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International Economics and Business

FROM CRYPTO CURRENCIES TO CENTRAL BANK DIGITAL CURRENCIES:

THE CASE OF DIGITAL EURO

DALLE CRIPTO MONETE ALLA MONETA DIGITALE DELLA BANCA CENTRALE:

IL CASO DELL'EURO DIGITALE

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Respectfully

Ardit KOKA

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Abstract

This study summarises the outcomes of the analysis of the ECB Crypto-Assets Task Force, then it moves to an examination of key considerations around central bank digital currency (CBDC) for use by the general public and it analyses the mechanisms through which commercial banks and the central bank could react to the introduction of a digital euro.

First, it proposes a characterisation of crypto-assets in the absence of a common definition and as a basis for the consistent analysis of this phenomenon. It analyses recent developments in the crypto-assets market and unfolding links with financial markets and the economy, and it assesses the potential impact of crypto-assets on monetary policy, payments and market infrastructures, and financial stability. The analysis shows that, in the current market, crypto-assets' risks or potential implications are limited and/or manageable on the basis of the existing regulatory and oversight frameworks. However, this assessment is subject to change and should not prevent the ECB from continuing to monitor crypto-assets, raise awareness and develop preparedness.

Then the study examines key considerations around central bank digital currency (CBDC) for use by the general public, based on a comprehensive review of recent research, central bank experiments, and ongoing discussions among stakeholders. It looks at the reasons why central banks are exploring retail CBDC issuance, policy and design considerations; legal, governance and regulatory perspectives; plus cybersecurity and other risk considerations. This study makes a contribution to the CBDC literature by suggesting a structured framework to organize discussions on whether or not to issue CBDC, with an operational focus and a project management perspective.

In July 2021 the Eurosystem decided to launch the investigation phase of the digital euro project, which aims to provide euro area citizens with access to central bank money in an increasingly digitalised world. While a digital euro could offer a wide range of benefits, it could prompt changes in the demand for bank deposits and services from private financial entities (ECB, 2020a), with knock-on consequences for bank lending and resilience. By inducing bank disintermediation, a central bank digital currency could in principle alter the transmission of monetary policy and impact financial stability. To prevent this risk, options to moderate CBDC take-up are being discussed widely. In view of the significant degree of uncertainty surrounding the design of a potential digital euro, its demand and the prevailing environment in which it would be introduced, analyses the mechanisms through which commercial banks and the central bank could react to the introduction of a digital euro.

Overall, effects on bank intermediation are found to vary across credit institutions in normal times and to be potentially larger in stressed times. Further, a potential digital euro's capacity to alter system-wide bank run dynamics appears to depend on a few crucial factors, such as CBDC remuneration and usage limits.

Sommario

Questo studio riassume i risultati dell'analisi della Task Force dei Cripto-Asset della BCE, passa all'esame le considerazioni chiave sulla proposta di una moneta digitale della banca centrale (MDBC/CBDC) per l'uso da parte del pubblico e analizza i meccanismi attraverso i quali le banche commerciali e la banca centrale potrebbero reagire all'introduzione di un euro digitale.

Inizialmente, propone una caratterizzazione dei cripto-asset in assenza di una definizione comune e generalmentw accettata. Analizza i recenti sviluppi nel mercato delle cripto valute e lo sviluppo dei collegamenti con i mercati finanziari e l'economia e valuta il potenziale impatto delle cripto valute sulla politica monetaria, sui pagamenti, sulle infrastrutture di mercato e sulla stabilità finanziaria. L'analisi mostra che, nel mercato attuale, i rischi o le potenziali implicazioni delle cripto valute sono limitati e/o gestibili sulla base dei quadri normativi e di supervisione esistenti. Tuttavia, questa valutazione è soggetta a modifiche e non dovrebbe impedire alla BCE di continuare a monitorare le cripto valute, aumentare la consapevolezza e sviluppare la preparazione.

Successivamente lo studio esamina le considerazioni chiave sulla moneta digitale della banca centrale (MDBC/CBDC) per l'uso da parte del pubblico, sulla base di un'ampia rassegna delle ricerche recenti, esperimenti delle banche centrali e discussioni in corso tra le parti interessate. Esamina i motivi per cui le banche centrali stanno esplorando l'emissione di MDBC al dettaglio, considerazioni politiche e di progettazione; prospettive legali, di governance e regolamentari; di sicurezza informatica e altre considerazioni sui rischi. Questo studio fornisce un contributo alla letteratura MDBC suggerendo un quadro strutturato per organizzare discussioni sull'opportunità o meno di emettere MDBC, con un focus operativo e una prospettiva di gestione del progetto.

Nel luglio 2021 l'Eurosistema ha deciso di avviare la fase di indagine del progetto euro digitale, che mira a fornire ai cittadini dell'area dell'euro l'accesso alla moneta della banca centrale in un mondo sempre più digitalizzato. Sebbene un euro digitale possa offrire un'ampia gamma di vantaggi, potrebbe indurre cambiamenti nella domanda di depositi bancari e servizi da parte di enti finanziari privati (BCE, 2020a), con conseguenze a catena per i prestiti bancari e la resilienza. Inducendo la disintermediazione bancaria, una moneta digitale della banca centrale potrebbe in linea di principio alterare la trasmissione della politica monetaria e influire sulla stabilità finanziaria. Per prevenire questo rischio, le opzioni per moderare l'assunzione di MDBC sono ampiamente discusse. In considerazione del notevole grado di incertezza che circonda la progettazione di un potenziale euro digitale, la sua domanda e l'ambiente prevalente in cui sarebbe introdotto, questo lavoro analizza i meccanismi attraverso i quali le banche commerciali e la banca centrale potrebbero reagire all'introduzione di un euro digitale .

Nel complesso, gli effetti sull'intermediazione bancaria variano tra gli enti creditizi in funzione dei tempi e appaiono potenzialmente maggiori in periodi di stress. Inoltre, la capacità di un potenziale euro digitale di alterare le dinamiche di corsa agli sportelli a livello di sistema sembra dipendere da alcuni fattori cruciali, come la remunerazione del CBDC e i limiti di utilizzo.

Introduction

Crypto-assets have been the subject of intense policy debate. In particular, crypto-assets have raised concerns with regard to money laundering, market integrity and consumer protection – among other things – as well as possible implications for financial stability. Financial sector authorities in Europe and worldwide undertake various activities on crypto-assets within their mandates. International fora such as the G7, the G20, the Financial Stability Board (FSB), and standard setting bodies (SSBs) conduct work on crypto-assets aimed at monitoring crypto-assets' implications for global financial stability and coordinating policy responses. The ECB has been studying this phenomenon since its inception, and published its first report on virtual currency schemes in 2012, followed by further analysis in 2015

The ECB Internal Crypto-Assets Task Force (ICA-TF) was established in March 2018 with the mandate to deepen the analysis around virtual currencies and crypto-assets. To fulfil this mandate, the ICA-TF has structured its work in three pillars: (i) characterising crypto-assets and related activities; (ii) monitoring crypto-assets and related activities, and the evolution of channels for the possible transmission of risks to the financial sector and the economy; and (iii) identifying potential control measures to mitigate such risks. The ICA-TF analysis is focused on assessing and helping to contain any adverse impact of crypto-assets on the use of the euro, the monetary policy and the safety and efficiency of market infrastructures, as well as on the stability of the financial system.

The ECB acknowledges that crypto-assets currently pose risks mostly with regard to money laundering/terrorism financing and consumer protection. On these aspects, as well as on the broader assessment of the EU regulatory framework in light of crypto-assets, the ECB defers the analysis to the relevant authorities, and supports their efforts as appropriate. As far as this study is concerned, selected regulatory issues are covered as part of the risks assessment and gap analysis.

In addition to monetary and financial stability roles, central banks play a core public sector role in the economy to provide a safe, efficient, and inclusive payment system. As technology, user needs, and regulation change, the payment system may have to adapt. In some economies, cash is disappearing as a means of payment, and new digital payment systems are challenging central bank roles. In other countries, the private sector lags in improving financial inclusion and reducing the operational costs and risks associated with the management of physical currency.

IMF staff have proposed a conceptual framework to assess the case for retail CBDC issuance from the perspectives of users and central banks (Mancini Griffoli and others, 2018). This assessment concluded that the impact of CBDC introduction will hinge on its design and country-specific characteristics. Overall, the note found no universal case for CBDC adoption yet, and that demand for CBDC will depend on the attractiveness of alternative forms of money. Some concerns have been expressed that CBDC issuance could hamper monetary policy transmission, but the paper concluded that this is unlikely, and it may even strengthen it through greater financial inclusion. A well-designed CBDC could enhance financial integrity compared to cash, but a poorly designed one could undermine the authorities' compliance with financial integrity standards. Also, while CBDC could increase deposit-taking institutions' funding costs, impact the funding structure of deposit-taking institutions, and intensify "run" risk, design choices such as tiered CBDC remuneration and various policy measures can help ease such concerns.

In July 2021 the Eurosystem announced the launch of a project to explore the case for a digital euro and consider its potential design. Introducing a central bank digital currency in the euro area could

offer several benefits, such as allowing general access to central bank money, supporting the Eurosystem's strategic objectives in the payment system and spurring financial innovation. At the same time, a digital euro, if not properly designed, could prompt changes in the demand for bank deposits and services from private financial entities, in turn affecting financial stability and monetary policy transmission. Specifically, lower demand for bank deposits could entail knock-on consequences for banking sector credit provision, risk-taking, profitability and resilience.

In the first chapter this study summarises the main outcomes of ICA-TF analysis. In particular, it provides an assessment of selected crypto-assets risks and the extent to which the current regulatory and oversight frameworks allow the propagation of these risks to the financial system and the economy to be contained. It discusses the ICA-TF characterisation of crypto-assets, then presents an overview of crypto-assets market trends and the evolution of links with the financial system; also it provides a risk assessment and gap analysis based on the current regulatory and oversight frameworks.

In the second and third chapter, this study takes a closer look at the design, risk, and operational considerations of issuing retail CBDC, based on published research, central bank experiments, and ongoing discussions among stakeholders. There are many papers that provide high-level overviews of CBDC implications for payments, monetary policy, and financial stability (BIS, 2018) or their effects on monetary policy instruments (European Money and Finance Forum, 2018 and Lariccia, 2018). There are general evaluations of CBDC models and their main attributes (Norges Bank, 2018) and considerations on how to design CBDC to ensure financial stability by pre-empting liquidity squeezes and system-wide run from bank deposits (Kumhof and Noone, 2018).

This study also builds on the recent literature that discusses detailed CBDC design considerations and technological solutions. Auer and Böhme (2020) provide an overview of underlying trade-offs and the related hierarchy of technical design choices, while others explore options and describe potential limits that the underlying technology may impose on the mix of policy objectives (e.g., Shah and others, 2020). There are proposals on platform models to provide a fast, highly secure, and resilient technology infrastructure that would provide the minimum necessary functionality for CBDC payments (BoE, 2020) and a two-tier remuneration of CBDC as a solution to the risk of structural disintermediation of banks risk and facilitation of systemic runs on banks in crisis situations (Bindseil, 2020).

The study focuses on CBDC intended to be used only within the borders of the issuing central bank. It lays out some of the most relevant elements being considered for keeping usage within those borders, including ensuring that foreign visitors have at least limited access. However, interoperability and standardization across national or international digital payment systems are important considerations to keep cross-border options open for future evolution. To this end, it would seem prudent for central banks to consider coordinating their CBDC efforts closely and introducing sufficient flexibility into their CBDC designs to facilitate cross-border interoperability and standardization across CBDC implementations.

The last chapter gives an overview of the impact a digital euro could have on bank intermediation in normal times based on aggregate and bank-level balance sheet data. It concludes that – irrespective of the adjustment options a bank chooses – the central bank would be able to ensure, through an offsetting liquidity-providing operation, that the economy-wide liquidity situation remains unchanged.

Anticipating the impact of a digital euro on monetary policy transmission and financial stability is challenging because of the uncertainty surrounding its demand, design and the prevailing environment in which it may be introduced. While the Eurosystem has stated that any digital euro would be intended for retail payments use only (ECB, 2020a), many other design features that will determine the convenience and ease of use of a digital euro, which have a direct impact on demand for it, are still to be decided. The economic and financial environment that would prevail at the time a digital euro might be issued is also uncertain, including the monetary policy environment and the potential availability of alternative digital moneys. Lastly, no major advanced economy to date has introduced a CBDC, resulting in a lack of data that could be used in empirical analyses. Therefore, at this stage, it is particularly challenging to estimate the effects of a digital euro and design the options to manage its take-up.

Bank-level data are used to illustrate how different factors such as bank regulatory constraints (e.g. liquidity regulation, Eurosystem collateral requirements) and institutional specificities (e.g. the deposit ratio, the funding structure) may affect banks' responses and, consequently, the extent to which a digital euro could alter bank intermediation. Market reactions to digital euro announcements are also used as a first test of these findings.

1. Crypto-Assets

For the purposes of this study, a crypto-asset is defined as a new type of asset recorded in digital form and enabled by the use of cryptography that is not and does not represent a financial claim on, or a liability of, any identifiable entity. Crypto-assets derive their novelty and specific risk profile, particularly their inherent high volatility, from the absence of an underlying fundamental value. Crypto-assets are highly speculative and could expose investors to large losses.

This study's conclusions are to be interpreted in relation to crypto-assets as defined herein. The ECB monitors crypto-assets and analyses potential implications for monetary policy and the risks they may entail for the smooth functioning of market infrastructures and payments, as well as for the stability of the financial system. To this end, the ECB established the Internal Crypto-Assets Task Force (ICA-TF).

1.1 Characterisation of crypto-assets

There is currently no international agreement on how crypto-assets should be defined. In the following discussion, the term "crypto-asset" denotes any asset recorded in digital form that is not and does not represent either a financial claim on, or a financial liability of, any natural or legal person, and which does not embody a proprietary right against an entity. Yet, a crypto-asset is considered valuable by its users (an asset) as an investment and/or means of exchange, whereby controls to supply and the agreement over validity of transfers in crypto-assets are not enforced by an accountable party but are induced by the use of cryptographic tools.

The emergence of crypto-assets has been enabled by distributed leger technology (DLT). Under some assumptions, DLT allows the supply of crypto-assets to be kept controlled and limited by enabling users to audit cryptographic links that certify the consistency of information updates over time and ensure that there is no unwarranted creation of crypto-assets. DLT also ensures that owners of crypto-assets are recognised as such by allowing (and sometimes even providing incentives for) users to converge towards a consistent view of crypto-asset holdings as testified by means of cryptography.

Although bitcoin is the most prominent application of blockchain-based DLT, the use of this technology is currently a necessary but not sufficient element to characterise crypto-assets as a new asset class. In fact, the distinctive feature of crypto-assets, as defined in this study, from which they derive their specific risk profile, is the lack of an underlying claim/liability. Units of a crypto-asset may be used as a means of exchange and are de-facto considered by their users as assets, in the sense of "something of value", although they do not correspond to the liability of, and claim on, any party. As a consequence, crypto-assets are fundamentally different from various forms of financial claims and/or their digital representation using the technology and possibly the infrastructure that underpin crypto-assets.

Crypto-assets as defined in this study would not qualify as electronic money (e-money) for the Second Electronic Money Directive (EMD2), to the extent that they are not and do not represent a claim on the issuer. E-money is electronically stored monetary value as represented by a claim on the e-money issuer, which is issued on receipt of funds, for the purpose of making payment transactions, and which is accepted by a natural or legal person other than the electronic money issuer.

Crypto-assets as defined in the first paragraph are not scriptural money in the form of commercial bank money (CoBM), which consists in commercial bank liabilities that take the form of deposits held at a commercial bank.

Crypto-assets as defined in this discussion are equally not scriptural money in the form of central bank money (CeBM), which is the liability of a central bank in the form of either (i) existing bank deposits held at a central bank for wholesale settlement purposes or (ii) digital base money (DBM) for the general public and central bank digital currency (CBDC).

Therefore, as the law now stands, crypto-assets as defined in this study would fall outside the scope of application of payment services regulation. The revised Payment Services Directive (PSD2) defines payment transaction as "an act, initiated by the payer or on his behalf or by the payee, of placing, transferring or withdrawing funds", whereas funds are "banknotes and coins, scriptural money or electronic money" and therefore do not include crypto-assets as described and defined by the ICA-TF.

A crypto-asset is not a financial instrument, as listed in Section C of Annex 1 of the Markets in Financial Instruments Directive (MiFID), as that would typically represent a financial liability or equity on the side of some issuer. On the other hand, crypto-assets could serve as the underlying of certain financial instruments, such as derivatives (e.g. relating to commodities) and financial contracts for difference (CFDs).

A crypto-asset as defined in this study is not a mere representation of any of the above-mentioned financial assets. Mere digital representations of existing assets are referred to as "tokens", which allow recording these assets by means of a different technology. The same technology-neutral rules and legal provisions shall therefore apply, to the extent possible, to the issuance, bookkeeping and use of these "tokens" as they apply to the financial assets they represent.

Finally, crypto-assets as defined in this study are not to be considered as virtual currencies or digital currencies, although these terms are often – inaccurately (Mersch, 2018a) – used to identify crypto-assets that are used and accepted by some as a substitute for money in particular circumstances. The absence of any specific institution (such as a central bank or monetary authority) protecting the value of crypto-assets hinders their use as a form of money, since their volatility: a) prevents their use as a store of value; b) discourages their use as a means of payment; and c) makes it difficult to use them as a unit of account.

1.2 Developments in crypto-asset markets

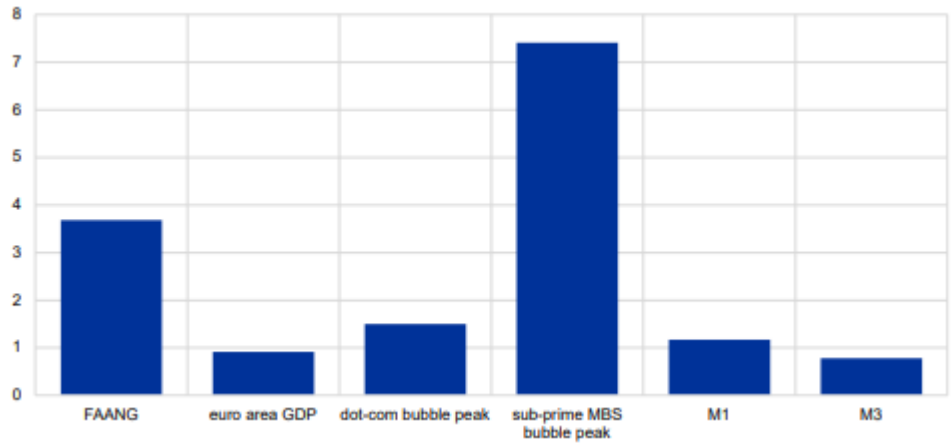
After an all-time high of more than $3000 billion in November 2021 and a subsequent abrupt correction, market capitalisation of crypto-assets has declined to less than $2000 billion in February 2022 and a deeper fall in less than $1000 in June 2022. Market capitalisation has moved in tandem with asset prices, as exemplified by the price of bitcoin, whose correlation with total market capitalisation amounts to 95%. In relative terms, the market capitalisation of crypto-assets stands at 4% of the market capitalisation of the so-called "FAANG" (the stocks of five prominent American technology companies: Meta (META) (formerly known as Facebook), Amazon (AMZN), Apple (AAPL), Netflix (NFLX); and Alphabet (GOOG) (formerly known as Google)) stocks and at 1% of euro area GDP. It is also smaller in size than the peak of the two major past bubbles, the dot-com bubble and the subprime mortgage securities bubble. When compared to monetary aggregates, the value of crypto-assets is 1.2% of the euro area M1 and 0.8% of the M3 monetary aggregates (Graph 1).

Graph 1

Crypto-assets' market capitalisation remains modest

Total market capitalisation of crypto-assets as a fraction of other markets, euro area GDP, past bubbles in stock and mortgage markets and euro area monetary aggregates

(percentages)



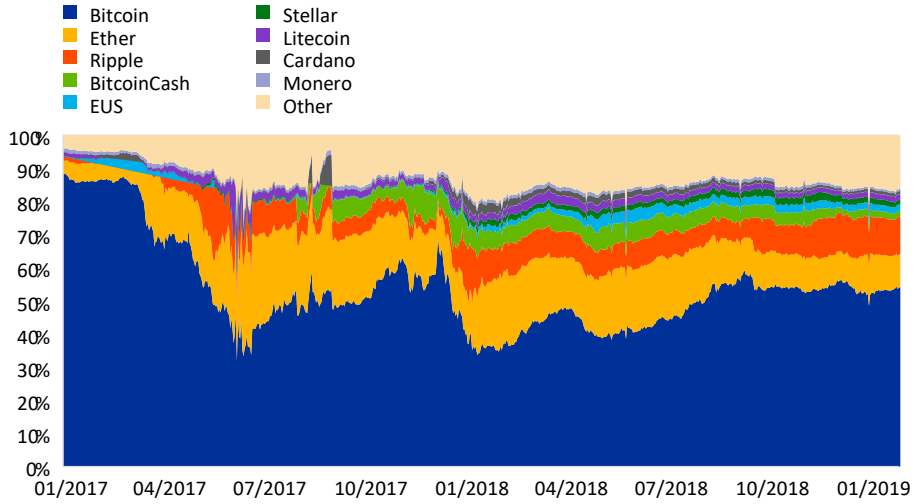
Source: Bloomberg, Cryptocompare, Coinmarketcap, Datastream, Haver, Sifma, ECB and ECB calculations.

Bitcoin continues to lead the pack of crypto-assets in terms of market capitalisation, user base and popularity. There exist around 1,900 crypto-assets, up from 7 in April 2013. Next to bitcoin, ether, ripple and bitcoin cash are considered the most important in terms of usage, market capitalisation or business model diversity. Although bitcoin lost some ground vis-à-vis other crypto-assets over the last two years in the face of increased competition and uncertainty about the relative success of the different business models underlying them, its market share recovered in the course of 2018 and currently stands at 54% (Graph 2).

Graph 2

Bitcoin's market share among crypto-assets currently stands at 54%

Percentage of total market capitalisation of crypto-assets

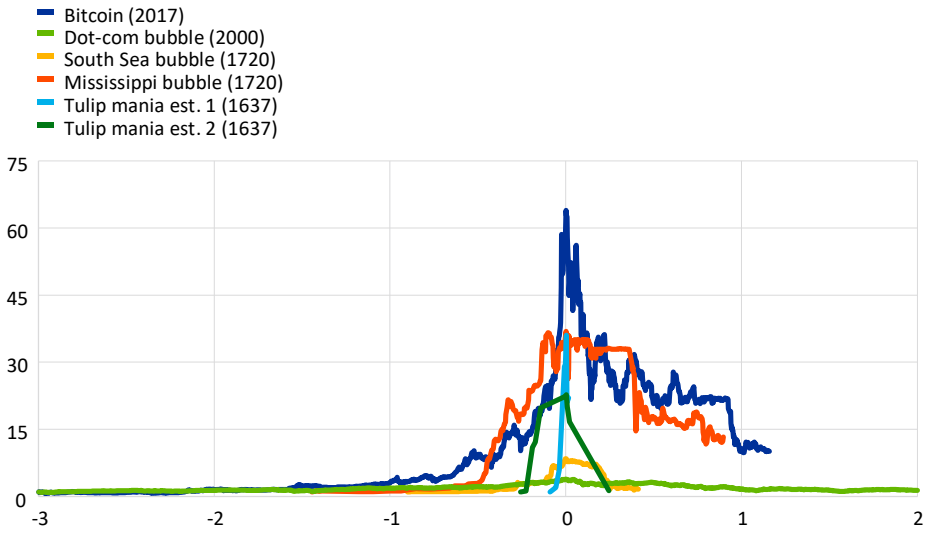


Sources: Cryptocompare, Coinmarketcap and ECB calculations.

Graph 3

Bitcoin price developments were more extreme than those of historical bubbles

Relative price changes in three-year run-up period before bubble peaks



Sources: Bloomberg, Cryptocompare, Coinmarketcap, Yale school of management and ECB calculations.

Price growth of crypto-assets had surpassed that of historical bubbles before the crash in early 2018. The price of bitcoin increased by a factor of 19.5 from the beginning of 2017 to the peak reached in January 2018. Still, bitcoin was significantly outperformed by other crypto-assets, which were at some point even 500 times higher than at the beginning of 2017. In comparison, the NASDAQ composite index was four times higher at the peak of the dot-com bubble than three years before, while the share price of the Mississippi Company at its peak in November 1720 spiked 36 times higher than in August 1718 (Graph 3).

