Wholesale financial markets and digital currencies: making headway in the tokenisation of central bank money

Sergio Gorjón

BANCO DE ESPAÑA

The author belongs to the Directorate General Operations, Markets and Payment Systems of the Banco de España, and is grateful for the comments received from Juan Ayuso, Carlos Conesa, José Manuel Marqués, Ana Fernández, José Luis Romero and an anonymous referee. Email for comments: sgorjon(at)bde(dot)es.

WHOLESALE FINANCIAL MARKETS AND DIGITAL CURRENCIES: MAKING HEADWAY IN THE TOKENISATION OF CENTRAL BANK MONEY

Abstract

The interest taken by central banks, and by society at large, in central bank digital currencies (CBDCs) has grown notably in recent years. Although the greatest efforts have focused on studying and experimenting on a new class of monetary liability with universal access (i.e. retail), a second variant, namely a wholesale or interbank CBDC, is gaining ground by leaps and bounds. Specifically, almost 20 monetary authorities are already actively exploring this field with the aim of determining whether or not wholesale CBDCs can enhance the efficiency, flexibility and security of the clearing and settlement process for payments and securities (including in cross-border transactions) and of the associated risk management procedures. These experiences, in turn, highlight the numerous practical and legal challenges that have yet to be resolved and illustrate a possible path for taking full advantage of them. This article analyses the characteristics of the initiatives that have made the most progress to date, placing particular emphasis on the most important lessons learnt.

Keywords: wholesale CBDCs, blockchain, tokenisation, cross-border payments, monetary system.

1 Introduction

To date, 73 central banks[1] in both emerging countries and more developed economies have launched projects relating to central bank digital currencies (CBDCs), focusing chiefly on retail or universal access CBDCs (see Kosse and Mattei (2022)). Although this is the largest group of initiatives, it coexists with a second set of CBDCs that is limited to the interbank arena and intended for executing large-value transactions. These are frequently dubbed "wholesale CBDCs" or "w-CBDCs".

The motivations behind this second class of CBDC are far more consistent. In general, they respond either to an attempt to adapt financial market infrastructures to the needs of the digital economy or to the search for new tools that facilitate the conduct of certain macro-financial policies. In this respect, in addition to individual efforts, w-CBDCs provide fertile ground for international cooperation between central banks, given their potential for contributing to improving ever-increasing cross-border financial flows.

1 In jurisdictions representing 74% of the world's population and 96% of global output.

This article first examines in depth the potential consequences of such digital currencies and goes on to offer a comprehensive view of the most noteworthy projects to date, setting out the key characteristics, objectives and challenges.

2 Possible implications of w-CBDCs

There are multiple design options for a wholesale CBDC. Some of them entail the w-CBDC being practically indistinguishable from the electronic reserves that commercial banks currently hold with the monetary authority. Others, conversely, confer distinctive features upon the w-CBDC. This article solely covers those w-CBDCs that are: i) represented through tokens,[2] and ii) registered and exchanged using blockchain technology.[3]

This latter class of w-CBDC promises to transform key organisational aspects of the financial markets. For example, they enable a financial transaction to be executed with the involvement of fewer parties. Similarly, they allow for continued automation of many of the processes underpinning the w-CBDC, thanks to what has been termed "programmability".[4] Moreover, as a settlement asset, and in contrast to private crypto-assets, w-CBDCs do not entail issuer's credit risk as they are, at all times, a monetary liability of a central bank. Consequently, it is precisely the clearing and settlement of both large payments and securities where the most progress is to be expected, especially in cases where several jurisdictions are involved (see Bech and Garatt (2017)).

Specifically, the introduction of a w-CBDC could lead to a distributed architecture being rolled out, either at the behest of the central bank itself or with third-party cooperation. This will depend on the w-CBDC's effective capacity to bring about a general improvement in operational resilience by avoiding unique points of compromise, but also on the extent to which its implementation can facilitate interoperability with a broad range of payment instruments, including newly developed ones. Similarly, a w-CBDC helps to extend current operating hours more easily, insofar as the use of smart contracts/programmability fosters more autonomous operations, with a minimum level of human intervention. In addition, it is more than likely that it can contribute to the shortening of the intermediation chain

2 For these purposes, the concept of token refers both to the form of representation of the settlement asset provided by the central bank and to the mechanism used to verify the transaction. In these cases, as occurs with cash, it is the object itself that is validated, not the identity of its holder. However, this does not prevent an identity layer from being deployed on the transmission circuit (Committee on Payments and Market Infrastructures (CPMI) (2019)).

3 Please note that these characteristics are not exclusive or essential to w-CBDCs. What is certainly specific to them is the fact that they are a central bank digital liability whose use is restricted to financial or similar institutions.

