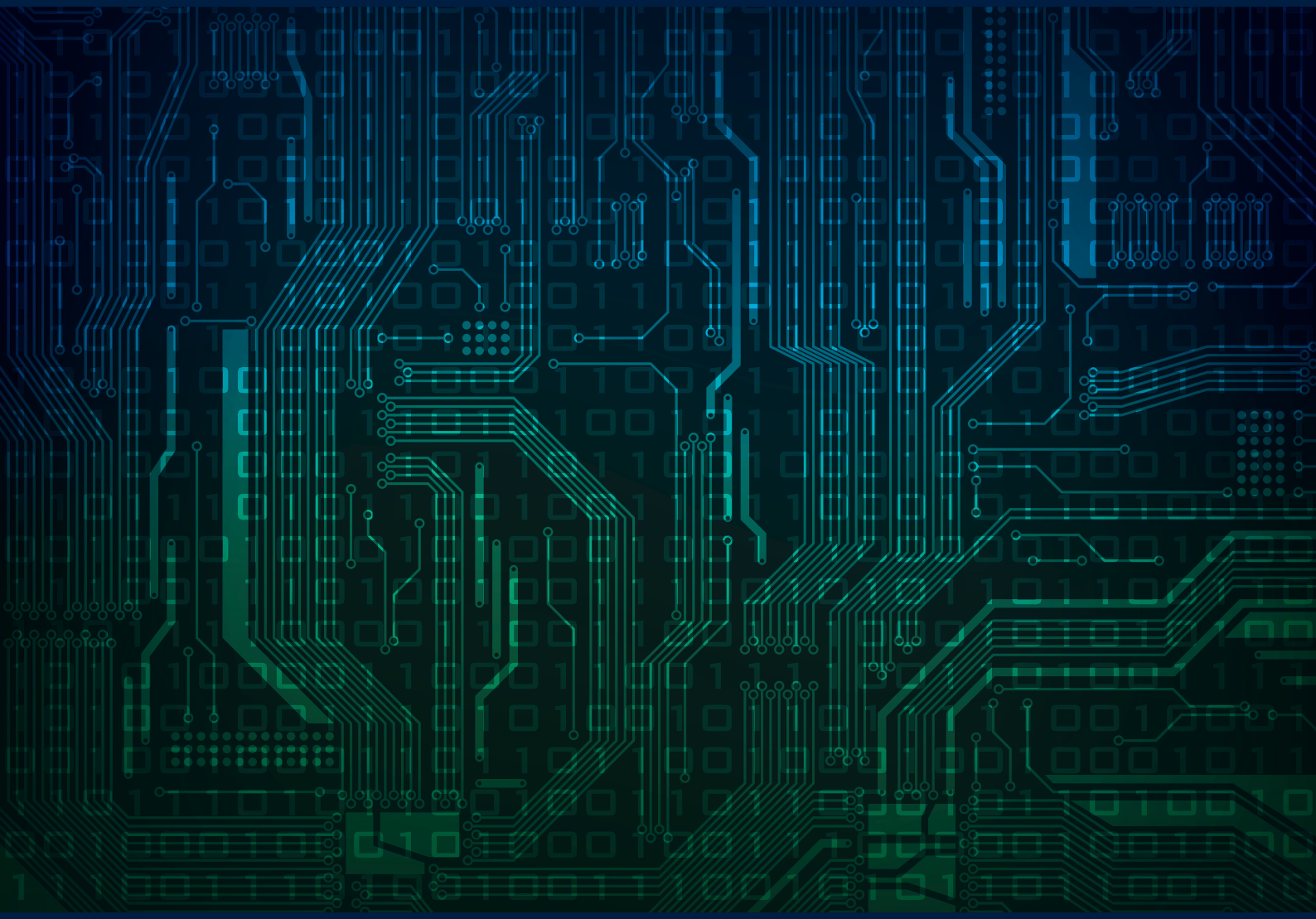
WHOLESALE CENTRAL BANK DIGITAL CURRENCY EXPERIMENTS WITH THE BANQUE DE FRANCE



Results & key findings

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Executive summary

The ongoing digitalisation of financial markets and payments brings the promise of substantial benefits through improvements in the functioning and efficiency of the financial system. However, this movement also comes with new challenges and potential risks for users, consumers and investors. In order to continue to fulfil their public objectives of monetary stability and financial stability while promoting sustainable innovation, central banks are considering issuing a new form of central bank money (CeBM), called central bank digital currency (CBDC), which can be used for retail or wholesale payments.

Meanwhile, the financial industry has been exploring the opportunities of new technologies, such as Distributed Ledger Technologies[1] (DLT) with a view to tokenising traditional financial instruments, i.e. designing a digital representation of rights and circulating them on a network in the form of tokens.