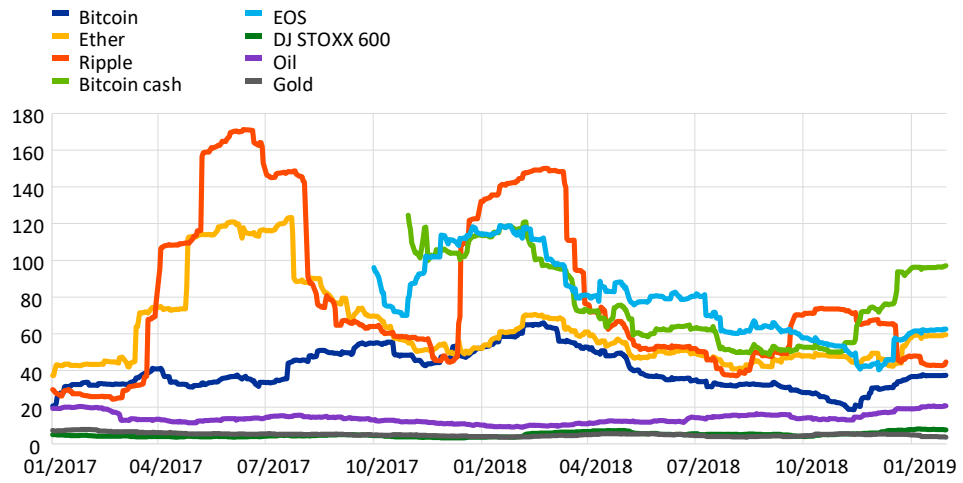
Crypto-asset prices remain highly volatile (see Graph 4). Over the last two years, the historical volatility of crypto-assets dwarfed not only the volatility of the diversified European stock and bond markets, but also that of the more volatile oil and gold prices, highlighting the market risk that crypto-asset investors are subject to. Compared to the beginning of 2018 when several crypto-assets experienced a price peak, the volatility has become smaller. Interestingly, bitcoin is not as volatile as other crypto-assets, which potentially reflects its wider investor base and its relatively higher maturity as an asset. The recent development of so-called "stablecoins" (**Stablecoins are digital units of value that rely on stabilisation tools to maintain a stable value relative to one or several official currencies or other assets (including crypto-assets))** attempts to overcome the volatility drawback of existing crypto-assets by claiming to exhibit a stable value through a flexible coin supply (i.e. algorithmic money) or backing the crypto-asset with collateral (i.e. collateralised stablecoins). In fact, some stablecoins, to the extent that they have an identified issuer, are not crypto-assets according to the definition used in this study and might qualify as e-money under some national legislation. So far, stablecoins seem to be used mostly by crypto-asset traders to hedge against market movements and have demonstrated different levels of price volatility depending on their business models.

Graph 4

Crypto-assets' volatility is much higher than volatility of stocks, bonds and commodities

Historical average return volatility

(percentages)



Sources: Cryptocompare, Datastream and ECB calculations.

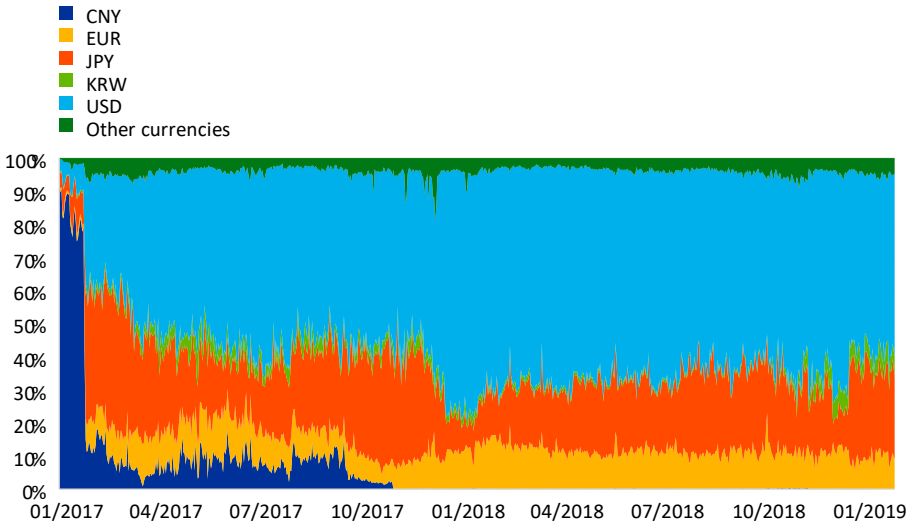
1.3 Evolution of linkages to the financial markets and the economy

An important share of bitcoin's trading volume is settled in euro, suggesting a non-negligible euro area exposure to crypto-assets. Euro-related trading has hovered around an average of 10% of the total with a daily standard deviation of 2.8% over the last two years. Compared to others, bitcoin is the crypto-asset most heavily traded. Over 2018, trades in bitcoin accounted for on average 61% of the total trading volume cleared in fiat currencies. All trading activities in Chinese Yuan shifted towards other currencies after September 2017, following an amendment in Chinese legislation regarding the treatment of bitcoin (see Graph 5). Private sector bitcoin holdings are quite concentrated suggesting that potential losses in case of a drastic price correction would be limited to a relatively small group of holders. The top 1,000 addresses (0.0018% of all active addresses) represent around 36% of all bitcoin holdings and the top 10,000 hold 58%. These graphs represent only a rough estimation of the concentration of holdings: on the one hand, it is possible for the same investor to hold multiple addresses, implying higher actual concentration; on the other hand, some addresses may belong to custodians/exchanges, implying that concentration is lower (ECB 2019).

Graph 5

Bitcoin trading cleared in euro hovers around 11%

Bitcoin trading volume by fiat currency



Sources: Cryptocompare and ECB calculations.

Current developments and activities, such as futures contracts linked to bitcoin prices and financial investment vehicles tracking crypto-assets, may increase links to the traditional financial sector and the real economy. This can possibly raise financial stability considerations if these links persist and further increase. Current links are limited, as the number of futures and investment vehicles are still small and futures volumes traded are low. The slow growth in the number of investment vehicles is also due to regulatory actions. For example, the US Securities and Exchange Committee (SEC) tentatively rejected ten bitcoin Exchange Traded Funds (ETFs) proposals in September 2018.

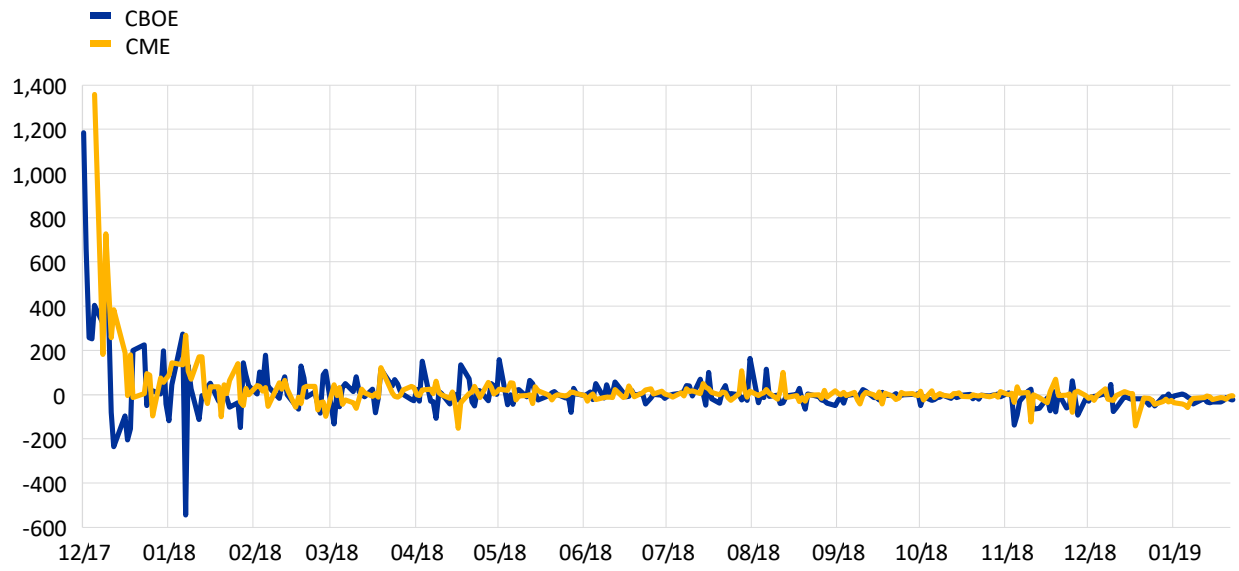
Futures contracts linked to bitcoin prices have been available in the US since December 2017 and are traded at low, but relatively stable volumes. The combined open interest for bitcoin futures in the two US exchanges offering these contracts trades (CME and CBOE) at prices that have become relatively tied to the spot market developments, indicating that market participants do not expect significant price movements over the next months (see Graph 6). In fact, the negative spike in the difference between spot and futures prices in November 2018 indicated that the market correction was not foreseen by the markets at this time. An expanding futures market may, however, increase the interlinkages between the financial sector and crypto-assets' price developments. This may – conditional on regulatory approval – also pave the way to the creation of more ETFs that use futures to track bitcoin prices, mirroring similar developments in commodity ETFs a few years ago.

Graph 6

Futures and spot bitcoin prices have converged

Difference between futures and spot bitcoin prices on CME and CBOE exchanges

(EUR)



Sources: Bloomberg and ECB calculations.

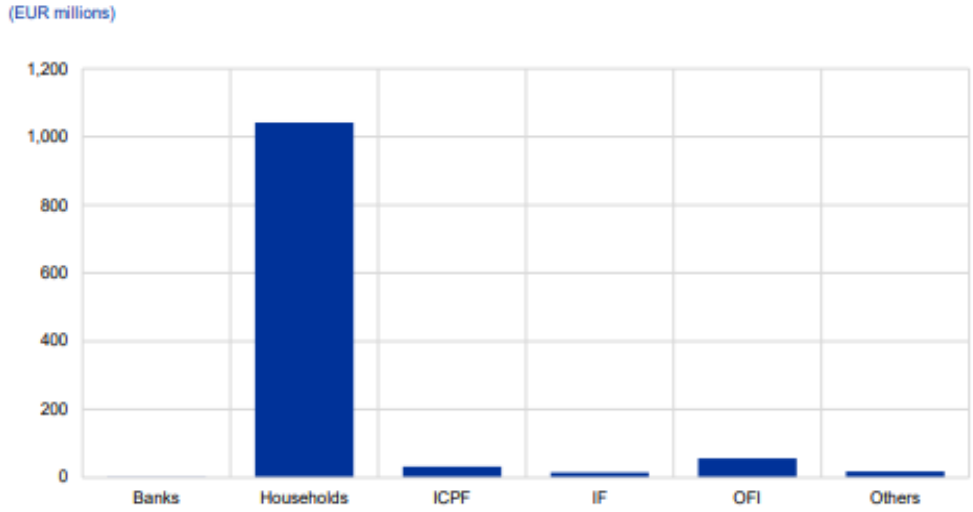
Other financial investment vehicles, such as trusts, Exchange Traded Notes (ETNs) and Contracts for Difference (CFDs) have started to offer exposure to crypto-assets to European clients. All such vehicles that can be found in ECB securities holdings data track either bitcoin or ether prices. Euro area holders of these instruments in Q3 2018 were mainly found in the household sector (Graph 7) with key markets in Belgium, Italy, and Germany. The size of these vehicles is small when compared to the size of the household sector's portfolios and minuscule in comparison to the overall size of the euro area securities market: at the end of Q3 2018, the combined holdings of these instruments by euro area sectors stood at €1,163 million. The total amount of holdings has grown rapidly, though. Exposures more than quadrupled in the course of 2018 starting from €269 million in Q4 2017.

According to currently available information, banks do not seem to have systemically-relevant holdings of crypto-assets. Their combined indirect exposures via ETNs and CFDs did not exceed €20,000 at the end of Q3 2018 (Graph 7). Nevertheless, there has been an indication of a strong interest among hedge funds and asset managers in crypto-assets-based products. Conditional on regulatory developments, exposures to financial instruments related to crypto-assets could, therefore, rise in future.

Graph 7

Households are key holders of investment vehicles tracking bitcoin and ether

Euro area holders of bitcoin and ether-based investment vehicles by sector



Sources: SHSS and ECB calculations.

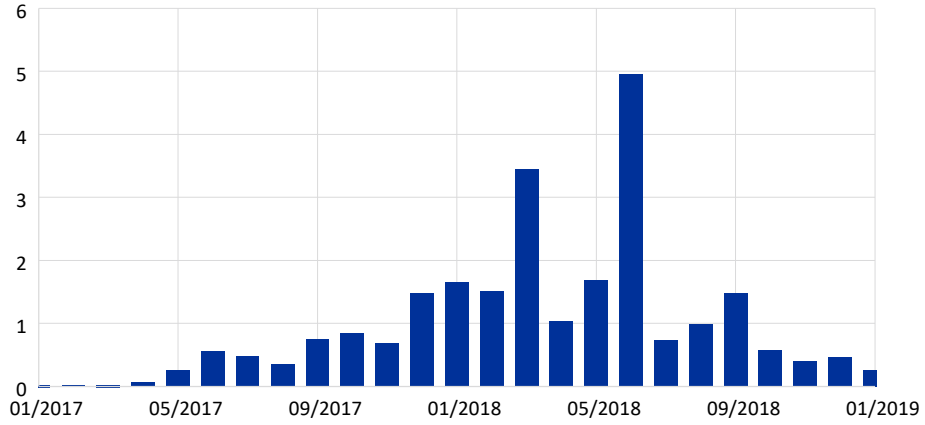
So-called initial coin offerings (ICOs), a largely unregulated way for firms to raise capital by generating new crypto-assets akin to initial public offerings, collected about €19 billion in 2018 (Graph 8). ICOs represented more than 9% of total equity raised in initial public offerings at the global level in 2018. While there is no systematic information about the jurisdictions and sectors of the holders of crypto-assets from ICOs, the importance of ICOs decreased significantly over the second half of 2018. A study by Satis Group (2018), an ICO advisory firm, found that 70% of the funds raised by ICOs were invested in projects that developed further to more mature stages, while 80% of all projects that raised capital via ICOs were identified as fraud. Moreover, ICO activities are correlated with price developments of some crypto-assets – for example ether, whose underlying technology ethereum is heavily used to launch ICOs (see Financial Times, 2018a). If the importance of ICOs as well as their connections to the wider financial system rises again to levels observed in 2018, the inherent volatility of many newly generated crypto-assets could adversely affect financial stability through similar channels to conventional equity markets.

Graph 8

Funds raised by initial coin offerings in 2018 amounted to €19 billion

Funds raised by initial coin offerings

(EUR billions)



Sources: coinschedule

1.4 Risks assessment and gap analysis

The ICA-TF monitors developments in crypto-assets with a view to analysing the risks they might pose to the financial system and the economy, and any possible adverse impact on the discharge of the ECB mandate. This section focuses on implications and/or risks of crypto-assets for: (i) monetary policy; (ii) financial stability; and, (iii) financial market infrastructures. Furthermore, it discusses supervision and regulatory issues arising from the analysis of the above risks.

For these risks, mitigating factors, where they exist, are identified, and the effectiveness of current regulatory and oversight frameworks in addressing the various risks is assessed. On this basis, this section identifies any remaining gaps and outstanding risks for which mitigating measures are not at hand or fall outside of the scope of the ECB remit.

1.4.1 Potential implications for monetary policy

At the current stage, crypto-assets do not fulfil the functions of money, and neither do they entail a tangible impact on the real economy nor have significant implications for monetary policy. In principle, implications for monetary policy could materialise in the event that crypto-assets were to turn into a credible substitute for cash and deposits. However, the reportedly low number of merchants that allow the purchase of goods and services with bitcoins also indicates no influence of the most prominent crypto-asset on price-setting at all. The high price volatility of crypto-assets, the absence of central bank backing and the limited acceptance among merchants prevent crypto-assets from being currently used as substitutes for cash and deposits, as well as making it very difficult for crypto-assets to fulfil the characteristics of a monetary asset in the near future.

As crypto-assets are not effectively competing against cash and deposits, their implications for economic developments and monetary policy are similar to those of other asset markets. Since the size of the sector remains small, and linkages to the wider financial system – let alone the real economy – remain limited, crypto-asset related developments have no direct implications for monetary policy at the present stage. At the same time, the dynamic nature of crypto assets, including the development of stablecoins, warrants continuous monitoring. In this regard, it remains to be seen whether algorithmic stablecoins can effectively offer the very substantial reduction in price volatility that a wider adoption would be likely to require. By contrast, stablecoins could become less volatile if the coins were collateralised by central bank reserves, for example. Such collateralisation could result in additional demand for central bank reserves, which could have implications for monetary policy and its implementation. However, such collateralised stablecoins are not crypto-assets as defined in this study.

There are hardly any suitable public data sources that allow the use of crypto-assets as substitutes for money to be measured and monitored. Statistics on the number and value of payments received by merchants in crypto-assets are not publicly available. Information on the number of merchants that accept crypto-assets is fragmented and un-vetted. The number of crypto-assets transactions from the blockchains (on-chain transactions) is publicly available but is both hardly indicative of retail payments and restricted to a fraction of total (on-chain, off-chain) transactions. These gaps in the crypto-assets monitoring framework could make it difficult to promptly identify and assess changes in the status quo that may warrant revising the above risk assessment, and need to be filled.

1.4.2 Risks to financial stability

Crypto-assets currently do not pose a material risk to financial stability in the euro area. Their combined value is small relative to the financial system. The sector nevertheless requires continuous careful monitoring, as market developments are dynamic and linkages to the wider financial sector may increase to more significant levels in the future.

There is no hard data on exposures of supervised entities to crypto-assets. While the ECB has gathered evidence of low and immaterial exposures, the lack of data is a gap to be filled, and a limitation in the assessment of systemic risks.

Incipient yet growing brokerage and post-trade services for institutional investors may lead to increased crypto-assets exposures. In the absence of such services, the interest of institutional investors in crypto-assets and the development and uptake of crypto-assets-based products may have been (technically) constrained. This might change in the near feature, thus possibly incentivising greater exposures.

Currently, the means to address these potential risks from a prudential perspective are lacking. There is no identified prudential treatment for crypto-asset exposures of financial institutions, whether direct investments, derivatives, or indirect investments. This gap needs to be filled while exposures do not give rise (yet) to systemic risk.

Clarifying the accounting treatment of crypto-assets could lead to a more conducive environment for such investments being created. In fact, the absence of accounting guidance for crypto-assets is perceived by the industry as a critical constraint on investment and growth in this business (Financial Times, 2018b).

1.4.3 Supervision and prudential treatment

The regulation on prudential requirements for credit institutions (CRR), as it currently stands, is not tailored to crypto-assets in light of their high volatility. Given their inherently high risk and the lack of fundamental value, the prudential treatment would justify a deduction of crypto-assets from CET1. At the time of writing, the BCBS (Blue Cross Blue Shield Association) has deliberated on advancing the analysis on the prudential treatment of crypto-assets, but no concrete developments have occurred so far.

A classification of crypto-assets as intangible assets (IAS 38) would automatically mean that crypto-assets would be deducted prudentially. Accounting standard setting bodies/authorities could pursue a harmonised accounting treatment by prescribing that banks should account for crypto-assets as intangible assets. Other accounting treatments (e.g. cash, foreign-exchange position, or commodities) would result in alternative prudential treatments under the market risk framework of the CRR that are not fully suited to capture the volatility of crypto-assets. Nevertheless, the accounting standard-setters might opt for an accounting treatment of crypto-assets other than IAS 38 intangible assets. In this case, Pillar 2 deductions would become an even more crucial element in addressing the risks of crypto-asset investments and activities.

Regardless of the type of exposure and prudential treatment, a specific risk management framework would be required to cover the specific risks entailed in crypto-asset activities. The governance and internal control arrangements of financial institutions undertaking crypto-asset investments and/or activities may not adequately reflect the specific nature and risk profile of these activities. Similarly, the internal capital adequacy assessment process (ICAAP) of supervised entities investing in crypto-

assets might not be fully in line with the risk taken in such activities and the relating consumption of internal capital.

With regard to liquidity requirements, crypto-assets are not included in the list of eligible instruments for the liquidity coverage ratio (LCR) liquidity buffer. Even if included, liquid assets also have to comply with the general and operational requirements specified in the LCR Delegated Regulation (LCR DR). In principle, in order to qualify as liquid assets, crypto-assets would need to meet some fundamental characteristics such as low price volatility. Given the high fluctuation of crypto-assets prices, it is questionable whether this requirement can be met. On the other hand, derivatives on crypto-assets would be currently treated as any other derivative transaction in the LCR.

Crypto-assets are most likely to be subject to a 100% stable funding requirement. This would apply irrespective of whether crypto-assets would be classified as intangible assets to be deducted from own funds. From a prudential perspective, a 100% stable funding requirement appears adequate in particular since it reflects the potential difficulties of monetising crypto-assets through sale (or using it as collateral in secured borrowing transactions) over the course of one year without significant expense. On the other hand, derivatives on crypto-assets would be currently treated as any other derivative transaction in the net stable funding ratio (NSFR).

Finally, the holistic approach of the supervisory review and evaluation process (SREP) allows for the review of crypto-assets' direct and indirect investments – when significant – from different risk perspectives, including: (i) credit and counterparty risk; (ii) market risk; (iii) operational risk; (iv) governance; (v) solvency risk; and (vi) liquidity risk. The Supervisory Manual and the supervisory tools should be updated in the future if investments in crypto-assets become material.

1.4.4 Risks to financial market infrastructures

The extent to which crypto-assets represent a risk to the safety of financial market infrastructures (FMIs) depends on how crypto-assets may enter FMIs. As it currently stands, the regulatory framework for FMIs serves as a first-line defence against crypto-assets risks.

Crypto-assets cannot be used to carry out money settlement in FMIs, since the Principles for Financial Market Infrastructures (PFMI) of the Committee on Payments and Market Infrastructures (CPMI) and the International Organisation of Securities Commissions (IOSCO) prescribe the use of central bank money where practicable and available and commercial bank money in the remaining cases. Crypto-assets are neither central bank money nor commercial bank money. The PFMI requirements on money settlement have been translated in the European Market Infrastructure Regulation (EMIR), the Central Securities Depositories Regulation (CSDR) and the ECB Regulation on oversight requirements for systemically important payment systems (SIPS Regulation) in equally strict terms.

Moreover, it is not envisaged in the CSDR that CSDs can undertake settlement of/in crypto-assets since crypto-assets do not qualify as transferable securities. For the same reason, crypto-assets schemes do not qualify as CSDs under CSDR. In principle, a trade involving the settlement of a transferable security against crypto-assets could nevertheless be executed in the form of a free-of-payment security transfer by the CSD while the crypto-asset leg would have to be settled separately. Free-of-payment arrangements expose counterparties to principal risk and additional costs linked to reconciliation, among others.

Current (limited) exposures to crypto-assets of European financial institutions have not been assessed to have an impact on FMIs participants' ability to meet their obligations in FMIs. Should the size of exposures increase and/or market circumstances evolve such that participants' activities in crypto-assets are assessed to pose a threat to the FMI safety, the FMI operator could, without prejudice to the principle of fair and open access, revise FMI participation requirements to ensure that crypto-assets business be segregated in order to minimise or eliminate spill-over risks.

Similarly, should risks arising from crypto-asset activities of TARGET2 participants be assessed to threaten the system's soundness and safety, the Eurosystem is in a position to revise TARGET2 Guideline along the lines above and also to terminate participation on grounds of prudence. For such measures to be viable and appropriate, they would have to be substantiated by a Eurosystem/EU-wide oversight policy stance and a robust argumentation about the direct link between limiting crypto-asset activities and promoting the smooth functioning of payment systems (Article 127(2) fourth indent of the Treaty on the Functioning of the European Union). It bears noting though that any segregation requirements emanating from TARGET2 would only apply to its direct participants, whereas the clients of participants' banks would be out of scope. Moreover, it is in any case not possible to prevent crypto-assets-related payments from being settled in TARGET2 or ancillary systems, as payment instructions in a system are disconnected from the underlying transaction, and are processed and settled regardless of the latter's legal validity.

EU CCPs may in the future undertake clearing of crypto-asset based products, provided that (i) they are authorised to do so and (ii) regulatory requirements can be satisfied. For the first condition to be met, crypto-asset-based products would need to be qualified as financial instruments, or at least considered "linked to clearing" by the national competent authorities and ESMA. Either way, should a positive conclusion on eligibility of crypto-asset-based products for clearing by CCPs under EMIR prevail, then the (prospective) clearing of crypto-assets-based products would most likely imply an extension of CCP services and activities, and hence trigger a consultation of the CCP's EMIR college. Certain EMIR requirements might need consideration with regard to their applicability in light of crypto-assets-based products.

Particularly regarding financial risk management, a CCP undertaking clearing of crypto-assets-based products would need to ensure that sufficient financial resources are available to the new clearing business. Crypto-assets pricing uncertainties and historic volatility would be critical elements in the assessment of adequacy of financial resources by the college. From a CCP credit risk management perspective, CCPs that operate multiple clearing services have the possibility to maintain separate default waterfalls for those clearing services. This means that losses incurred in one service line cannot be covered by dedicated prefunded or unfunded resources posted or committed by the clearing members and the CCP (i.e. initial margin, default fund contributions, skin-in-the-game, assessments or cash calls) to support another service line. Setting up separate default funds is entirely the choice of the CCP. A CCP employing this structure should conduct separate credit risk stress tests in order to size the different default funds. Furthermore, the separated structure also holds for the unfunded commitments (e.g. assessments or cash calls). It should be noted though that even if the CCP had separated default funds, at the end of the default waterfall (i.e. after exhausting all prefunded and unfunded resources dedicated to the relevant service line, including the part of the CCP's overall skin-in-the-game allocated to the service), the CCP's own remaining capital would be exposed to the overall loss allocation.