4 In this context, programmability refers to the existence of mechanisms embedded in the technical infrastructure that enables the settlement asset (central bank money) to respond to predefined events, without the need for human intervention, in certain circumstances.

as there will be less of a need to resort to correspondent banks for executing international payments. A w-CBDC may also reduce the potential dependence on certain classes of validators, usually associated with more centralised structures (see Demmou and Sagot (2021)).

Overall, these two factors would help shorten transaction execution times – particularly in operations involving securities or that are cross border –, thereby releasing liquidity and limiting the time that positions remain open with counterparties. This would reduce credit and liquidity risks – which arise so frequently in such transactions and may, by extension, jeopardise settlement – and lead to an appreciable decrease in current collateral needs (see Fernández de Lis and Gouveia (2019)). These benefits appear all the more pronounced, the lower the degree of standardisation of the underlying financial instruments, e.g. those traded on over-the-counter (OTC) markets which are settled in commercial bank money.

Further, in a purely cross-border setting, w-CBDCs may prompt the arrangement of new and modern global payment platforms (or of a framework of common technical conditions), thereby overcoming existing connectivity problems. Consequently, the accessibility and transparency of international payment circuits may also be improved (see World Bank (2021) and CPMI (2021)). The viability of these approaches depends, in turn, on the mutual trust between the central banks involved and on the effectiveness of the monitoring and control mechanisms they are provided. Promoting cooperation between such institutions is therefore essential.

Insofar as w-CBDCs are equivalent to having a digital, risk-free, settlement asset, they could make a greater impact in areas in which there was previously no room for central bank money.[5] This would open the door to further contain the factors that could give rise to systemic risks on the payment operations side. Conversely, it would pose other challenges, such as those stemming from allowing broader participation of agents who may have a lower technical and financial solvency than that of banks. Nevertheless, the opportunities offered by w-CBDCs in this respect, together with the greater transparency and automation of operations, would lead to a knock-on adjustment in compliance costs, provide greater stability to the economic and financial system and, at the same time, provide a flexible space for innovation.[6]

---

5 Mainly those entities, such as payment institutions and electronic money institutions, that provide financial services and rely on bank money to make their payments, as they do not have access to a central bank's books. Despite there being notable exceptions, it is more common for this type of agent to be prevented from opening an account at a central bank. This measure is designed to contain the size of the risks to which the balance sheet of these entities would be exposed. Conversely, tokenising monetary liabilities would provide an alternative channel for accessing this settlement asset, overcoming part of the obstacles mentioned.

6 One illustrative example of the possibilities that w-CBDCs open up is that of conditional payments. Insofar as they prove to be technically able to support programmability, they will be able to establish ex ante rules for the automatic execution of payments. This would, for example, allow the current delivery-versus-payment (DvP) mechanisms to be extended beyond national borders or to infrastructures that, because they are supported by technologies not compatible with traditional large-value payment systems, currently do not have access to liquidity in central bank money.

Also, as with retail CBDCs, a w-CBDC may impact monetary policy, boosting the mechanism whereby monetary impulses are transmitted to interest rates of other financial markets, or be used as a tool for tackling the so-called zero lower bound problem. Although it appears unlikely that a w-CBDC could compromise its current operational framework, it has useful implications for both its definition and its implementation (see CPMI and Markets Committee (2018)).[7] The greater or lesser impact will ultimately depend on the degree to which w-CBDCs are finally accepted and whether or not they incorporate features to make them more appealing compared with other money market instruments. Against this backdrop, many authorities have included in their analytical agenda topics such as using them for meeting the reserve requirement, the potential emergence of a specific intraday market, changes in overnight demand for central bank money, as well as the risk of a potential fragmentation of the money market and the possibility of monetary policy being executed in real time (see Swiss National Bank, Bank for International Settlements (BIS) and SIX Group (2022)).

In addition, given that the launch of a w-CBDC could alter both the structure and the functioning of financial markets, it will also likely have consequences for financial stability. However, there are as yet very few papers on this subject, and many of them are not conclusive. Some authors argue that implementing a w-CBDC could help contain the rollover risk of private debt. Others, however, are more concerned about potential distortions to the repos or short-term public debt markets, since, by expanding access to central bank money, demand for high-quality liquid assets would be affected. However, to calibrate these effects, specific details must be known about how the w-CBDC is implemented. Indeed, the implications of an introductory phase, in which access is limited, may differ from those that could arise in more advanced stages where this is not the case. Likewise, liquidity fragmentation across several classes of central bank money could make its management more complicated (see Swiss National Bank, BIS and SIX Group (2020)).