More generally, the landscape for payments is rapidly shifting, at both the retail and wholesale level. Along with the rise of new technologies such as DLT, new crypto-assets are emerging – including stablecoins – and new actors such as BigTechs, are entering the market for payments and financial services, or amplifying the role they already play. These trends could raise three types of challenges from the perspective of central banks. First, they could lead to a loss of sovereignty in the field of payments if foreign players become dominant in those markets. Secondly, as foreign CBDCs or stablecoins linked to foreign currencies develop, monetary sovereignty could be challenged. Finally, the role of CeBM could then be challenged up to a point where it no longer serves as an effective anchor for the financial system. These challenges require central banks and policymakers to adopt a holistic approach with three types of response. The first one is regulatory, to ensure that new actors do not benefit from regulatory arbitrage. The second one is to facilitate the development of private initiatives which sustain innovation and autonomy in Europe. Finally, the last response is for central banks to become innovators themselves and to conduct their own experiments.

Against this background, the Banque de France decided to launch an experimentation programme in 2020 jointly with market participants to explore the issuance and use of a wholesale CBDC (W-CBDC), understood as a new form of CeBM that could be made available on a distributed ledger.

Following a call for applications, the Banque de France initiated nine experiments[2] focusing on the use of CBDC for wholesale payments, including cross-border and cross-currency payments and securities settlement. This report presents the findings of the Banque de France's W-CBDC experimentation programme.

As of November 8th 2021, all but two experiments had been completed. These experiments showed how a W-CBDC can be used (i) to settle securities in various configurations and for many asset classes, and (ii) to complete cross-border and cross-currency transactions.

(i) The experiments explored different ways in which central banks could make CeBM available for securities settlement using DLT-based platforms, including by leveraging existing infrastructures such as TARGET services in Europe.

In this context, a W-CBDC could contribute to the secure development of tokenised financial markets, allowing market participants to benefit from the advantages of DLT (such as the integration of processes

1 The Blockchain technology is a type of DLT.

2 Two experiments remain to be completed by end 2021, Project Jura and the experimention led with HSBC.

and straight-through-processing of securities settlement), while continuing to provide safe settlement in central bank money, in line with central banks' mandates and the pivotal role of CeBM for interbank settlement, as confirmed after the 2008 financial crisis.

(ii) Additionally, the experiments indicated how a wholesale CBDC could be used to complete cross-border transactions, including cross-currency payments. As various jurisdictions may possibly issue a CBDC in the future, interoperable CBDC systems could help to simplify and enhance the performance and accessibility of cross-border and cross-currency payments. The Banque de France's experiments pursued this approach, comprehensively exploring the various possible types of multiple CBDC (mCBDC) arrangements.

The experiments also tested several ways in which central banks could retain control over CeBM on DLT, notably by leveraging blockchains' ability to implement programmability features. Overall, they showed that these technologies provide several tools for central banks to retain control over CeBM from a technical perspective.

Finally, the Banque de France's experiments involved the use of various technologies, including private and public blockchains, as well as other distributed systems. They highlighted that a W-CBDC can be implemented on various types of DLT and would be an effective means of payment, enriching CeBM with new functionalities and use cases as well as promoting innovation in financial markets.

In addition to presenting the findings of these experiments, this report also raises some open questions that would need to be examined further. One of them relates to access to CeBM. The issuance of a W-CBDC could trigger demand from financial actors that do not currently have access to CeBM, but want to be able to settle in CBDC in order to enhance their settlement and benefit from the security of CeBM. However, issuing a W-CBDC and making it available to a larger set of participants could have wide macroeconomic impacts and substantial implications for monetary policy that would need to be clarified. Another potential open question has to do with the technology that could support the issuance and distribution of a W-CBDC. Central banks must continue their assessment of this aspect, carefully weighing the implications of the various technical options available to them.

These open issues, such as interoperability with existing conventional systems as well as cross-border and multi-currency use cases for a W-CBDC, could be addressed through additional experiments. Further analysis of the uses, merits and technical options of DLT for a W-CBDC would be a useful and necessary complement to the Eurosystem's ongoing work on a retail CBDC, given the important synergies between retail and wholesale CBDCs. It would also help to ensure that financial stability and monetary sovereignty are maintained in the face of continued dissemination of crypto-assets (including stablecoins) as settlement assets, as well as the emerging growth of decentralised finance (DeFi).

The analysis presented in this report presents the key takeaways from the Banque de France's CBDC experimentation programme. It neither pre-empts any decisions nor does it commit the Eurosystem to providing a CBDC. The statements in this report about the legal aspects of a CBDC are only working hypotheses. They are neither definitive nor binding for the Banque de France.

1. Rationale

Central Bank Money (CeBM) acts as the cornerstone of the monetary and financial system, ensuring trust in money and guaranteeing monetary and financial stability.

CeBM takes two main forms. It is first made available to citizens in the form of banknotes, whose convertibility at par with commercial bank money contributes to maintaining public trust in money. It is also made available to banks in the form of deposit money which is held at the central bank. While less visible than banknotes, this latter form of CeBM is crucial for settling large-value transactions in a risk-free way. It is thus the cornerstone of financial stability, playing a pivotal role in the functioning of payment systems and market infrastructures (CPSS[3], 2003). In this sense, the financial crisis of 2008 served as a reminder of the value of settling in CeBM (Bindseil and Terol,[4] 2020). The importance of settlement in CeBM was set in stone in the Principles for Financial Market Infrastructures (PFMIs) issued in 2012, Principle 9 of which recommends the use of CeBM to settle financial transactions to avoid credit and liquidity risks, where practical and available.

However digitization is affecting the pivotal role of CeBM.