Ultimately, difficulties in operationalising EMIR requirements for clearing of crypto-assets may as well prevent CCPs from offering the service in practice, or incentivise CCPs and their competent authorities to apply stricter risk management standards than currently required by the regulatory

framework, in particular to minimise the crystallisation of spill-over risk between clearing of crypto-assets-based products and other products (e.g., via separate default funds).

On the other hand, CCPs cannot use crypto-assets as collateral under EMIR because crypto-assets do not fall within the list of eligible collateral of Commission Delegated Regulation (EU) 2016/2251. Moreover, the use of crypto-assets would run counter to the objective to mitigate an FMI's own credit risk as crypto-assets do not have the characteristics of assets with low credit, liquidity, and market risk, as prescribed in the PFMI. Similarly, CCPs cannot use crypto-assets as investments. Permitted CCP investments under EMIR are limited to debt instruments issued or explicitly guaranteed by a government, a central bank, a multilateral development bank, the European Financial Stability Facility or the European Stability Mechanism. This condition de facto excludes crypto-assets from being used by CCPs as non-cash investments.

This analysis shows that risks arising from a scenario where crypto-assets enter FMIs could in principle be managed within the current regulatory and oversight frameworks. That does not mean that risk-taking in relation to crypto-assets should be encouraged. From an ECB perspective, the value proposition of crypto-assets is far from clear, whereas EU FMIs would incur heightened risks and additional costs. It bears noting, though, that today European clearing members (CMs) and their clients can already clear crypto-asset derivatives at third-country recognised CCPs (TC-CCPs) without restrictions. Where TC-CCPs are authorised by their third-country competent authority to clear crypto-asset derivatives (such as CME Clearing in the United States by the Commodity Futures Trading Commission) and these CCPs have been already recognised under EMIR, ESMA would have no power to prohibit the provision of those clearing services to EU CMs under the existing equivalence regime (currently under revision). European CMs and their clients that do not make use of such services face spill-over risks from this activity indirectly through the CCPs' default funds.

1.4.5 Regulatory issues

At the time of writing, the legal status of crypto-assets varied among countries, absent a common taxonomy of crypto-assets, and a shared understanding of how crypto-assets should be treated from a regulatory standpoint. Given the global dimension of the crypto-assets phenomenon, uncoordinated and/or inconsistent regulatory approaches undertaken at the country level may prove ineffective and create incentives for regulatory arbitrage. Whilst this need not pose an immediate threat to the financial system, it calls for vigilance at the level of the EU, to prevent a proliferation of national initiatives from triggering regulatory arbitrage and, ultimately, hampering the resilience of the financial system to crypto-asset market-based shocks.

Under EU law as it stands, crypto-assets as defined in this report do not appear to fit under any of the subject matter-relevant EU legal acts (particularly PSD2 and EMD2, and MiFID as shown previously). As a consequence, crypto-assets as defined in this report and related activities are 8unregulated, with the exception of anti-money laundering following the adoption of the fifth Anti Money Laundering Directive (AMLD5), which envisages extending the scope of AMLD4 to providers engaged in exchange services between virtual currencies and fiat currencies and custodian wallet providers. For completeness, the Settlement Finality Directive (SFD) – predating the advent of crypto-assets – is not applicable to crypto-asset networks or intermediaries.

Given the current state of law, there is limited scope for public authorities to intervene; moreover, regulatory intervention would be further complicated by the lack of governance and distributed architecture of crypto-assets. Finally, the cross-border dimension of this phenomenon challenges the effectiveness of (uncoordinated) interventions at the domestic level.

Still, there could be avenues for the regulation, at EU level, of crypto-assets business at the intersection with the regulated financial system, i.e. aimed at crypto-asset "gatekeeping" services, namely crypto-assets custody and trading/exchange services. This would allow risks to be addressed at the point where they enter and propagate into the regulated financial sector, and to protect users of these services. Moreover, regulating the gatekeepers would facilitate monitoring of crypto-assets via transparency and reporting obligations that would otherwise not be possible to impose/enforce on unregulated activities. Importantly, EU regulation in this area would prevent diverging approaches at the Member State level from proliferating thus leading to fragmentation.

In a context where a large part of crypto-asset-related activity is carried out by centralised service providers, this set-up is no different from the traditional financial intermediation business, hence a similar framework could be used to regulate and authorise the activities of (centralised) crypto-asset gatekeepers. While investors in crypto-assets can hold and trade units with their peers by using any personal device with an internet connection, they are more likely to rely on third party service providers or gatekeepers (e.g. custodian wallet providers, trading platforms and exchanges). Gatekeepers participate in the networks where crypto-asset transactions are instructed and validated to hold, buy and sell crypto-assets on behalf of their clients.

However, the above regulatory approach is not suited to decentralised gatekeeping activities that do not foresee the involvement of an identifiable intermediary; in this case, a principles-based approach, complemented by a formal mechanism to validate the observance of such principles, could be considered. A way to (indirectly) regulate crypto-asset gatekeeping services and, at the same time, safeguard the regulated intermediaries/infrastructures with which those decentralised networks may interact, would be to (at least) subject decentralised networks (and the cryptographic algorithms and protocols they are built upon) to a minimum set of principles, such as: (i) technological integrity, meaning, inter alia, no back doors/loopholes or hidden functionalities, no white listing of malware, no fraudulent collusion, responsible cryptographic key management, and the pursuit of the state of the art; (ii) algorithms/protocol service performance and transparency so as to ensure the correct performance of the service and facilitate any necessary audit; (iii) stress-tested operational security and cyber-resilience; (iv) regulatory compliance intended as audibility by users and supervisors in line with the regulatory obligations/requirements that may be triggered by participation in or use of the network.

It cannot be excluded that regulation of crypto-asset gatekeepers could have an unintended impact on the market. First, because centralised gatekeeping services will be held to a greater level of scrutiny than decentralised services (which cannot be as effectively supervised), there is a risk of an uneven playing field and a shift from centralised to decentralised services. Furthermore, regulating and supervising gatekeepers entails significant resources on the side of public authorities, particularly with regard to the mechanisms to ensure compliance. Finally, regulation could be perceived as (unintentionally) legitimising crypto-assets business.

2. CBDC and motivations for issuing

CBDC is a digital representation of a sovereign currency issued by and as a liability of a jurisdiction's central bank or other monetary authority. However, the taxonomy of digital representations of money is still evolving, and there are no universally accepted CBDC definitions (IMF, 2020).

This study focuses mainly on CBDC issued directly by the central bank, as opposed to "synthetic" CBDC (sCBDC) which is privately-issued digital money backed by central bank reserves, regulated and supervised by the central bank (Adrian and Mancini-Griffoli, 2019a). The intention of the study is not to advocate for retail CBDC issuance, but to take stock of recent research, central bank experiments, and ongoing discussions among stakeholders on the topic. It also intends to summarize existing literature, providing central bankers and researchers with a deep dive into the complex interrelated policy issues beyond just whether to issue retail CBDC, including operating models, design considerations and risk management issues. Given the limited practical experience with the topic, these are just initial observations and are not meant to be prescriptive, exhaustive, or universal.

At the conceptual level, most of the major central banks and monetary authorities considering CBDC issuance are following similar workflows that start with clearly identifying objectives and then thoroughly assessing expected benefits, costs, and risks. The authorities exploring CBDC issuance cite different objectives, two primary ones being to improve financial inclusion and to maintain the central bank's relevance in the monetary system. Other objectives include reducing costs associated with physical cash, increasing payment system efficiency, improving monetary policy formulation and implementation, strengthening financial integrity, addressing potential issues related to private payment systems such as privacy or monopolistic power, and more recently following the COVID-19 global crisis, to expedite stimulus payments and to make payment systems more resilient against shocks.

2.1. Considering CBDC research and development efforts

Spurred by competition from innovative payment solutions developed by the private sector, central bank digital currency (CBDC) has received significant attention in both policy circles and academia. Central banks around the world have been researching the concept and design of digital currencies for several years. As early as 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)).

Concurrently, with the growing popularity of Bitcoin and distributed ledger technology (DLT), a number of central banks have started internal projects to better understand DLT and its potential application to currencies. In the Netherlands, the Netherlands Bank ("De Nederlandsche Bank", DNB) did internal experiments starting in 2015 with a DLT-based coin called the Dukaton (DNB (2018)). This was named after the dukaat, a golden coin used at the time of Dutch independence from Spain in the 16th century. The Bank of England, Monetary Authority of Singapore, Bank of Canada and others ran similar internal experiments around this time. They generally concluded that DLT was not yet mature enough for use in major central bank payment systems (see Bank of

England (2017)). In March 2016, the Deputy Governor of the Bank of England gave thoughts on the wide-reaching implications of CBDCs (Broadbent (2016)) – the first of many subsequent policymaker speeches that have grappled with CBDCs and their implications for central banks and societies.

From 2016 onward, a number of central banks launched research projects on digital currencies for specific purposes. The Monetary Authority of Singapore launched its own Project Ubin (named after the island Pulau Ubin) at the Singapore FinTech Festival in November 2016 (MAS (2016)). This, too, focused on interbank payments, and specifically on a tokenised form of the Singapore dollar on DLT. The Hong Kong Monetary Authority (HKMA) launched Project LionRock (named after a mountain in Hong Kong) in January 2017. The European Central Bank (ECB) and the Bank of Japan launched the first known example of cooperation between two central banks on CBDCs in 2017 with Project Stella, focused on cross-border payments (ECB-BoJ (2017)). 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); BoT-HKMA (2020)).

The first publicly announced work on retail CBDCs was conducted by the Swedish Riksbank (Sveriges Riksbank (2017)). In Sweden, cash use has been declining in recent years, 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. In February 2020, the Riksbank announced it would conduct a pilot project with Accenture aimed at developing a proposal for a technical solution for an e-krona (Sveriges Riksbank (2020)). While announced somewhat later, perhaps the most advanced CBDC project at present is that of the People's Bank of China (PBC). Known as the Digital Currency Electronic Payment (DC/EP), this CBDC is now being piloted in four cities in China. DC/EP will be a cash-like liability of the PBC available to the general public – and to foreign visitors of China – through account-based interfaces.

The Eastern Caribbean Central Bank (ECCB) has launched a pilot called DXCD (ECCB (2019)), and the Central Bank of the Bahamas has launched a pilot called the Sand Dollar (CBB (2019)).

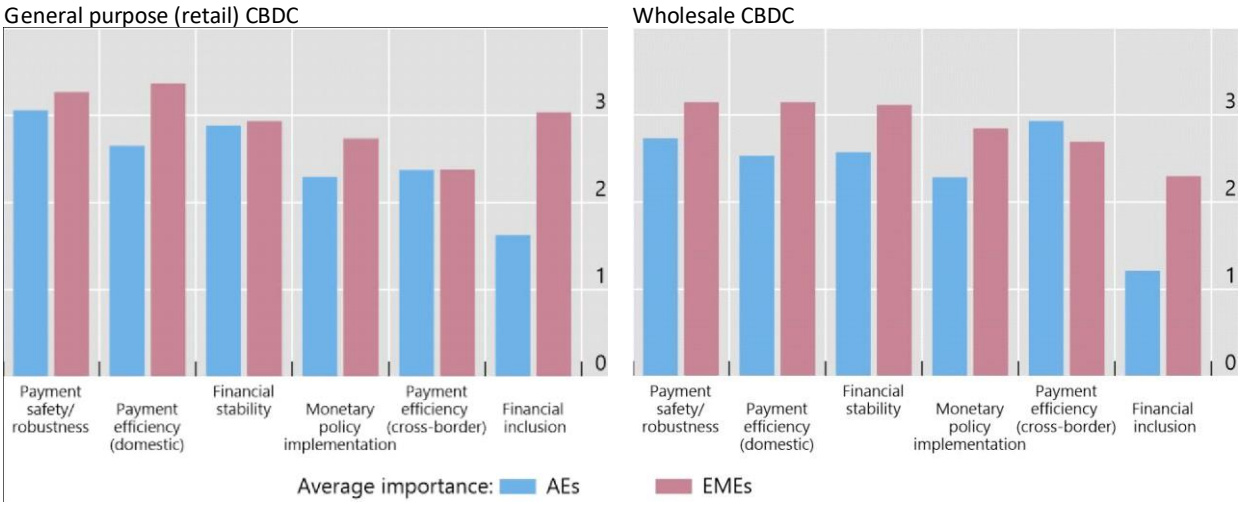
As of mid-July 2020, at least 36 central banks have published retail or wholesale CBDC work. At least three countries (Ecuador, Ukraine and Uruguay) have completed a retail CBDC pilot. Six retail CBDC pilots are ongoing: in the Bahamas, Cambodia (Bomakara (2019)), China, the Eastern Caribbean Currency Union, Korea (Bank of Korea (2020)) and Sweden). Meanwhile, 18 central banks have published research on retail CBDCs (eg Harahap et al (2017), Burgos and Batavia (2018), Kiselev (2019) and Bank of Japan (2020)), and another 13 have announced research or development work on a wholesale CBDC.

In parallel, a growing number of central bank governors and board members have made public speeches about CBDCs. In 2017 and 2018, many of these had a negative or dismissive stance, particularly toward retail CBDCs. Since late 2018, the number of positive mentions of retail and wholesale CBDCs in speeches has risen, and in fact, there have now been more speeches with a positive than a negative stance. The motivations for such work differ across jurisdictions. Based on a survey of central banks in the BIS Committee on Payments and Market Infrastructures (CPMI) in late 2019, Boar et al (2020) show that in advanced economies (AEs), central banks are researching CBDCs to promote safety and robustness, or domestic payments efficiency (Graph 9). Financial stability concerns may also be an important driver of research and development work. Especially in emerging market economies (EMEs), financial inclusion is an important motivation.

Graph 9

Motivations for issuing a CBDC

Average importance



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

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

Recently, the Covid-19 pandemic may have accelerated work on CBDCs in some jurisdictions. For instance, in the United States, early versions of Congress bills on 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)). In parallel, the Federal Reserve has continued its 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 new CBDC 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.

It should be noted 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. 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.

2.2. Why to consider CBDC issuance?

There is a wide range of objectives for issuing CBDC and this section will explain the reasons that central banks have spotted for issuing or not issuing CBDC and factors that may affect the decision. Below are the summarized and more deeply reviewed objectives:

1. CBDC could meliorate monetary policy strength to achieve the aimed policy, or to utilize further crude liquidation statistics to build up macroeconomic prognostication.

2. CBDC may boost payment methods competition, efficaciousness, and elasticity in front of expanding accumulation by several colossal enterprises.

3. CBDC could be a system to assist financial digitalization, diminish expenditures relevant to printing and governing physical cash, and enhance financial involvement, in particular in regions with lagging financial systems and a lot of unbanked population.

4. CBDC may serve to diminish or restrict the acquiring of privately issued currencies, which could endanger monetary pre-eminence and financial resilience, and be delicate to manage and adjust.

5. CBDC may assist to better off absorption of domestic currency as manners of liquidation in administrations trying to curtail dollarization.

1- CBDC issuance could meliorate monetary policy effectiveness. Interest-bearing CBDC may tolerate for deeply negative policy rates, even though only if cash were prohibited as argued in (Rogoff, 2014), causing it to be expensive to hold as suggested in Bordo and Levin (2018), or made to depreciate against CBDC, which would be assumed as the exclusive legal tender (Agarwal and Kimball, 2015). However, deeply negative rates may cause criticism from the community and essentially undermine public confidence in the central bank (Mersch, 2020). CBDC could also consent for the application of non-linear transfers based on user account balances (Davoodalhosseini and others, 2020) or "helicopter drop" monetary stimulus to ease adverse impacts deriving from natural disasters or public health crisis or simplify other "unprecedented policies," bordering on fiscal policy, such as those proposed by Boivin and others (2019). CBDC could also be programed to augment money velocity by stimulating specific patterns of consumer consumption (Copic and Franke, 2020). For example, "cash back" liquidations could be finalised on acquiring from domestic merchants and/or certain industries, or CBDC possessions could incur a fee to stimulate people to spend it promptly. The central bank would credit citizens' CBDC accounts or wallets possessors CBDC tokens. Nevertheless, doing so would not consequently arrive at all citizens, and the central bank would have to determine how much to assign to each possessor, an unpleasant affair given the distributional consequences. Finally, more contemporary monetary policy could discourage innovation in existing payment systems (BoE, 2020), lead to a uneven concentration of power in the central bank, and be peculiar with the concepts of distinguishing monetary from fiscal policy and central bank independence (Mersch, 2020).

Central banks could use CBDC for targeted monetary policy establishment and attitude. Central banks could penetrate real-time and more granular contextual payment metadata to increase monetary policy establishment and macroeconomic projections (Bergara and Ponce, 2018). Access to historical transaction data and the expertise to monitor the economy's response to shocks or policy evaluation in near real-time and more precisely would be important from a financial and macroeconomic stability perspective (Burgos and Batvia, 2018). This micro level outline of payment statistics would assist policymakers acknowledge the macro-financial impacts of seasonality, natural disasters or consumer behavior. Central banks could utilize statistics in machine learning and more advanced quantitative models to update macroeconomic projections, administrate liquidity and reserves, or establish the real velocity of money. Machine learning models based on sample recognition could assist forecast demand for CBDC by determined regions or sectors. Before aggregating and exploiting micro-level consumer data, it would be essential to apply proper data protection and cyber-resilience measures to eliminate theft or misappropriate of that data. Without these preventions in place, central banks endangers high reputational damage, which would surpass any possible benefits from CBDC.

2- CBDC could be projected at comforting the market sovereignty of private payment systems or diminishing concentration risk in such payment systems. Payment systems may drift to develop into natural monopolies, reflecting secure system externalities (the value of using a specific payment system is greater the larger the user community, counting savings from netting transactions), economies of scale (decreasing average costs, including high fixed development and maintenance expenses), and economies of scope, (gains from collecting data to give extra services - Bolt, 2005, and Gowrisankaran and Stavins, 2004). Nevertheless, a few private money issuers may not incorporate the social cost of potential systemic disturbance from operational failure, along with cyberattacks, and thereby may underinvest in security. In addition, monopolistic private issuers may misuse that capability and head to inefficiency by offering incomplete, weak and expensive services. They could in addition commercialize aggregated user data, even if these could also invite rivalry, relying on the barriers to entry. These reasoning might sustain CBDC issuance or some arbitration accord to setup fast payment systems, which also allow them control over a fundamental piece of the payment architecture. If monopolistic bias signal concerns, antitrust regulations and data protection jurisdiction could be a response (CGAP, 2019).

CBDC could enhance financial involvement in countries with not fully developed financial systems and low financial insight. In countries with large remote or rural areas, or more of the citizens moving to digital forms of money, the infrastructure for offering cash may not be possible or has deteriorated, and companies may resist dealing with it. Their commercial banks and other deposit-taking institutions might be financially forced or not highly motivated to offer banking services to some segments of the population. One policy option may comprise subsidizing the distribution of cash to distant areas and/or supply of banking services via other options to those underserved community such as mobile money (e.g., M-Pesa in Kenya and PayTM in India). However, the insufficiency of digital financial services could link to poor digital transmitting framework calling for the prioritization of attemptions to upgrade it. Nevertheless, if barriers to financial involvement stem from a reluctance to or difficulties in accomplishing formalization, neither CBDC nor other digital initiatives would be enough.

3- Issuing CBDC and pushing financial services digitization may diminish costs linked with issuing and administrating physical cash. Alvez and others (2019) calculated that the private costs of using

cash in Uruguay were about 0.6 percent of GDP. In a review of the relevant literature, they discovered that such private costs ranged from 0.2 percent (Norway) to 0.6 percent (Belgium). Kosse and others (2017) found similar data for cash usage in Canada (0.5 percent of GDP), but Banka (2018) reported much greater costs for Albania (1.0 percent) and Guyana (2.5 percent). Costs fall mainly on banks, firms, and households. Even though launching and maintaining CBDC would probably lead to significant fixed costs, marginal operational costs would possibly be low, apart from the necessity for customer service. Relating to this, the cost efficiency case to legitimate CBDC may be better for larger jurisdictions ready to absorb the fixed costs. In addition, taking into account that managing digital cash is approximately as complicated as managing physical cash, it should not be assumed that digitalization will automatically drive to cost reduction. For example, some of the fixed costs to the central bank and commercial banks connected with physical cash will remain. Finally, there are further development and operational costs related with CBDC as illustrated in Table 1.

Table 1 Operational costs related with CBDC

Cost Category	Examples
Labor	IT consulting firm; developers; user experience specialist; wallet maintenance costs, etc.
Infrastructure	Cloud or on-premise servers
Software	Licenses; service fees
Cyber Security	Threat modeling; protection; identification; response management; penetration tests. Etc.
Support	Help desk; training; communication

Source: (IMF, 2020)

4- CBDC would assist sustain monetary central banks' monetary sovereignty. Stablecoin-based payment systems like Facebook's Diem could earn a significant share of payments markets. Especially in developing market and emerging economies (EMDEs) they could threaten monetary sovereignty by urging currency substitution (e.g., dollarization) and undermine financial stability (Diez de los Rios and Zhu, 2020; FSB, 2020). Expanding migration into stablecoins could dimish commercial bank deposits which could reduce their sources of stable funding, as well as their access into transactions data, and impede credit supply to the economy (Brainard, 2020). Global stablecoins that are accredited across numerous jurisdictions could be hard to control and/or adjust, especially for EMDEs likely acting as hosts to most institutions in a stablecoin system, which may have the operational base elsewhere (Feyen and others, 2020). A well-designed CBDC or sCBDC might guarantee that public money remains a suitable unit of account (Brunnermeier and others, 2019).

5- Traction of domestic currency would be enhanced by leveraging cbdc as a payment method in jurisdictions in an effort to curtail dollarization. Nevertheless, CBDC would not by itself forward causes of dollarization or differ the engaging of foreign currency as store of value, particularly where residents have lost confidence in the domestic currency as a result of insecure domestic policies and macro instability (current instability or episodes of past instability). CBDC could also support financial involvement, accelerating use of domestic currency in payments, and possibly support to de-dollarization as part of an inclusive strategy that delivers the principal causes of dollarization across coherent fiscal, monetary, and financial policy mix that sustains the

macroeconomic framework, reduces inflation, establish a healthy financial system, and develops domestic currency titled instruments (such as a local bond market and availability of hedging instruments against foreign exchange rate exposures).

2.3. Costs and Benefits of CBDC

The ultimate decision as to whether to issue CBDC will come down to weighing the costs and benefits of CBDC issuance against those of the alternatives. The initial decision-making process starts with understanding thoroughly the problem to be solved and the full array of solutions. Central banks in several countries are working on improving existing payment systems to match the speed and convenience of digital currencies. For example, the U.S. Federal Reserve is developing so-called fast payments, allowing nearly instantaneous and low-cost settlement of inter-bank retail payments (U.S. Federal Board, 2019). In some instances, deploying fast payments would offer enhanced control over essential payment systems without issuing CBDC. In other countries, similar systems have improved payment services and injected competition in payments, especially if paired with other reforms, such as public digital identities, common communication standards, open application programming interfaces (APIs, which allow banking applications to interoperate and to be extended by third-party developers), and data portability and protection standards (Cœuré, 2019). If the objective for considering issuing CBDC is to expand financial inclusion or react to dwindling cash usage, other options could include promoting mobile money, incentivizing private-sector financial institutions to improve their product offerings or changing or instituting relevant legislation to ensure merchants accept cash.

What are the potential benefits and challenges related to CBDC implementation?

Central banks highlight a number of potential benefits of CBDC. These include:

- *Cost of cash:* In some countries, the cost of managing cash is very high due to an especially vast territory, or particularly remote areas including small islands. CBDC could lower costs associated with providing a national means of payment.
- *Financial inclusion:* CBDC may provide a safe and liquid government-backed means of payment to the public that does not require individuals to even hold a bank account. Some central banks view this as essential in a digital world in which cash use is progressively diminishing, especially in countries where banking sector penetration is low.
- *Stability of the payment system:* Some central banks are concerned by the increasing concentration of the payment system in the hands of few very large companies (some of which are foreign). In this context, some central banks view CBDC as a means to enhance the resilience of their payment system.
- *Market contestability and discipline:* Relatedly, some central banks view CBDC as potentially offering competition for large firms involved in payments, and thus as a means to cap the rents they can extract.
- *Countering new digital currencies:* Some central banks view CBDC as healthy — potentially necessary—competition against privately issued digital currencies, some of which may be denominated in foreign currencies. These central banks believe a domestically issued digital currency backed by the government, denominated in the domestic unit of account, would help reduce or prevent the adoption of privately issued currencies, which may be difficult to regulate.

- *Support Distributed Ledger Technology (DLT):* Some central banks see the virtue of DLT-based CBDC to pay for DLT-based assets. If these assets proliferate, DLT-based currency would facilitate automatic payments when assets are delivered (so-called "payment-versus-delivery," or "payment-versus-payment," which could be automated using smart contracts). Some central banks are considering the option of providing CBDC only to institutional market participants in order to develop DLT-based asset markets.

