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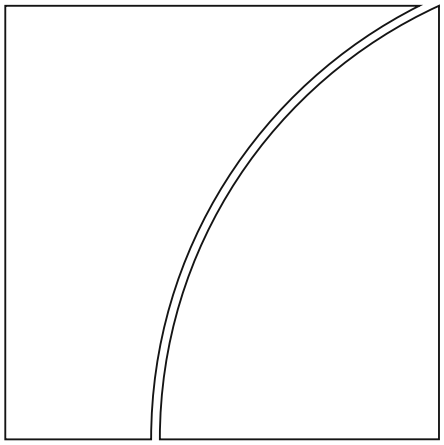

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by Raphael Auer, Jon Frost, Leonardo Gambacorta, Cyril Monnet, Tara Rice and Hyun Song Shin

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Central bank digital currencies: motives, economic implications and the research frontier

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Abstract

In just a few years, central banks have rapidly ramped up their research and development effort on central bank digital currencies (CBDCs). A growing body of economic research informs these activities, often focusing on the "reserves for all" aspect of CBDCs for retail use. However, CBDCs should be considered in the full context of the digital economy and the centrality of data, which raises concerns around competition, payment system integrity and privacy. This paper gives a guided tour of the growing literature on CBDCs on the microeconomic considerations related to operational architectures, technologies and privacy, and the macroeconomic implications for the financial system, financial stability and monetary policy. A set of questions, particularly on the cross-border dimensions of CBDCs, remains unresolved, and calls for further work to expand the research frontier.

Keywords: money, digital currencies, central banks, central bank digital currencies, CBDC, stablecoins, cryptocurrencies, distributed ledgers, big tech, data privacy.

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Introduction

The digitalisation of economies has far-reaching implications for many areas of economic inquiry, not least for monetary economics and the concept of money itself. With the massive volumes of data that digital activities generate come new opportunities and challenges for societies and the monetary system.

A tradition in monetary economics is to view money as a coordination device that serves as a substitute for the complete list of economic transactions – ie as society's "memory" of all economic transactions (eg, Kocherlakota (1998)). Yet this abstract definition of money leaves open its institutional underpinnings, upon which the welfare consequences of the institution of money may crucially depend. In particular, due to the inherent network effects in payments (Rochet and Tirole (2006)) and the potential for the proprietary use of data, digital forms of money pose substantial challenges for competition, privacy and integrity. It is in this context that an important public debate has arisen on the issuance of new, digital forms of central bank money and how they will affect the architecture of the monetary system.

The idea that central banks would issue digital forms of money for general use is a natural progression from the issuance of physical cash. In addition, banks have had access to digital forms of central bank money for several decades in the wholesale payment system. However, the debate on the issuance of digital central money that is accessible to ordinary users has picked up pace only recently. Initially, policy reports took a cautious approach to issuance (eg CPMI-MC (2018)). The last few years have witnessed a broadening of the debate. Alongside the rise and fall of cryptocurrencies, the emergence of global stablecoin proposals such as Facebook's Diem, and increasing technological disruption in finance, central banks have adopted a more proactive stance by anticipating a future when innovation and the entry of new private forms of money will already have transformed the monetary system, rather than treating the current system as the benchmark. Central banks have begun to engage in research on CBDCs and, in some instances, also their development. According to a survey from late 2020, 86% of global central banks are conducting research on CBDCs, and as of July 2021, 56 central banks have publicly communicated their research or development efforts (see Boar and Wehrli (2021) and Auer et al (2020)). At the time of writing, two central banks have launched CBDCs and several are conducting pilots. However, there is as yet no broad consensus among central banks on the need for CBDC issuance.

Alongside a fast-changing and intense policy debate, a still nascent but rapidly growing academic literature has emerged that examines the broader economic implications of CBDCs. The focus to date has mostly been on the "reserves for all" aspect of CBDCs, and the associated balance sheet implications for central banks in their interactions with commercial banks, the impact on the effectiveness of monetary policy, and the implications for financial stability.[2] In policy circles, meanwhile, there is growing confidence that a targeted economic design can achieve public policy goals while limiting systemic implications. Hence, the discussion focuses more on the potential enhancements to payments inclusion and efficiency, and the policy objectives of ensuring competition, data privacy and integrity of payment systems (see Auer and Böhme (2020, 2021) and BIS (2021)).[3] Many central banks, meanwhile,

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[2] See the discussion in Section 4. Studies assess how the issuance of retail CBDCs could affect the balance sheets of central and commercial banks and the respective volatility (ie Kumhof and Noone (2018), Brunnermeier and Niepelt (2019)), lending and the interest rates of commercial banks (Andolfatto (2021)), and the bounds and effectiveness of monetary policy (ie Bordo and Levin (2017), Davoodalhosseini et al (2020)).

[3] See also Kiff et al (2020), Bank of Canada (2020), ECB (2020), Bank of England (2020), People's Bank of China (2021).

see CBDCs as a public infrastructure that could help to ensure competition and open markets in the face of competitive threats from the incursion of big techs into payment systems.[4]

This chapter gives a guided tour of the growing literature on CBDCs in economics and other related disciplines. It investigates the motivations for retail CBDC issuance, analyses the underlying trade-offs in their design, and discusses their potential macroeconomic implications. In so doing, the chapter brings together an academic and a policy perspective. It bridges these discussions and identifies potential avenues for future research.

As currently discussed, CBDCs can be defined as a form of digital money, denominated in the national unit of account, which is a direct liability of the central bank (Group of central banks (2020)). These can be either for wholesale use (ie by financial institutions) or retail use (ie by households and businesses – the general public). CBDCs can be either account-based, meaning that they rely on some form of identification, or token-based, meaning that they allow for anonymity in payments. CBDCs can be based on either distributed ledger technology (DLT) or conventional technological infrastructures. In most cases, CBDCs are being designed such that they preserve the two-tier structure of the monetary system, with a division of labour between the public and private sector.

Focusing mostly on retail CBDCs, research is helping to inform their design, as central banks have worked with economists, computer scientists, legal scholars and other specialists to understand the challenges and opportunities of CBDCs. Moreover, the research literature on CBDCs is developing rapidly to keep pace with developments in economies around the world, fusing theory and practice. Yet there are notable gaps in this literature. In particular, there are important questions around CBDCs and cross-border payments, on which policy development is marching beyond the research frontier, and where research insights could help to inform the design and international coordination of CBDC projects. Understanding the international implications of CBDC issuance for issuing and receiving countries, as well as the potential for CBDCs to improve cross-border payments and integrate (digital) economies, remain important challenges where research can usefully inform real-world policy efforts.

The paper is organised as follows. Section 1 gives a brief historical account of CBDC research and development, from predecessors of modern digital currencies to the work of central banks in the past decade. Section 2 discusses the motivations of central banks to issue CBDCs in the light of the challenges of the digital economy. Section 3 discusses microeconomic considerations on CBDC architectures, technological infrastructures and data privacy. Section 4 then discusses the macroeconomic implications for the financial system, monetary policy and society. Section 5 discusses the cross-border implications and potential of CBDCs – a set of issues at the research frontier. Finally, Section 6 concludes.

1. A brief history of CBDC initiatives

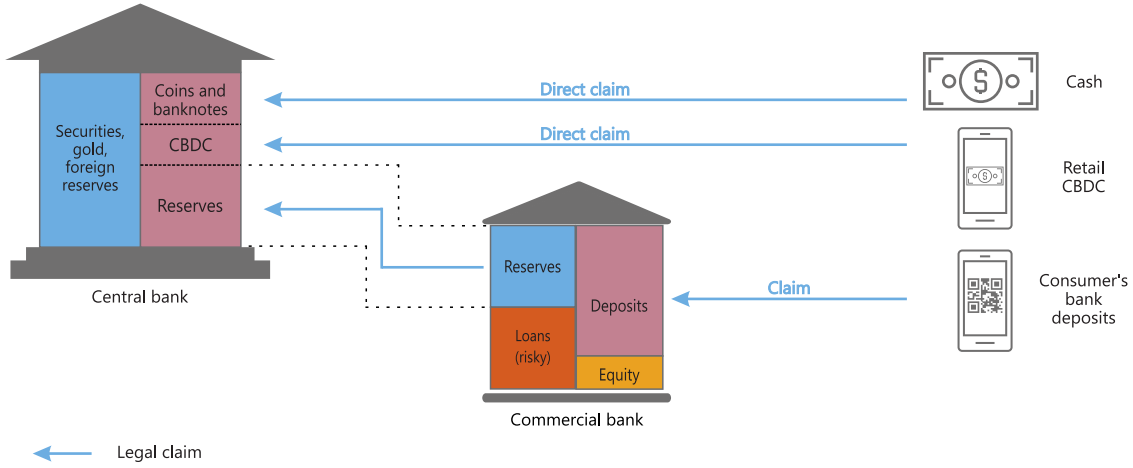
Over the centuries, various forms of money have emerged to meet the economic needs of the time. Coins, banknotes, cheques and credit cards were each innovations in their own day (Giannini (2011)). In recent decades, new payment technologies have been added to this list, from phone-based mobile money to smartphone-based payment apps, and from stablecoins to a new form of central bank-issued money in the form of CBDCs.