The use of CeBM in retail payments is declining whereas there is continuous growth in the use of crypto-assets and stablecoins as settlement assets, including through new decentralised finance (DeFi) applications which are continuing to be developed.

In the euro area, cash payments accounted for 73% of transaction volumes in 2019 i.e. 6 percentage points less than in 2016, while the share of card payments reached 24% i.e. 5 percentage points more than in 2016.[5] The recent health crisis has accelerated this transition towards digital payments. While CeBM is still widely used in wholesale payments, the latter are not immune to changes related to digitalisation. New tradable assets based on the use of innovative technologies like distributed ledger technologies (DLT) have emerged. These new assets may change the functioning of market infrastructures through which wholesale payments currently flow. The development of tokenised assets circulating on a distributed ledger could create demand from financial intermediaries seeking to benefit from a settlement asset that allows them to settle transactions directly on the ledger. There is thus a risk that intermediaries could turn to private assets (e.g. stablecoins or even first generation crypto-assets) in lieu of CeBM to settle transactions involving tokenised instruments. The declining use of CeBM could affect both financial stability and the efficiency of monetary policy implementation (see Brunnermeier, James and Landau, 2019).[6]

To address the challenges related to digitization, an increasing number of central banks[7] are considering issuing new types of central bank money in digital form, commonly referred to as Central Bank Digital Currencies (CBDC).

A CBDC would complement existing forms of CeBM and could be used for retail and wholesale purposes. Issuing a CBDC would allow central banks to cater to the needs of increasingly digitalised

3 CPSS, *The role of central bank money in payment systems*, 2003. CPSS stood for Committee on Payment and Settlement Systems and became the Committee on Payments and Market Infrastructures (CPMI) in 2014.

4 Bindseil (U.) and Terol (I.) (2020), "The evolving role of central bank money in payments", Central Banking, 15 July

5 *Study on the payment attitudes of consumers in the euro area (SPACE)*, European Central Bank, 2019.

6 Brunnermeier (M. K.) & James (H.) and Landau (J-P.) (2019). "The Digitalization of Money", NBER Working Papers 26300, National Bureau of Economic Research, Inc.

7 See Auer (R.), Boar (C.), Cornelli (G.), Frost (J.), Holden (H.) and Wehrli (A.) (2021), "CBDCs beyond borders: results from a survey of central banks", BIS Papers No 116, Bank for International Settlements, June. The survey shows that about two thirds of central banks are conducting CBDC experiments or pilots.

economies while maintaining the pivotal role of CeBM, which is key to the fulfilment of central banks' mandates of monetary and financial stability.

In addition, issuing a CBDC could also contribute to ongoing global efforts to improve the efficiency of cross-border payments. Cross-border payments currently face significant challenges related to their high costs, slow speed, limited access and insufficient transparency.[8] These challenges are directly linked to the existence of a number of frictions, which include fragmented data standards, lack of interoperability, complexities in meeting compliance requirements, including for AML/CFT and data protection purposes, different operating hours across different time zones; and outdated legacy technology platforms.[9] In light of these persistent inefficiencies, the G20 has made enhancing cross-border payments a priority since early 2020. Under its aegis, the Financial Stability Board (FSB), in coordination with the Committee on Payments and Market Infrastructures (CPMI), has developed a roadmap comprising a set of 19 building blocks designed to address the challenges mentioned above. This roadmap identifies the issuance of a CBDC as a possible way forward to improve cross-border payments (building block 19 of the roadmap). As part of this building block, the CPMI, the Bank for International Settlements' Innovation Hub (BISIH), the International Monetary Fund (IMF) and the World Bank released in July 2021 a joint report to the G20 on central bank digital currencies for cross-border payments,[10] highlighting conceptually how cross-border CBDC arrangements could facilitate cross-border payments. While promising, the analysis presented in the report would need to be further investigated, especially from a practical point of view. Implementing efficient multi-CBDC arrangements would also require strong international coordination.

In the euro area, the Eurosystem has conducted significant work on the development of a retail CBDC since the beginning of 2020. On 14 July 2021, the Governing Council of the European Central Bank decided to launch an investigation phase, lasting two years, to examine the possible issuance of a digital euro.

Complementing the Eurosystem work, the experimentation programme launched by the Banque de France in 2020 aimed to examine the benefits, risks and technical implementation of a wholesale CBDC (W-CBDC) issued and made available on DLT platforms.

Considering (i) that CeBM is the cornerstone of payment systems, and (ii) the current movement towards the tokenisation of financial assets and settlement assets, the Banque de France focused its analysis on the possibility of issuing a wholesale CBDC (W-CBDC).

Over the past three decades, innovation has enhanced the efficiency and functioning of market infrastructures. The Eurosystem has spearheaded this push towards innovation, displaying a lasting commitment towards the integration of financial markets in Europe and the associated reduction of liquidity fragmentation. This commitment materialised through the launch of the TARGET services: first TARGET2 (T2), then TARGET2-Securities (T2S) and TARGET Instant Payment Settlement (TIPS), and finally the forthcoming consolidation of T2 and T2S. The future Eurosystem Collateral Management System (ECMS), in which CeBM plays a pivotal role, allows the management of assets used as collateral in Eurosystem credit operations, and contributes to smooth liquidity management.