On the international front, w-CBDCs simultaneously emerge as a formula for pressing forward in market integration, helping to mitigate foreign exchange risk and expanding the investment and risk coverage opportunities accessible through such markets. This may, in turn, help reduce the current levels of fragmentation typical of international markets. Nevertheless, in the absence of appropriate control tools, greater prominence of w-CBDCs may also increase capital flow and exchange rate volatility, exacerbate contagion risk or foster greater business cycle synchronisation (see Ferrari, Mehl and Stracca (2020) and International Monetary Fund (2020)). For this reason, their design aspects, as well as the review of the regulatory and control framework, are a key part of central banks' ongoing considerations.

7 The cited publication mentions, for example, the upward pressure that a remunerated w-CBDC could place on the short-term sovereign yield curve, to ensure demand from institutional investors.

Among the broad range of implications, the most immediate ones pertain to payment circuits, which is precisely where greater headway has been made in experimentation. The knowledge thus accumulated is also enriching the debate on retail CBDCs, insofar as it illustrates their respective similarities and differences as well as their specific problems.[8] Without prejudice to the details of these experiences, which are set out in the following section, it is worth making a number of general considerations beforehand that could help explain why the payments segment has become so relevant for this discussion.

In general, a payment system can be understood as a series of instruments, procedures and rules intended to facilitate the exchange, clearing and settlement of funds transfer orders between participating agents (see Committee on Payments and Market Infrastructures and Technical Committee of the International Organization of Securities Commissions (IOSCO) (2012)). Along with the systems conceived for settling the purchase/sale of financial assets, these infrastructures play an essential role in the normal course of economic and financial activity. Of all their possible representations, those with systemic implications prompt greater interest among authorities.

In response to these concerns, central banks not only closely monitor and control payment systems, but they also occasionally assume an operating role and act as provider of the related settlement asset. This is often the case with circuits that present greater risks or whose functioning provides singleness to the currency, guaranteeing full convertibility, at par, between its different forms of representation (see Committee on Payment and Settlement Systems (2003)).

To meet these objectives, central banks must periodically update the infrastructures they manage, with a view to preserving their usefulness and preventing new value proposals from potentially relegating them to a secondary role. Hence, w-CBDCs and the various underpinning technological alternatives are particularly appealing as a possible response to the challenges posed to these infrastructures by the digital transformation. A notable example is that of stablecoins,[9] which in certain spheres — such as that of international transfers or decentralised finance — threaten to overshadow either the infrastructure service offerings typically associated with central banks or the settlement assets under their exclusive control.

---

8 For example, the debate about settlement models (centralised versus decentralised) bears very strong parallels with wholesale and retail CBDCs. By contrast, the value that offline operations could potentially provide appears to be a matter of greater interest for those environments involving consumers and a physical presence than for those cases only involving exchanges between large financial institutions. The same occurs with considerations relating to privacy levels.

9 Where the pace of modernisation of the payment infrastructures offered by central banks does not meet market expectations, stablecoins may be considered an alternative for accessing many of the new functionalities inherent to digital assets. This would erode central bank money's core role as a settlement asset. In this respect, some private entities, either individually or through the creation of consortia (e.g. Fnality), are exploring the issuance of proprietary stablecoins backed by the balances in their reserve accounts with the central bank, as an alternative formula to directly using a w-CBDC.

As mentioned above, compared with the status quo, w-CBDCs may offer a differential value in both efficiency and transparency terms and may help uncouple access to central bank liabilities from the need to open an account at that central bank. Consequently, they may safeguard central bank money's core role in the economy, extending the benefits of trust and security to the area of digital assets (be they native or tokenised)[10] (see Marqués Sevillano (2022)). These types of considerations are all the more pressing given the scope of possibilities emerging as a result of the legislative proposal for a regulation of the European Parliament and of the Council for a pilot regime for market infrastructures based on distributed ledger technology (DLT).

3 Key projects: objectives, characteristics and current status

In contrast to universal access CBDCs, there are barely more than 20 jurisdictions with wholesale projects. Nevertheless, as shown by Figure 1, their regional impact is considerable. In the developed countries, interest in this field of research primarily stems from its capacity to make cross-border payments more efficient.[11] Conversely, in the emerging market economies – especially in those that lack sound and modern financial market infrastructures (FMI) – the primary objective is to bring about a general improvement to the channels supporting financial transactions (see Boar, Holden and Wadsworth (2020)).