CBDCs can be seen as a digital extension of the existing forms of central bank money, namely cash (bills and coins) and central bank settlement accounts. As a digital liability of the central bank, wholesale CBDCs could become a new instrument for settlement between financial institutions. Retail (or general

[4] That said, the motivations differ across countries. Particularly in emerging market and developing economies, CBDCs are often seen as a means to enhance financial inclusion, granting universal access to digital means of payment (see ie Boar and Wehrli (2021). In the light of a more globalised economy, CBDCs are also being explored to enhance cross-border payments.

purpose) CBDCs would be a central bank liability, a form of "digital cash" accessible to all.[5] Graph 1 gives a schematic overview that compares retail CBDC with cash and a consumer's bank deposits.

The monetary system with a retail CBDC — Graph 1



Source: Auer and Böhme (2021).

The idea of extending central bank money in digital form to the public is not new. For instance, Tobin (1987) proposed the idea of "deposited currency", or "*a medium with the convenience of deposits and the safety of currency*", to enhance payments and reduce the reliance on deposit insurance.

Over the past several years, a number of central banks have started internal projects to better understand the technology of cryptocurrencies and more broadly the potential application of distributed ledger technology (DLT) to government-issued digital currencies.[6] Starting in 2015, central banks in eg Canada, the Netherlands, Singapore and the United Kingdom ran internal experiments. These generally concluded that DLT was not yet mature enough for use in major central bank payment systems.

From 2016 onward, a number of central banks launched research projects on digital currencies for wholesale purposes. Several focused on DLT for the settlement of high-value interbank payments.[7] Some involved cooperation between central banks on wholesale CBDCs for cross-border payments.[8]

5 "General purpose" and "retail" are used interchangeably to refer to CBDCs that individuals and non-financial firms could access. For an overview and relevant definitions, see Bech and Garratt (2017) and CPMI-MC (2018).

6 Grym (2021) discusses the Avant payment card, created by the Bank of Finland in the 1990s for retail use, as an early form of CBDC. In 2014, the Central Bank of Ecuador launched a project called "Dinero electrónico" (electronic money) to allow individuals to make mobile payments through a central bank-operated system (Valencia (2015)). Yet the system failed to attract a significant number of users, and was discontinued in 2016 (White (2018); Arauz et al (2021)).

7 For instance, the Bank of Canada launched Project Jasper in early 2016 (Bank of Canada (2017)). In November 2016, the Monetary Authority of Singapore launched Project Ubin (MAS (2016)), on a tokenised form of the Singapore dollar on DLT. The Bank of Canada, Bank of England and MAS subsequently worked in collaborative research with banks on challenges in cross-border payments and settlement and how various initiatives – including wholesale CBDC – could help. See Bank of Canada-MAS-Bank of England-HSBC (2018).

8 For instance, Project Stella involved joint research between the ECB and Bank of Japan (2019). Later, the monetary authorities of Saudi Arabia and the United Arab Emirates, and of Hong Kong SAR and Thailand, also announced cross-border work on wholesale CBDCs (SAMA-UAECB (2019); Bank of Thailand and HKMA (2020)).

The first publicly announced work on retail CBDCs was conducted by Sweden's Riksbank (Sveriges Riksbank (2017)). In Sweden, cash use has been declining precipitously (see Sveriges Riksbank (2020)), and the Riksbank has initiated a societal discussion on access to a central bank payments instrument for the general public. Over time, this "e-krona" project has been further developed (Sveriges Riksbank (2020)).

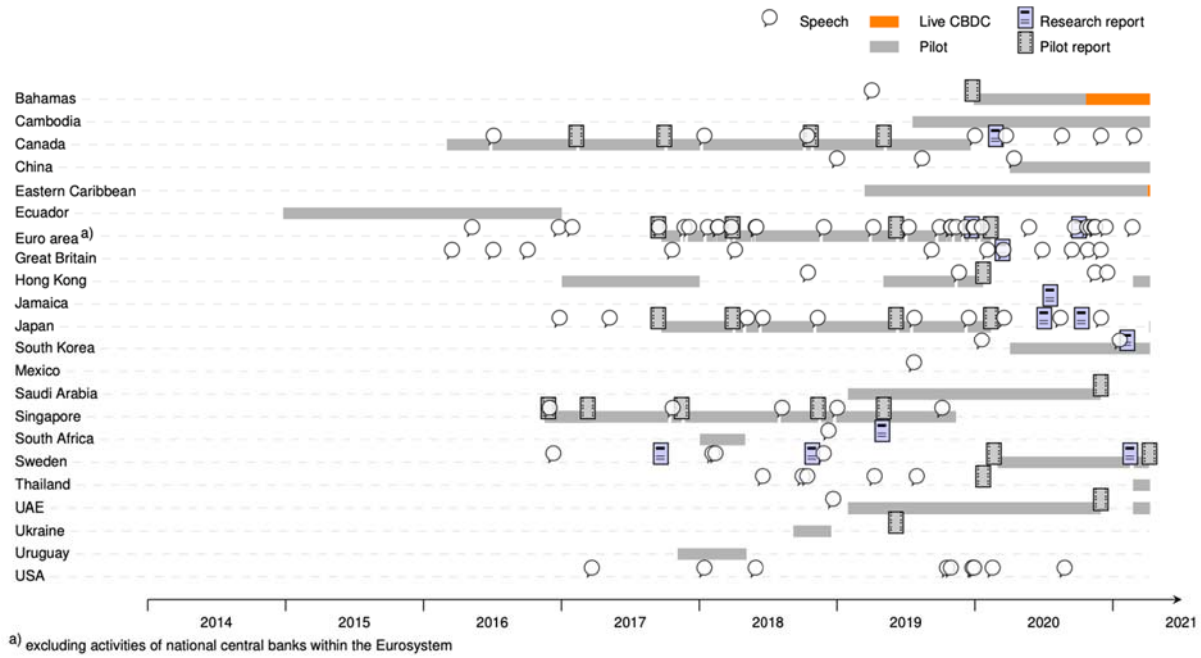
Another particularly advanced CBDC project at present is the electronic Chinese yuan (e-CNY) of the People's Bank of China (PBC). Since 2020, this CBDC has been piloted in several cities in China. The e-CNY will be a cash-like liability of the PBC available to the general public – and to foreign visitors of China – through account-based interfaces.

Meanwhile, in October 2020, the Central Bank of the Bahamas issued the Sand Dollar, widely considered to be the first live retail CBDC. The Sand Dollar is issued through authorised financial institutions and allows accessibility to a digital wallet for residents via either a mobile phone application or a physical payment card. The Eastern Caribbean Central Bank (ECCB) launched its DCash in March 2021. DCash is distributed by licensed financial institutions and used for financial transactions between consumers and merchants, as well as in people-to-people (P2P) transactions.

Graph 2 gives a timeline of these and other CBDC projects. Overall, it is clear that work on CBDCs has been under way at a number of central banks since at least the mid-2010s, accelerating into the 2020s. The stocktake in Auer et al (2020) of all central bank publications shows that, as of mid-July 2021, at least 56 central banks had published retail or wholesale CBDC work. At least three countries (Ecuador, Ukraine and Uruguay) have completed a retail CBDC pilot. Eight retail CBDC pilots are ongoing, including in China, Korea and Sweden.[9] Meanwhile, 40 central banks have published research on retail CBDCs, and 19 have announced research or development work on a wholesale CBDC (in some cases in addition to work on retail CBDCs).

[9] Additionally, the Marshall Islands, which currently use the US dollar as legal tender and have no monetary authority, have launched the SOV (short for sovereign) project, a digital currency proposed by private developers. This project is not included in the database, as it is not a central bank project. See IMF (2018) for a critical discussion.

Timeline of CBDC projects since 2016 Graph 2



Sources: Auer, Cornelli and Frost (2020); Auer and Böhme (2021).

2. Motivations for CBDC research and development

Motivations for retail CBDC research and development are driven by global trends, but also by country-specific circumstances. Broadly, CBDCs should be seen in the context of the digitalisation of economies and the growing centrality of data – particularly personal data – both in the economy and the monetary system. The growing role of data brings many opportunities to reduce information asymmetries, cut costs and enable new forms of money.[10] Yet data also lead to new challenges for competition, privacy and integrity – issues that the economics literature is only beginning to grapple with. Due to the network effects inherent to money, new private players may quickly dominate the monetary system, leading to serious competition concerns and working against the public interest.