Among the most recent innovations, tokenisation appears to be a potential game changer that central banks have to address. The potential enhancements that DLT and tokenisation could bring are now largely recognised across the financial community, and the Banque de France continues to support

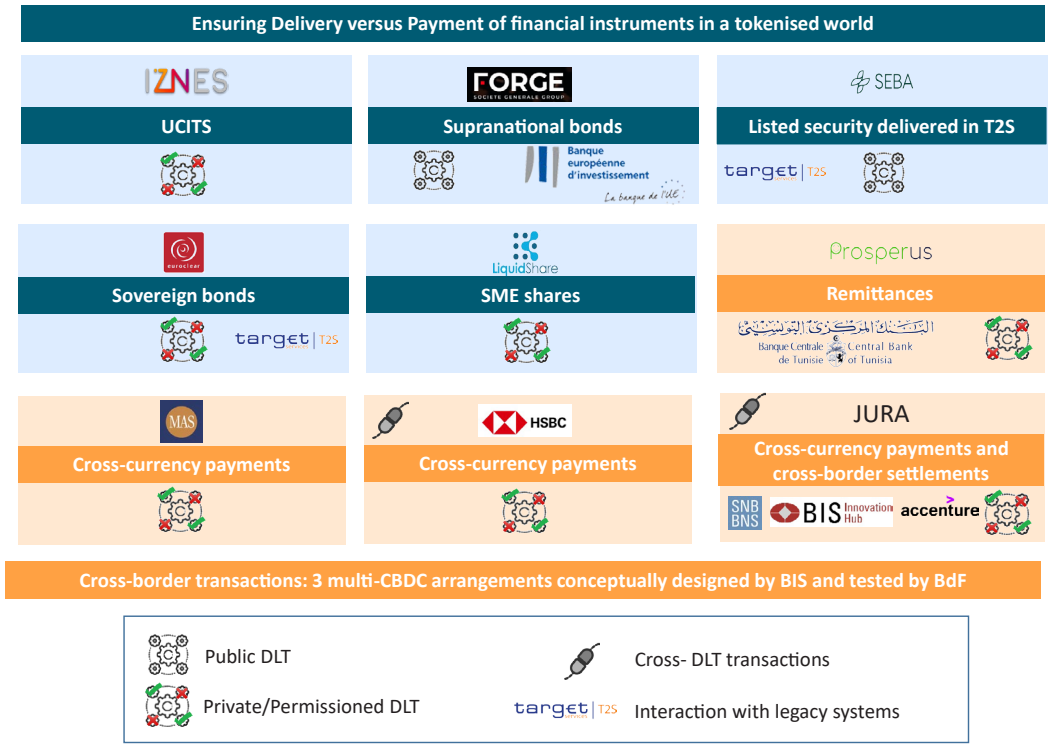
8 Financial Stability Board (2020), *Enhancing Cross-border Payments – Stage 1 report to the G20*, April.
9 Ibid.
10 *Central bank digital currencies for cross-border payments: Report to the G20*, July 2021.

this development of new technologies. At the same time, it will be important to ensure that the use of new technologies does not trigger negative side effects and generate new risks for the financial system such as liquidity fragmentation, lower integration of financial markets, and disruption of ecosystems. The need to balance innovation and safety was key in the Banque de France's decision to launch a series of experiments on a W-CBDC in March 2020, in conjunction with interested market participants. These experiments explored the risks and opportunities triggered by the availability of a CBDC on DLT for the wholesale payment, clearing and settlement of tokenised financial assets, and allowed market participants to investigate the opportunities posed by decentralised finance and DLT.

The intention was to go beyond a purely conceptual perspective to innovation, and instead promote a hands-on approach, with the aim of gaining practical knowledge of new technologies and insights into their implications for the financial system. These experiments were conducted within the existing regulatory framework – in other words, not in a sandbox regime – in order to test different technologies in real life conditions and shed light on the technical limitations and regulatory challenges of the current framework. Thus, the finality of settlement of the "cash leg" of real tokenised financial instruments was achieved in T2, and W-CBDC tokens were used as proxies to simulate settlement in CeBM on DLT environments, as CBDC is not yet legally qualified. In contrast, tokenised financial instruments were settled on DLT-environments. In short, the "cash leg" was experimental, while the "securities leg" was real on DLT environments.

The industry warmly welcomed the call for experimentation. The Banque de France received around 40 applications, covering a diversity of use cases, financial instruments and types of technologies. They also came from a diverse set of geographical origins and user ecosystems. Out of these 40 applications, the Banque de France selected 8 (see Figure 1). The Banque de France set up an additional experiment with the Monetary Authority of Singapore. Applications had to propose one

FIGURE 1 – THE BANQUE DE FRANCE'S CBDC EXPERIMENTS AT A GLANCE



Note: Project Jura and the experiment with HSBC are not completed as of 8 November 2021

or more use cases using CBDC. Most of the selected applications focused on delivery-versus-payment of financial instruments (7 use cases), for both listed and unlisted securities, and cross-border payments (4 use cases), including cross-currency payments.

The Banque de France did not impose any specific technology choices, but innovativeness was another key selection criterion. As a result, all experiments relied on various types of DLT, in particular blockchain technologies (see Figure 1).