- *Monetary policy:* Some academic scholars view CBDC as a means to enhance the transmission of monetary policy. They argue that an interest-bearing CBDC would increase the economy's response to changes in the policy rate. They also suggest that CBDC could be used to charge negative interest rates in times of prolonged crisis (thus breaking the "zero lower bound" constraint), to the extent cash were made costly.

Despite these potential benefits, various challenges could emerge. Some of these can be attenuated by the appropriate design of CBDC.

- *Banking-sector disintermediation:* Deposits could be withdrawn from commercial banks, should people decide to hold CBDC in significant volume. Banks would have to raise more expensive and runnable wholesale funding, or raise interest rates on deposits to retain customers. As a result, banks would either experience a compression of margins, or would have to charge higher interest rates on loans. The extent to which CBDC will compete with commercial bank deposits in normal times will depend in part on interest rates paid on CBDC, if at all. A non-interest bearing CBDC would come closest to simply replacing cash.

- *"Run risk":* In times of crisis, bank customers could flee from deposits to CBDC, which might be seen as safer and more liquid. However, in many jurisdictions, credible deposit insurance should continue to dissuade runs. In addition, safe and relatively liquid assets already exist in many countries, such as government bond funds, or state banks. Though evidence and country coverage is limited, academic studies do not point to systematic runs towards these alternative assets in crisis times. Moreover, if a run occurred, the central bank would be more easily able to meet deposit withdrawal requests with CBDC as opposed to cash. In addition, in many countries around the world, bank runs typically coincide with runs from the currency. Thus, whether or not local-currency CBDC existed, depositors would seek refuge in a foreign currency.

- *Central bank balance sheet and credit allocation:* In case demand for CBDC is high, the central bank's balance sheet could grow considerably. In addition, the central bank may need to provide liquidity to banks that experience rapid and large funding outflow. As a result, central banks would take on credit risk, and have to decide how to allocate funds across banks, opening the door to political interference.

- *International implications:* CBDC of reserve currency countries available across borders could increase currency substitution ("dollarization") in countries with high inflation and volatile exchange rates. These prospects need to be studied further, along with implications for the international financial system. IMF staff are currently investigating these questions.

- *Costs and risks to the central bank:* Offering CBDC could be very costly for central banks, and it could pose risks to their reputations. Offering full-fledged CBDC requires central banks to be active along several steps of the payments value chain, potentially including interfacing with customers, building front-end wallets, picking and maintaining technology, monitoring transactions, and being responsible for anti-money laundering and countering the

financing of terrorism. Failure to satisfy any of these functions, due to technological glitches, cyber attacks, or simply human error, could undermine the central bank's reputation.

In summary, each country will have to weigh the pros and cons of the case for CBDC depending on its particular circumstances.

Countries may consider the option of public-private partnerships that may achieve many of the same benefits of CBDC, while potentially reducing central bank involvement and operational risks. IMF staff have coined this solution "synthetic CBDC."

More specifically, the synthetic CBDC model envisions private sector firms issuing digital coins to the public (which can either be accounts or tokens leveraging DLT). These firms would thus be responsible for doing what they do best: innovating and interfacing with customers. The central bank, instead, would provide trust to the system, by requiring that coins be fully backed with central bank reserves, and by supervising the coin issuers. This arrangement preserves the comparative advantage of each participant—whether it is a private-sector firm or a central bank—and induces competition among private-sector firms to offer attractive coins and interfaces. At the same time, it limits costs to the central bank, as well as some of the risks.

2.4. The Risk of Issuing CBDC

Monetary policy transmission could be influenced by the launch of CBDC. For example, CBDC would differ the demand for base money and its structure in unpredictable ways and might change the sensitivity of the necessity for money to adjust in interest rates (Carstens, 2019). However, Mancini-Griffoli and others (2018) argue that this effect is rare to be substantial under plausible CBDC designs. Indeed, monetary policy delivery could strengthen if CBDC increases financial inclusion and, therefore, exposes more households and firms to interest-sensitive mechanisms.

Indeed, if CBDC increases financial inclusion, monetary policy delivery could strengthen, and, thus, reveals more households and firms to interest-sensitive mechanisms. The exchange rate communication channel may be altered by the presentation of CBDC because it would mitigate more active currency administration, which could lead to stronger/faster exchange rate fluctuations for specific market rate changes (Armelius and others, 2018). If central banks give consistent funding by recycling deposits back into the banking system, the bank lending communication channel, by which monetary policy influences bank creditworthiness and cost of funding could also be kept. If it competes with bank deposits, depending on design, CBDC could involve financial stability and banking intermediation (Fernández-Villaverde and others, 2020). The level to which CBDC will compete with commercial bank deposits will hinge in part on interest rates paid on CBDC, if at all. A non-interest bearing CBDC would come closest to mimicking cash (IMF, 2020). Banks with a bigger share of retail deposits will face competition from CBDC, especially an interest-bearing CBDC, hence they may have to increase deposit rates to stand competitive. Such higher deposit rates would diminish interest margins, and banks could try to enhance lending rates, even though at the cost of loan demand. The capacity of banks to answer and sustain profitability will rely on their strength in loan markets (Agur and others, 2019). Deposit insurance favour banks to fund themselves with deposits at lower cost than with other instruments. If banks lose more uninsured than insured deposits, issuing CBDC could diminish market discipline, which could lead to banks taking on more risk (IMF, 2020).

Banks could also raise their trust on wholesale funding, with implications for funding cost and stability, and market discipline. However, under prevailing regulatory liquidity requirements, they may have to shorten lending or corporate bond holdings (BIS, 2013 and 2014). In addition, it would not be an applicable option in countries with less developed capital markets. However, even when and where shifting from deposit to wholesale funding is achievable, it could appear in lower bank profits or higher lending rates to sustain margins. Bank funding could also become more volatile. Consequently, banks might have to maintain more liquid assets to meet regulatory requirements or cut back on lending probably at the expense of financial inclusion or growth-enhancing policy measures.

Relying on the CBDC conversion modality, issuing CBDC could have crucial impacts on central bank balance sheets. If disintermediation materializes, the central bank could lend the funds diverted from commercial bank deposits back to those banks so they can keep on lending (Brunnermeier and Niepelt, 2019). However, this implies a drastic step away from typical central bank mandates, and they would have to decide how to allocate funds across banks, opening the door to political interference. CBDC is least disruptive if issued only against existing physical cash, as it merely results in a switch on the liability side of the central bank balance sheet from cash to CBDC. However, the impact is more ambiguous when CBDC is issued against central bank reserves, which will be the case if users convert from commercial bank deposits. More specifically, to the extent that CBDC are paid for with reserves, the size of the central bank balance sheet will remain unchanged, as reserves and currency are both liabilities, although there will be a shrinkage of commercial bank balance sheets.

Several suggestions have been put forward to control the potential resulting banking sector disintermediation that could result from this balance sheet shrinkage. Panetta (2018) suggests imposing holding limits, but that could limit the number or size of payments, as user CBDC holdings would have to be known in order to finalize the payment. Bindseil (2020) suggests a way around the payment finality issue would be for CBDC users to designate a “waterfall” account to which payments that push holdings over the cap would be automatically transferred. This is the approach adopted in the Central Bank of Bahamas CBDC pilot (CBOB, 2019). Kumhof and Noone (2018) propose a more radical approach that would limit commercial banks’ ability to provide on-demand convertibility of deposits into CBDC. Bindseil (2020) argues that it is unnecessary to introduce such far reaching, albeit conditional, changes banking and central banking core principles relating to convertibility. He proposes instead to control the quantity of CBDC through a tiered remuneration system with a relatively attractive rate applied up to some holding ceiling, while a lower interest rate would be applied to amounts beyond the threshold.

A poorly designed CBDC may accelerate bank runs by offering a readily available, safe, and liquid alternative to deposits. However, Mancini-Griffoli and others (2018) argue that the increase in run-risk will depend on whether bank deposits are covered by credible deposit insurance, and the type of crisis. In many jurisdictions, credible deposit insurance should continue to dissuade runs. In addition, safe and relatively liquid assets already exist in many countries, such as government bond funds, or state banks. In cases of individual bank insolvency, running from one bank to another bank is already technically possible with the click of a button in most jurisdictions, so having CBDC is not likely to affect the likelihood of runs in that scenario. However, depending on the design of the CBDC and its ecosystem, including potential convertibility limits, CBDC could increase the risk of generalized runs out of the banking sector. On the other hand, in the event of such a run, CBDC could allow the central bank to offer liquidity faster to distressed commercial banks to avoid the first-come-first-serve dynamics that fuel runs to begin with. Moreover, CBDC is

unlikely to increase generalized run risk in a currency or sovereign crisis, because depositors would typically run from all local assets.

CBDC of reserve currency countries available across borders could increase currency substitution ("dollarization") in countries with high inflation and volatile exchange rates. These prospects need to be studied further, along with implications for the international financial system.

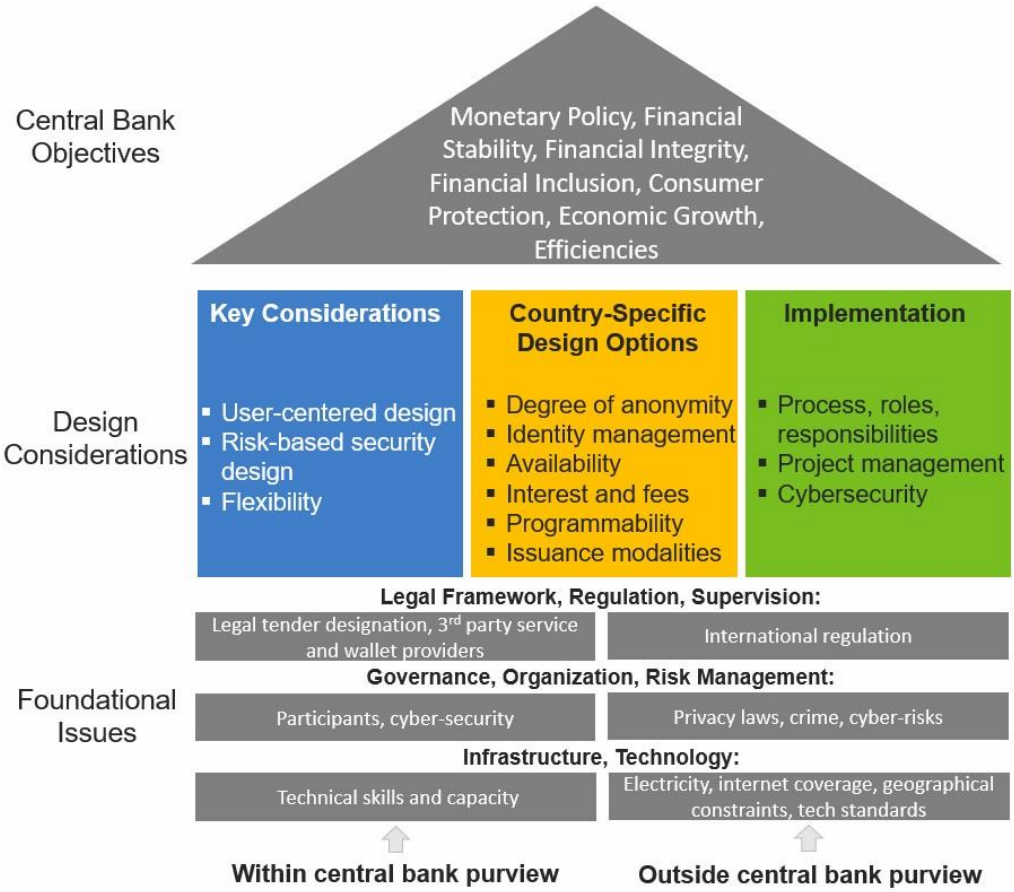
2.5. The Preconditions for Issuing CBDC

Before even thinking about issuing CBDC, advanced economy central banks are carefully reviewing the legal and institutional preconditions. These would include robust national data privacy protection legislation and regulations, strong central bank cyber resilience and national payment system regulations that comply with pertinent international standards. Another important precondition is having sufficient central bank resources to devote to the decision-making process.

Graph 10 suggests foundational issues that could help determine whether a country's circumstances are appropriate for CBDC issuance. There are no universally applicable best practices or prescribed rules that will guarantee the ultimate success of CBDC issuance, but this maturity assessment could facilitate the decision-making process and also help policymakers identify and address any gaps or deficiencies in their infrastructure, regulatory and supervisory framework, governance and risk management, and central bank legislation. Coordinating with other line ministries and government agencies will ensure that foundational elements outside the central bank purview are given attention. Issuing CBDC is a complex national project that will involve multiple stakeholders beyond the traditional central bank counterparts (such as the Ministry of Finance). Interest in and impact of the CBDC extends also to the legal framework. For example, depending on the existing legal framework, CBDC might require changes in the governing, accounting and financial reporting standards to recognize the CBDC. It will also affect multiple public agencies, such as financial intelligence units, tax, capital market, and statistical agencies, plus supervisors, consumer protection agencies and private sector stakeholders, including merchants and users. Depending on the local circumstances, the central bank might consider the establishment of a national consultative committee of stakeholders to facilitate communication and engagement with various stakeholders, including via surveys and focus groups. Clear mandates and effective collaboration among stakeholders can help prioritize tasks and maximize resource efficiency (Taylor, 2019). Issuing CBDC requires an adequately developed technological infrastructure. Developing the needed infrastructure to support CBDC includes insuring a high level of availability and resilience of the general infrastructure such as electricity grids, mobile network and internet coverage. Depending on their circumstances, countries may opt for a combination of submarine fiber optic cables, landlines, and satellite connections. Investments in cable and satellite can be balanced based on the need for greater bandwidth in high-density areas and the reliability of satellite in remote areas or as backup in case of outages (George, 2018). In some circumstances, strong motivations to issue CBDC might accelerate a country's infrastructure investment and the digitalization of the financial system. CBDC issuance is best considered in the broader context of national payment systems development, and driven by needs, objectives, and capacity rather than technology. A payment is the process by which monetary instruments, typically cash and deposit claims, are transferred between two parties (payer, payee) to finalize a transaction. A national payment system is the configuration of diverse institutional arrangements and infrastructures that facilitates the transfer of monetary value between parties. As part of international guidance, the identification of all user needs in the national payments system are critical for guiding development (BIS, 2016). CBDC implementation calls for

an analysis of business and resource requirements, and capabilities, which are drawn from stocktaking exercises and stakeholder consultations. The development of skilled and knowledgeable human resources is equally critical to the development of physical infrastructure, including training personnel in developing, operating and managing CBDC arrangements and supporting education programs for users as well as service providers.

Graph 10



Source: (IMF, 2020)

Launching a CBDC is a multidimensional undertaking that extends beyond the central bank's normal information technology project management frameworks. Issuing a CBDC will require political support, extensive senior management commitment, and focus on detailed product design choices and operational processes. The new currency could lead to major disruptions affecting monetary policy transmission, financial stability, financial sector intermediation, the exchange rate channel, and the operation of the payment system. The issuing central bank will need to consider the existing operating environment and the impact of the CBDC issuance including the degree of public acceptance, use, the nature of financial sector response, and consumer dynamics. The central bank will also have to weigh the availability of in-house capacity against options to outsource selected operations to handle this expanded role. Since CBDC involves many aspects of central bank operations, the impact of its issuance on central bank internal operations will need to be considered. The real-time nature of CBDC will require adequately skilled resources and quick decision-making structures and response time within the central bank to address urgent issues, ensure business continuity and operational resilience. Even for operations that the central bank outsources, it will need to develop monitoring, oversight and risk management functions, evaluate

vendor and thirdparty risks, and establish systems to respond to potential CBDC disruptions that could result from operational failures, cyber breaches, or mistakes in execution. For the operations that the central bank does not outsource, redundant systems and business continuity will need to be established. It is important to factor in the impact of a 24/7/365 CBDC environment into the cost analysis including its implication for staffing, support for CBDC life cycle, and cyber-security. A strong commitment to the CBDC by the issuing central bank and government and trust in the currency will be critical for its acceptance. Just like with the issuance of regular physical currency, the central bank and the government will have to show strong commitment and readiness to take the steps needed to ensure that the CBDC is perceived as no less viable and stable than the physical currency by companies and the general public. Public confidence in economic and financial stability, in the value of the digital currency, and the central bank itself is essential. Real or perceived macro-economic or central bank related challenges that might undermine public confidence in the country's currency or the central bank, require a mix of different macro-economic policy measures and adjustments. Given the importance of underlying trust in a currency (analog or digital), policymakers efforts are better spent on trust-building policy measures before considering CBDC issuance.

3. CBDC design and operating models considerations

Central banks exploring CBDC issuance are considering different business models based on issuance, distribution, and transfer of CBDC to execute payments. All are thinking to retain the issuance function, but most are planning to outsource the distribution and payments components to private financial institutions. Some are focusing on running on a traditional centralized ledger, and some on a distributed ledger technology (DLT) platform in which the ledger is replicated and shared across several trusted participants within a private permissioned network. Balancing the need to ensure privacy of user identity and transaction data while meeting financial integrity standards is also an important design challenge. Some academic research advocates paying variable interest rates to CBDC holders to modulate demand or provide a new monetary policy instrument, but few central banks are considering doing so at the outset.

This chapter also reviews some of the processes, roles, and responsibilities that would need to be defined for creating, issuing, distributing, freezing, deactivating, and destroying CBDC. Central banks considering issuing CBDC are also discussing how to address up-front cybersecurity risks at the business, process, and infrastructure layers.

3.1. CBDC design considerations

Central banks that have made the decision to more seriously explore CBDC issuance are focusing on a common set of key design choices. These include the operating model, the platform (centralized versus decentralized database technology, or token-based), degree of anonymity/privacy, availability/limitations, and whether to pay interest. These design decisions, which will be discussed in more detail below, are driven by country-specific factors and balance the need to achieve the policy objectives that launched the exploration process and be attractive to users and merchants.

CBDC demand will ultimately be shaped by the level and trend in cash usage in a specific country, and incentives for stakeholders, including end-users and merchants. While access to CBDC might become more convenient than withdrawing cash from an automatic teller machines (ATM), it could only make CBDC like a bank debit card (Khiaonarong and Humphrey, 2019). If the CBDC is not interest-bearing, the only incentive to use CBDC is related to convenience of access and ease-of-use compared to cash. Cost-sharing and interoperability arrangements for point-of sale terminals could incentivize merchants to accept CBDC for the purchase of their products or services. Hence, CBDC demand may be weak in countries where cash usage is already very low, due to a preference for cash substitutes (cards, electronic money, mobile phone payments). Where cash usage is high, demand for CBDC could be stronger, due to a lack of cash substitutes.

The design thinking may also have to consider scenarios in which CBDC and other retail digital payment platforms drive cash out of common usage. There may be some people who cannot afford the necessary hardware and those with limited internet connectivity. For example, a survey found that 17 percent of the U.K. population would struggle to cope in a cashless society, comprised mostly of the poor and elderly (Access to Cash Review, 2019). Sweden dealt with this issue by passing legislation that came into effect January 1, 2020 that requires banks to provide adequate cash services, although it does not oblige merchants to accept cash (Sveriges Riksbank, 2020). Some of the ways for CBDC design features to accommodate some of these special needs are discussed below.

Central banks that are seriously exploring CBDC are using various techniques to weigh user perspectives into the design process. Optimal user satisfaction and usability can also be achieved through best practices in the product design processes such as user-centered design and user experience analysis. For the Bank of Canada, this has included basing analysis on surveys and focus groups of potential users (Bank of Canada, 2020, Huynh and others, 2020). For example, Huynh and others (2020) and Sun (2020) find that the most important features are low transaction costs, ease-of-use, affordability, and security perceptions, in order of decreasing importance. Involving users (including merchants) throughout the iterative design process promotes highly usable and accessible products that promote adoption, enhance robustness and may instill trust (Interaction Design Foundation, 2019).

According to the BoE (2020), there are a number of attributes that are key to CBDC success. The CBDC system should provide 24/7 payments, including offline under certain conditions, with no planned downtime and be able to recover quickly from operational disruption. It should be able to handle increased volumes if demand for CBDC payments increases significantly. The payment process should complete as quickly as possible, with certainty over completion. Users should be able to make real-time peer-to-peer payments, and the process should be intuitive, involving the minimum number of steps and required level of technical literacy. The CBDC payment system should be designed to minimize barriers to use from disabilities, and hardware or mobile data network access. In addition, users should expect privacy in lawful transactions, and the system should conform with all relevant privacy laws and regulations. The costs of making payments in CBDC should be clear to all users.

More broadly, the design decision-making process starts with a comprehensive review of the financial integrity, cyber-security, and privacy risks. Key issues like mitigation of the financial integrity and cyber-security risks are not after-thoughts. Instead they are drivers of architecture design decisions. The effective implementation of financial integrity measures is important in all cases. This entails ensuring compliance with the Financial Action Task Force (FATF) standard and taking effective action to mitigate money laundering and terrorist financing risks. Some aspects of the financial integrity considerations driving the design of CBDC are mentioned below. Cyber-security across different product layers forms the basis for a reliable and resilient CBDC payment system that is resistant to fraud and cyber-attacks as reviewed in-depth in Section

Incorporating flexibility into the architecture can support future-proofing the CBDC to account for changing user needs, regulations, and technology. A flexible design could reduce costs associated with required re-works or upgrades of the operating model or design features the central bank chooses or needs to adopt. This type of architecture could allow a controlled open architecture enabling third parties, such as payment system providers, to integrate or build their own services on top of the CBDC platform. Such an open architecture could facilitate a competitive market for CBDC-related payment services, although its design should ensure that there are no structural factors that could lead to winner-take-all market dynamics for such provision (BoE, 2020). It would also be useful if such payment systems were interoperable with each other and enable prospective cross-border CBDC payments.

3.2. A stocktaking framework: the CBDC Pyramid

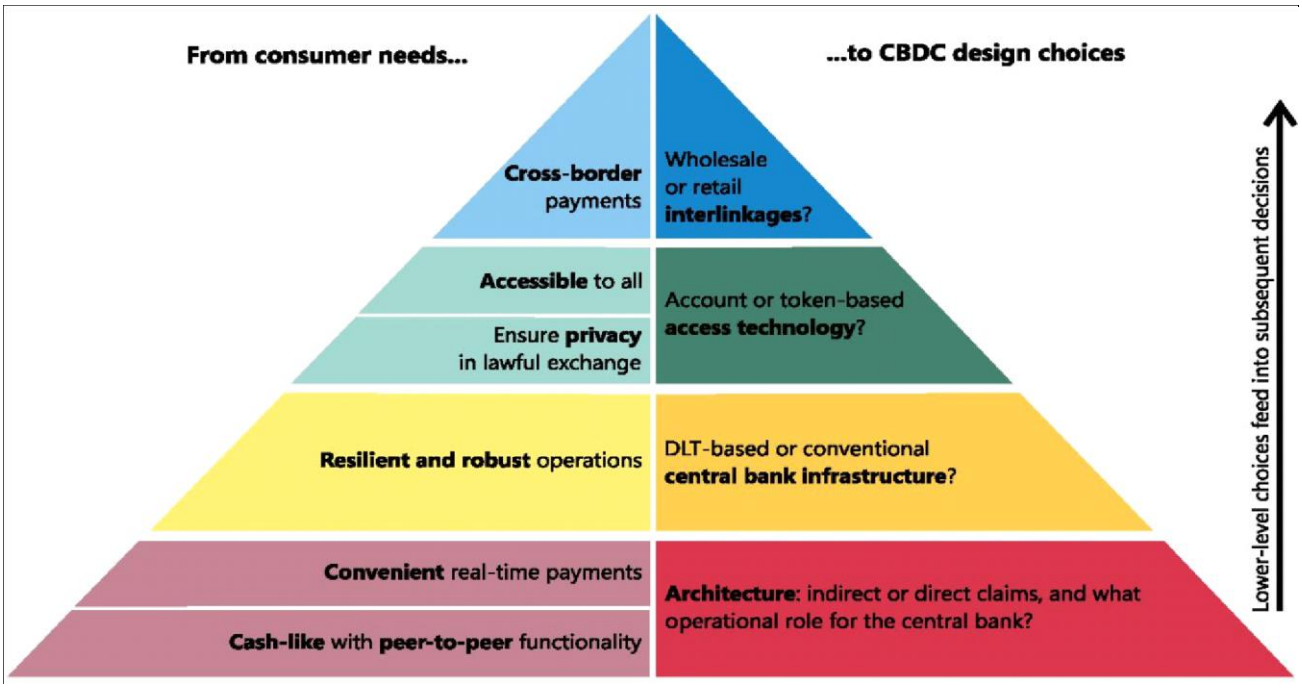
Approaches to CBDC design are heterogeneous across countries, requiring us to distil the main design choices and the dimensions along which national approaches differ. One way to classify design approaches is the "CBDC Pyramid" (see Auer and Böhme (2020) and Graph 11). This approach starts from the consumer needs that a retail CBDC could address, identifies associated technical design trade-offs, and then derives the design choices.