These issues have been underscored by four developments. The first was the rapid rise in interest in Bitcoin and other cryptocurrencies that compete with traditional forms of money (see Carstens (2019)). However, cryptocurrencies are speculative assets rather than money. They are extremely volatile, making it difficult to use them as a means of payment. In many cases, they are used to facilitate money laundering, ransomware attacks and other financial crimes (Foley et al (2019), Paquet-Clouston et al (2019)). Bitcoin in particular has few redeeming public interest attributes when its wasteful energy consumption is taken into account. For instance, it is estimated that the Bitcoin network currently uses as much electricity as the Netherlands (BIS (2021)).

[10] For instance, the ability to keep full digital ledgers of transactions increasingly makes it feasible for agents to have a full record of their interactions with other agents in the past – or money as memory (Kocherlakota (1998)). Moreover, new "smart contracts" can make money programmable, allowing agents to automate important functions (Bank of England (2020)).

A second development is the advent of private sector-issued stablecoins. Distinct from other cryptocurrencies, stablecoins are designed to maintain a stable value through their backing of assets. As such, these are only as good as the governance behind the backing. Despite progress made from initial proposals,[11] they still have the potential to fragment the liquidity of the monetary system and detract from the role of money as a coordination device.[12] In any case, to the extent that the purported backing involves conventional money, stablecoins are ultimately only an extension of the conventional monetary system.

A third development is the entry of big tech into payments, and more generally the disruption that platform-based business models and big data bring to the financial system. The huge volume of personal data that is collected and processed as an input into big tech business activity presents several challenges for central banks (BIS (2020)). The first is that network effects make the payment system prone to concentration and enable the formation of data silos that entrench the market power of firms that have exclusive use of the data. The second is data privacy and governance. However, both the competition and data governance imperatives need to be met while ensuring a third imperative: that of ensuring the safety and integrity of the payment system against money laundering, ransomware attacks and other illicit activities. Thus, digital innovation implies a "triple imperative" for the central bank in its role at the centre of the monetary system: competition, data privacy and the integrity of the payment system (Shin (2021)).

Finally, the Covid-19 pandemic has accelerated the adoption of digital payment technologies – a trend that recalls previous epidemics (Saka et al (2021)). With that shift, it has also accelerated central banks' work on CBDCs in some jurisdictions. In the United States, early versions of Congressional proposals for the pandemic-related fiscal stimulus included references to a "digital dollar" as a means of quickly executing government-to-person payments, as an alternative to credit transfers and slow and costly cheques (Brett (2020)).[13]

The general global trends aside, the motivations for CBDC research and development differ across jurisdictions. Based on a survey of central banks of the BIS Committee on Payments and Market Infrastructures (CPMI) in late 2019, Boar and Wehrli (2021) show that in advanced economies, central banks are researching CBDCs to promote safety and robustness, or domestic payments efficiency (Graph 3). In other words, central banks see CBDCs as an opportunity to address risks to the safety of digital payments, to reduce costs and to support central banks' mandates for the smooth functioning of retail and wholesale payments. Financial stability concerns are also an important driver of research and development work – particularly in the light of the threat that private alternatives to sovereign fiat currency may become dominant, issued by actors who are not accountable to the public and may not support the stability of the financial system. Moreover, especially in emerging market economies (EMEs), financial inclusion is an important motivation. Many central banks see CBDCs as a means of enhancing access to payment services for the unbanked, ie those without access to a transaction account.

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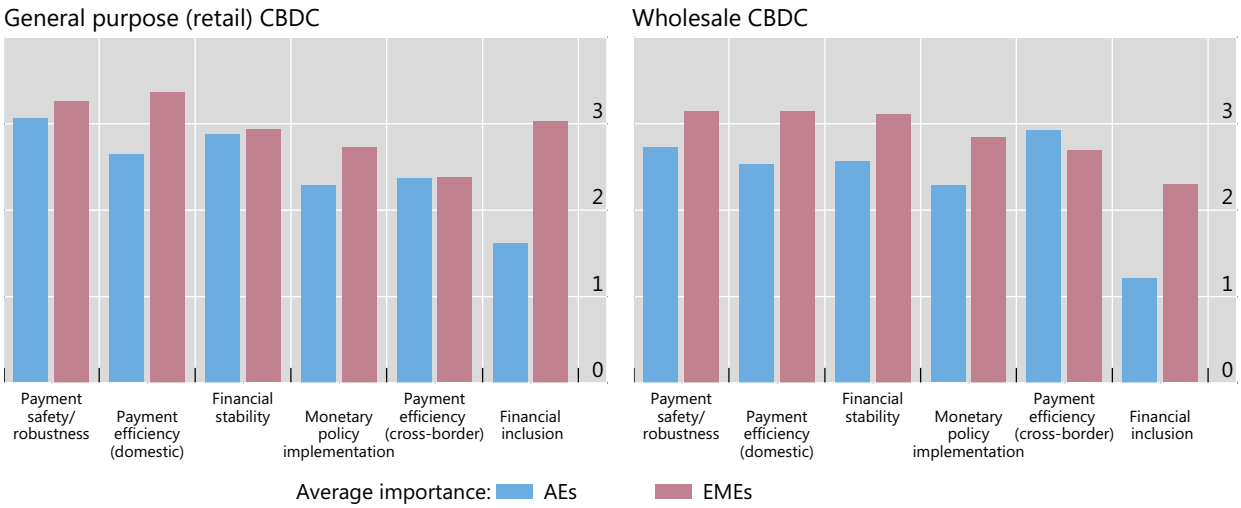
11 See for example the White Paper of the Diem Association, www.diem.com/white-paper/.

12 For a discussion of the risks to stablecoins' value backing, see Arner et al (2020) and Frost et al (2020).

13 The Federal Reserve has ongoing research on retail CBDCs (Brainard (2020a,b)). In the Netherlands, the central bank has emphasised that the pandemic underscores the need for a backup to private money (DNB (2020)). In China, pilot testing for the e-CNY is coinciding with a phasing-out of pandemic-related mobility restrictions. In Sweden, testing of the e-krona project continues even amidst central bank crisis management measures.

Motivations for issuing a CBDC

Average importance — Graph 5



1 = not so important; 2 = somewhat important; 3 = important; and 4 = very important.

Sources: CPMI survey of central banks; Boar et al (2020).

In addition to the stated preferences of central banks, some research looks at "revealed policy preferences", ie the factors that correlate with actual CBDC projects. Table 1 from Auer et al (2020) shows that CBDC projects are more advanced in more digitised economies (as measured eg by mobile cellular subscriptions) and in countries with a high capacity for innovation (measured by the World Intellectual Property Organisation (WIPO) innovation output score). Moreover, they find that work on retail CBDCs is more advanced where the informal economy is larger – consistent with the notion that CBDCs, by creating a data trail for transactions, may help to formalise informal activities. Wholesale CBDC projects are found to be more advanced in markets with greater financial development, which may have higher demand for more efficient clearing and settlement services. Beyond research and design issues, some central banks have sketched out scenarios in which they may consider CBDC issuance, such as the encroachment of private stablecoins or cryptoassets, or a reduction in the use of cash – eg Bank of Canada (2020), ECB (2020), Bank of England (2020)).

Multivariate ordered probit regressions on CBDC project indices[1] Table 1

	Overall CBDC project index		Retail CBDC project index		Wholesale CBDC project index	
Mobile cellular subscriptions	0.013**	0.015***		0.011**		0.022**
(per 100 people)	(0.005)	(0.006)		(0.005)		(0.010)
Innovation output score	0.045***		0.067***	0.082***		
(WIPO)	(0.010)		(0.017)	(0.019)		
Informal economy		0.027*	0.033*	0.042***		-0.009
(% of GDP)		(0.015)	(0.018)	(0.016)		(0.026)
Financial development		3.909***			3.303***	4.287***
Index[2]		(0.867)			(0.775)	(1.299)
Trade openness[3]		-0.003		-0.016**	0.004*	-0.001
		(0.004)		(0.007)	(0.003)	(0.004)
Number of observations	118	105	110	100	132	105
Pseudo R^2	0.167	0.241	0.144	0.244	0.263	0.352

Robust standard errors in parentheses; ***/**/* denotes results that are significant at the 1/5/10% level. Constants are not reported.

[1] The table reports coefficients from an ordered probit model for the probability of a central bank engaging in no work on CBDCs (0), research (1), a pilot (2) or a live retail or wholesale CBDC (3), as of August 2020. All independent variables are an average over the period 2013–19, subject to data availability. [2] Svirydzenka (2016). [3] Sum of imports and exports divided by the country GDP. Data for 2018.

Source: Auer et al (2020).

While it is clear what drives central banks' research efforts, the discussion on CBDCs also raises more fundamental issues on their optimality, eg on the role of public versus private money and the key distinctions between the two (eg Brunnermeier and Niepelt (2019), Bech and Garratt (2017), Adrian and Mancini-Griffoli (2019), Fung and Halaburda (2016), Ketterer and Andrade (2016)). CBDC issuance might also lead to an intensification of the competition between global currencies, and the need for central banks to respond (or not) to CBDC issuance in other jurisdictions.