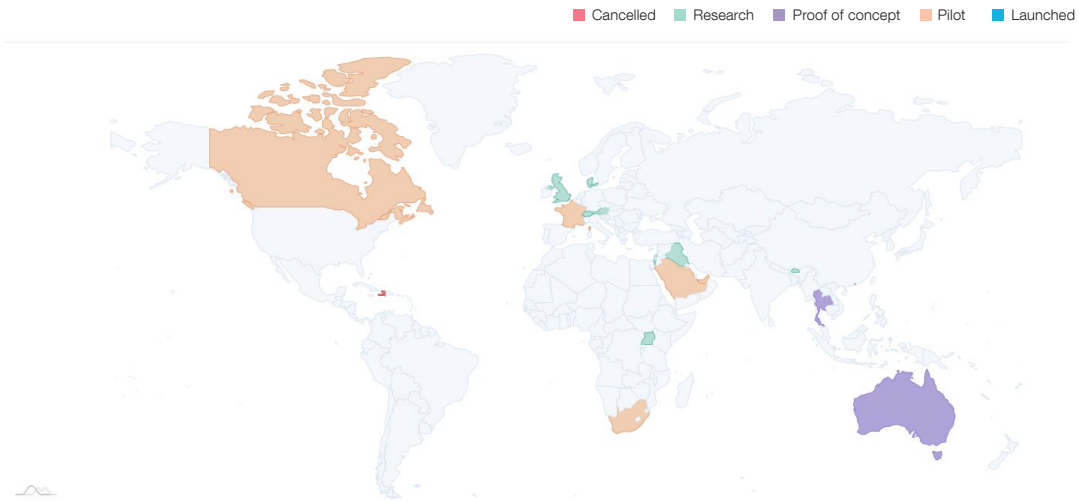
These projects include most notably, on the one hand, those of Singapore and Canada (projects Ubin and Jasper, respectively) and, on the other, those of Thailand and Hong Kong (projects Inthanon and LionRock), which later converged into a bilateral joint effort that, ultimately, turned out to be critical for broadening their scope of action. Also of note are the Helvetia Project, developed by the BIS Innovation Hub with the participation of the Swiss National Bank and the SIX Group, and the nine lines of work promoted by the Banque de France for 2020-2021.[12] The

10 To this end, several configurations are possible. Without seeking to be exhaustive, from a strictly theoretical perspective, consideration could be given to the link between different DLT platforms (some for cash and others for another type of financial instrument) or the integration of both types of tokens in a single decentralised infrastructure, be it managed by either a central bank or by a private agent.

11 Indeed, they are considered to be one of the possible ways of attempting to address the problems regarding slowness, cost and insufficient transparency that currently weigh on cross-border payments and are defining the priorities of the G20 (see Financial Stability Committee (2020)).

12 Each of these clusters is devoted to a specific dimension of the w-CBDCs, ultimately providing a broader vision of the existing possibilities. Despite the importance of each individual experiment, the "Jura" project is particularly interesting. By capitalising on elements of Helvetia, it explores the potential benefits of a w-CBDC in the settlement of cross-border payments where multiple currencies are involved. To this end, based on a platform managed by a third party, Jura allows for direct transfers between non-resident institutions of tokens representing central bank money that are issued by the central banks of France and Switzerland, respectively. These tokens play an exclusively transactional role; they do not constitute a new central bank monetary liability. As such, they are only available temporarily (intraday), meaning that, owing to the restrictions of the current legal framework, the effective finality of transactions may only be achieved through the real time gross settlement system (the case of France).

Figure 1
GLOBAL STATUS OF W-CBDC INITIATIVES AS AT APRIL 2022



SOURCE: https://cbdctracker.org/.

Eurosystem and the Bank of Japan's Stella Project is one of the most notable examples of international cooperation.

The experiments underlying these initiatives are generally organised by phases or components that are deployed sequentially. This helps lay down the necessary building blocks to move on to the next stage. The complete life cycle of a transaction, from the issuance of different types of assets on the new platform to their exchange, clearing, settlement and redemption, is replicated through the use of blockchain technology and the tokenisation of financial instruments and official currencies.

In terms of scope, the road map typically commences with testing the performance of interbank payments within national borders and subsequently explores their synchronisation with securities transactions. In the final phases – usually in collaboration with various central banks – dimensions like delivery versus payment (DvP) and/or payment versus payment (PvP),[13] both on the international front and in real time,[14] are further analysed. Additionally, trials are carried out on a series of

13 Settlement procedures that ensure the simultaneous transfer of securities against funds or across the different currencies that are being transacted. To this end, several formulas were tested. For instance, in the case of Jasper/Ubin and Stella, Hash Time Locked Contracts (HTLCs) were used. These are cryptography-based protocols that coordinate the various processes into which a transaction involving different networks can be broken down. These protocols determine whether the transaction is either carried out or revoked. However, in the case of Inthanon/LionRock, a corridor was set up as a bridge between the respective national DLTs, allowing for direct settlement through wallets.