Current electronic retail money represents a claim on an intermediary, rather than functioning as the digital equivalent of cash. CBDCs could potentially provide a cash-like certainty for peer-to-peer payments. At the same time, they should offer convenience, resilience, accessibility, privacy and ease of use in cross-border payments. Different technical designs meet these criteria to varying degrees, with attendant technical trade-offs. We explore these issues. The aim is not to promote or highlight any particular approach, but to lay some groundwork for more systematic discussions.

The scheme of design choices forms a hierarchy in which the lower, initial layers represent design decisions that feed into subsequent, higher-level decisions. To reflect this hierarchy, the choices are displayed as a pyramid.

They start by introducing the four main design choices, as represented in the four layers of the CBDC pyramid. Then they assess the legal structure of claims and the operational roles of the central bank and private institutions in different CBDC architectures. In addition, they discuss the choice between distributed ledger technology (DLT) and a centrally controlled infrastructure. Also, they compare token-based systems and account-based systems. Before concluding, they assess how the development of CBDCs might reinforce current efforts to overhaul cross-border payments.

Graph 11 The CBDC pyramid



The CBDC pyramid maps consumer needs onto the associated design choices for the central bank. The left-hand side of the CBDC pyramid sets out the consumer needs and associated features that would make a CBDC useful. The pyramid's right-hand side lays out the associated trade-off – forming a hierarchy in which the lower layers represent design choices that feed into subsequent, higher-level decisions.

Source: Auer and Böhme (2020).

The focus of this approach is the “retail” aspect of CBDC; we ask what consumer needs a CBDC could address. Thus, they sketch the development of a CBDC through an approach that proceeds from consumer needs to design choices. The left-hand side of the CBDC pyramid (Graph 11) sets out such consumer needs and six associated features that would make a CBDC useful. Starting with cash-like peer-topeer usability, these features also comprise convenient real-time payments, payments security, privacy, wide accessibility and ease of use in cross-border payments. The pyramid’s right-hand side lays out the associated design choices.

The consumer’s prime need is that the CBDC embodies a cash-like claim on the central bank, ideally transferable in peer-to-peer settings. Today, even consumers who normally prefer to pay electronically are confident that, if an episode of financial turmoil were to threaten, they could shift their electronic money holdings into cash. This flight to cash has been seen in many crisis episodes, including recent ones. The main concern is that if, in the future, cash were no longer generally accepted, a severe financial crisis might create further havoc by disrupting day-today business and retail transactions. At the same time, consumers are unlikely to adopt a CBDC if it is less convenient to use than today’s electronic payments. Banks and payment service providers run sophisticated infrastructures that can handle peak demand, such as on Singles Day in China or Black Friday in the United States. And intermediaries help to smooth the flow of payments by taking on risk, for example during connectivity breaks or offline payments.

These two needs – cash-like safety and convenience of use – lead to the foundational design consideration for a CBDC (see lowest layer of pyramid in Graph 11): the choice of the operational architecture, and how it will balance the consumer’s demand for a cash-like claim on the central bank with the convenience that intermediaries confer on the payment system. The choice is shaped by two questions. Is the CBDC a direct claim on the central bank or is the claim indirect, via payment intermediaries? What is the operational role of the central bank and of private sector intermediaries in day-to-day payments?

Further, the consumer’s need for cash-like payment safety means that a CBDC must be secure not only from the insolvency or technical glitches of intermediaries, but also from outages at the central bank. The choice is whether to base this infrastructure on a conventional centrally controlled database or instead on DLT – technologies that differ in their efficiency and degree of protection from single points of failure. Importantly, this decision can only be made once the architecture has been decided upon, as DLT is only feasible for some operational setups. This is why the choice of infrastructure lies in the pyramid’s second layer. Two further consumer needs are easy, universal access and privacy by default. From a technical perspective, there is an underlying trade-off between privacy and ease of access on the one hand and ease of law enforcement on the other. The associated design choice – the pyramid’s third layer – is whether access to the CBDC is tied to an identity system (ie an account-based technology) or instead via cryptographic schemes that do not require identification (ie an access technology based on so-called digital tokens).

The final consumer need we consider is that CBDCs should also enable cross-border payments. At a design level, this could be arranged via technical connections at the wholesale level that are built on today’s systems. Alternatively, novel interlinkages could be envisaged at the retail level, ie allowing consumers to hold foreign digital currencies directly. Importantly, the means of implementing the latter option would depend on whether the CBDC was account- or token-based. This is why this design choice belongs in the top layer of the pyramid.

A. Architecture

The CBDC pyramid's bottom layer is the legal structure of claims and the respective operational roles of the central bank and private institutions in payments. Our analysis starts with an overview of possible technical architectures for CBDCs. In all three architectures shown in Graph 11, the central bank is, by definition, the only party issuing and redeeming CBDC. We note that all three architectures could be either account- or token-based, and might run on various infrastructures. These choices are discussed below.

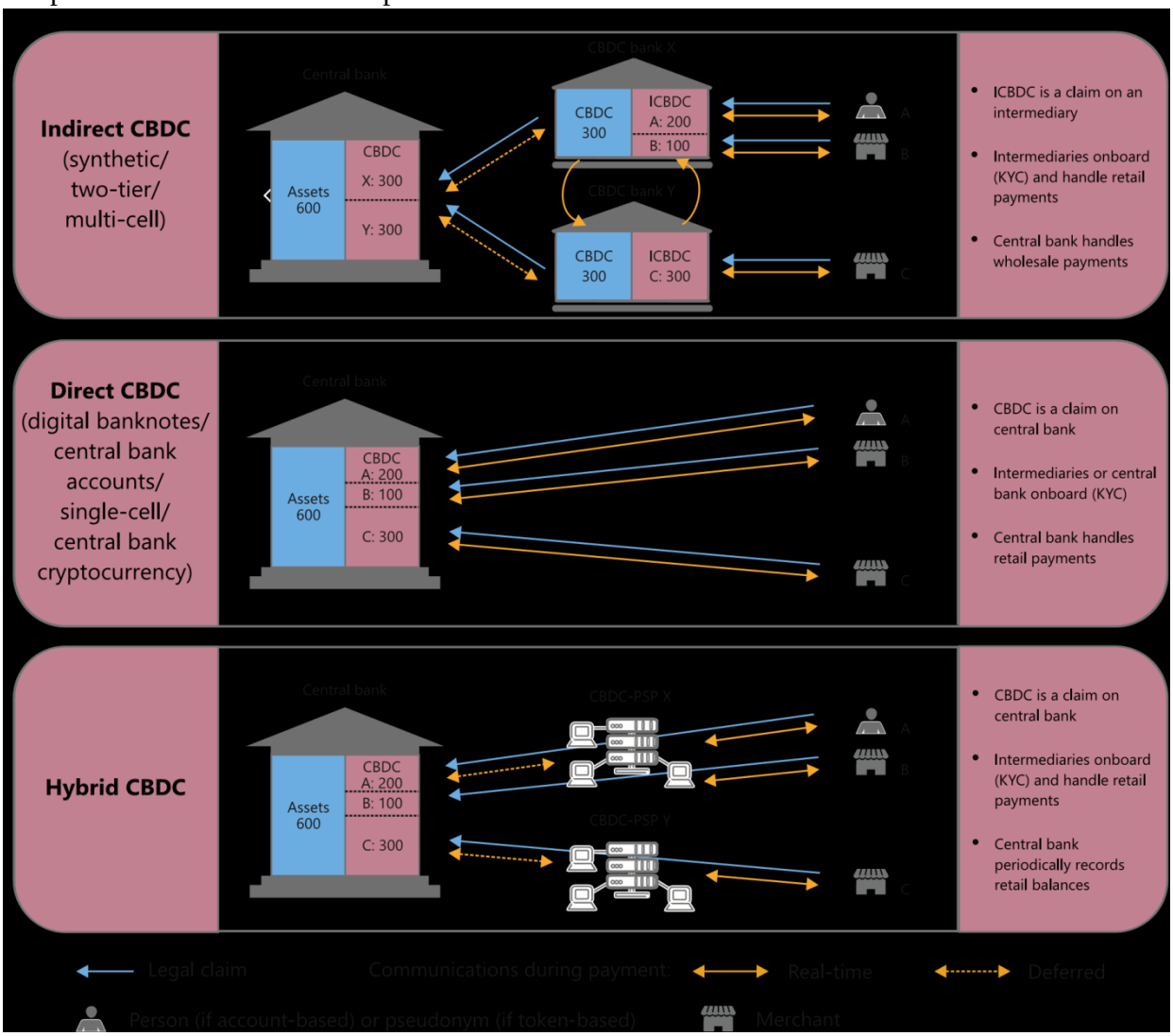
The key differences here are in the structure of legal claims and the record kept by the central bank. In the "indirect CBDC" model (Graph 12, top panel), the consumer has a claim on an intermediary, with the central bank keeping track only of wholesale accounts. In the "direct CBDC" model (centre panel), the CBDC represents a direct claim on the central bank, which keeps a record of all balances and updates it with every transaction. The "hybrid CBDC" model (bottom panel), is an intermediate solution providing for direct claims on the central bank while allowing intermediaries to handle payments.

Consider first the indirect CBDC model (top panel). This term is used by Kumhof and Noone (2018), and is equivalent to the "synthetic CBDC" in Adrian and Mancini-Griffoli (2019). This model is also known as the "two-tier CBDC" for its resemblance to the existing two-tier financial system; a token-based variant is proposed as a "multi-cell CBDC" in Ali (2018). For consumers, this type of CBDC is not a direct claim on the central bank. Instead, the intermediary (labelled "CBDC bank" in Graph 12 for its close resemblance to a narrow payment bank) is mandated to fully back each outstanding indirect CBDC-like liability to the consumer (labelled "ICBDC" in Graph 12) to retail consumers via its holding of actual CBDCs (or other central bank money) deposited at the central bank. Just as in today's system, intermediaries handle all communication with retail clients, net payments and send payment messages to other intermediaries and wholesale payment instructions to the central bank. The latter settles wholesale CBDC accounts with finality.

Besides offering the convenience of today's systems based on intermediaries, the indirect CBDC also relieves the central bank of the responsibility for dispute resolution, know-your-customer (KYC) and related services. But the downside is that the central bank keeps no record of individual claims (only the intermediaries do, whereas the central bank records only wholesale holdings) nor is there any cash-like direct proof of the claim. Thus, the central bank cannot honour claims from consumers without information from the intermediary. If the intermediary is under stress, determining the legitimate owner might involve a potentially lengthy and costly legal process with an uncertain outcome. This model's regulatory and supervisory issues, as well as those pertaining to deposit insurance, are hence similar to those of today's system.

Consider next a CBDC directly operated by the central bank, the direct CBDC architecture (centre panel). One version would comprise accounts managed by the central bank. Several private sector companies are developing token-based variants, or "digital banknotes". In this architecture, KYC and customer due diligence could be handled by the private sector or the central bank or another public sector institution. The central bank, however, would be the only institution handling payment services.

Graph 12 An overview of potential retail CBDC architectures



In all three architectures, the CBDC is issued only by the central bank. In the indirect CBDC architecture (top panel), this is done indirectly, and an ICBDC in the hands of consumers represents a claim on an intermediary. In the other two architectures, consumers have a direct claim on the central bank. In the direct CBDC model (centre panel), the central bank handles all payments in real time and thus keeps a record of all

Source: Auer and Böhme (2020).

The direct CBDC is attractive for its simplicity, as it eliminates dependence on intermediaries by doing away with them. However, this entails compromises in terms of the payment system's reliability, speed and efficiency. One aspect is that building and operating technical capacity on this scale is often viewed as being better undertaken by the private sector, as seen in today's credit card networks. Second, even if a central bank were to build the necessary technological capability, the resulting CBDC might be less attractive to consumers than today's retail payment systems. Electronic payments must deal with connectivity outages or offline payments, which involves risk-taking by intermediaries. Importantly, it is the customer relationship – based on KYC – that allows the intermediary to accept such risks. Unless a central bank were to take on responsibility for KYC and customer due diligence – which would require a massive expansion of operations, well beyond existing mandates – it would find it difficult to provide this service.

In addition to these two pure options, one can also envisage novel future solutions that merge elements of both the indirect and the direct CBDC. They label this third type of architecture the hybrid CBDC (bottom panel). In this model, a direct claim on the central bank is combined with a private sector messaging layer. Again, variations on this theme might include both token- and account-based ones. One key element of the hybrid CBDC architecture is the legal framework that underpins claims, keeps them segregated from the balance sheets of the payments service providers (PSPs), and allows for portability. If a PSP fails, holdings of the CBDC are not considered part of the PSP's estate available to creditors. The legal framework should also allow for portability in bulk, ie give the central bank the power to switch retail customer relationships from a failing PSP to a fully functional one. The second key element is the technical capability to enable the portability of holdings. Since the requirement is to sustain payments when one intermediary is under technical stress, the central bank must have the technical capability to restore retail balances. It thus retains a copy of all retail CBDC holdings, allowing it to transfer retail CBDC holdings from one PSP to another in the event of a technical failure.

The hybrid CBDC would have both advantages and disadvantages vis-à-vis the indirect or direct CBDC architectures. As an intermediate solution, it might offer better resilience than the indirect CBDC, but at the cost of a more complex to operate infrastructure for the central bank. On the other hand, the hybrid CBDC is still simpler to operate than a direct CBDC. As the central bank does not directly interact with retail users, it can concentrate on a limited number of core processes, while intermediaries handle other services including instant payment confirmation.

B. Infrastructure

What infrastructure might the different CBDC architectures require for the central bank, and how could they be implemented in the most resilient way? This choice, represented as the second tier of the CBDC pyramid, follows immediately after the decision on architecture because the infrastructure requirements for the central bank differ substantially across the three architectures shown in Graph 12.

For the central bank, the indirect CBDC implies loads similar to those of today's system. By contrast, the direct CBDC would require massive technological capabilities, as the central bank processes all transactions by itself, handling a volume of payments traffic comparable with that of today's credit or debit card operators. The hybrid CBDC architecture is more complex to operate than the indirect model, as the central bank does maintain retail balances. Nevertheless, it could be implemented at scale using today's technology and with a relatively modest infrastructure even in the world's largest currency areas.

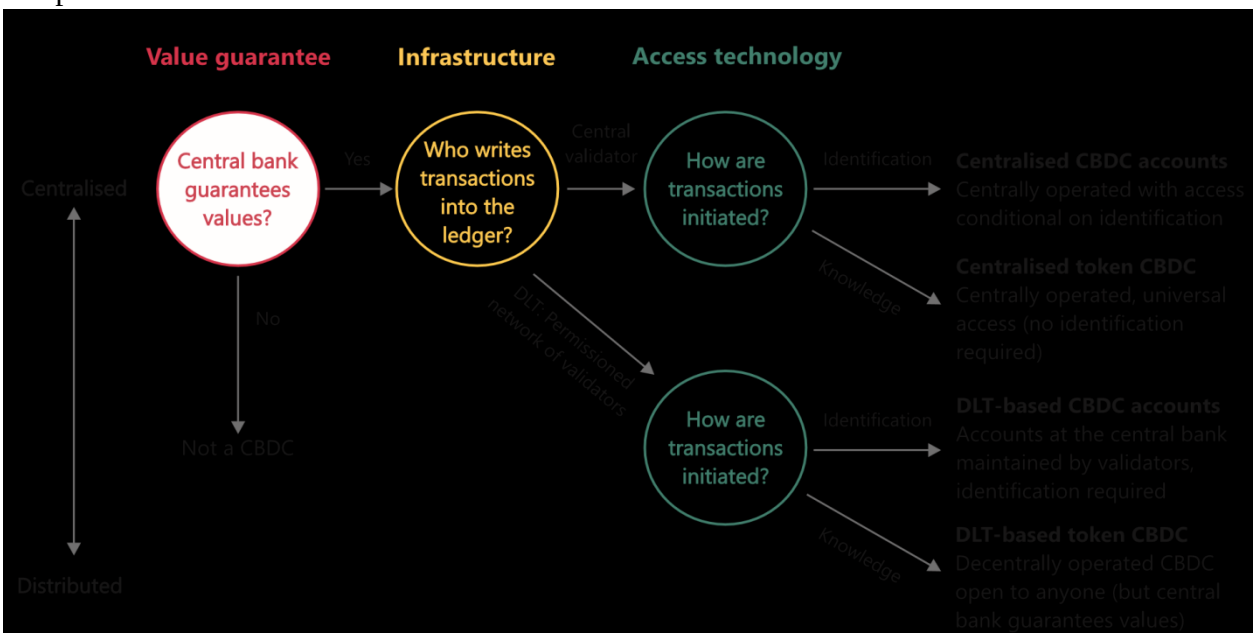
The infrastructure could be based on a conventional centrally controlled database, or on a novel distributed ledger. Graph 13 shows how elements of DLT could play a role in CBDC. The first DLT-related design choice hinges on whether the authority to update the database is centralised or delegated to a network of identified and vetted validators. Conventional and DLT-based infrastructures often store data multiple times and in physically separate locations. The main difference between them lies in how data are updated. In conventional databases, resilience is typically achieved by storing data over multiple physical nodes, which are controlled by one authoritative entity – the top node of a hierarchy. By contrast, in many DLT-based systems, the ledger is jointly managed by different entities in a decentralised manner and without such a top

node. Consequently, each update of the ledger has to be harmonised between the nodes of all entities (often using algorithms known as "consensus mechanisms"). This typically involves broadcasting and awaiting replies on multiple messages before a transaction can be added to the ledger with finality. The overhead needed to operate a consensus mechanism is the main reason why DLTs have lower transaction throughput than conventional architectures. Specifically, these limits imply that current DLT could not be used for the direct CBDC except in very small jurisdictions, given the probable volume of data throughput. However, DLT could be used for the indirect CBDC architecture, as the number of transactions in many wholesale payment systems is comparable with that handled by existing blockchain platforms, as also demonstrated in several wholesale CBDC experiments conducted by central banks (Bech, Hancock, Rice and Wadsworth (2020, in this issue)). Enterprise versions of DLT might also be feasible for the hybrid CBDC architecture.

When it comes to achieving resilience, neither a DLT-based system nor a conventional one has a clear-cut advantage. The vulnerabilities are simply different. The key vulnerability of a conventional architecture is the failure of the top node, for example via a targeted hacking attack. The key vulnerability of DLT is the consensus mechanism, which may be put under pressure, for example, by a denial-of-service type of attack. Overall, one needs to weigh carefully the costs and benefits of using DLT. This technology essentially outsources to external validators the authority to adjust claims on the central bank balance sheet, which is advantageous only if one trusts this network to operate more reliably than the central bank. Ongoing assessments of DLT-based proofs-of-concept tend to be negative (see box for a brief overview). Among the DLT-based projects that are still ongoing, it remains to be seen whether scalable implementations will actually rely on the technology.

That said, even if one decides against using DLT as the backbone infrastructure of a CBDC, one closely related technology might still be useful. Whether or not the infrastructure is based on DLT, access can still be based on cryptography rather than identification – Graph 13 outlines the possible combinations, and the box shows which combinations are being investigated by central banks.

Graph 13 Elements of decentralisation: DLT and token-based access



This graph maps out the four possible combinations of whether a CBDC infrastructure is distributed or centralised and whether access is based on identification (accounts) or cryptographic knowledge (digital tokens). All four combinations are possible for any CBDC architecture (indirect, direct or hybrid), but in the different architectures, the central bank and the private sector operate different parts of the respective infrastructure.

Source: Auer and Böhme (2020).

C. Access

Once the CBDC's architecture and infrastructure have been chosen, the question arises of how and to whom one should give access. This is the third layer of the CBDC pyramid.

A first option is to follow the conventional account model and tie ownership to an identity. Claims are represented in a database that records the value along with a reference to the identity, just as in a bank account. This has drawbacks in the case of CBDCs. In particular, it depends on "strong" identities for all account holders – schemes that map each individual to one and only one identifier across the entire payment system. Such schemes can present a challenge in some jurisdictions, thus impairing universal access.

The second option is for the central bank to honour claims solely when the CBDC user demonstrates knowledge of an encrypted value – an option sometimes referred to as digital tokens. One example is when the secret part of a public-private key pair is used to sign a message, a technology outlined by Auer, Böhme and Wadsworth (2020, in this issue).

A token-based system would ensure universal access – as anybody can obtain a digital signature – and it would offer good privacy by default. It would also allow the CBDC to interface with communication protocols, ie be the basis for micropayments in the internet of things. But the downsides are severe. One is the high risk of losing funds if end users fail to keep their private key

secret. Moreover, challenges would arise in designing an effective AML/CFT framework for such a system. Law enforcement authorities would run into difficulties when seeking to identify claim owners or follow money flows, just as with cash or bearer securities. Retail CBDCs would thus need additional safeguards if they followed this route.

They emphasise that the privacy dimension goes far beyond the question of whether the system is based on accounts or digital tokens. Transaction-level financial data reveal sensitive personal data. Hence, two aspects of privacy by default are crucial for the design of a CBDC. First is the amount of personal information transaction partners learn about each other when the system is operating normally. Second is the risk of large-scale breaches of data held by the system operator or intermediaries. Crucially, a CBDC that lets merchants collect and link payment data to customer profiles transforms the very nature of payments, from a simple exchange of value to the exchange of value for a bundle of data. Hence, a CBDC should preserve its users' privacy vis-à-vis their transaction partners, ie by default, transaction partners would interact via "unlikable pseudonyms", as envisaged in Chaum's (1985) pioneering work on electronic money. In such a system, a merchant is presented with a proof that the payment for a specific invoice has been made, but no information about the payee is revealed.

Depending on the involvement of intermediaries and the information they receive, technical safeguards for data protection need to be complemented by a legal framework restricting data collection by front-end applications, for example the smartphone payment app. Data loss is a further threat, given that payment systems are a prime target for cyber attacks. In this context, it must be noted that not all privacy-enhancing technologies are mature. For example, some so-called zero-knowledge proofs have already been shown to be vulnerable (Ruffing et al (2018)). The only sure-fire way to avoid losing much data is not to store it or to irrevocably delete old transactions as soon as possible. This principle of data minimisation is embodied in many data protection laws. Where this is not an option, aggregation and anonymisation must be relied on. A last resort is storage in physically separated (and offline) places guarded by legal access procedures.

D. Cross-border payments

Once a CBDC's configuration is clear, as well as how resident consumers can access it, the question arises whether it can be used only domestically or also elsewhere. This is the topmost layer of the CBDC pyramid.

The demand for seamless and inexpensive cross-border payments has grown in parallel with growth in international e-commerce, remittances and tourism. A CBDC might come with the same wholesale interlinkage options explored in the current system (Bech, Faruqui and Shirakami (2020, in this issue)).

Here, one noteworthy aspect is that a coordinated CBDC design effort could take a clean-slate perspective and incorporate these interlinkage options right from the start. This would represent a unique opportunity to facilitate easier cross-border payments (eg Carney (2019) and Cœuré (2019)), reducing inefficiencies and rents by shortening the payment value chain.

CBDCs would also permit novel retail interlinkages if they were to allow consumers to hold multiple currencies. In today's account-based system, a cross-border transaction is inseparably linked to a foreign exchange transaction. The intermediary processing the transaction can apply

extra fees and unfavourable exchange rates. In contrast, if consumers were given the option of buying foreign currency in advance, before spending it abroad, just as they can with cash, this would separate the payment from the foreign exchange transaction. In turn, this would open up the possibility of interfacing retail wallets directly with competitive foreign exchange markets.

Importantly, the scope for such retail interlinkages and their design would depend on the national access framework. If a national system is based on digital tokens, it will by default be accessible to foreign residents. If it is account-based, interoperability would be a design choice, one that could also be coordinated internationally.

3.3 CBDC Operating Model

Central banks can adopt a tiered approach to the CBDC operational model (Graph 14). In broad terms, in a single-tier model the central bank would perform all the tasks involved, from issuing the CBDC to running user wallets (Graph 14, Panel 1). In a multi-tier model, the central bank issues and redeems CBDC, but distribution and payment services would be delegated to the private sector (Panels 2 and 3). The operating model serves as a conceptual framework, the ultimate decision as to which model to adopt in practice will depend on country-specific circumstances. These might be related to the breadth and depth of its financial sector, the robustness of its financial integrity, financial market infrastructure standards and supervision, and resource and capacity constraints.

In a single-tier model, a CBDC transaction would resemble transactions with commercial banks, except accounts would be held with the central bank. A payer would log in to an account at the central bank—for example, through a web or mobile application—and request a transfer of funds to a recipient's account, also at the central bank. The central bank would ensure settlement by updating a master ledger, but only after verification of the payer's authority to use the account, enough funds, and authenticity of the payee's account. This mode gives central banks more control over the product design and implementation process. However, the central bank would need to assume a more active role in distribution and payment services, which may exceed the scope of its core mandate and capacity to manage the entire process. Moreover, central banks would directly compete with existing digital payment service providers aggravating disintermediation concerns. Conceptually, the single-tier model may be appropriate for a country with a well-resourced central bank in which the financial sector is extremely underdeveloped, so that there are no institutions to assume distribution and provision of payment services, as is the case in some low-income countries and small island states in the Pacific.