One concern with digital currencies in general, initially voiced with regard to global stablecoins, is that they could threaten individual countries' monetary sovereignty by displacing domestic currencies. New "digital currency areas" may arise based on the business empires of individual digital platforms rather than the boundaries of legal jurisdictions (Brunnermeier et al (2019)). Could similar concerns apply to CBDCs? Many countries, particularly EMEs, already know the phenomenon of "dollarisation" (or "euroisation" etc), where households and businesses use a foreign currency widely in daily transactions and financial contracts (Levy Yeyati (2021)). Could CBDCs promote "digital dollarisation"?

Research on these aspects of CBDC issuance is scarce, but there are good reasons to think that these risks could be mitigated. First, dollarisation is generally driven by the lack of public trust that the domestic monetary authorities will maintain a stable value for the local currency – in particular a history of high inflation or a lack of financial market development – rather than by the technological format of a domestic or foreign currency. Second, a number of policy tools exist to address such risks. In particular, an account-based design for CBDCs, based on identification, would mean that both the issuing central bank and the central bank of a receiving country would need to agree to cross-border use, and would have insights into aggregate cross-border use of a CBDC (see next section). Third, central bank cooperation could mitigate the risks of currency substitution, as central banks from different jurisdictions would have little interest in destabilising one another's economies through widespread use

of a CBDC beyond the issuing country's borders, and the FX mismatches for users that this entails.[14] Thus, these concerns are unlikely to be a primary motivation of central banks to issue their own CBDC.

What of the concern that CBDCs could challenge the role of the US dollar as an international reserve currency? In the public debate and in international relations research, such concerns have been aired prominently (see Kumar and Rosenbach (2020)). Yet here too the economic drivers of international reserve currency status are likely to far outweigh the availability of a sovereign fiat currency in digital form. In particular, reserve currencies gain ground through deep capital markets with a large availability of safe assets and hedging capabilities; trust in the long-term value of the currency and soundness of the legal and regulatory system; and use in international trade, particularly for invoicing. In all these areas, it is unlikely that a currency would displace the dollar by virtue of its digital nature alone. Chorzempa (2021) refutes the idea of a "first mover advantage" in CBDC research and development, showing that CBDC work in countries like China and the United States is driven primarily by domestic motives, with little animus for currency competition. Still, this will likely remain an area of debate as plans for the e-CNY, digital dollar and the digital euro move ahead, together with the projects of other reserve currency central banks.

3. Microeconomic considerations: operations, technology, and privacy

Central bank motivations for issuing CBDCs are primarily of a microeconomic nature. They aim to enhance payments inclusion and efficiency, as well as ensure competition, data privacy and the integrity of their payment system. What does this imply for the optimal CBDC design and how such designs would affect consumer welfare?[15] This raises important issues pertaining to CBDC operational architecture, the associated public-private sector cooperation and the welfare implications for consumers, also in the context of data privacy considerations. In these cases, the literature has already helped to inform the design of actual CBDC research and development, and to shed light on how CBDCs may affect consumers. This section considers these issues in turn.

Operational architectures: what role for the private sector in a CBDC system?

A first consideration is how users would be convinced to adopt CBDCs in practice, and how the operational architecture could involve the private sector so as not to overburden the central bank operationally. One aspect is that retail payment behaviours show great inertia. For example, Brown et al (2020) find that an exogenous introduction of more convenient payment methods led only to a moderate average reduction in the cash share of payments. Arifovic et al (2017) show with experimental evidence how fees influence the behaviour of buyers and sellers, and ultimately the take-up of a new payment method.[16] For CBDCs to be launched, to be adopted by the public and to enhance payments efficiency, they must carefully define the role of the central bank and the private sector in line with their

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[14] Of course, the threat of dollarisation may discipline central banks and encourage low and stable inflation. In some EMDEs, dollarisation is an active policy choice to import monetary stability. These considerations, too, are largely independent of whether the foreign "hard currency" is offered in digital form.

[15] For example, Bofinger and Haas (2020) see little justification for CBDCs based on allocative efficiency or user demand. Yet notably, the starting point for their analysis is the current payment system, not the counterfactual of platform dominance or widespread domestic currency substitution in the digital economy.

[16] However, when behaviours change, they often do so quite persistently. In the same manner, changed payment behaviours caused by the Covid-19 crisis, such as a greater use of digital payments, could have far-reaching effects in the future.

respective comparative advantages, and improve payments without disintermediating the private financial sector.

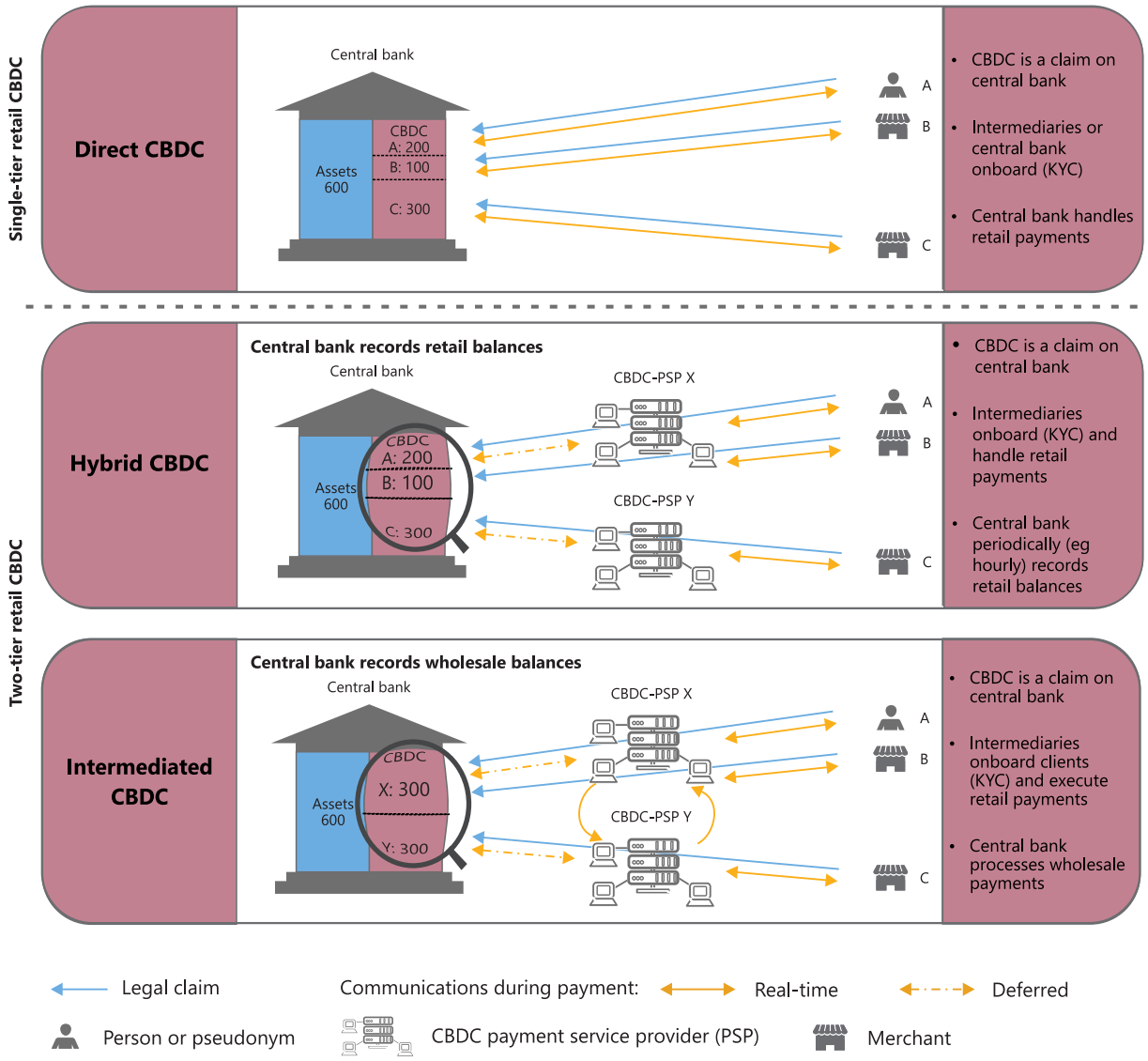
Almost all central banks considering a CBDC envisage that the private sector will play an important role in a CBDC system, particularly in serving households and businesses. Both commercial banks and non-bank PSPs must be able to provide consumer-facing services so that users can transfer funds from a bank account, credit card or other payment services to a CBDC wallet. Users should further have the choice to pay using a variety of payment devices, such as prepaid CBDC devices, cards with offline capabilities or smartphone wallets that are standalone or integrated with bank or big tech apps. These considerations show that there are cogent arguments for why a one-tier system fully operated by the central bank (a so-called "Direct" CBDC following Auer and Böhme 2020 and 2021)) is undesirable. Direct CBDCs would imply a large shift of operational tasks (and costs) from the private to the public sector. Central banks neither aspire to replacing the private sector in these consumer-facing activities, nor are they in a position to do so (Carstens (2019)).