The Banque de France did not impose any specific technology choices, but innovativeness was another key selection criterion. As a result, all experiments relied on various types of Distributed Ledger technologies (DLT), in particular on Blockchain technologies (see Figure 1).

The following part of this report presents the experimentation programme's results and key findings.

Part 2 highlights two main use cases. Section 2.1 builds upon the implementation of delivery-versus-payment (DvP)[11] with CBDC during experiments to understand how a W-CBDC can help to safeguard the anchoring role of CeBM, minimising settlement risk and avoiding liquidity fragmentation. Section 2.2 presents how a W-CBDC could facilitate cross-border and cross-currency payments based on multiple setups.

Part 3 reports on two additional key technical findings. Section 3.1 illustrates how the central bank can control the issuance of a W-CBDC on a DLT. Section 3.2 draws some lessons from the comparison between the different technologies used during the experiments. The variety of use cases and the diversity of market participants in the Banque de France's experiments provide useful insights into the technical feasibility and efficiency of a W-CBDC issued and distributed on a DLT.

11 DvP is a securities settlement mechanism which links a securities transfer and a funds transfer in such a way as to ensure that delivery occurs if – and only if – the corresponding payment occurs. The transaction is then said to be atomic, eliminating the risk of a delivery without payment or of a payment without delivery. See Banque de France (2018), Payment and market infrastructures in the digital era, chapter 13.

2. Two main use cases

The results of the experimentation programme confirm that W-CBDC could promote sustainable innovation on financial markets in two ways.

2.1 A Wholesale CBDC could help ensuring the safe development of tokenised financial markets by preserving the pivotal role of central bank money

The financial industry has been exploring the tokenisation of financial instruments with a view to improving the functioning of market infrastructures. Its goal is to enhance transparency through better tracking of transactions and ownership, to achieve cost-efficiency and to ensure availability around the clock. Reducing delays between trade and settlement also appears as a major objective. Tokenisation could also help to simplify transaction processes for a number of financial assets (i.e. small cap bonds, structured finance, OTC-traded products) that do not benefit from systematic and automated delivery-versus-payment (DvP). These transaction processes are complex and are not standardised, making them a significant source of operational risks. Therefore, these assets would benefit from being issued and settled on DLT in a tokenised form, as this would reduce counterparty risk, ensure the transferability of collateral and optimise liquidity.

The settlement of transactions involving tokenised assets can occur in existing infrastructure by building a link between DLT settlement systems and the existing central bank payment system where CeBM is available for settlement. In this set-up, the settlement leg of a DvP transaction involving tokenised securities initiated on the DLT is automatically settled in existing conventional systems in CeBM. Another possibility is to directly settle the tokenised transactions on the DLT, by "putting cash on the ledger". This involves offering a settlement token on a DLT ecosystem and allowing transactions (either DvP or PvP[12]) to have both legs settled on the DLT. The Banque de France's experiments explored this second approach, where the W-CBDC is made available directly on a DLT.

One way to settle both legs of transactions on the DLT would be to use crypto-assets, or stablecoins, as a settlement asset. However, there are significant regulatory, financial and operational uncertainties surrounding these assets, despite ongoing international efforts, making them very risky for financial intermediaries to use at the current time. Moreover, looking forward, if numerous private initiatives were to compete to provide tokenised settlement assets, this could lead to market fragmentation due to heterogeneous standards and a lack of interoperability between DLT systems, undermining the Eurosystem's long-standing efforts towards greater financial market integration.

In this context, the main question is whether the settlement asset for these tokenised markets can be CeBM in order to preserve the anchoring role of central bank money and settlement safety. Several experiments focused on the use of CBDC for securities settlement, for both unlisted (Jura[13], LiquidShare[14],

12 PvP is defined by the PFMIs as a cash settlement mechanism under which final settlement of one leg in a currency can only be made if, and only if, final settlement in the other currency (or other currencies) has actually been made. See Banque de France, *Payment and market infrastructures in the digital era*, chapter 9.

13 "Banque de France, Swiss National Bank and Bank for International Settlements Innovation Hub collaborate for experiment in cross-border wholesale CBDC", press release by the Banque de France, June 10th 2021.

14 "The Banque de France conducts a successful experiment on the use of central bank digital money with a consortium of actors driven by LiquidShare", press release by the Banque de France, July 5th 2021.

Iznes[15], Société Générale – Forge[16]) and listed (Euroclear[17], Seba Bank[18]) securities. For the latter, the experiments notably allowed demonstrating that securities settlement can occur on conventional systems linked to DLT environments. The Banque de France's experiments relating to the settlement of tokenised financial instruments actually provide meaningful insights on how W-CBDC could accompany the rise of tokenised finance by: ensuring access to CeBM for settlement on tokenised financial markets (2.1.1) and avoiding potential liquidity fragmentation in new market situations (2.1.2).