14 Three conceptual models advocated by Auer, Haene and Holden (2021) are used for this purpose, either in isolation or in parallel.

functionalities common to traditional FMIs, such as those relating to liquidity optimising mechanisms, managing different aspects of the life cycle of bonds (corporate actions), increasing the traceability of transactions and preserving their privacy.

These exercises also cover other particularly interesting aspects, such as interconnecting one or several DLTs[15] with traditional infrastructures and allowing central bank money to circulate either outside the issuing jurisdiction or between counterparties that have traditionally not had access to central bank accounts. As regards international payments, the architecture usually embeds automated currency exchange procedures (again, with atomic settlement)[16] that happen seamlessly prior to actual value transfer. In all cases, conducting these exercises requires collaborating with private-sector firms, including both financial institutions and technology suppliers.

Aside from certain discrepancies regarding the preference of a specific blockchain platform over another (e.g. Corda or Hyperledger), the main difference between the projects of Singapore, Canada, Thailand and Hong Kong[17] and the others lies in the nature of the w-CBDC. Rather than a central bank monetary liability, the token used by the former set of projects is a digital representation of a right (depository receipt) to claim ownership over an already created monetary liability; in short, over central bank money that has been blocked previously on behalf of its user in a transitory account.[18] Therefore, the underlying central bank money is the actual settlement asset.

The former variant is sometimes called "w-CBDC indirect access model" to distinguish it from that used by the other central banks. Evidently, the legal implications of the two differ. This poses a series of practical challenges as regards their possible status as a support for a systemically important payment circuit that should comply with certain internationally accepted risk management principles (see CPMI and Technical Committee of IOSCO (2012)). As regards local and regional specificities, some of the exercises also addressed compliance with certain legal obligations[19] through functionalities directly provided by the related blockchains.

---

15 Distributed ledger technologies, which provide replicated, shared and synchronised digital databases geographically spread across multiple sites, countries and/or institutions.

16 A process consisting of interlinking the transfer of two assets such that the delivery of one occurs only upon delivery of the other one. Otherwise, the transaction is not completed. This concept can be extended to unidirectional transactions involving several agents or legs (e.g. an issuer, a recipient and two intermediaries). In these cases, the transaction (for instance, a payment) will only be deemed completed if each and every party performs their respective tasks as expected. Otherwise, the payment does not go through.

17 As regards this special feature, Project Jura also forms part of this group of initiatives.

18 Insofar as the correspondence between the token and the blocked central bank money is one to one, the monetary base remains unchanged. Also, for simplicity, the accrual of interest is not considered. In turn, there are technical differences between the projects.

19 Both regulatory reporting and exchange rate obligations (for instance, to prevent speculation against the Thai currency).

Table 1 summarises the most notable features of the projects mentioned above and of others with similar characteristics.

Overall, these initiatives helped provide evidence about the level of maturity that blockchain technology had reached and, by extension, they also demonstrated its potential feasibility in connection with future developments in wholesale settlement infrastructures. Among other aspects, distributed platforms were found to be able to reduce costs and financial risks,[20] especially in the case of on-ledger money, i.e. where a w-CBDC is issued directly on a blockchain (see Romero Ugarte et al. (2021) and Bank of Canada (2018)). However, this type of CBDC poses the greatest operational, governance and policy challenges.

The tests also proved that blockchain[21] could successfully address the elements putting liquidity under strain and that, despite the features of this architecture, privacy need not be compromised, thanks to the use of different techniques.[22] Other differential advantages emerged in terms of resilience, the system's overall security[23] and its potential for both accelerating migration to a 24/7 environment and for integrating different networks, even where these are not formally interconnected, without comprising their independence.

In this light, the experiments helped underscore the desirability of leveraging w-CBDCs as a pivotal element for clearing and settlement in order to further promote integration.[24] As a result, it should help to shore up the role of central bank money as an anchor of the financial system and be conducive to an orderly development of tokenised financial instruments markets, minimising their adverse consequences for financial stability.

Lastly, this experience also revealed a potential roadmap to ensure that authorities maintain, at all times, effective control over developments surrounding this new type of monetary liability. Specifically, they showed that objectives such as preserving

---

20 For instance, by automating post-trade processes through the use of smart contracts, giving access to better exchange rates and reducing the number of intermediaries or processes required to complete a transaction; in other words, by combining trading, payment and settlement. By way of illustration, in one of the projects coordinated by the Banque de France, consisting in the purchase of a national financial asset with a foreign currency, the number of intermediaries required decreased by 45%.