An alternative is an operational architecture in which the private sector conducts all retail payments, while the central bank operates a backup infrastructure. This class of "Hybrid" CBDC architectures (see Graph 4, upper panel) combines the credibility of a direct claim on the central bank with the convenience of private sector payment services. If a PSP fails, the central bank must be able to unambiguously honour claims and, ideally, resume payments for the failing PSP's customers without much delay. This capability requires sufficient information about retail accounts (or pseudonyms in anonymous designs) to be available to the central bank.

Some central banks may shy away from running a record of all retail data, for example due to concerns about privacy and data security – an aspect that has been discussed in several advanced economies (see below). Therefore, another option is a design in which the central bank has no information on retail transactions, just as in today's payment systems. One variant is an "Intermediated" architecture, in which the central bank records only the wholesale balances of the individual PSPs (Graph 4, bottom panel). The downside is that the central bank needs to honour claims of which it has no direct record. Consequently, to safeguard cash-like credibility, PSPs would need to be closely supervised to ensure at all times that the wholesale holdings they communicate to the central bank add up to the sum of all retail accounts.

A smart operational design may have profound welfare implications for consumers. Huynh et al (2020) look at consumer preferences and adoption costs for various combinations of payment methods and examine how the introduction of a CBDC affects welfare. Ultimately, CBDCs need to be designed so that banks and PSPs continue to perform their core economic functions and maintain their resilience, but do not exploit market power to collect excessive rents. There may be a role for the central bank to set low fees on CBDC transactions to offer a competitive alternative and exert pressure in the margins of private firms. This role is examined in Chiu et al (2019).

Retail CBDC architectures and central bank-private sector cooperation Graph 4



In the direct CBDC model (top panel), the CBDC is a direct claim on the central bank, which also handles all payments in real time and thus keeps a record of all retail holdings. A hybrid CBDC architecture (middle panel) incorporates a two-tier structure with direct claims on the central bank, while real-time payments are handled by intermediaries. The central bank however periodically retains a copy of all retail CBDC holdings. An intermediated CBDC architecture, instead, runs a wholesale ledger (lower panel). In this architecture, PSPs would need to be closely supervised to ensure at all times that the wholesale holdings they communicate to the central bank indeed add up to the sum of all retail accounts.

Source: adapted from Auer and Böhme (2021).

Importantly, while the vast majority of central bank CBDC research and development projects involve either a hybrid or intermediated (rather than direct) architecture (Auer et al (2020)), many academic studies continue to describe CBDCs as if the central bank were taking on all operational tasks, without any role for private intermediaries (see Section 4). In future, it will be important to model more realistic CBDC designs, in line with the latest design choices of central banks. This will improve upon current models that assume that the central bank conducts retail services or that CBDCs are offered in unlimited quantities, fully displacing bank deposits.

CBDC technologies: how centralised is a CBDC?

Beyond the architecture of the operational design, a second consideration is the optimal technology underpinning it. In this context, much emphasis has been put on novel forms of decentralisation enabled via distributed ledger technology (DLT). The latter comes in two forms: the permissionless technology that is used in Bitcoin, Ethereum and other cryptocurrencies, and the permissioned variant, in which a network of known and vetted validators jointly augment a ledger.

CBDCs could in theory be run on a permissionless design that resembles Bitcoin, but this would be inefficient and environmentally harmful. While it is technically possible to use the technology, based on costly computing (ie "proof of work") in which unknown validators perform the updating of transactions, the economic cost is very high. Every batch of transactions has to be accompanied by a proof that a substantial quantum of otherwise useless computations has been performed. This is not only inefficient (see ie Budish (2018), Chiu and Koeppl (2019), and Auer (2019)), but it can lead to multiple equilibria (ie "forks", see Biais et al (2019)). For all these reasons, permissionless DLT based on proof of work is not a viable technology for CBDCs.[17]

Instead, a number of central banks are considering decentralisation in the form of "permissioned" DLT, in which a network of preselected entities performs the updating.[18] Importantly, operational resilience can also be achieved in traditional systems that store data multiple times and in physically separate locations. The difference is that DLT is updated in a decentralised manner: in many DLT-based systems, the ledger is jointly managed by different entities that do not trust each other's data and independently verify each new transaction. The cost is that each update of the ledger must be harmonised between the nodes of all entities (generally known as "consensus mechanisms"), which, due to the multiple involved rounds of communication, takes time.

Permissioned DLT is no silver bullet, however, and it only has economic merit under certain circumstances. Such "permissioned" designs may have economic potential in financial markets and payments due to enhanced robustness and the potentially lower cost of achieving good governance. However, this does not come for free. In the setup of Auer, Monnet and Shin (2021), designated validators verify transactions and update the ledger at a cost that is derived from a supermajority voting rule. Without giving proper incentives to validators, however, their records cannot be trusted because they cannot commit to verifying trades – thus giving rise to a public good provision game – and they can accept bribes to incorrectly validate histories. These two frictions challenge the integrity of the ledger on which credit transactions rely, and the process of permissioned validation supports decentralised exchange as an equilibrium only if the rents validators receive are high enough. This analysis suggests that a centralised operational design is often superior, unless weaknesses in the rule of law and contract enforcement would necessitate a decentralised ledger.[19]

Data privacy and integrity

A third consideration centres on CBDCs and data privacy. The digitisation of payments is increasingly generating a "data trail" of information on individual transactions, which can be easily transferred across counterparties and used for a wide variety of purposes. For instance, transactions data from any digital

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[17] Abadi and Brunnermeier (2018), Saleh (2021), and Fanti et al (2019) examine the "proof-of-stake" variant, ie betting on the truth instead of costly computation. However, it is unclear how robust this design is, due to the possibility of so-called "long-range attacks" (see the survey of Deirmentzoglou et al (2019)).

[18] Auer et al (2020) give a stocktake of CBDC designs, showing that DLT is envisioned in many current retail CBDC prototypes that rely on software packages such as Corda, Hyperledger or Quorum.

[19] This is closely related to Amoussou-Guenou et al (2019) whose analysis is the first to model the interaction between validators as a game entailing non-observable effort to check transactions and amidst costly voting.

payment service can be used to determine individuals' willingness to pay for goods and services and thus to price-discriminate; individuals' creditworthiness, ie ability to repay a loan; and – when combined with other data sources – to give deep insights into individuals' behaviour, beliefs and habits. A growing strand of literature in economics assesses concerns around data privacy (Acquisti et al (2016)), which are highly context-dependent. Digital applications generate troves of data but also severe information asymmetries for users, who do not always know whether and where data are being collected and for what purpose. As is already known in the literature on payments, cash has value to consumers because it is by nature anonymous, thus protecting individuals' privacy (Kahn and Roberds (2009)). Yet what happens as cash use declines, and households are left only with private digital alternatives?

Several new papers model the privacy characteristics of different payment instruments and assess the implications of their use for consumer welfare, including externalities between users. For instance, Garratt and van Oordt (2021) discuss privacy in payments as a public good. Because individuals do not internalise the full cost of using digital payment platforms, which fail to protect their privacy and help to price discriminate against future consumers, social welfare is sub-optimally low. Introducing "electronic cash" in the form of CBDC is one remedy. Relatedly, Garratt and Lee (2021) show that payment data can drive the formation of a monopoly. Issuing a CBDC can help to preserve the market structure and improve consumer welfare by giving an outside option to consumers that protects privacy. This enables them to monetise private information. Key in this framework is that the central bank, as a non-commercial entity, has no incentive to use private transaction data, and can credibly commit to leaving such data untouched in a way that a private bank or digital platform provider could not. Agur et al (2021) derive implications for an optimal CBDC design, which should trade off concerns about bank disintermediation (competition with deposits) against the social value of maintaining a diverse set of payment instruments (deposits, CBDC and cash) that offer different privacy benefits.

While CBDCs may thus offer benefits in terms of users' privacy, there are trade-offs with other goals. The most salient one is between user privacy and the integrity of the payment system. A fully anonymous CBDC design, analogous to cash, could have severe downsides for payment system integrity, allowing for illicit transactions, money laundering, terrorism financing etc. Wang et al (2021) shows that a fully cash-like CBDC design could also increase tax evasion. Yet maintaining a full record of transactions attached to users' identities leads to its own challenges, in particular around cyber security, with the potential for the central bank to become an attractive "honeypot" of data to hackers (see Schilling (2019)). This is a further reason for some central banks to prefer an intermediated architecture, as discussed above.[20]

Importantly, design features can help mitigate such trade-offs, as privacy does not need to be synonymous with anonymity. In this area, too, research is helping to inform actual CBDC design. Darbha and Arora (2020) outline the range of choices around the type of information to keep private and who to keep it private from, as well as the cryptographic techniques and operational arrangements that can support such decisions. Central banks can engineer systems to have greater privacy than private sector systems, but there are costs involved, and adequate designs require public review and oversight. Gross et al (2021) develop a proposal for cash-like privacy for users while addressing regulatory constraints, using zero-knowledge proofs in a software-based CBDC system. Moreover, application programming interfaces (APIs) in a CBDC system can constrict data exchange to only the necessary information for any given transaction and give users greater control over the data that they generate (BIS (2021)).