2.1.1 The experiments show how a wholesale CBDC could minimize settlement risk as tokenised finance develops

Many of the Banque de France's experiments (Jura, Société Générale – Forge, LiquidShare, Iznes) focused on the implementation of delivery-versus-payment (DvP) procedures in CBDC for unlisted financial instruments[19],that is to say non-standardised market segments where financial instruments are traded over the counter (OTC-traded) and not necessarily settled in existing market-wide infrastructures such as T2S. Such financial instruments are not required to be administered by central securities depositories (CSDs) and therefore are not necessarily delivered through a securities settlement system under European (EU) Regulation 909/2014 on central securities depositories (CSDR). They are currently deposited at custodians[20] or international CSDs (iCSDs), where settlement occurs in commercial bank money on the books of the banks of the investors or fund managers. In these experiments, DLT-based issuance occurred in accordance with Articles L. 211-3 and seq. of the French Monetary and Financial Code resulting from Ordinance No. 2017–1674 of 8 December 2017 on the use of a distributed ledger for the representation and transmission of financial non-listed securities.

To fully leverage its potential, a necessary but not sufficient condition[21] is that the tokenisation of financial instruments benefit from safe and secure settlement in CeBM. As a result, the Banque de France looked at how to provide settlement in CeBM for new tokenised financial instruments, in order to accompany innovation. It should be noted that some unlisted instruments that are currently managed on a DLT and settled in commercial bank money were previously (before the French ordinance) administered by a CSD (although this was not compulsory) and consequently settled in CeBM in T2S. This shows that, in the absence of a suitable form of CeBM that can be used as a settlement asset on a DLT, tokenised finance raises questions about settlement safety. With the future pilot regime proposed by the European Commission,[22] DLT-based issuance will be possible for non-listed and listed securities, contributing further to the development of tokenised finance and making these questions all the more significant. The Banque de France's experiments tested how these tokenised instruments could be settled in CeBM thanks to a W-CBDC.

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15 "The Banque de France conducted a successful experiment with IZNES on the use of central bank digital money for interbank settlement purposes", press release by the Banque de France, January 19th 2021.

16 "In partnership with the European Investment Bank (EIB) and Société Générale - FORGE, the Banque de France successfully carried out on April 28th an experiment on the use of Central Bank Digital Currency (CBDC) for settling digital bonds issued by the EIB on a blockchain", press release by the Banque de France, April 29th 2021.

17 Experimenting settlement of French government bonds in Central Bank Digital Currency with blockchain technology, insight report, Euroclear, October 2021.

18 "Banque de France conducted with a group of participants formed around SEBA Bank a central bank digital currency experiment for settlement of listed securities", press release by the Banque de France, June 21st 2021.

19 In this case, DvP was implemented for the following instruments: real native commercial paper, real native tokenised bond issued by the European Investment Bank, non-listed shares and the subscription of real native tokenised fund shares.

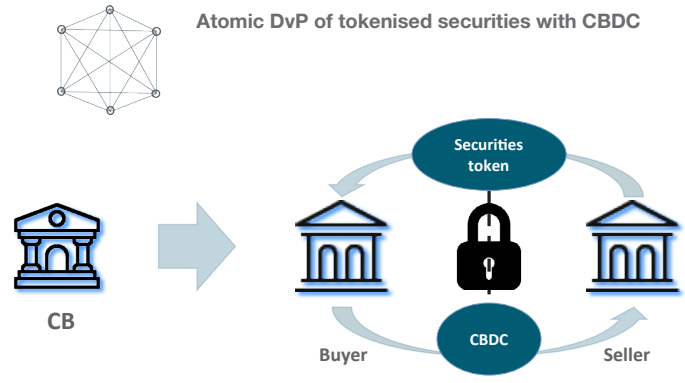
20 The "custody" of securities consists of booking the securities in the account opened in the name of their holder; it is not strictly speaking an investment service, but a so called "ancillary" service to investment services which requires, in France, approval by the *Autorité de contrôle prudentiel et de résolution* (ACPR – French Prudential Supervision and Resolution Authority) for credit institutions and investment firms that wish to provide it. Custodians also provide a number of bespoke services to their clients to enable them to exercise the rights attached to the securities they hold, such as, for example the receipt of payments to holders (e.g. coupons or dividends), or the exercise of voting rights in shareholders' meetings. See Banque de France (2018), *Payment and market infrastructures in the digital era,* chapter 12.

21 For instance, other constraints could include the scalability, efficiency and resilience of distributed ledger technologies.

22 Proposal for a Regulation of the European parliament and of the Council on a pilot regime for market infrastructures based on distributed ledger technology (COM (2020) 594 final).

From a technical perspective, the experiments tested multiple set-ups for the atomic DvP of tokenised financial instruments with a W-CBDC (see section 3.2), including with both public (SG Forge, Seba Bank) and private DLTs, relying on different protocols. In all these set-ups, the Banque de France could perform the different actions related to W-CBDC management on DLT using a node that gave it specific prerogatives. In particular, the Banque de France developed smart contracts, which are computer programs embedded on the DLT, through which the W-CBDC tokens were issued and managed. Other smart contracts were deployed related to the securities leg and to implement atomic DvP.