21 By setting up a sort of queue when the balance available is insufficient to carry out a transaction immediately. These queues act autonomously, have their own multilateral optimisation mechanisms and offer functionalities which are typical of centralised systems, such as setting priorities and freezing or cancelling transactions.

22 For example, zero-knowledge-proof, private bilateral channels, confidential identities and shared information under the principle of necessity, limiting who has access to it. Likewise, the experiments proved that privacy is not incompatible with providing the pertinent authorities with the information they may require in a swift, reliable and efficient manner.

23 For example, through the use of self-executing contracts – applicable even to anomalous situations, such as errors or breaches by any of the parties –, or sharing secrets (or hashes), duly coded and off-chain, among a transaction's counterparties, enabling them to substantiate claims to their respective rights.

24 The Stella Project proved that, although atomic settlements can be completed with assets from different infrastructures, it adds complexity and gives rise to new risks requiring management.

Table 1

SALIENT FEATURES OF DIFFERENT W-CBDC PROJECTS

Name	Participants	Technological partners	Duration	Scope	Other aspects of interest
Ubin (Singapore)	Monetary Authority of Singapore Association of Banks in Singapore, Singapore Exchange and 12 private banks	Accenture, BCS Information Systems, ConsenSys, Deloitte, IBM, Microsoft, R3	2016-2020 (5 phases)	– Interbank payments – Liquidity optimisation mechanisms – Domestic and cross-border DvP – Cross-border PvP – Connectivity with other blockchain networks / other cases of use	– Tokenised central bank money and securities – Anquan, Corda, Fabric, Quorum – Zero-Knowledge-Proof (ZKP) and other
Jasper (Canada)	Bank of Canada and Payments Canada TMX Group and 7 private banks	Accenture, Microsoft, R3	2016-2019 (4 phases)	– Interbank payments – Liquidity optimisation mechanisms – Domestic DvP – Cross-border PvP	– Tokenised central bank money and securities – Corda, Ethereum – Credit to brokers
Blockbaster (Germany)	Bundesbank and Deutsche Börse AG	Amazon Web Services, IBM	2016-2018 (1 phase)	– Interbank payments – Domestic DvP – FoP settlement of securities – Coupon issuance, redemption and payment	– Tokenised central bank money and securities – Fabric – W-CBDC redemption at end of day
Inthanon (Thailand)	Bank of Thailand 8 private banks	ConsenSys, Microsoft, R3	2018-2020 (a) (4 phases)	– Interbank payments – Liquidity optimisation mechanisms – Domestic DvP – Issuance, redemption, margin calls and payment of coupons – Reconciliation and automation of regulatory compliance – Cross-border PvP	– Tokenised central bank money and securities – Corda – Raft and Practical Byzantine Fault Tolerance (PBFT)
LionRock (Hong Kong)	Hong Kong Monetary Authority 3 private banks		2016 (1 phase)	– Interbank payments	– Corda
Stella (Eurosystem and Japan)	Eurosystem and Bank of Japan	DG Lab, IBM, R3, W3C	2016-2020 (4 phases)	– Interbank payments – Liquidity optimisation mechanisms – Domestic DvP – Cross-border PvP – Confidentiality and auditability in DLT	– Corda, Elements, Fabric – Practical Byzantine Fault Tolerance (PBFT) – Interledger Protocol – Privacy Enhancing Techniques (PET) (b)

SOURCE: Devised by authors, drawing on the public reports of the different projects.
NOTE: See the References section at the end of this article to obtain further details about the similarities and differences between these projects.

a Remains open. In 2020 the joint initiative Inthanon-LionRock was renamed Multiple CBDC (m-CBDC) Bridge Project, also welcoming the People's Bank of China and the Central Bank of the United Arab Emirates.
b Although different variants were analysed (concealment, segregation and disconnection), the experiments focused on two specific implementations: i) Pedersen commitment and ii) hierarchical deterministic wallets.