Of course, technical design alone may not be sufficient to counter concerns that public authorities (central banks and other government institutions) would use CBDC systems as an instrument for state surveillance and control. It is easy to imagine how sensitive transactions data could allow authorities to

[20] Even in a hybrid system, it may be possible to separate the individual transaction data from information on individual user identities, and to enact rules and technological arrangements that restrict use of data to specific, pre-defined purposes. For instance, the Bank of Jamaica is designing a CBDC system to require a court order for insight into individual transactions.

track individuals, and to block their access to CBDC payments. Even if systems are designed to prevent such practices, public concerns could also limit adoption of CBDCs. Here, institutional safeguards may help to prevent abuse and ensure accountability for authorities.[21]

It is notable that in recent consultations, the public in some key jurisdictions has flagged privacy as a key motivation for adopting a future CBDC (see ECB (2020)). Moreover, survey evidence shows that users place greater trust in public authorities and traditional financial institutions, when it comes to safeguarding their personal data, than they do in new players such as big techs (Armantier et al (2021)). Sound technical designs and institutions for CBDC systems will be critical to ensure that the public trust is maintained and that CBDCs deliver on the promise to users while upholding high standards of payment system integrity.

4. Implications for banks, financial stability and monetary policy

Alongside a fast-changing and intense policy debate on CBDC technology and privacy, a growing academic literature has emerged on the macroeconomic implications of CBDC introduction. This academic literature centres around three main themes. First is the effect of CBDC issuance on commercial banks and aggregate lending or investment. Second are the effects of introducing CBDCs on financial stability, ie the ability of the financial system to absorb shocks and thus the likelihood of financial crises. The third theme concerns CBDCs as a new monetary policy tool. In this section, we review the academic literature according to these three themes.

CBDC issuance and commercial banks

Academics have pointed out that the structure of the banking system can determine the efficiency gains (or losses) of introducing a CBDC. Three papers stand out here: Andolfatto (2021), Keister and Sanches (2020) and Chiu et al (2019). They respectively consider the effects of introducing CBDC on a monopolistic banking system with the perspective of the liability side, ie bank deposits (Andolfatto (2021)), a perfectly competitive banking system (Keister and Sanches (2019)) and an imperfectly competitive (but non-monopolistic) banking system (Chiu et al (2019)). On the asset side, ie loans, banks can be considered as operating in a competitive market in all three papers. The line of reasoning is quite similar across these papers: by offering a CBDC, the central bank induces commercial banks to make their deposits more attractive and increases the costs of funds for commercial banks, which can adversely impact aggregate lending and investment.

All three papers start from the premise that commercial bank deposits are used as a means to pay some (digital) transactions where cash is not accepted by sellers. Banks, however, cannot satiate the economy with deposits because they face some governance issues: they need to hold some assets as collateral, and their net worth has to be positive. As a result, deposits carry a liquidity premium and they pay a relatively low interest rate, making them a cheap and preferable source of funds for banks.[22] However, the low interest rate reduces the value of deposits as a means of payment because it increases the opportunity cost of holding funds in deposits (low payment efficiency).

When the central bank issues an interest-bearing CBDC, banks have to adjust the remuneration on their deposits, since otherwise deposit holders would convert them into the better remunerated CBDCs. Hence, bank deposits become a more expensive source of funds for banks (impacting banks negatively)

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21 For instance, the Bank of Jamaica has clarified that individual CBDC data can only be shared with a court order.

22 Deposit insurance is another reason why deposits are a cheap source of funds, as we do not internalise the cost of bank's bankruptcy and do not require a risk premium in our deposits.

while they become a more sought after means to pay (impacting deposit holders in a positive manner). This is the essential trade-off in these papers.

When the banking system is perfectly competitive, banks have no room to buffer the shock on their funding cost and they pass it through to borrowers. As a result, aggregate lending and investment falls. Keister and Sanches (2019) show that when payment efficiency is low (when banks' governance friction is high), introducing a CBDC may imply sufficiently large gains in payment efficiency to compensate for the loss in aggregate investments. Of course, when the banking sector is imperfectly competitive (on the liability side), introducing a CBDC can only make things better. Indeed, in that case, banks enjoy a buffer that they can use to offset the increase in the cost of funds. In this context, Andolfatto (2021) and Chiu et al (2019) show that introducing a CBDC with a relatively low interest rate always achieves a higher allocative efficiency. Maybe more surprisingly, it can even increase the level of aggregate investment by making deposits more attractive. The CBDC rate cannot be too high, however, as otherwise banks deplete their buffer and they will start passing through to borrowers the increased costs of funds.

In their calibration, Chiu et al (2019) find that a CBDC expands bank intermediation if its interest rate is between 0.30% and 1.49%. At the maximum, it can increase loans and deposits by 1.96% and total output by 0.21%. The CBDC leads to disintermediation, however, if its rate exceeds 1.49%.

If central banks issue CBDC, they can surely lower the cost of funds for commercial banks by lowering the rate of their lending facility (while preventing banks, eg via regulation, from arbitraging between CBDC and the lending rate).[23] Under this scenario, the central bank becomes the main intermediary between CBDC holders and the real economy. Analysing this, Brunnermeier and Niepelt (2019) and Fernández-Villaverde et al (2021) derive a Modigliani-Miller theorem of sorts: when it is free to move funds around and commercial banks do not face any cost to expand their balance sheet, the equilibrium allocation the economy attains without a CBDC can also be attained with a CBDC. Yet this result (like the Modigliani-Miller theorem) is fragile. For example, Piazzesi and Schneider (2020) show that, when banks have to hold (liquid) assets to back their deposits and face asset management costs, then the equivalence breaks down, even though banks could obtain funding directly from the central bank.

One potential question is why don't banks tap other sources of funds if deposits become more expensive. In particular, banks could retain earnings to increase equity funding, or issue longer-term bonds. This could offer more stable sources of funds to commercial banks to limit disintermediation. These options are generally not present in the academic literature, or if they are, they are not used in equilibrium (see Chiu et al (2019)), which makes the disintermediation result quite "easy" to obtain. The reason for their absence is one of tractability: it is difficult to model the evolution of a bank's balance sheet in a dynamic model. Monnet et al (2020) take a first stab at this problem and consider how introducing a CBDC would modify the way banks fund their investments. This is also important for the effect of a CBDC on financial stability (see below). They show that, again, banks can buffer the higher cost of funding after a CBDC issuance by changing the structure of their assets and passing those gains on to deposit holders, to leave them indifferent between a CBDC and bank deposits. However, the true reason for disintermediation is when the central bank increases its remuneration rate on reserves, a tool that central banks in many jurisdictions already use. As this rate increases, banks find it profitable to stop lending to the real economy and hold reserves instead.[24] In a somewhat similar vein, Niepelt (2021) shows that when the interest rate on reserves is set too high, banks could expand their balance sheets beyond the optimal level by, for example, issuing too many deposits. However, in his setup, a CBDC is

[23] This also raises the question: why was there investment inefficiency in the first place?

[24] See eg Belton et al (2020), who examine the 2011 FDIC change in the assessment base for bank deposit insurance. They show that banks can engage in liquidity hoarding and lower credit creation in the case of a relatively high remuneration rate on reserves.

unable to correct that inefficiency because it can only increase the cost of funds for banks, while optimality would require a low (negative) interest rate on deposits.

Relatedly, Eren et al (2021) argue that bank disintermediation can be efficient when it is accompanied by lower reserves. In the long run, CBDC can mitigate negative externalities and allow banks to increase lending despite a smaller balance sheet.

All the papers above take a stance on the structure of the banking sector, with little or no impact on the broad end result: CBDCs can improve allocative efficiency as long as their remuneration rate is not too high. However, note that CBDCs could also modify the structure of the banking system itself, by weakening smaller banks without access to large funding markets. In this case, introducing a CBDC might lead to a wave of mergers and acquisitions and ultimately to a more concentrated banking sector (see Garatt and Zhu (2021)). Then, assessing the benefits of a CBDC on allocative efficiency becomes intertwined with an equilibrium analysis of the structure of the banking sector, and so becomes more elusive than ever.

The effects of CBDCs on financial stability

Being a liability of the central bank, a CBDC is a safe substitute for commercial bank deposits. Since the latter can be risky when the amount held is more than the threshold defined by the deposit insurance, there is a risk that, in a crisis, the availability of a CBDC would induce deposit holders to shift their holdings from the commercial banking system to the CBDC. Note that it is the risk of a systemic run that increases, rather than just the risk of a run on a single individual bank. The reason is that, with or without a CBDC, households can always stage a run on an individual bank by moving their deposits to a bank they think is safer, but leaving funds within the banking system. The presence of a CBDC will not affect this type of run, but it could well increase the probability of a systemic bank run (Fernández-Villaverde et al (2021)). Also, systemic bank runs may be reinforced by the fact that banks have lower equity buffers when a CBDC is made available (see the previous subsection).