FIGURE 2 – DVP WITH SETTLEMENT IN CBDC IN THE BANQUE DE FRANCE'S EXPERIMENTS

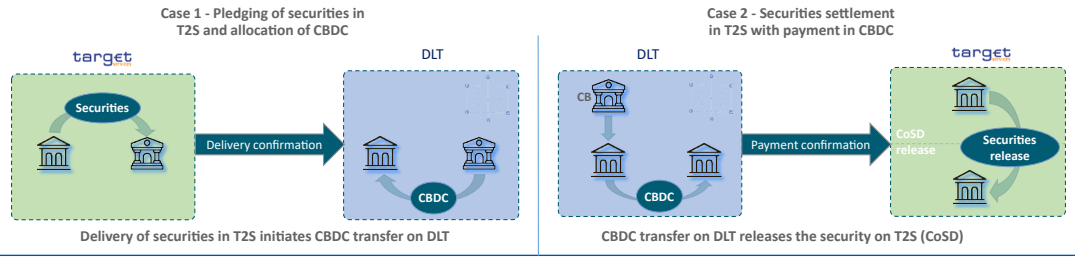


Atomic DvP ensures the securities are delivered if and only if payment is performed

2.1.2 The Banque de France's experiments also provide insights into how a W-CBDC could facilitate the integration and straight-through-processing (STP) of clearing and settlement activities, and avoid liquidity fragmentation

The Banque de France's experiments also showed how the need to integrate securities issuance processes on a single platform (straight-through-processing) could drive the adoption of DLT, including for listed securities not currently managed in T2S. The experiments with Euroclear and Seba Bank showed how market participants could also use DLT for the settlement of listed securities. These instruments, which are currently settled in conventional systems with CeBM (T2S), could thus be settled on multiple DLT environments in the future, in accordance with the pilot regime in Europe proposed by the European Commission.[23] There is a risk, however, that the current trend of financial market integration could be halted and that liquidity could become fragmented across multiple non-interoperable systems. With a view to preventing these risks, the experiments looked at how conventional systems and DLT-based arrangements can be made interoperable (see Figure 3).

FIGURE 3 – TESTING INTEROPERABILITY BETWEEN CONVENTIONAL SYSTEMS AND DLT-BASED ARRANGEMENTS



23 The pilot regime could apply to several categories of financial instruments, including some listed instruments.

In these experiments, the settlement of listed securities occurred through steps performed on DLT and steps performed on conventional systems (T2S), as shown by Figure 3.

These experiments provide examples of how technical interoperability between conventional systems and DLT-based arrangements for securities settlement could be achieved. This would help to mitigate the liquidity fragmentation that would occur on financial markets if more and more financial instruments, listed or not, were settled on various DLT systems with heterogeneous standards and a lack of interoperability.

The first case in Figure 3 shows that, in one experiment, securities were pledged in conventional systems against a W-CBDC transferred on DLT. This experiment also tested the implementation of DvP on DLT. In this case, some financial optimisation – such as autocollateralisation[24] and securities recycling mechanisms – was implemented directly on a DLT. The case also highlights the possible benefits of implementing straight-through-processing[25] on a DLT: by having the whole ecosystem for a given market segment on a DLT, including investors, issuers and custodians, there is less need for reconciliation[26].

In the second case in Figure 3, the functionalities of conventional systems, such as conditional settlement (conditional delivery of securities – CoSD in T2S) were leveraged for securities settlement in W-CBDC. The securities to be delivered were reserved in a conventional system to ensure their availability ("CoSD blocking"): the buyer then transferred W-CBDC to the seller on the DLT. Once payment was confirmed, the reserved securities were transferred to the buyer in T2S ("CoSD release").

In this context, CBDC could play a unifying role for financial markets in Europe and avoid a situation where settlement occurs on multiple non-interoperable systems, fragmenting liquidity.

2.2 Issuing a wholesale CBDC could help improve cross-border and cross-currency payments

The report to the G20 on central bank digital currencies for cross-border payments pointed out that cross-border and cross-currency payments such as *"International remittances raise a number of well-known issues, […] and suffer [in particular] from the absence of interoperability between domestic systems. […] On the wholesale side, inefficiencies are patched by the correspondent banking network, which can be costly and slow in the case of long correspondent banking chains. Appropriate CBDC solutions could tackle some of the issues related to the international transactions."*[27]

In this context, a recent survey by the Bank for International Settlements (BIS) shows that about two thirds of central banks are conducting CBDC experiments or pilots (BIS, June 2021).[28] As various jurisdictions could possibly issue a CBDC in the future, ensuring interoperability by design through coordination between central banks would be key to ensuring the efficiency and accessibility of cross-border and cross-currency payments. The same survey shows that about 30% of respondent central banks are considering options to make CBDCs interoperable by forming multi-CBDC ("mCBDC") arrangements. Unlike incremental efforts to improve the functioning of current cross-border arrangements, which can be weighed down by the burden of legacy infrastructure, CBDC offers the opportunity to overhaul radically the functioning of cross-border payments to make them frictionless and more efficient.

24 Auto-collateralisation is an intraday credit operation that is triggered, when a buyer does not have sufficient funds to settle a securities transaction, in order to improve its cash position by obtaining credit against securities provided as collateral to credit provider.

25 See Banque de France, *Payment and market infrastructures in the Digital Era*, chapter 14.

26 Reconciliation is an accounting process that compares two sets of records stemming from different systems to check that figures are in agreement. On DLT, all participants (issuer, CSD, custodian) could have their accounting information on the same ledger.