Table 1
SALIENT FEATURES OF DIFFERENT W-CBDC PROJECTS (cont'd)

Name	Participants	Technological partners	Duration	Scope	Other aspects of interest
Khokha (South Africa)	South African Reserve Bank JSE Limited and 8 private banks	Accenture, Adhara, Block Markets Africa, ConsenSys, Deloitte, Microsoft	2018-2021 (a) (2 phases)	– Interbank payments – Domestic DvP	– Tokenised central bank money and securities – Quorum – Istanbul Byzantine Fault Tolerance (IBFT) – ZKP, Pedersen – Phase 2 includes DvP against delivery of private stablecoins
Helvetia (Switzerland)	Swiss National Bank BIS Innovation Hub and Six Group		2020-2021 (2 phases)	– Interbank payments – Domestic DvP	– Tokenised securities
w-CBDC experiments (France)	Banque de France Monetary Authority of Singapore, Swiss National Bank, Central Bank of Tunisia, BIS Innovation Hub, Iznes, European Investment Bank, Euroclear France, LuxCSD, SIX Digital Exchange, Treasury, 19 private banks, 2 institutional investors and 1 asset manager	Accenture, ConsenSys, IBM, Nomadic Labs, ProsperUs, SG Forge, R3	2020-2021 (9 experiments)	– Liquidity optimisation mechanisms – Domestic DvP – Coupon issuance, redemption and payment – FoP in accordance with the Conditional Delivery of Securities – Cross-border PvP – Migrant remittances	– Corda, Fabric, Quorum, SETL – IBFT – ZKP

SOURCE: Devised by authors, drawing on the public reports of the different projects.
NOTE: See the References section at the end of this article to obtain further details about the similarities and differences between these projects.

a Phase 2 announced.

issuance management, limiting the type of counterparties with access to a w-CBDC and restricting its use to specific purposes or periods of time can be achieved by combining several design factors. In particular, by: i) conferring central banks an exclusive capacity to validate w-CBDC transactions (notary nodes); ii) providing them with continuous visibility over the blockchains' records (observer node) so as to be able to perform reconciliation tasks; and iii) deploying smart contracts.

As for the drawbacks, the experience was useful to illustrate the limitations of different configurations regarding scalability and latency. It also revealed new sources of risk, such as those associated with liquidity fragmentation and the loss of principal owing to network coordination or technology failures, all of which are being analysed in depth. In particular, the growing importance of cloud computing services and the challenge posed by ensuring a timely control framework and an acceptable level of interoperability were noted. The experience also stressed the need to reflect

on how to exert effective governance over the components of a blockchain and how they technically evolve, as well as the importance of exploring the legal dimension of both these platforms and w-CBDCs, including the question of finality.

4 Conclusions

Experimentation around CBDCs is one of the areas that is currently eliciting the most interest among central banks. Although CBDCs with a wholesale scope have in many cases been the raison d'être for these initiatives, in comparison with those aiming at offering universal access, they are much less known by the public at large. This is an expected outcome given their higher level of specialisation and the limited number of parties involved. However, this does not detract from the scope of their potential contributions, compared with those of a retail CBDC, as evidenced by the wide range of projects showing promising results in terms of enhancing international payment circuits and, in general, modernising and adapting financial market infrastructures to avoid their becoming a source of transmission of shocks to the entire financial system.

Therefore, w-CBDCs are complementary to universal access ones, spurring a reciprocal debate about common points of interest and, in turn, posing a series of differential challenges which call for an independent line of research. Aware of this circumstance, a growing number of monetary authorities are developing a strategy around w-CBDCs and openly committing to promoting international cooperation as a way of exploring their full potential.

As shown in previous sections, this cooperation is proving particularly intense with regard to the wholesale payment circuits, especially those whose management falls, albeit not exclusively, to central banks. Ongoing efforts attempt to determine the effective capacity of this new type of monetary liability to respond to many of the challenges raised by the growing digitalisation of the economy's assets. They also intend to shed some light as to how w-CBDCs can help overcome the obstacles that have to date made cross-border payments expensive, opaque, inefficient and insecure. Fortunately, the path ahead seems full of opportunities.

REFERENCES

Association of Banks in Singapore and Monetary Authority of Singapore (2017). *Project Ubin Phase 2: Re-imagining Interbank Real-Time Gross Settlement System Using Distributed Ledger Technologies.*

Auer, R., P. Haene and H. Holden (2021). "Multi-CBDC arrangements and the future of cross-border payments", *BIS Papers,* No 115.

Bank of Canada (2017a). *Project Jasper.*

Bank of Canada (2017b). *Project Jasper: A Canadian Experiment with Distributed Ledger Technology for Domestic Interbank Payments Settlement.*

Bank of Canada (2018). *Jasper Phase III: Securities Settlement Using Distributed Ledger Technology.*

Bank of Canada and Monetary Authority of Singapore (2019). *Jasper–Ubin: Enabling Cross-Border High Value Transfer Using Distributed Ledger Technologies.*

Bank of Thailand (2019a). *Inthanon - Phase I: An application of Distributed Ledger Technology for a Decentralised Real Time Gross Settlement system using Wholesale Central Bank Digital Currency.*

Bank of Thailand (2019b). *Inthanon – Phase II: Enhancing Bond Lifecycle Functionalities & Programmable Compliance Using Distributed Ledger Technology.*

Bank of Thailand and Hong Kong Monetary Authority (2020). *Inthanon-LionRock: Leveraging Distributed Ledger Technology to Increase Efficiency in Cross-Border Payments.*

Banque de France (2021). *Wholesale Central Bank Digital Currencies Experiments with the Banque de France: Results & Key Findings.*

Bech, M. and R. Garatt (2017). "Central Bank Cryptocurrencies", *BIS Quarterly Review,* September.