While this intuitive point has been made very early on, also in speeches by policymakers (eg Broadbent (2016)), it is not always true that CBDC will increase fragility, and models can help clarify which assumptions are necessary to drive the increased fragility result. Also, the picture is not all dark. CBDCs being a digital instrument could help to alert the central bank as to whether a bank run is under way (Keister and Monnet (2019)). Further, it might well be that, while bank runs may be inevitable, they are less damaging to the economy when a CBDC is available (Williamson (2019)). The canonical model of a bank run – Diamond and Dybvig (1989) – has become one of the most useful benchmarks for studying the fragility of the banking system. The so-called DD model is a real model in the sense that only real resources are deposited in the bank, and there is no cash; it places maturity transformation, rather than liquidity issuance, at the forefront of the bank's business. Depositors may run on the bank's resources when they expect that others will run as well because the bank will then not have enough to pay them what it promised later. This run equilibrium depends, among other things, on an implicit sequential service constraint.

Fernández-Villaverde et al (2021) analyse the effect of a CBDC in the context of the DD model. They recognise that deposits in a CBDC would give the central bank access to real resources that it can invest. They assume that, while the central bank does not have the ability, knowledge or technology to invest in productive assets, it can lend to investment banks who have these attributes. They thus obtain another equivalence result whereby the allocation obtained with a CBDC is the same as without it. Yet there is more: they argue that CBDCs would eliminate the run equilibrium because deposits at the central bank are not callable and nobody can force the central bank to liquidate the long-term project. In other words, central bank deposits are protected against forced liquidation.[25] Therefore, a CBDC

[25] A similar argument is found in Brunnermeier and Niepelt (2019).

eliminates the run equilibrium in their model, and the allocation is efficient, because the central bank can freely lend to investment banks that compete with commercial banks. This, however, comes at the cost of having the central bank being the sole provider of deposits, which allows it to deviate from the socially optimal contract (although it is not very clear why an independent central bank would want to do so – see discussion above). It would also have the power to invest only in specific projects and face pressure from political authorities. In this case, a CBDC could jeopardise the independence of the central bank. See also Niepelt (2021) for a discussion of the political economy arguments surrounding CBDCs.

Schilling et al (2020) take the model with a monopoly central bank a step further by relaxing the assumption that a CBDC is a real deposit claim. Rather, a CBDC is a nominal asset that households can spend. Although households cannot force the central bank to pay them well, they can "run" on the central bank by trying to get rid of CBDC holdings, ie they can engage in a "spending spree". Such a spree is triggered by the belief that a CBDC will lose its purchasing power in the future, which makes it optimal to spend it today. They then show that the central bank will not be able to achieve allocative efficiency, financial stability and price stability all at once. For example, to obtain financial stability the central bank must make sure that a CBDC has enough purchasing power in the future – that is, there must be enough goods produced later on – which might distort allocative efficiency. But we are very far from this type of extremely centralised economy, and no major central bank is considering a CBDC with these features.

Williamson (2019) departs from the basic DD structure to study the role of banks as providers of liquidity insurance.[26] In this setup, buyers do not know if they will meet sellers who only accept digital deposits, or also cash. Holding a bank deposit insures buyers against those events. Williamson does not impose the sequential service constraint but instead assumes that banks can go bankrupt because of bad investment choices. After observing some signals, deposit holders learn that some banks will fail, but they do not know if their bank will fail. This uncertainty may trigger a switch to the "safe harbour" of a central bank liability instead, thus triggering a bank default. In addition, a novel aspect of Williamson's model is that bank deposits circulate as a means of payment, while in DD they are just used for saving. In this, Williamson gets closer to the very idea underlying deposit insurance, that a bank's default is costly because it disrupts the payment system.

In this context, Williamson shows that, when cash (earning a zero interest rate) is the only withdrawal option, the incentive to run is lowest when the nominal interest rate on a safe and illiquid asset (typically government debt) is high; ie the interest rate spread is high. The reason is that in this case, holding cash has a large opportunity cost and so households know that banks do not hold much of it. Since the bank's cash holdings will be split pro rata in the case of a run, they do not expect to receive much cash if they run on the bank. This makes running a sub-optimal strategy.

Introducing an interest-bearing CBDC has a direct advantage: it improves payment efficiency because it can be traded with all sellers, while cash was only accepted by a subset of sellers. However, the relevant spread for the run decision is now smaller and runs will now be more likely. However, a CBDC improves payment efficiency, so that runs will be less disruptive to the overall economy. There is hence a greater tendency with CBDCs for banking panic equilibria to dominate equilibria without panics, and Williamson concludes that "CBDC issuance may encourage banking panics, but that goes hand-in-hand with panics being less disruptive than in a world with physical currency."

All the above papers have in common that they consider how a safe, government-issued instrument affects the stability of the financial system. Putting aside payment efficiency considerations, it is worth stressing that households can already run on the banking system by eg purchasing government debt,

[26] Maturity transformation could easily be included in Williamson's analysis.

the long-term debt of large corporates, or any other non-bank related assets.[27] These assets are usually absent from the DD model. Speculating, it is likely that the effect of government debt on financial fragility is the same as CBDCs when it is considered as a savings instrument (as in Fernández-Villaverde et al (2021)), but CBDCs also bring payment efficiency. All in all, it is likely that a CBDC would not modify the incentives to run, but it may well improve efficiency.

Keister and Monnet (2019) show that, aside from payment efficiency, another benefit of a CBDC is information efficiency. As DD show, information is key when it comes to preventing a manageable situation from becoming unmanageable from the banking regulator's viewpoint. But more often than not, banks have the incentives to delay relaying information about their situation, in the hope that, for instance, they will be bailed out when the situation becomes unattainable. When households make a run on the financial system by withdrawing cash, the central bank only becomes aware of this with a lag. In the case of a CBDC, the story is different because transfers are digital and (should be) immediate. When households make a run on the financial system, they transfer their commercial bank deposits into a CBDC. Then the central bank can learn the origin of the funds that are being transferred. With such real-time data, the central bank can react quickly and take measures to stop the outflow of funds, either by proclaiming a bank holiday or by lending funds to the institutions undergoing a run.

While intuitive, the argument that a CBDC increases financial fragility is actually difficult to justify when considering it in a general equilibrium model, with all facets of CBDCs. Therefore, design recommendations based on financial stability arguments should be taken with a grain of salt. This includes eg Kumhof and Noone (2018) who argue that bank deposits should not be freely convertible into a CBDC, or Bindseil (2020) who argues for position limits on a CBDC. While these designs would indeed make CBDCs more innocuous for financial stability, they would distort payment efficiency in all states of nature where financial fragility is not an issue, ie in most states of the world.

Finally, we note that the higher payment and information efficiency that a CBDC brings in normal times as well as in crisis time should induce the regulator to reflect on current policies to address too-big-to-fail and banking sector resilience, including deposit insurance. These existing frameworks are certainly not costless and addressing the subsidy to banks from systemic importance remains an important area of international policy efforts (FSB (2021)).

The effects of CBDCs on monetary policy

As discussed in the previous subsection, the digital nature of CBDCs implies that they provide information that the central bank can exploit in order to make the financial system less fragile. The same applies for monetary policy: CBDCs supply information to the central bank regarding the economy, and being digital they are also, almost de facto, programmable. These features considerably enlarge the monetary authority's toolkit. For example, Davoodalhosseini (2021) shows that by making transfers to those who need money the most, the central bank improves the allocation relative to "helicopter drops" that would affect all households in the same way. In short, the central bank has a better idea of when households are using the CBDC, allowing it to act on that information. Also, when a CBDC is available to all, it allows for a direct implementation of monetary policy, hitting the core of the intertemporal decisions of households and firms, rather than through the indirect and imperfect banking channel. With such a CBDC in its toolkit, the monetary authority can then rethink its overall monetary policy

[27] Moreover, these risks are not new. Baubeau et al (2021) show that runs from commercial banks to government-backed savings banks, which were only permitted to hold government securities or cash, worsened the credit contraction in the French Great Depression in 1930–31. They suggest that this argues for careful CBDC design.

strategy (Bordo and Levin (2017)). The estimated gains for the United States could be substantial and amount to a permanent increase of GDP of as much as 3% (Barrdear and Kumhof (2016)).[28]

In addition to being programmable and thus allowing information-specific monetary transfers, a CBDC can change the implementation framework of monetary policy. In Assenmacher et al (2021), the central bank essentially operates a corridor system "for all" – that is, all firms in the economy can access the central bank lending facility and not only banks. The corridor is defined as the difference between the CBDC lending and the CBDC deposit rate. They find that payment efficiency requires that there is no cost of holding CBDC, which in this model means that the lending rate should be equal to the deposit rate. Also, for investment efficiency there should neither be a cap on CBDC loans nor any haircut on the collateral pledged to secure a loan, so that CBDC loans should be unconstrained.

