one another then changes in their relative supplies in the privately held portfolio will have consequences for prices and yields. Empirical literature on the recent asset programmes of the Federal reserve, Bank of England, European Central Bank and Bank of Japan shows significant incidences of this channel of transmission. See Bhattari and Neeley (2016) for a survey of the literature on the US experience, Joyce, Liu and Tonks (2014) among others for the UK, and Meaning and Zhu (2011, 2012).

Conducting asset purchases with CBDC could theoretically strengthen this channel of transmission. This is because portfolio rebalancing is stronger the greater the difference in the assets being exchanged. QE with a CBDC exchanges a truly risk-free asset for a riskier asset (usually a bond) whereas, from the point of view of the non-bank private sector, existiing QE exchanges bank deposits, which contain an inherent amount of risk. Therefore in exchanging a risky asset for CBDC, the net reduction in risk held by the private sector is greater than if the same asset were exchanged for commercial bank deposits. This means that the private sector portfolio is further away from the aggregate preferred habitat - given the existing constellation of prices - and therefore prices and interest rates must adjust by more to find a new equilibrium that clears all markets.

In practice this strengthening is likely to be small though, and we put little weight on it, especially relative to the other changes a CBDC would bring. However, to the extent that it existed it would be at its largest when the risk perception of bank deposits was furthest away from that of a CBDC.

5 Alternative CBDC designs

The analysis thus far has focussed on a universally accessible CBDC that is employed as a monetary policy instrument. However, this is not the only potential design option for CBDC and a number of others have been suggested in the literature. Here we discuss two. The first is an interest-bearing CBDC that pays a differentiated rate of interest to different types of user. The second is a non-interest bearing form of electronic bank notes, or e-cash, that is accessible to everyone, but also coexists with central bank reserves that are only available to a limited subset

of the economy.

5.1 Differentiated rates of interest on CBDC

In our analysis so far, both banks and non-banks receive the same interest rate (the CBDC rate) on the electronic central bank money that they hold. However, there may be a case for paying banks a different rate to non-banks. This is because banks are a key part of the monetary transmission mechanism specifically the bank lending channel since their lending creates new money and purchasing power (McLeay *et. al.*, 2014). This is in contrast to non-bank lenders, who simply act to transfer existing purchasing power from savers to borrowers, but do not create new purchasing power in the process of lending.

In the current monetary regime, central banks use their policy rate to influence the bank lending channel (as well as a range of other rates). When CBDC is introduced, banks will continue to create money through lending, and so central banks will still want to influence them through adjusting the rate banks receive on their holdings of central bank money. However, the appropriate rate to pay banks on their CBDC may be quite different from the rate that is appropriate to pay non-banks. If banks and non-banks receive the same rate, this creates a problem of having one tool to achieve two objectives. Consequently, it might be important to distinguish CBDC accounts based on whether the holder is a bank or non-bank, and pay different rates to each the bank rate and the non-bank rate.[17] The bank rate would play the same role as todays policy rate, whilst the non-bank rate would be lower.

Paying separate rates to banks and non-banks may alleviate one issue that arises when both are paid the same rate: since the CBDC rate sets the floor for all other rates, banks must pay a deposit rate that is equal to the CBDC rate plus a (potentially very small) risk premium. However, they will only earn the CBDC rate on CBDC that they hold for settlement and liquidity purposes. This means they will make a negative interest margin on all CBDC that they hold, and so will have a strong incentive to hold the minimum CBDC possible. Regulations place a limit on the minimum liquidity that banks must hold, but it may be undesirable to build in a structural incentive for them to hold only this regulatory minimum. Paying banks a slightly higher rate than non-banks would remove this incentive.

Paying differentiated rates would pose a number of policy questions. For example, is there a natural limit to the minimum or maximum spread between the bank rate and non-bank rate? Would both rates have to move in lock-step or could they be varied differently? Would having two rates complicate the communication of the stance of monetary policy? These questions need further analysis, but are outside of the scope of this paper.

5.2 CBDC as e-cash

Another alternative to our interest-bearing, universally accessible baseline assumption is that a new CBDC is introduced as a form of electronic banknote, or e-cash. The purpose of such an asset differs from the policy-focused currency that forms the majority of this paper as it would primarily be aimed at providing secure and efficient payments services via the central bank's balance sheet. This form of CBDC would not be used as an effective instrument for monetary policy as the interest rate would be essentially fixed at zero. [18] It would also have to be supplied perfectly elastically in order to clear the market at that fixed rate. This is currently the case with physical bank notes. In order to conduct monetary policy the central bank would still be required

[17] Note that some non-banks currently have access to reserve accounts at the central bank, for example, certain financial market infrastructures or dealer-brokers. Our distinction is not between those who currently have access to central bank reserves and those who do not, but between those institutions that create money in the process of lending (i.e. banks) and those that do not.

[18] Although this could conceivably be fixed at a non-zero value as well.

to maintain a restricted access CBDC in the form of reserves, Boel (2016).

The demand for e-cash is likely to be a function of, inter alia, other interest rates in the economy as changes in the rate paid onother assets changes the relative return on e-cash. These shifts in demand could drive flowsbetween deposits and e-cash, and vice versa. In this way demand for e-cash is likely to be countercyclical to policy rates. The flows in and out of an e-cash CBDC could be a source of instability in the banking sector, and could also affect the level of liquidity on banks' balance sheets and the cost/availability of bank funding. These may in turn act as unintentional attenuators of a change in policy. For instance, a lowering of the policy rate would lower the return on deposits held with commercial banks and make e-cash more attractive. This could lead to a withdrawal of bank deposits and either an increase in the funding cost of banks, or a smaller balance sheet for the aggregate banking sector, both of which would offset the intended monetary policy loosening.

6 Concluding remarks

While the current debate around CBDC is full of novel and complex elements intertwined with fast-evolving technology, at its heart a CBDC should seem familiar to anyone with an understanding of the monetary process. It is in essence electronic narrow money, although this general definition contains within it a significant number of subsets. The assertion of this paper is that under a universally accessible CBDC, monetary policy could operate in much the same way as it currently does, guiding the economy through varying the rate of interest paid on balances of 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 highly uncertain, but we believe the most likely consequence would be that the monetary transmission mechanism would be slightly stronger than currently, for a given change in policy instruments. Different designs of CBDC may lead to changes in this conclusion and any ultimate benefits or costs for monetary policy will need to be weighed against the impact on other areas of concern for policymakers, such as financial stability and payments. What is more, this paper is intended as an early step in our understanding of CBDC and the monetary transmission mechanism. Significant work, both theoretical and, eventually, empirical will be required to have an understanding of sufficient depth to inform policymakers fully.

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