Boar, C., H. Holden and A. Wadsworth (2020). "Impending arrival – a sequel to the survey on central bank digital currency", *BIS Papers,* No 107.

Boar, C. and A. Wehrli (2021). "Ready, steady, go? – Results of the third BIS survey on central bank digital currency", *BIS Papers,* No 114.

Committee on Payment and Settlement Systems (2003). *The role of central bank money in payment systems*, BIS.

Committee on Payments and Market Infrastructures (CPMI) (2019). *Wholesale digital tokens,* BIS.

CPMI (2021). *Central bank digital currencies for cross-border payments,* BIS.

CPMI and Technical Committee of International Organization of Securities Commissions (IOSCO) (2012). *Principles for financial market infrastructures,* BIS.

CPMI and Markets Committee (2018). *Central bank digital currencies,* BIS.

Deloitte and Monetary Authority of Singapore (2016). *The future is here. Project Ubin: SGD on Distributed Ledger.*

Deloitte, Singapore Exchange and Monetary Authority of Singapore (2018). *Delivery versus Payment on Distributed Ledger Technologies. Project Ubin.*

Demmou, L. and Q. Sagot (2021). "Central bank digital currencies and payments: a review of domestic and international implications", *Economics Department Working Papers,* No 1655, OECD.

European Central Bank and Bank of Japan (2017). *Stella - a joint research project of the European Central Bank and the Bank of Japan / Payment systems: liquidity saving mechanisms in a distributed ledger environment.*

European Central Bank and Bank of Japan (2018). *Stella - a joint research project of the European Central Bank and the Bank of Japan / Securities settlement systems: delivery-versus-payment in a distributed ledger environment.*

European Central Bank and Bank of Japan (2019). *Stella – joint research project of the European Central Bank and the Bank of Japan / Synchronised cross-border payments.*

European Central Bank and Bank of Japan (2020). *Stella – joint research project of the European Central Bank and the Bank of Japan / Balancing confidentiality and auditability in a distributed ledger environment.*

Fernández de Lis, S. and O. Gouveia (2019). "Monedas digitales emitidas por bancos centrales: características, opciones, ventajas y desventajas", *Documento de Trabajo* n.º 19/03, BBVA Research.

Ferrari, M., A. Mehl and L. Stracca (2020). "The international dimension of a central bank digital currency", VoxEU.

Financial Stability Committee (2020). *Enhancing Cross-border Payments - Stage 3 roadmap.*

International Monetary Fund (2020). "Digital Money Across Borders: Macro-Financial Implications", Policy Paper No 2020/050.

Kosse, A. and I. Mattei (2022). *"Gaining momentum – Results of the 2021 BIS survey on central bank digital currencies"*, *BIS Papers,* No 125.

Marqués Sevillano, J. M. (2022). "*El euro digital: una pieza más en la adaptación a un nuevo escenario en el sistema de pagos", Documento de Trabajo sobre Dinero Digital y Sistemas de Pago* No 2021, Fide.

Romero Ugarte, J. L., A. Sánchez Martín, C. Martín Rodríguez and J. Arenillas Cristóbal (2021). "Implications for financial market infrastructures of a wholesale central bank digital currency based on distributed ledger technology", *Financial Stability Review,* No 40, Banco de España.

South African Reserve Bank (2018). *Project Khokha: Exploring the use of distributed ledger technology for interbank payments settlement in South Africa.*

Swiss Federal Council (2019). *Digitales Zentralbankgeld: Bericht des Bundesrates in Erfüllung des Postulats 18.3159, Wermuth, vom 14.03.2018.*

Swiss National Bank, BIS and SIX Group (2020). *Project Helvetia: Settling tokenised assets in central bank money.*

Swiss National Bank, BIS and SIX Group (2022). *Project Helvetia Phase II: Settling tokenised assets in wholesale CBDC.*

Temasek and Monetary Authority of Singapore (2020). *Project Ubin Phase 5 - Enabling Broad Ecosystem Opportunities.*

World Bank (2021). *Central bank digital currencies for cross-border payments: a review of current experiments and ideas,* Payment Systems Development Group, International Bank for Reconstruction and Development / The World Bank.