Previous papers, however, do not say much on how CBDC would affect monetary policy over the business cycle. Bordo and Levin (2017) offer some avenues in their discussion. They argue that the CBDC interest rate could serve as the main tool for conducting monetary policy. With the disappearance of cash, that interest rate could be set to (any) negative levels, thus doing away with the "zero lower bound" on nominal rates. While the zero lower bound has been "broken" on central bank reserves in many jurisdictions, the zero lower bound on nominal interest rates has often been used by central banks to justify positive (and distortionary) levels for the inflation target, so as to get some room for manoeuvre in recessions. On top of that, the zero lower bound has been found to be the basis for a multiplicity of equilibria and the existence of an equilibrium with liquidity traps in some models (Benhabib et al (2001)). Doing away with the zero lower bound would contribute to establishing optimal inflation targets in all stages of the business cycle and possibly eliminate the presence of liquidity traps.

At a time when many central banks are adjusting their monetary policy strategy, Bordo and Levin (2017) argue that CBDC would allow moving away from inflation targeting to price level targeting. In their views, contingent CDBC transfers could make price level targeting easier to implement. They argue that price level targeting would facilitate the formulation of consumption and investment plans of households and firms because the cost of a representative basket of consumer items (as measured in terms of the CBDC) would be reasonably stable over the medium run and roughly constant in the longer run. They argue this could benefit lower-income households and small businesses, which typically have little or no access to sophisticated financial planning advice or complex financial instruments that can help insure against such risks.

While CBDCs would allow for targeted transfers and negative interest rates conditioned on data or the stage of the business cycle, they would further blur the distinction between fiscal and monetary interventions, thus making issues around the fiscal-monetary nexus more acute (see Bassetto and Sargent (2020)). Some authors have argued that the central bank's balance sheet would balloon if it were to introduce CBDC as a central bank account for all (Bindseil (2020)), and the dangers of large central balance sheets for their independence from the fiscal authority are well known. These were discussed by Plosser (2019) in the context of quantitative easing. The fact that the central bank would be able to make targeted positive or negative transfers would magnify these issues.

Finally, CBDCs could alter the international transmission of monetary policy. With a two-country dynamic stochastic general equilibrium (DSGE) model, Ferrari et al (2020)) find that the presence of a CBDC amplifies the international spillover of shocks. Yet such spillovers can be significantly dampened if the CBDC possesses specific technical features, such as adjusting the remuneration rate on the CBDC flexibly (eg using a Taylor rule). Careful design of CBDCs could help mitigate potentially adverse macro-financial implications. For instance, CBDCs could be designed to preclude or limit their use outside the

[28] The role of positive transfers in achieving better allocations is illustrated in Levine (1991). Davoodalhosseini et al (2020) shows that the results extend when the information remains private, and the central bank can use a menu of transfers of both cash and CBDCs so that households give (some of their) information by choosing from the menu.

issuing country, eg through limits on non-resident holdings or fees on very large or frequent cross-border transactions.

5. CBDCs, cross-border payments and the international monetary system

CBDCs raise many questions at a domestic level, but they raise even more in the cross-border dimension. Research in this area is still in its infancy. This section thus sheds light on issues at the research frontier, in particular around the promise of CBDCs for improving cross-border payments in an increasingly globalised economy. In what follows, we sketch the issues, and then offer avenues for future research to inform international policy debates and CBDC design efforts.

Cross-border payments suffer from four primary challenges: they are generally costly, often slow, suffer from low traceability and transparency, and are not widely accessible to some people. For this reason, the G20 has made enhancing cross-border payments a priority, endorsing in 2020 a multi-year, multi-dimensional programme to enhance such payments. Faster, cheaper, more transparent and more inclusive cross-border payment services would deliver widespread benefits for citizens and economies worldwide, supporting economic growth, international trade, global development and financial inclusion (CPMI (2020)). CBDCs are seen by many central banks as an opportunity to address these persistent challenges. However, most CBDC projects focus on domestic issues and use cases. Given this early state of play, the thinking behind CBDCs for cross-border use is exploratory and will be subject to considerable further economic and practical examination before the investigation of their cross-border use gathers pace.

A key difference between CBDCs and efforts to improve the existing payments infrastructure is the opportunity to start with a "clean slate". Because many of today's frictions are rooted in differences between domestic payment systems (eg opening hours, technical standards, data requirements), making large-scale changes across jurisdictions is challenging. If central banks take the international dimension into account when designing their domestic CBDCs and commit to interoperability, consistent standards and coordination of CBDC designs, many problems inherent in today's legacy technologies and processes could be avoided. That said, if CBDCs are not designed with the international dimension in mind, fragmentation of CBDC systems similar to the current fragmentation of payment systems is possible. That is why central banks are focusing on this issue from the get-go. A survey of 50 central banks conducted in early 2021 shows that a quarter are thinking of incorporating interoperable features in their CBDC design with a view to reducing frictions in cross-border and cross-currency settlement (Auer, Boar, Cornelli, Frost, Holden and Wehrli (2021) and CPMI et al (2021)).

Cross-border CBDC arrangements could be designed in such a way that they allow a more diverse group of banks and non-banks access to central bank money for settling payments. This might lead to a greater variety of "front-end" cross-border payment services, helping to achieve more inclusive cross-border payment services. In particular, Auer, Haehne and Holden (2021) consider three models for multi-CBDC arrangements – ranging from basic compatibility between individual CBDCs to the establishment of a single multi-CBDC system. A first model is one of compatible CBDC systems, which could provide an additional means of settling transactions from existing markets in central bank money across borders, allowing a more diverse group of banks and non-banks to settle payments in central bank money, and hence a broader variety cross-border and cross-currency payment services. A second model involves interlinked CBDC systems that could build on these potential improvements to offer additional safety via payment-versus-payment (PvP) settlement through a technical interface between domestic systems. Alternatively, common clearing mechanisms could also add efficiencies, especially when linked with FX trading venues. The third multi-CBDC model, a single multi-CBDC system, could offer the same improvements as interlinking systems but with additional integration. In such a single system, the

participating central banks jointly set the rule books and operate the infrastructure, and mutually recognise each other's participants.[29] In a single jointly operated system, all foreign exchange settlements would be PvP by default and trading venues could also be integrated into mCBDC systems to further reduce complexity. Any design principles for such multi-CBDC arrangements would need to be coordinated at the global level so that they meet the needs of all countries and are widely adopted to limit arbitrage. Here multilateral collaboration is paramount.

6. Conclusion

CBDCs are an idea whose time has come. If properly designed, they present an opportunity to improve payments with a technologically advanced representation of central bank money, one which preserves the core features of finality, liquidity and integrity that only the central bank can provide. They could form the backbone of a highly efficient new digital payment system by enabling broad access, and they may also help to provide strong data governance and privacy standards.

Yet in order to achieve the potential benefits for public welfare while preserving financial stability and public-private sector cooperation, further exploration on CBDC design choices and their macro-financial implications is essential. Adam Smith defined money by the three main roles it plays in society: as a unit of account, the yardstick of economic activity; a means of exchange to make payments; and as a store of value to transfer purchasing power over time. With CBDCs, central banks' main goal is to provide a universal means of exchange for the digital economy. They do not, however, intend to disintermediate the financial sector by offering a universal store of value.

In this context, research is helping to understand how the usefulness of CBDCs as a means of payments can be maximised, while limiting the overall inflows to central bank balance sheets. Beyond this, various important and complex questions are still to be further analysed, for instance as regards the interoperability between existing and new infrastructures, the access to and control of central bank money, the distinction between wholesale and retail CBDCs and especially the cross-border implications of CBDCs.

To further push the frontier in the cross-border dimension, researchers will have to grapple with the specifics of cross-border payments. While CBDCs have unique features, enhancements in existing payment systems and arrangements, such as aligning regulatory, supervisory and oversight frameworks for cross-border payments, AML/CFT consistency, PvP adoption and payment system access will also be critical for cross-border CBDC use. Moreover, the eventual international adoption of CBDCs is likely to proceed at different speeds in different jurisdictions, calling for interoperability with legacy payment arrangements. Hence, the analysis of interoperability with non-CBDC payment arrangements calls for further work. Answering these open questions will be crucial for a correct design of CBDCs as a new form of money in the digital era.

[29] See Auer, Haehne and Holden (2021) for more details. Such a model has, for instance, been adopted for Project Dunbar and in Project Aber (see SAMA and CBUAE (2019, 2020)), which even goes a step further via the joint issuance of a CBDC that is used in the single mCBDC arrangement. Because both the Saudi riyal and the UAE dirham are pegged to the US dollar, the newly issued CBDC was effectively guaranteed to have a fixed exchange rate vis-à-vis both local currencies.

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