In a multi-tier or "platform" operating model the central bank issues the CBDC but outsources some or all the work of administering the accounts and payment services (Graph 15). However, CBDC remains the liability of the central bank and thus CBDC holders would not be exposed to default risk of the engaged payment service providers (PSPs). Auer and Böhme (2020) suggest that this risk can be mitigated by a legal framework that keeps user CBDC holdings segregated from PSP balance sheets so that the holdings are not considered part of a failed PSP's estate available to creditors. They also suggest that the legal framework should also give the central bank the power to switch user accounts in bulk from a failed PSP to a functional one. They also point out that, in order to do this expeditiously, the central bank would have to retain a copy of all retail CBDC holdings.

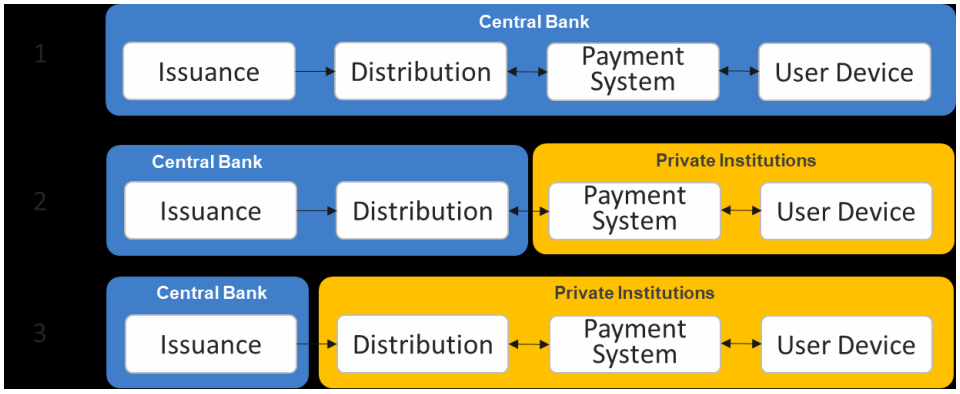
The multi-tier model is less disruptive than the single-tier one as financial institutions play their traditional roles in distribution and payment services (Panels 2 and 3 of Graph 14). In addition, this layered approach facilitates the integration of new types of consumer electronic devices without the need to alter the core of the system, and it supports the ability for third parties to build on top of the core (Shah and others, 2020). So far, this has been the favored model in central bank CBDC pilots and ruminations. For example, the People's Bank of China (PBOC) is proposing and piloting a "two-tier" model in which the central bank distributes CBDC to selected banks or payment platforms (distribution layer), who distribute CBDC to users through their payment system layers. (Fan, 2020).

Sun (2020) identifies the preconditions that could contribute to multi-tier CBDC model success based on an in-depth examination of Alipay's experience. First, the ecosystem should create economic incentives for PSPs, whether they be commercial banks or fintech firms, to participate in ways that serve central bank interests (making the CBDC broadly available to the public, across regions, etc.). There should be a cost-effective business model for such PSPs with enough revenues

from interest spreads, fees, and cross-subsidization, as well as controllable fixed and variable costs. Also, regulations should leave room for enough users to reach critical mass and incentivize network buildup while promoting PSP market competition. For example, regulations that encourage interoperability of competing payment systems to encourage new entrants and reduce concentration risk should take care not to adversely impact network build-up.

An approach not included in Graph 14 is for the central bank to allow stablecoin issuers and/or private-sector PSPs access to their reserve accounts (Kumhof and Noone, 2018, Adrian and Mancini-Griffoli, 2019a). Such stablecoin issuers and PSPs would have accounts at the central bank and cross-provider payments would be settled on the central bank's books. A sCBDC license would establish the conditions to widen access to central bank reserves. Such access would be given only under strict conditions and within the central bank's mandate, and appropriate regulations would protect reserve accounts in which the collateral is kept safe from issuer or other creditor bankruptcy.

Graph 14. Central Banks can Adopt Different Degrees of Responsibilities

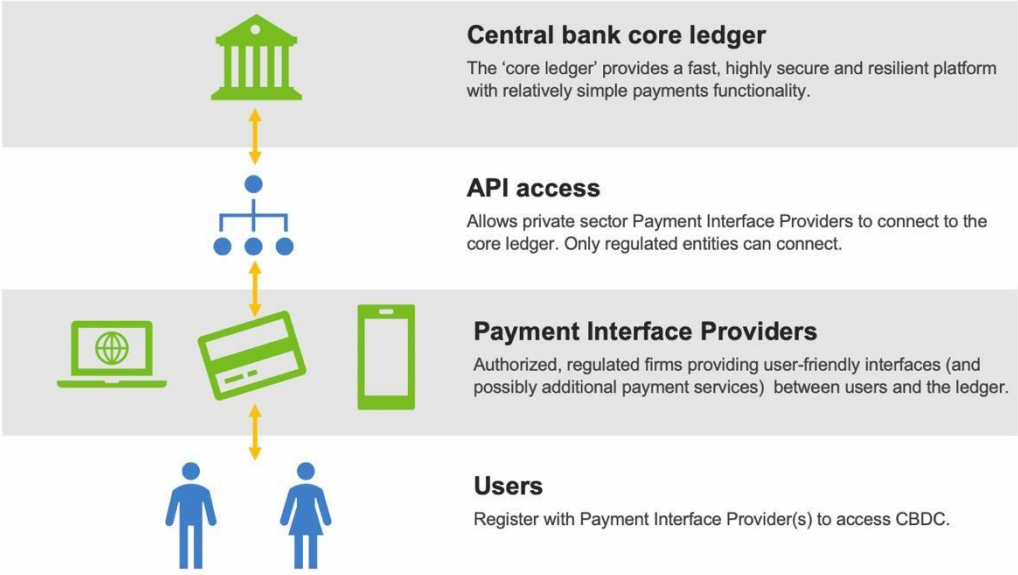


Source: Roberto Giori Company.

The choice of business model will also have important regulatory implications. In a one-tier ecosystem, the central bank alone would need to conform to any existing oversight and regulatory norms. In a multi-tier ecosystem, it would seem to be important that the engaged third parties are subjected to robust regulatory oversight and supervision, to protect customers and avoid risks to financial stability. Some aspects of these might bear some similarities to what crypto-asset and stablecoin operators, and custodians are subjected to. These would include market conduct, especially with respect to the entities that engage directly with customers.

In the case of sCBDC central banks could establish clear conditions to grant licenses to sCBDC issuers. This would include strict supervision and oversight by the central bank or other authority. For instance, selected providers would be responsible for appropriate customer screening, transaction monitoring and reporting in accordance with know-your-customer and anti-money-laundering regulation, as well as security of wallets and customer data. Control over who can receive and hold sCBDC may also prove helpful to limit its spread beyond a country's borders, for instance.

Graph 15. CBDC Platform Model



Source: BoE, 2020

3.4 Centralized Versus Decentralized Authority

Centralized authority is the most current CBDC architectures that experiments are focus on. However, decentralized or hybrid architectures, or even ledger-less offline peer-to-peer stored value platforms are possible. In the digital asset world, "decentralization" usually refers to the decentralization of authority to verify and commit transactions to the ledger. In a traditional centralized ledger (client-server model with no distributed components) transaction processing would entail the payor connecting to the central ledger keeper and initiating a funds transfer to the recipient's account. The ledger would be updated after the payor has been confirmed as the account holder who has enough funds to carry out the transaction. In a partially-decentralized authority model, the central bank could issue tokens to selected financial institutions that act either to safeguard funds or act as intermediaries. Intermediaries that are banks or licensed deposit-taking institutions would have additional flexibility, due to the fractional reserve system, as they are not expected to deliver the exact number of tokens as deposited by payors.

Alternatively, the ledger could be run on a distributed ledger technology (DLT) platform, in which the ledger is replicated and shared across several participants (U.K., 2016). With a DLT platform the central bank could have a centralized, decentralized or partially decentralized authority for verifying and/or committing transactions. The best-known public and decentralized DLT implementation is the technology underlying Bitcoin (Nakamoto, 2008). DLT platforms can be "public" (accessible by anyone) or restricted to a group of selected participants ("consortium" or "private"). Ledger integrity can be managed by a selected group of users ("permissioned") or by all network participants ("permissionless").

Permissioned DLT-based platforms appear to be better suited for retail CBDC due to governance and oversight considerations. Thus far, DLT-based CBDC experiments have focused on private permissioned (centralized authority) platforms as these allow for control over platform participants and their access to the platform, and role-based oversight and visibility of transactions. Private permissioned platforms also ensure that the central bank retains full control over money issuance and monetary policy. Permissionless platforms (with decentralized authority), on the other hand, fall short on scalability, and settlement finality, and financial integrity risk management.

The Committee on Payments and Market Infrastructures (CPMI) DLT analytical framework outlines key considerations for using such arrangements (BIS, 2017). These include processing speed, processing costs, reconciliation speed and transparency, credit and liquidity management costs, and potential smart contract applications. Safety issues include operational and cybersecurity risks, data management and protection, and governance will require more attention since the usage of a DLT-based CBDC will possibly expose more of the system due to the distributed nature of the DLT architecture.

An offline peer-to-peer stored value CBDC platform would take the form of a card or a mobile wallet app on which prepaid values are stored locally. Such a CBDC platform could be of interest for countries where large population segments are excluded from the formal financial sector or internet access. However, attempts to implement such systems during the 1990s via rechargeable smart cards like MintChip, Mondex and VisaCash failed to develop enough customer acceptance to become viable (Matonis, 2012; Bátiz-Lazo and Moretta, 2016). Also, at the time, computer scientists argued that such smartcards could never be strong enough to support existing currency schemes (Stalder, 2002). However, rapid technological progress since then is likely to have addressed some of these security concerns, such as the complex offline capable dynamic data

authentication/combined dynamic data authentication security features for stored value cards (Secure Technology Alliance, 2014).

-Some of the reasons why some central banks are considering DLT-based CBDC platforms

A key CBDC platform implementation decision is whether to run it on a decentralized (DLT) platform, rather than on a traditional centralized database. Central banks are still debating the advantages and disadvantages of each approach, assessing parameters such as security, resilience, performance or long-term tokenization strategy.

Centralized vs decentralized authority: The key question for central banks considering DLT-based CBDC, is whether the purported benefits of partially- or fully decentralizing the authority to adjust claims on their balance sheets outweigh the risks. These risks are discussed below, along with some of the ways that they can be mitigated. However, DLT-based ledger keeping was developed mainly to overcome a lack of trust in a central authority, so there may be a tension between the idea of DLT-based CBDC and some of the central tenets of central banking and central bank money.

Security: Most central banks already have a mature security posture to manage centralized databases. Their internal systems are typically secured via multiple protection layers, such as audits, middle-tier services, authentication/authorization and firewalls. CBDC projects would open up these centralized databases, which brings new security concerns. DLT-based platforms keep multiple copies of databases across a number of participants or “nodes” which makes it more difficult for malicious attempts to alter the data. Most central banks considering issuing DLT-based CBDC are opting for “permissioned” platform, which limit the ability to update databases to themselves and selected financial institutions.

Resilience: Neither centralized platforms nor DLT-based CBDC offer complete resilience. Both face cybersecurity risks, hardware issues, power or network outages or cloud service interruptions. The DLT architecture may offer enhanced resiliency by reducing single points of failure. Furthermore, potential data loss at one node can be recovered through replication of the ledger from other nodes when it comes back online. Despite their resilience, DLT-based platforms may experience attacks against the network or applications layer which includes the consensus mechanism by which database updates are approved (Auer and Böhme, 2020).

Performance: Centralized platforms usually process transactions more quickly. For reference, the VISA network can theoretically handle up to 65,000 transactions per second (TPS), while private DLT platforms are slower at around 20 TPS. Rapid technological progress is expected to address this issue with networks provided by new entrants achieving up to 10,000 TPS (Mearian, 2019).

Tokenization in this context involves the recording of assets, properties, rights or currencies on a DLT platform. Financial ecosystems are expected to use asset tokenization to facilitate delivery versus payment (Accenture, 2019). It may be complicated to implement digital assets, with properties such as double-spending prevention or immutability, on “legacy” centralized systems without essentially recreating the equivalent of a DLT architecture.

3.5 Financial Integrity, Privacy and Transparency

Financial Action Task Force (FATF) has issued a set of standards that countries should implement on a risk basis to prevent money laundering and terrorist financing that will impact CBDC design considerations. These include requirements on financial institutions, virtual asset service providers and designated non-financial businesses and professions to implement customer due diligence measures, monitor transactions and report suspicious transactions, amongst other obligations. In most instances, this means that some information on CBDC users would likely need to be collected, transmitted and, when necessary, made available to competent authorities. Some form of proportionality would likely be applied as well for instance in cases where the risk of money laundering and terrorist financing is low, such as in occasional, low value transactions.

Further guidance on the balance between digital developments and financial system integrity is to be expected. On November 4, 2019, the FATF published its draft guidance on digital identity (FATF, 2019). The document seeks input from the financial sector and other stakeholders on the FATF's guidance on determining "how digital ID systems can be used to conduct certain elements of customer due diligence (CDD) under FATF Recommendation 10." The FATF stresses that "the growth in digital financial transactions requires a better understanding of how individuals are being identified and verified in the world of digital financial services."

Central banks have been exploring different options to strike the right balance between financial integrity, privacy and transparency requirements in their CBDC design thinking. Financial integrity could be maintained if strict limits are placed on the size of anonymous CBDC transactions and holdings. The European Central Bank (ECB) tested out "anonymity vouchers" in a Proof of Concept (PoC). These vouchers allow users to anonymously transfer a limited amount of CBDC over a defined period whereby a user's identity and transaction history cannot be seen by the central bank or intermediaries other than those chosen by the user. The enforcement of limits on anonymous electronic transactions is automated, and additional checks are delegated to a financial integrity authority (ECB, 2019). China's Digital Currency Electronic Payment (DCEP) platform is expected to include "controllable or voluntary anonymity" in its design. Although the PBOC will be privy to the identity of its users as they are required to provide their real identities when they first sign up to preempt tax evasion and money laundering, users will have the ability to control what information they expose to counterparties that they are dealing with (Qian, 2018). Complete third-party anonymity would jeopardize financial integrity, so the PBOC's proposed solution aims to keep the degree of anonymity within a controllable range by requiring the disclosure of transaction data only to the central bank (Fan, 2020). Some stablecoin solutions, which could be applied to CBDC as well, require compliance with Know-Your-Customer (KYC) requirements notably at the point when coins are exchanged for bank account holdings or vice versa. Intermediate users in peer-to-peer transactions of CBDC, on the other hand, would not need to be identified (Lewis, 2019). However, in the case of a successful CBDC implementation, the frequency of exchanges would be low as most transactions are expected to be peer-to-peer. DLT-based CBDC could include other privacy enhancing capabilities such rotating public keys, zero-knowledge proof and enclave computing (ECB, 2019).

Whatever design is chosen, an important consideration is how to accommodate the implementation of effective financial integrity measures. Allowing some level of anonymity in the CBDC design would foster usability, provide a more ubiquitous access to CBDC, and assuage data privacy concerns. However, true anonymity for any digital form of money will be very difficult to achieve

and most of the existing CBDC solutions could be regarded “pseudo-anonymous” at best. Even when no identification is required at registration, such is the case for ECB anonymity vouchers, transactional metadata can be used to devise user identities based on knowledge graphs. Ensuring adequate data privacy protection and compliance with financial integrity standards is a delicate political decision that involves a collaborative approach by legislators, regulators as well as policy and decision-makers across different line ministries.

There are trade-offs between satisfying legitimate user preferences for privacy and mitigating risks to financial integrity for policymakers. A fully transparent CBDC, where information on its users and all their transactions is accessible by relevant authorities, has oversight benefits (as it would likely facilitate detection, supervision, monitoring and law enforcement efforts), but could be less appealing to legitimate users as an alternative to the anonymity of cash. CBDC that are subject to full identity authentication might disadvantage citizens without access to identification, which could impair financial inclusion efforts. The complete lack of anonymity in financial transactions could potentially infringe on the right to be forgotten stipulated in legislation such as the European Union General Data Protection Regulation (GDPR). Moreover, it could aggravate privacy advocates’ concerns of digital surveillance and CBDC being used to carry out sanctioning measures against citizens, especially in cases of already low trust in public institutions. Conversely, a CBDC that is fully opaque regarding transactions and users could infringe on financial system integrity and consumer protection, introducing significant money laundering and terrorist financing risks, as illicit transactions and fraud would go undetected. This risk would likely be greater than in the case of cash, notably due to the ease and speed with which transactions can be performed and their potential global reach.

The current financial privacy debate spans across those in favor of full anonymity to safeguard citizens’ rights to privacy and those in favor of fully transparent financial transactions and stringent identification requirements. Reasons for anonymity include reducing the risk of identity theft and spamming, and of being stalked or robbed (Kahn and others, 2005). A low-cost privacy-preserving method of payment could also reduce the impact of negative externalities involved with sharing payments data as data revealed by one person can be used to make interference about the purchasing habits of others (Garratt and others, 2019). Bech and Garratt (2017) specify two types of financial anonymity – counterparty and third-party anonymity. Counterparty anonymity means that a payor initiating a payment need not reveal their identity to the recipient. The more stringent thirdparty anonymity means that the payor is invisible to all other parties, including the entity that is running the payment system. Some argue that, because third-party anonymity facilitates criminal activity, terrorist financing or money laundering, it should not be allowed (Bech and Garratt, 2017). However, some users may regard a lack of third-party anonymity as revealing too much information about users’ private activities (Chaum, 1983), while other studies cast doubt on how highly consumers value anonymity (Bech and Garratt, 2017).

4. Considerations on changes to structural bank intermediation

This section investigates the implications of a digital euro on bank balance sheets, providing some preliminary insights into the possible impact of rolling out a CBDC on bank intermediation. As a digital euro can potentially substitute for a portion of bank deposits, the framework distinguishes between four different adjustment channels. The balance sheet mechanics show that – except when the introduction of a digital euro is matched by a reduction in excess reserves or banknotes – the central bank would need to inject liquidity to accommodate the demand for the CBDC.

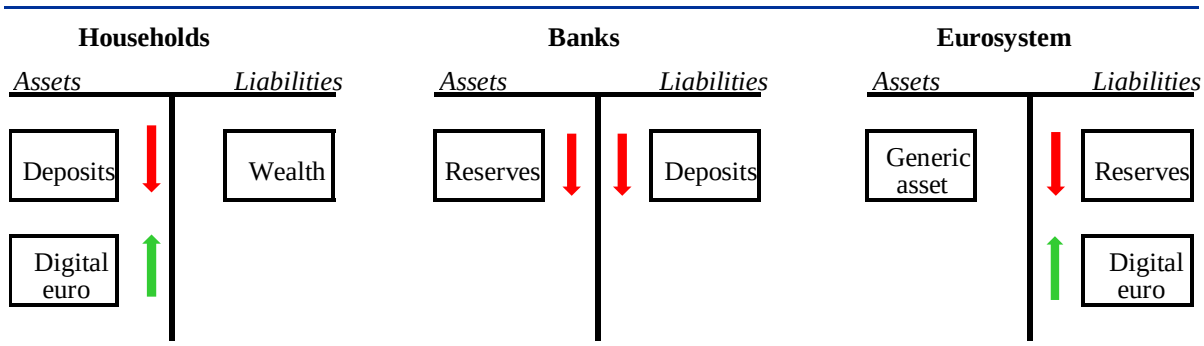
The following analysis assumes that liquidity regulation and collateral constraints, among other frictions, are not binding, allowing the central bank to fully offset the effects of CBDC demand on the banking sector (Brunnermeier and Niepelt (2019) and Fernández-Villaverde et al. (2020)). This conclusion corresponds to the equivalence results that have been offered in the academic literature. While the existence of frictions, such as collateral and liquidity constraints, modifies these conclusions, available data and estimates of the impact of digital euro news on banks' stock prices suggest that the effects of a digital euro on the intermediation capacity of the euro area banking sector would likely be manageable. Importantly, heterogeneities within the banking system imply that the impact of a digital euro can vary significantly across credit institutions.

4.1 A stylised balance sheet approach

Balance sheet relations provide a consistent framework to analyse how the introduction of a digital euro would alter banks' balance sheet positions and affect banks' intermediation capacity. The mechanisms through which a digital euro is put into circulation, with banks' reserves at the central bank as the immediate counter-position, provide an intuitive starting point for this analysis. In resemblance to banknotes, it is assumed that banks intermediate the distribution of digital euro. This implies that banks must first obtain the digital euro from the Eurosystem and then "resell" it to the final holder. In doing so, banks pay the Eurosystem with reserves and debit the bank account of the final holder (Graph 16). While both final holders and banks could obtain digital euro in exchange for banknotes, beyond this channel, banks need to hold reserves to put digital euro in circulation.

Graph 16

The mechanics of putting digital euro into circulation



Source: ECB

There are four channels through which banks' balance sheets would adjust to the introduction of a digital euro. Specifically, in order to put digital euro in circulation, banks can: (I) return (or intermediate the return of) banknotes to the Eurosystem. Alternatively, they can (II) reduce their stock of excess reserves with the Eurosystem. Banks can also obtain additional reserves via (III) increasing their borrowing from the Eurosystem, or (IV) seling assets to the Eurosystem. From the Eurosystem's viewpoint, options I and II represent a swap from existing Eurosystem liabilities (bank reserves or banknotes) to digital euro, while Options III and IV represent an asset expansion in a situation in which the issuance of digital euro is larger than the reduction in reserves or banknotes. All adjustment options strictly linked to the introduction of a digital euro require the involvement of the Eurosystem balance sheet.

Which of these adjustment strategies banks will actually use depends on the preferences of customers, the choices of banks and the policies of the Eurosystem. Depending on the size of the deposit substitution, banks, owing to profitability and regulatory considerations, may have a preference for a specific adjustment course and may also engage in additional re-optimisations of their balance sheets. Finally, the Eurosystem plays a key role: first, it influences the size of its balance sheet by steering the quantity of digital euro in circulation through the attractiveness of holding digital euro, or by imposing hard limits; second, the Eurosystem decides on the composition of its assets and its collateral policy.

4.1.1 Adjustment channels

This subsection considers the adjustment mechanisms linked to the introduction of CBDC. These channels are not exclusive and can operate in parallel to each other. However, to facilitate the exposition, each channel is investigated separately, under the assumption that there are no market frictions and that regulatory constraints are not binding. The role of constraints and frictions in the adjustment process is discussed in Section 4.1.3 and throughout the rest of Section 4.

Channel I: Banknotes for digital euro

Replacing banknotes with digital euro amounts to a swap between two types of Eurosystem liabilities, with no implications for banks' balance sheets. Banks would act merely as distributing agents: money holders would return banknotes to the Eurosystem and exchange them for digital euro, leaving other Eurosystem assets and liabilities untouched.

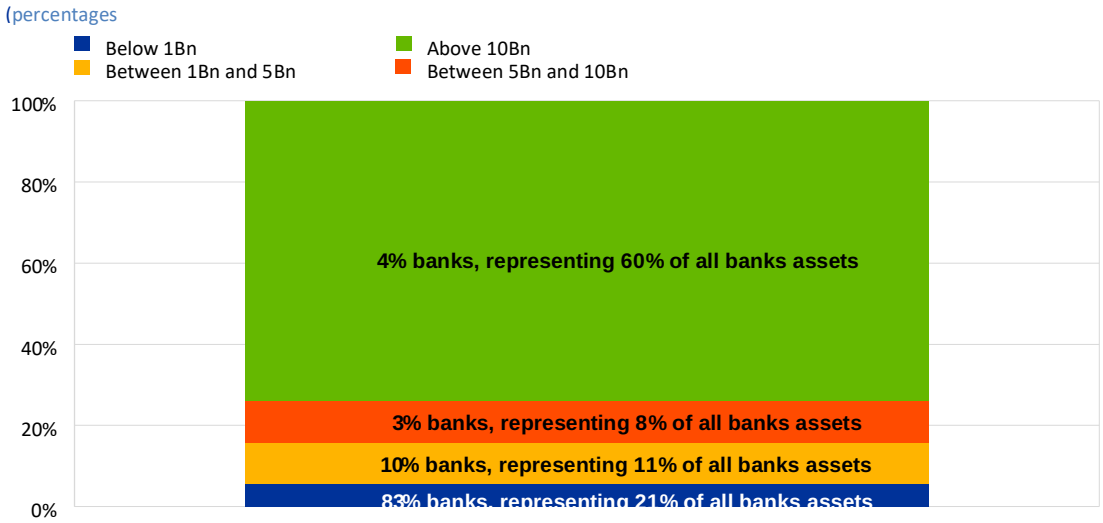
Channel II: Existing bank reserves for digital euro

Banks reduce their holdings of reserves with the Eurosystem in an amount equal to the deposit loss, without further impacting other items on the asset side of their balance sheets. Reserves decline as banks use them to acquire digital euro from the Eurosystem in order to pass it on to their customers in exchange for deposits. Other bank assets remain unchanged. For the Eurosystem, this option represents a swap in its liabilities, with digital euro covering the reduction in bank reserves (Graph 16).

On the individual level, banks would likely need to engage in interbank borrowing given that customers' demand for digital euro may differ across banks and reserves are distributed unequally in the market. In the third quarter of 2021, 4% of euro area banks, representing 60% of the main assets of the banking sector, accumulated more than 74% of excess reserves in the euro area (Graph 17).

Graph 17

Distribution of excess reserves across euro area banks



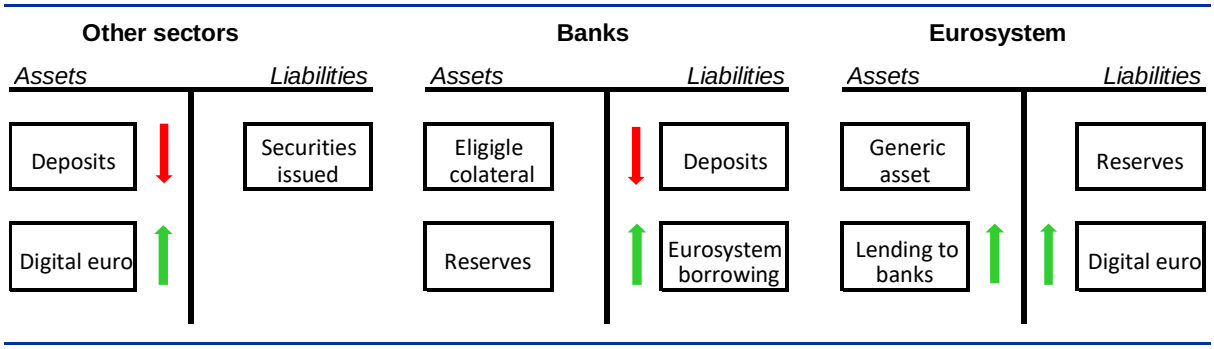
Source: ECB and iBSI.

Chanel III: Central bank borrowing for digital euro

Banks replace the deposits transformed into digital euro with increased Eurosystem borrowing, with no further changes in other balance sheet items. Either because they lack the necessary amount of reserves or because they prefer to keep a certain amount of them, banks may be willing to borrow additional reserves from the Eurosystem to meet their customers' demand for digital euro. In such a case, the Eurosystem would instantaneously recycle back to banks the funding lost because of the transformation of deposits into digital euro. This results in a lengthening of the Eurosystem's balance sheet equal in size to the deposit substitution, which avoids a contraction in bank credit to the economy (Graph 18).

Graph 18

Banks increase their borrowing from the Eurosystem



Source: ECB

Channel IV: Assets for digital euro

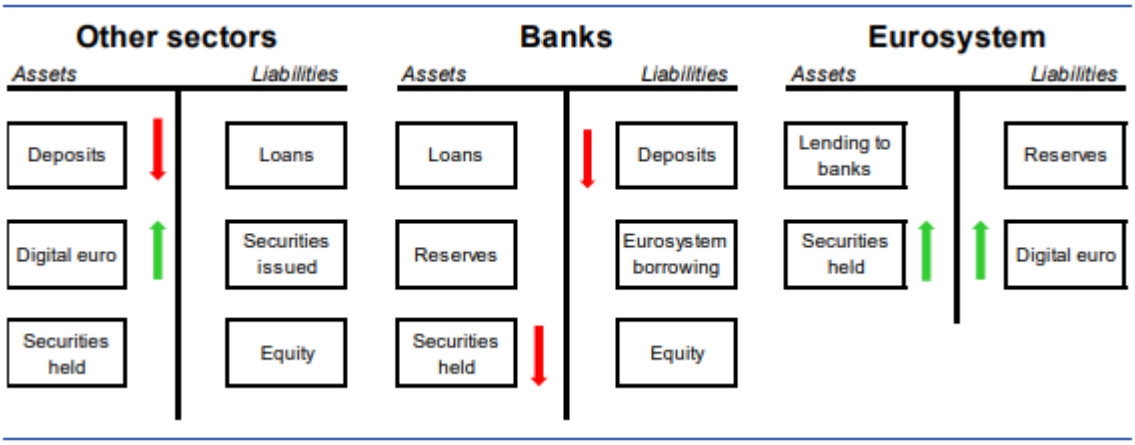
As an alternative to borrowing, banks can also obtain reserves by selling assets to the Eurosystem, either from their own portfolios or on behalf of their customers. When acquiring assets, the Eurosystem pays the seller with reserves. Banks can then use the newly created reserves to acquire from the Eurosystem the digital euro demanded by their customers. When selling assets to the Eurosystem, banks can do so: (IV.a) from their own portfolio, or (IV.b) on behalf of their customers, the latter resulting in the creation of new customer deposits. Option IV.a leaves the amount of money in the hands of the public unchanged (as, from the money holders' perspective, the decrease in deposits is offset by the increase in CBDC), while Option IV.b results in an increase in the volume of money in the hands of the public, as it entails the creation of new customer deposits, which adds to the issuance of CBDC.

Option IV.a: Banks sell part of their own assets to the Eurosystem

Banks' deposit loss is matched by a reduction in banks' assets. Banks sell assets to the Eurosystem to obtain reserves to acquire the digital euro demanded by their customers; customers receive the digital euro in exchange for deposits. Therefore, putting digital euro in circulation via this channel results in a simultaneous contraction of bank deposits and assets. The contraction in banks' balance sheet is commensurate to the expansion of the Eurosystem's balance sheet, leaving the balance sheet size of the MFI sector unchanged (Graph 19), as well as the amount of money in the hands of the public.

Graph 19

Banks sell part of their own assets to the Eurosystem



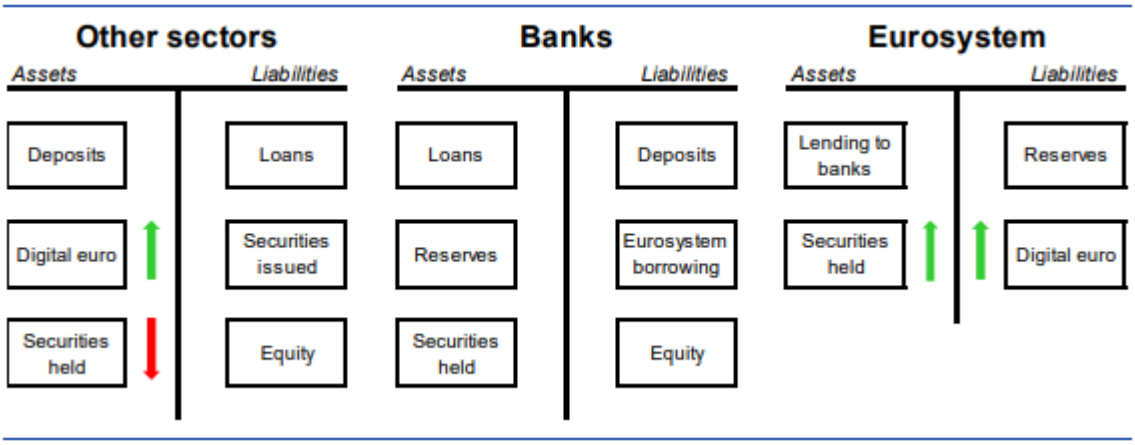
Source: ECB

Option IV.b: Banks sell assets to the Eurosystem on behalf of other sectors

While the volume of bank deposits in this option is not affected by the issuance of digital euro, the overall amount of money in the hands of the public increases. As the first step of this option, a bank acquires an asset from another sector. In doing so, it typically pays for it by crediting a deposit account held by the seller, hence creating deposits. Subsequently, the bank sells the asset to the Eurosystem, thereby obtaining the reserves needed to acquire the digital euro demanded by its customers. If this is the only channel to put digital euro in circulation, the aggregate volume of bank deposits is not affected: the loss of deposits caused by those customers transforming their deposits into digital euro is fully offset by the increase in deposit balances of those investors selling assets to the banks (Graph 20).

Graph 20

The Eurosystem purchases assets from other sectors via banks



Source: ECB

4.1.2 The role of frictions and constraints in the adjustment process

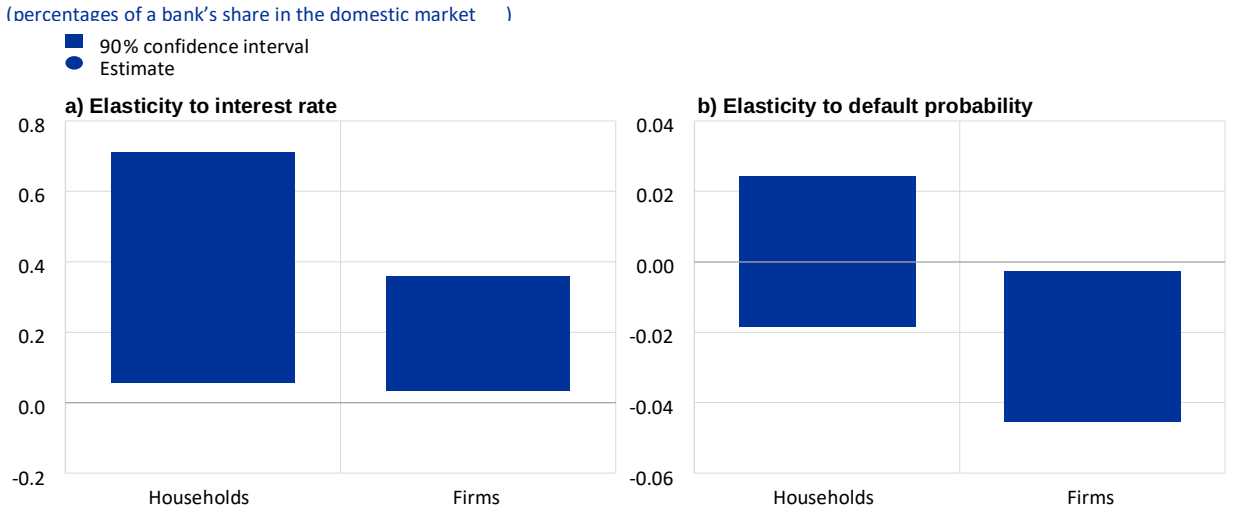
The stylised balance sheet analysis corroborates results in the literature that in a completely frictionless economy, the introduction of a digital euro would be neutral for banks' intermediation capacity.(Brunnermeier and Niepelt (2019); Kumhof and Noone (2021)) From an accounting point of view, this is predicated on the fact that to put digital euro into circulation, the Eurosystem's balance sheet will also adjust, preventing the emergence of a funding gap. With perfect interbank markets, this result extends from the aggregate to the individual bank level, as banks that find themselves in the need to borrow excess reserves to meet their customers' demand for digital euro would not face any restrictions to obtain liquidity from other banks.

However, the presence of constraints and frictions, such as collateral requirements or liquidity regulation, modifies this outcome. For instance, based on the regularities observed over the past decade, a reduction in excess liquidity coupled with an increase in interbank borrowing (Option II) is likely to lead to higher interest rates in the money market because banks that are short in reserves are typically also facing higher risk premia. A lack of perfect substitutability between banks' funding sources, e.g. if the conditions of Eurosystem borrowing (Option III) do not fully replicate those of bank deposits, may also affect bank funding costs. Frictions and constraints linked to an increased level of Eurosystem borrowing (e.g. stigma, collateral scarcity or binding liquidity regulation) may affect banks' willingness to supply credit. General equilibrium effects should also be considered.

At the same time, not all departures from the frictionless economy may cause a negative impact on banks' intermediation capacity; some may contain it. For instance, depositors' responses to the risk-return trade-off of deposits would decrease the substitutability between retail deposits and the digital euro (Graph 21). A digital euro offers to some extent similar services to retail deposits but with a lower risk. Yet, for the same reason insured deposits, especially if backed by strong sovereigns, may be less sensitive to substitution into digital euro in normal times. As for uninsured deposits, interest rates earned by depositors generally already reflect inherent bank-specific risks. Therefore, a positive remuneration of deposits, capturing the relevant risk-return trade-off, can be expected to make those deposits less prone to substitution than what might be suggested by aggregate graphs. Additional stickiness in deposits may derive from relationship lending, whereby depositors would be more hesitant to terminate a deposit account with a bank with which they may also maintain a credit relation.

Graph 21

Elasticity of deposits to deposit rates and banks' default probability



Sources: ECB (individual balance sheet items (iBSI) data) and ECB calculations.

Nevertheless, frictions and regulatory constraints are pervasive in the current financial system and need to be accounted for. Consequently, when evaluating the conditions under which a potential introduction of a digital euro could take place, a careful assessment of such frictions and the implications that they would have on banks' funding options is required.

4.2 Simulated bank responses to CBDC demand under liquidity risk preferences and regulation

To meet customer demand for CBDC, individual banks face a trade-off between balancing their profitability and liquidity risks. To exchange retail deposits with CBDC, a bank can either use its own reserves or acquire new reserves via central bank funding, or market funding, in particular repo instruments with a short- (ST), medium- (MT), or long-term (LT) maturity. When choosing between these options, a bank faces a trade-off: secured funding is generally cheaper than unsecured funding and short-term funding is cheaper than long-term funding.

However, using its own reserves or obtaining funding secured by high quality liquid assets (HQLA) negatively impacts banks' liquidity positions. Drawing down or encumbering its stock of HQLA depletes the pool of assets that can be liquidated in times of need. Furthermore, using short- rather than long-term funding increases roll-over risk in times of stress.

The monetary policy stance prevailing at the time the digital euro is introduced further influences these trade-offs. While acknowledging the uncertainty regarding the future macroeconomic environment and central bank response, the analysis presented here focuses on bank balance sheets and their potential adjustment. The analysis uses bank-specific data regarding the stock of deposits, available collateral, reserves, and liquidity buffers as of Q3 2021 for the euro area's significant institutions and those less significant institutions that report excess reserves, collateral, and liquidity ratios. Abstracting from the current extraordinary central bank response to the pandemic crisis, we assume that the prices of short- and medium-term market funding are above the deposit facility rate and below the main refinancing operations (MRO) rate. The monetary policy stance at the time of CBDC introduction will determine the DFR and MRO rates and conditionalities and influence market prices.

A bank's reaction to CBDC demand is simulated using a constrained optimisation model in which a bank is expected to minimise its funding costs, subject to a number of constraints. First, a liquidity constraint: it is assumed that a bank wants to hold a voluntary buffer above its regulatory requirement which is at least as high as half of its current liquidity buffer. To note, unsecured long-term funding and long-term central bank funding collateralised with non-HQLA, such as additional credit claims (ACCs), do not have a negative impact on liquidity ratios. Second, a collateral constraint: secured funding from the repo market must be secured by HQLA. The collateral constraint does not apply to central bank funding as it can also be secured by non-HQLA collateral such as ACCs. Third, banks face two types of reserve constraints: each bank faces individual reserve constraints and the banking sector as a whole is constrained by the amount of reserves in the system. If a bank uses the reserves borrowed from another bank to meet CBDC demand, the amount of available reserves in the system falls. In the simulation, banks will resort to the cheapest funding option unless they are faced with a constraint. Therefore, banks that are either liquidity or collateral constrained must resort to unsecured or non-HQLA secured funding. In case the current stock of reserves available in the system is insufficient to meet CBDC demand, or in other words when banks cannot obtain sufficient reserves in the interbank market, banks can obtain additional reserves from the central bank: via MROs if they are not NSFR constrained and via special long-term central bank funding if they are.

The simulation suggests that for low levels of CBDC demand, most banks will be able to meet customers' demand for CBDC by using their own reserves without excessively dipping into their voluntary unencumbered HQLA buffer.

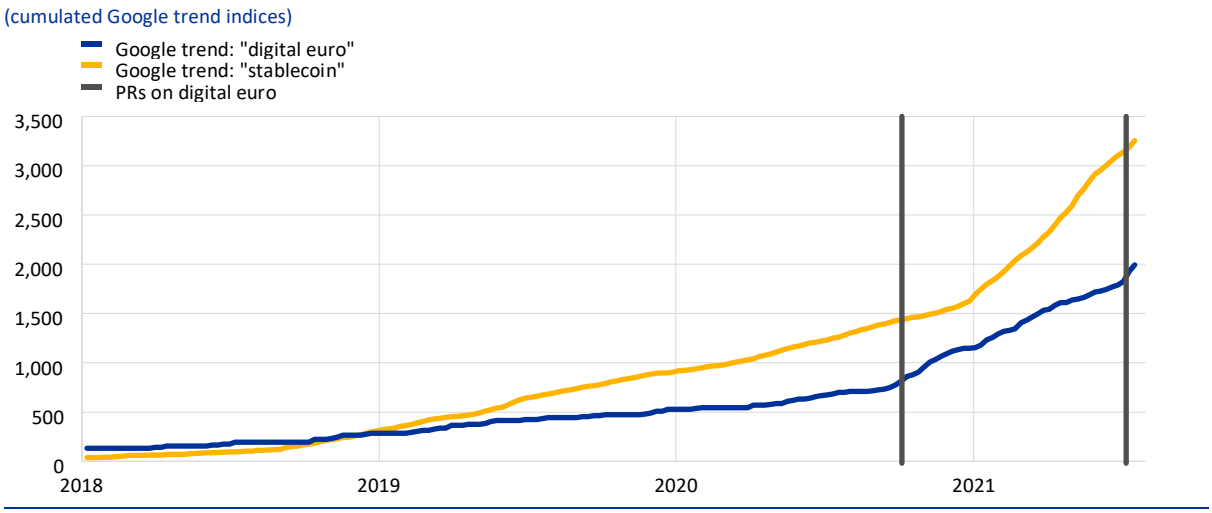
To meet high levels of CBDC demand, banks have to rely on central bank funding provided against non-HQLA collateral. If a digital euro was introduced now in the presence of such high reserves, most banks could accommodate CBDC demand as anticipated in scenarios A and C using their own reserves, under assumed liquidity preferences. A bank balance sheet simulation model suggests that most banks could accommodate CBDC demand using their own reserves with low CBDC demand. However, it suggests that bank-level heterogeneity with respect to liquidity preferences and reserve and collateral availability could result in diverging bank responses to CBDC. Furthermore, liquidity regulation or voluntary liquidity buffers reduce the total amount of reserves that banks are willing to use or sell to facilitate CBDC conversion. Thus, the central bank should be prepared to provide non-HQLA long-term lending (>1 year) or non-HQLA purchases to ensure that banks do not have to go below their preferred liquidity ratios to meet CBDC demand.

4.3 Potential impact of a digital euro on bank intermediation capacity and lending conditions: insights from bank valuations

The impact of a digital euro on banks' intermediation capacity, and implicitly their lending conditions, depends on the adjustment in banks' funding and profitability. Effects are likely to be heterogeneous across banks, mirroring, among other things, banks' reliance on deposit funding. If, for example, the potential for deposit disintermediation has a bearing on banks' profitability, this might also have implications for banks' intermediation capacity and, ultimately, lending conditions. At the same time, the introduction of a digital euro – if intermediated through the banking system – could allow banks to develop an additional business area by offering access to and services building on the digital euro, as well as incentives for efficiency gains. This section explores the potential implications for bank intermediation capacity making use of market reactions to digital euro announcements. Market participants are likely to have been paying attention to the perceived impact that a digital euro might have on financial markets, and on the profitability of the euro area banking industry. A change in the pace was visible after the publication of the Eurosystem report on the digital euro (ECB, 2020a), and again more recently with the decision to launch the digital euro project on 14 July 2021 (Graph 22).

Graph 22

Search interest around stablecoins and digital euro over time



Sources: Google trends and ECB calculations.

Bank valuations provide some insight as to what investors currently think a digital euro might entail for banks' business models. To the extent that banks' stock prices reflect also the present discounted value of the future stream of profitability, their changes around events that define agents' expectations about the digital euro, net of a potential change in discount factors, can be a measure of the impact of the digital euro on bank profitability. Since the digital euro project is still under development, stock market developments might be one of the few, however partial, sources of evidence one can look at to gain insights over expectations over the digital euro and its consequences for the euro area banking system.

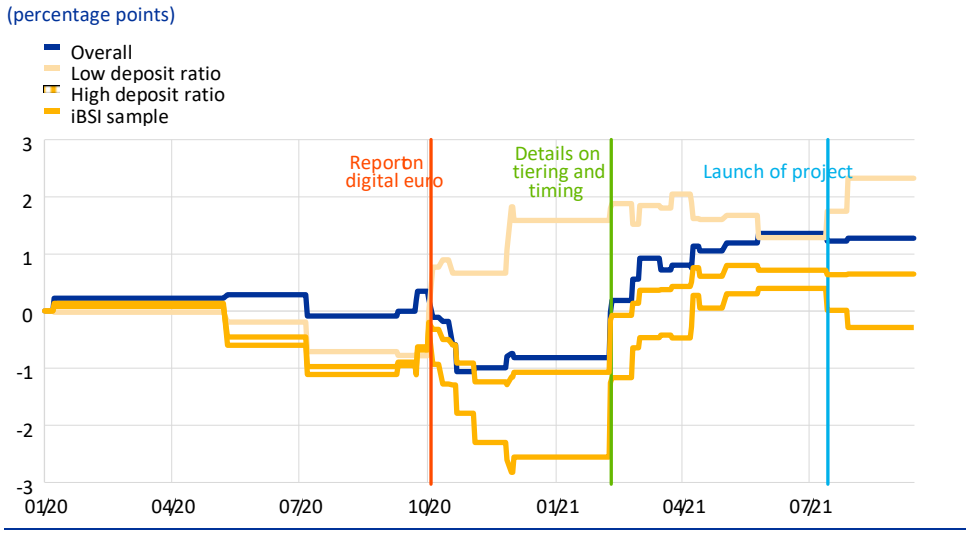
In order to analyse banks' stock price reactions to news related to the digital euro, the change in overall and bank-specific stock prices is accounted for. In a first step, the reaction of bank stock prices is gauged through the lens of a standard factor model of stock market returns fitted to euro area banks' stock market returns at a daily frequency. A 3-factor Fama-French model is fitted to euro area banks' stock market returns at a daily frequency to identify potentially abnormal returns around events related to the digital euro, or digital currencies more in general (Burlon, Montes-Galdón, Muñoz and Smets (2022)). Returns are classified as abnormal to the extent that they deviate from the returns explained by the regularities captured by Fama-French factors. The sample is based on close to 140 banks from 1 January 2007 to 30 April 2021, and a (continually expanding) series of daily events related to digital euro or stablecoins distributed over the last three years is explored.

Bank characteristics like the reliance on deposit funding can help explain bank-specific stock price reactions around digital euro events. The first step of the analysis allows to characterise potentially abnormal returns of banks around events related to the digital euro or digital currencies. In the second step, the evolution of abnormal returns estimated in the first step is assessed against the type of information that each event carries and the bank characteristics of the cross-section of banks associated with a positive or a negative reaction to CBDC news. Abnormal returns are regressed on bank specific characteristics such as the reliance on deposits, the non-performing loan (NPL) ratio, the RoA, the cost-to-income ratio, the holdings of securities, the excess liquidity holdings, the amount of unused TLTRO borrowing allowance or the relevance of TLTROs in the overall balance sheet, the price-to-book ratio, the market capitalisation or the CDS spread.

Bank stock market valuations for banks relying on deposit funding reacted more strongly to news about the digital euro, with an initial drop followed by a reversal (Graph 23). Following the publication of the ECB report in early October 2020, stock prices more reliant on deposit funding declined but recovered fully as more details about actual design and timing of the project were made public. Stocks reflected the cleavage between banks perceived to be more exposed to the new technological threat, like those relying on deposit funding, and other banks. This reaction is consistent with market participants either discounting a potentially large disintermediation effect or needing several months to absorb the information flow on this subject. The connection between deposit funding and banks' reactions has become particularly intense since then (Graph 25, LHS panel). In line with the considerations on the potential positive impact on profitability, related to the potential new business opportunities created by the digital euro, stock prices of banks with low reliance on deposits increased in response to digital euro events ever since the publication of the ECB report in October 2020. Interestingly, valuations for smaller banks recorded an upward trajectory since October 2020, consistent with the idea that, ultimately, the digital euro could also be a considerable support towards the digitalisation of the euro area banking sector, levelling the playing field for smaller banks.

Graph 23

Stock market reactions to CBDC news by euro area banks

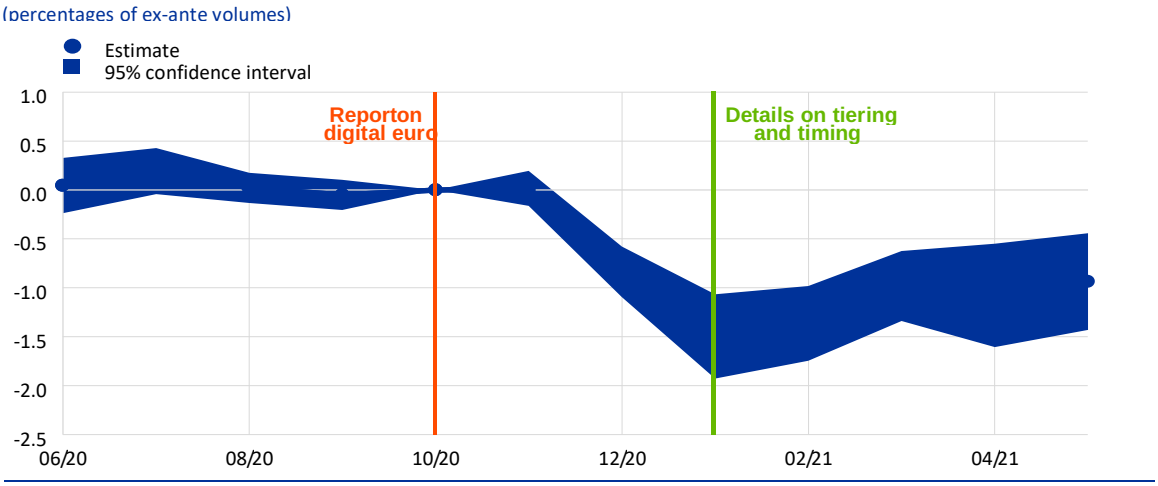


Source: Burlon, Montes-Galdón, Muñoz and Smets (2022).

The evolution of valuations seems to point to investors anticipating diverging, but temporary, implications for lending conditions across bank business models (Graph 24). These seem to be perceived by markets as being differentially affected by the introduction of a digital euro, with some poised to benefit, and others to lose. The reallocation in market shares that this differentiated impact might entail can be quantified by studying the reaction of banks themselves in the months spanning the events outlined above (and as measured by the difference between the dotted and dashed yellow lines). Looking at the developments in loan markets using transaction level data and controlling for potentially confounding factors such as loan demand, the cross-sectional difference in the reaction of stock prices to digital euro news (amounting to roughly 4 percentage points) has been associated with a reallocation of market shares of around 1.5% of ex ante volumes at the peak (Burlon, Montes-Galdón, Muñoz and Smets (2022)). This reallocation was, in fact, temporary and limited to the period leading up to the communication of further details about the project.

Graph 24

Change in loan volumes to firms associated with a 4% cumulated gap in bank stock prices

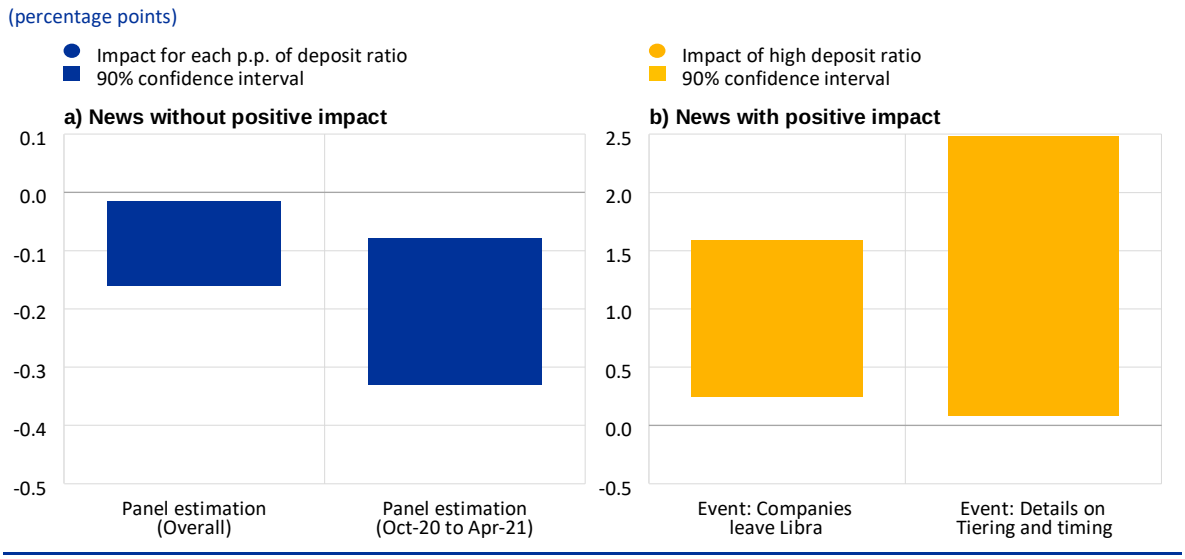


Source: Burlon, Montes-Galdón, Muñoz and Smets (2022).

Reactions to news are not confined to digital euro-related events but mirror also developments in the broader ecosystem of stablecoins, suggesting that markets may be discounting a counterfactual scenario for the absence of a digital euro where the void is filled by alternative digital currencies. The counterfactual for the impact of the digital euro on banks' valuations might not be a world without any CBDCs or stablecoins, but rather one where banks' business models are threatened by the availability of these assets and the rise of new actors, like Big Tech companies, with ex-ante competitive advantages in responding to new forms of demand for digital currencies and cryptoassets. Accordingly, valuations of banks relying heavily on deposit funding also respond to news about stablecoins more broadly. For example, the abnormal (positive) returns observed on 11 October 2019 and 10 February 2021 depended similarly on the reliance on deposit funding (Graph 25, right panel). While the second event squarely referred to the digital euro, when potential details about the project in terms of the threshold of the tiering system (€3,000 per user) and the timing of the project (four to five years) were communicated to the public, the first event was connected to stablecoins more broadly, when eBay, Mastercard, Stripe, Visa and Mercado Pago all left the Libra project, following PayPal's departure one week earlier.

Graph 25

Impact of deposit funding on market reactions to Libra- and digital euro-related news



Sources: ECB website, Dealogic and ECB calculations.

The estimated stock market reactions are suggestive of perceived implications for bank funding and profitability, although the role of central bank balance sheet is unlikely to be factored in yet. The actual impact of the introduction of the digital euro on banks' balance sheets will depend on the evolution of the balance sheet of the central bank as well. This is because the central bank can react to the potential increase in liabilities induced by the increased demand for digital currency by either accepting to compress its other liabilities or by expanding its assets. On the one hand, the difference in reactions between banks that rely on deposit funding and other banks does suggest a link with the perceived value of the deposit franchise. On the other hand, the reaction of bank market valuations to digital news might not fully discount these mechanics, as they are arguably a form of externality via the central bank reaction function or the wider customer base of banks' depositors that agents are unlikely to factor in, akin to banks' stock price reactions to NIRP cuts or increases in asset purchases.

Conclusions

In conclusion, in the present market conditions, crypto-assets risks/implications for financial stability, monetary policy, and payments and market infrastructures are limited and/or manageable within the current framework. Even at their peak the outstanding value of crypto-assets was too small to give rise to concerns for the EU financial system and the economy.

The current assessment does not prevent the ECB from analysing the resilience of the financial system to possible future developments, and from identifying gaps to be filled. Crypto-assets market developments are dynamic and links to the financial sector and the economy may increase in the future. Greater direct and/or indirect exposures to crypto-assets may result from many factors, from market developments to unintended "legitimising" effects of clarifying the application of standards (e.g. accounting standards) or regulating crypto-asset activities. Depending on how they are regulated, crypto-assets may more easily enter the FMI environment, and deteriorate the FMI risk profile.

It is therefore important that the ECB continue to monitor the crypto-assets phenomenon, raise awareness and develop preparedness for any adverse scenarios, in cooperation with other relevant authorities. Financial institutions investing directly or indirectly in crypto-assets should have in place relevant governance arrangements, also in line with the licensing criteria, and commensurate to the materiality of investments in crypto-assets and/or crypto-assets-related activities.

As new forms of digital money emerge, central banks have started exploring retail CBDC issuance. In some economies, retail CBDC are expected to serve as a tool to tackle the dwindling use of cash, while other economies seek innovative methods to expand financial inclusion. The underlying rationale for CBDC issuance may vary based on the central banks mandate, macro-financial circumstances or market and regulatory environment.

A solid use case and rationale for retail CBDC issuance is critical as it will inform the design and implementation process. In terms of technology development best practices, an agile project management approach can optimize development costs, reduce project risks and facilitate gradual user adoption and trust. The iterative nature of an agile approach will support a non-linear decision-making flow and ensure that any deficiencies or gaps in the design or implementation can be addressed immediately. Involving key stakeholders, such as end-users, into the implementation process will ensure CBDC usefulness and contribute to building adoption and trust.

The operating model determines the degree of central bank hands-on involvement in CBDC distribution and user engagement. For example, a single-tier direct-access account-based approach would have users holding accounts directly at the central bank that also provides and manages users' digital wallets. Under a two-tier indirect approach, the central bank would issue CBDC, but private institutions would carry out the work of administering accounts and providing user payment services, perhaps mitigating financial disintermediation risk. Under an sCBDC approach CBDC issuance is effectively outsourced to private digital money issuers by giving them access to central bank reserves in exchange for submitting to strict supervision and oversight by the central bank or other authorities.

Design features depend on CBDC policy objectives and country circumstances, while key design principles are foundational and independent. Key design principles like cybersecurity, user-centricity, flexibility, and financial integrity provide the foundation for the specific design features

such as the technology platform, the degree of transparency, availability, usage limits, whether it will be interest bearing, and usage fees.

Cyber risk management capacity becomes critical in a digital currency world. It covers the business and/or the infrastructure layers, each requiring unique and appropriate security controls and practices to mitigate malicious attacks and breaches. Business layer risks revolve around people, processes and technology, while the infrastructure layer risks are concerned with high-level threat modeling and an architecture risk analysis. A big decision is whether to outsource the running of the CBDC network to third-party cloud providers and how to manage any associated risks.

A central bank's decision to issue CBDC and, if yes, how, involves a holistic assessment of policy considerations and risks, product design, cybersecurity, operational, technical, legal and regulatory requirements. Options can be tested in a closed and controlled environment such as an innovation hub or regulatory sandbox using an agile approach to help gain a more practical understanding of the implications and risks the choices might introduce. This approach would also help build capacity among central bank staff.

In July 2021, the Eurosystem announced the launch of a project to explore the case for a digital euro and consider its potential design. A digital euro would offer several economic benefits but, depending on its design, could prompt changes in the demand for bank deposits, in turn affecting financial stability and monetary policy transmission. Specifically, reduced demand for bank deposits could have consequences for banking sector credit provision, risk-taking, profitability and resilience. To investigate these and other implications of CBDCs, the Eurosystem has recently launched a multi-year digital euro project aimed at ensuring that the ECB is ready to issue a CBDC if needed.

If markets were perfectly competitive and there were no constraints, a digital euro would not be expected to alter the intermediation capacity of banks. A stylised balance sheet perspective shows that, in the absence of market imperfections as well as regulatory and collateral constraints, a digital euro would not affect the capacity of banks to intermediate funds. Instead, it would trigger an offsetting liquidity operation by the central bank to ensure that the economy-wide liquidity situation is kept unchanged. Analyses based on bank-level data show that a digital euro can affect bank intermediation if imperfections and constraints surface. Euro area bank-level data reveal that in the presence of imperfections and constraints, such as regulatory and collateral constraints, a digital euro may affect bank funding structures and in turn their intermediation capacity. Furthermore, individual responses to the introduction of a digital euro may significantly vary because of institution-level specificities including, for example, different business models, deposit ratios and funding structures.

References

Accenture. 2019. “The (R)evolution of Money II.

Access to Cash Review. 2019. “Access to Cash Review: Final Report.”

Adrian, T., and T. Mancini-Griffoli. 2019a. “The Rise of Digital Money,” IMF Fintech Note 19/01.

----. 2019b. “Central Bank Digital Currencies: 4 Questions and Answers,” International Monetary Fund Blog, December 12.

Agarwal, R., and M. Kimball. 2016. “Breaking through the Zero Lower Bound,” IMF Working Paper 15/224, International Monetary Fund, Washington, DC.

Agur, I., A. Ari, and G. Dell’Ariccia. 2019. “Designing Central Bank Digital Currencies,” IMF Working Paper WP/19/252, International Monetary Fund, Washington, DC.

Alvez, M., R. Lluberas and J. Ponce. 2019. “The Cost of Using Cash and Checks in Uruguay,” Documento de trabajo del Banco Central del Uruguay 004-2019.

Altavilla, A., Boucinha, M. and Burlon, L. (2020), “The Economic Consequences of Negative Interest Rates”, CESifo Forum, ifo Institute – Leibniz Institute for Economic Research at the University of Munich, 21(01), pp. 13-17.

Altavilla, C., Burlon, L., Giannetti, M., and Holton, S. (2021), “Is there a zero lower bound? The impact of negative policy rates on banks and firms”, Journal of Financial Economics, forthcoming

Armelius, H., P. Boel, C.A. Claussen and M. Nessén. 2018. “The e-Krona and the Macroeconomy,” Sveriges Riksbank Economic Review, Third Quarter.

Auer, R. and R. Boehme. 2020. “The Technology of Retail Central Bank Digital Currency,” Bank for International Settlements Quarterly Review, March.

Bank of Canada. 2020. “Contingency Planning for a Central Bank Digital Currency,” February 25.

Bank of England (BoE). 2020. “Central Bank Digital Currency: Opportunities, Challenges and Design,” Discussion Paper, March.

Banka, H. 2018. “Initial findings from the implementation of the Practical Guide for Measuring Retail Payment Costs,” World Bank Private Sector Development Blog, May 28. https://blogs.worldbank.org/psd/initial-findings-implementation-practical-guide-measuringretail-payment-costs

Bátiz-Lazo, B., and Moretta, T. 2016. “Mondex and VisaCash: The First (Failed) Attempt at an Electronic Purse,” in B. Bátiz-Lazo and L. Efthymiou (eds.) The Book of Payments: Historical and Contemporary Views on the Cashless Economy, London: Palgrave-Macmillan (Springer Nature), pp. 177-186.

Barbiero, F., Boucinha, M. and Burlon, L. (2021), “TLTRO III and bank lending conditions”, ECB Economic Bulletin, Issue 6/2021.

Bech, M. and R. Garratt. 2017. “Central Bank Cryptocurrencies,” BIS Quarterly Review, Basel: Bank for International Settlements, September.

Bech, M., Y. Shimizu and P. Wong. 2017. “The Quest for Speed in Payments,” BIS Quarterly Review, Basel: Bank for International Settlements, March.

Bergara, M. and J. Ponce. 2018. “Central Bank Digital Currency: The Uruguayan E-Peso Case,” in Gnan, E. and D. Masciandro. 2018. Do We Need Central Bank Currency? Economics, Technology and Institutions, Société Universitaire Européenne de Recherches Financières.

Bindseil, U. 2020. “Tiered CBDC and the Financial System,” European Central Bank Working Paper No. 2351, January.

Bindseil, U. and Panetta, F. (2020), “Central bank digital currency remuneration in a world with low or negative nominal interest rates”, VoxEU, 5 October.

Bindseil, U., Panetta, F. and Terol, I. (2021), “Central Bank Digital Currency: functional scope, pricing and controls”, ECB Occasional Paper 286.

Boivin, J., E. Bartsch, S. Fischer, P. Hildebrand. 2019. “Dealing with the Next Downturn,” Blackrock Investment Institute.

Borisov, A., Goldman, E. and Gupta, N. (2016), “The Corporate Value of (Corrupt) Lobbying”, The Review of Financial Studies, Volume 29, Issue 4, pp. 1039-71.

Boar, C., H. Holden and A. Wadsworth, 2020, “Impending Arrival - A Sequel to the Survey on Central Bank Digital Currency,” Bank for International Settlements Paper No. 107.

Bolt, W. and D. Humphrey. 2005. “Public Good Issues in TARGET: Natural Monopoly,

Scale Economies, Network Effects and Cost Allocation,” European Central Bank Working Paper 505, July. https://www.ecb.europa.eu/pub/pdf/scpwps/ecbwp505.pdf

Bordo, M., and A. Levin. 2018. “Central Bank Digital Currency and The Future of Monetary Policy,” Monetary Policy and Payments, Vol. 3, pp. 143-178.

Brainard, L. 2019. “Digital Currencies, Stablecoins, and the Evolving Payments Landscape,” Speech at the Future of Money in the Digital Age, Peterson Institute for International Economics and Princeton University’s Bendheim Center for Finance, Washington, D.C.

----. 2020. “The Digitalization of Payments and Currency: Some Issues for Consideration,” Speech at the Symposium on the Future of Payments, Stanford, California, February 5.

Brunnermeier, M.K., H. James and J.-P. Landau. 2019. “The Digitalization of Money,” National Bureau of Economics Research Working Paper 26300, September.

Brunnermeier, M.K. and D. Niepelt. 2019. “On the Equivalence of Private and Public Money,” Journal of Monetary Economics, Vol. 106, October.

Broadbent, B (2016), “Central Banks and Digital Currencies”, speech at the London School of Economics, 2 March.

Burgos, A. and B. Batavia. 2018. “Currency in the Digital Era,” Banco Central do Brasil Working Paper, July.

Burlon, L., Montes-Galdón, C., Muñoz, M. A. and Smets, F. (2022), “The optimal quantity of CBDC in a bank-based economy”, CEPR Discussion Papers.

Carstens, A.. 2019. “The Future of Money and Payments,” Speech at the Central Bank of Ireland. March 22.

Central Bank of the Bahamas (CBOB). 2019. “Project Sand Dollar: A Bahamas Payments System Modernisation Initiative.”

Chaum, D. 1983. “Blind Signatures for Untraceable Payments,” Advances in Cryptology, Proceedings of Crypto ‘82, pp 199–203.

Consultative Group to Assist the Poorest (CGAP). 2019. “Fair Play: Ensuring Competition in Digital Financial Services.”

Cœuré, B. 2019. "Towards the Retail Payments of Tomorrow: A European Strategy," Speech at the Joint Conference of the ECB and the National Bank of Belgium on “Crossing the chasm to the retail payments of tomorrow,” November 26.

Copic, E. and M. Franke. 2020. "Influencing the Velocity of Central Bank Digital Currencies," Unpublished manuscript.

Davoodalhosseini, M., F. Rivadeneyra, Y. Zhu. 2020. “CBDC and Monetary Policy,” Bank of Canada Staff Analytical Note 2020-04, February.

Diez de los Rios, A. and Y. Zhu. 2020. “CBDC and Monetary Sovereignty,” Bank of Canada Staff Analytical Note 2020-5, February.

European Central Bank (ECB). 2016. “Distributed Ledger Technology.”

----. 2018. “What is TARGET Instant Payment Settlement (TIPS)?”

----. 2019. “Exploring Anonymity in Central Bank Digital Currencies,” ECB In Focus, December.

Eyers, J. 2019. “Facebook to Man Barricades Against Libra Hackers,” Financial Review, June 20.

Fama, E. and French, K. (1993), “Common risk factors in the returns on stocks and bonds”, Journal of Financial Economics, 33(1), pp.3-56.

Fan Y. 2020. “Some Thoughts on CBDC Operations in China,” Central Banking, April 1.

Financial Action Task Force (FATF). 2019. “Public Consultation on FATF Draft Guidance on Digital Identity,” Paris: FATF.

Financial Times (2018a), “The rise and fall of ethereum”, published online, 19 October. Last accessed 12 February 2019.

Financial Times (2018b), “Auditors grapple with crypto and blockchain”, published online, October 28. Last accessed 12 February 2019

Fernández-Villaverde, J., D. Sanches, L. Schilling, H. Uhlig. 2020. "Central Bank Digital Currency: Central Banking for All?" Federal Reserve Bank of Philadelphia Working Paper WP 20-19, June.

Feyen, E., J. Frost and H. Natarajan. 2020. “Digital Money: Implications for Emerging Market and Developing Economies,” VoxEU, January 16.

Financial Stability Board (FSB). 2020. “Addressing the Regulatory, Supervisory and Oversight Challenges Raised by Global Stablecoin Arrangements,” FSB Consultative Document, April 14.

Garratt, R. and M. van Oordt. 2020. “Privacy as a Public Good: A Case for Electronic Cash,” Bank of Canada Staff Working Paper 2019-24, July.

George, A. 2018. “How Satellite Internet Could Provide Disaster-Proof Coverage,” Popular Mechanics, February 19.

Gowrisankaran, G. and J. Stavins. 2004. “Network Externalities and Technology Adoption: Lessons from Electronic Payments,” RAND Journal of Economics 35 (2): 260–276.

He, D., K. Habermeier, R. Leckow, V. Haksar, Y. Almeida, M. Kashima, N. Kyriakos-Saad, H. Oura, T. Saadi Sedik, N. Stetsenko, and C. Verdugo-Yepes. 2016. “Virtual Currencies and Beyond: Initial Considerations,” IMF Staff Discussion Note 16/03.

He, D., R. Leckow, V. Haksar, T. Mancini-Griffoli, N. Jenkinson, M. Kashima, T. Khiaonarong, C. Rochon, and H. Tourpe. 2017. “Fintech and Financial Services: Initial Considerations,” IMF Staff Discussion Note SDN/17/05.

Huynh, K., J. Molnar, O. Shcherbakov and J. Yu. 2020. “Demand for Payment Services and Consumer Welfare: The Introduction of a Central Bank Digital Currency,” Bank of Canada Staff Working Paper 2020-7.

International Monetary Fund (IMF). 2018. “Republic of the Marshall Islands: Selected Issues,” Washington, D.C.: International Monetary Fund, September.

----. 2019. “Staff Proposal to Update the Monetary and Financial Policies Transparency Code,” Washington, D.C.: International Monetary Fund, May.

Kahn, C. M., F. Rivadeneyra and T.-N. Wong. 2018. “Should the Central Bank Issue EMoney?” Bank of Canada Staff Working Paper 2018-58., December.

Khan, A. 2016. “Central Bank Governance and the Role of Nonfinancial Risk Management,” IMF Working Paper 16/32. Washington, D.C.: International Monetary Fund.

Khiaonarong, T. 2003. “Payment Systems Efficiency, Policy Approaches, and the Role of the Central Bank,” Bank of Finland Discussion Paper 1/2003, Helsinki.

Khiaonarong, T. and D. Humphrey. 2019. “Cash Use Across Countries and the Demand for Central Bank Digital Currency,” IMF Working Paper WP/19/46, Washington, D.C.

Kosse, A., H. Chen, M.-H. Felt, V. D. Jiongo, K. Nield, and A. Welte. 2017. “The Costs of Point-of-Sale Payments in Canada,” Bank of Canada Staff Discussion Paper 2017-4, Ottawa.

Kumhof, M., and C. Noone. 2018. “Central Bank Digital Currencies - Design Principles and Balance Sheet Implications,” Bank of England Staff Working Paper No. 725. Lariccia, F. 2018. “Central Bank Digital Currency: A Macro-Financial Perspective.”

Matonis, J. 2012. “MintChip Misses the Point of Digital Currency,” Forbes, April 12.

Mersch, Y. 2020. “An ECB digital currency – a flight of fancy?” Speech at the Consensus 2020 Virtual Conference, May 11.

Mills, D., K. Wang, B. Malone, A. Ravi, J. Marquardt, C. Chen, A. Badev, T. Brezinski, L. Fahy, K. Liao, V. Kargenian, M. Ellithorpe, W. Ng, and M. Baird. 2016. “Distributed Ledger Technology in Payments, Clearing, and Settlement,” Finance and Economics Discussion Series 2016-095. Washington: Board of Governors of the Federal Reserve System.

Nakamoto, S. 2008. “Bitcoin: A Peer-to-Peer Electronic Cash System.” National Bank of Ukraine. 2019. "Analytical Report on the E-Hryvnia Project."

Norges Bank. 2018. “Central Bank Digital Currencies,” Norges Bank Paper 1, Oslo.

Panetta, F. 2018. “21st Century Cash: Central Banking, Technological Innovation and Digital Currency,” SUERF SUERF Policy Note, Issue No 40.

Rogoff, K. 2014. “Costs and Benefits to Phasing Out Paper Currency,” NBER Working Paper 20126, National Bureau of Economic Research, Cambridge, MA.

Satis Group (2018), “Crypto-asset market coverage initiation: network creation”, July

Schneier, B. 2018a. “Spectre and Meltdown Attacks Against Microprocessors,” Schneier on Security, January 5.

----. 2018b. “Quantum Computing and Cryptography,” Schneier on Security, September 14.

Schwartz, M. J. 2017. “NotPetya Patient Zero: Ukrainian Accounting Software Vendor Backdoored Software Facilitated Malware Attack, ESET Finds.” BankInfoSecurity, July 4.

Secure Technology Alliance. 2014. “Giesecke & Devrient Offers the Most Advanced U.S. Debit EMV Solution.”

Shah, D., R. Arora, H. Du, S. Darbha, J. Miedema, and C. Minwalla. 2020. “Technology Approach for a CBDC,” Bank of Canada Staff Analytical Note 2020-6.

Sveriges Riksbank. 2020. “Do We Have the Right to Pay in Cash?” in Payments in Sweden 2019.

Stalder, F.. 2002. "Failures and Successes: Notes on the Development of Electronic Cash," The Information Society, 18 (3).

Sun, T. 2020. “Preconditions for Digital Money Adoption − What Can we Learn from Alipay?” IMF Working Paper, forthcoming.

Taylor, C., Wilson, C., Holttinen, E., Morozova, A. 2019. “Institutional Arrangements for Fintech Regulation and Supervision,” IMF Fintech Note 19/02.

United Kingdom Government Office for Science. 2016. “Distributed Ledger Technology: Beyond Block Chain,” London.

United States Department of Homeland Security (U.S. DHS). 2016. “Cyber Resilience

Review (CRR) Method Description and Self-Assessment User Guide.”

United States Federal Reserve Board. 2019. “Federal Reserve Announces Plan to Develop a New Round-the-Clock Real-Time Payment and Settlement Service to Support Faster Payments,” Press Release, August 5.