27 *Central bank digital currencies for cross-border payments: Report to the G20*, July 2021.

28 Auer (R.), Boar (C.), Cornelli (G.), Frost (J.), Holden (H.) and Wehrli (A), op. cit.

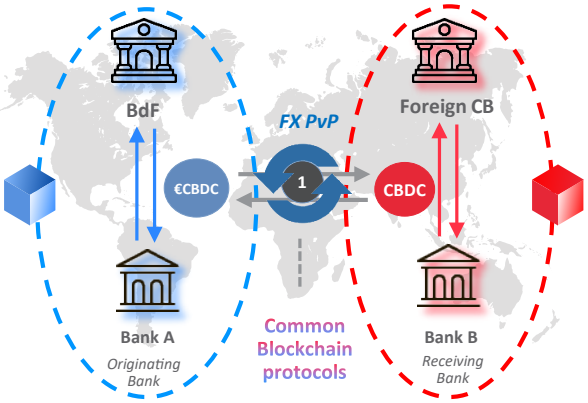
The G20 report explores some CBDC arrangements, focusing on the interoperability of CBDCs. One option to achieve CBDC cross-border payments is for different jurisdictions to cooperate and coordinate in order to give access to CBDC solutions by means of mCBDC arrangements. These mCBDC arrangements – design frameworks including technological, market structure and legal aspects that facilitate payments between CBDCs in different jurisdictions – are intended to establish interoperability by design between national CBDCs (also see CPMI, 2020;[29] Carstens, 2021;[30] Auer et al, 2021[31]). They closely mirror current efforts to make traditional payment systems interoperable, as the arrangements would bridge the payment legs occurring in two jurisdictions.

In this vein, some of the Banque de France's experiments (Jura, MAS,[32] ProsperUs,[33] HSBC) explored this mCBDC arrangements approach comprehensively.[34] Conceptually, different levels of payment system interoperability can be used to group potential mCBDC arrangements according to the three BIS stylised types proposed by Auer et al. (2021): compatible CBDC systems (arrangement 1); interlinked CBDC systems (arrangement 2); and a single system for mCBDC (arrangement 3). These arrangements differ in terms of the nature and governance of the infrastructure set-up.[35] One of the Banque de France's experiments also tested how a single CBDC could improve cross-border payments (remittances) even if the jurisdiction where the payment beneficiary is located does not issue a CBDC. While the BIS's arrangements are technologically agnostic and do not require the use of DLT, the Banque de France experiments' use of a W-CBDC on a DLT made it possible to assess the different ways in which DLT-based CBDC systems could be made interoperable (see section 2.2.1).

2.2.1 Description of the Banque de France's cross-border experiments

This section provides an overview of each experimental set-up with cross-border use cases, and indicates how each of these experiments implemented one of the BIS arrangements previously mentioned (see Figures 4, 5 and 6). One experiment (see Figure 7) was an ad hoc arrangement aimed at streamlining remittances with a single issued CBDC.

FIGURE 4 – mCBDC ON MULTIPLE SUB-BUSINESS NETWORK



BIS arrangement 1: Compatible CBDC systems

In the first experimental set-up, two networks acted as central banks' respective systems. Each network managed its rulebook and had its own governance (including which participants had access to the network).

29 CPMI (2020), *Enhancing cross-border payments: building blocks of a global roadmap – Stage 2 report to the G20*, July.

30 Carstens, A (2021), "Central bank digital currencies: putting a big idea into practice", remarks at the Peterson Institute for International Economics, 31 March.

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

32 "Monetary Authority of Singapore and Banque de France Break New Ground in CBDC Experimentation", press release by the Banque de France, July 8th 2021.

33 "Banque de France, in cooperation with Banque Centrale de Tunisie, successfully conducts an experiment on the use of central bank digital money with a consortium of actors driven by Prosperus", press release by the Banque de France, July 13th 2021.

34 In the case of HSBC and Jura, results are preliminary.

35 Conceptually, different levels of payment system interoperability can be used to group potential mCBDC arrangements into three stylised types:
- In the first arrangement, interoperability is achieved through compatibility between two distinct CBDC systems, each with their own rulebook and governance. It requires that both jurisdictions agree on common standards, without the need to jointly operate a shared infrastructure.
- In the second arrangement, two distinct CBDC systems are linked. While each system remains under the control of its jurisdiction's central bank, it does require that both central banks jointly set up either a shared technical interface or a common clearing mechanism.
- The final arrangement sees the implementation of a single shared CBDC system where cross-border payments are settled, jointly operated by both jurisdictions.

Both networks were based on the same protocol (common messaging system), making the two networks compatible, as in the set-up for TARGET1, where multiple RTGS based on different technologies were interoperable thanks to a common interlinking system.

BIS arrangement 2
Interoperable CBDC systems
In the second experimental set-up, the two networks did not share the same communication protocols and were made interoperable through a specific infrastructure, for instance an interface.

As in the first set-up, each system still managed its own rulebook and had its own governance, including for defining access to its system and validating transactions in its respective currencies. However, unlike in the first set-up, a common governance was required for the interface.

BIS arrangement 3:
Single multi-currency system
In this experimental set-up, a single CBDC system was set up, on which multiple currencies were exchanged. The concept required having a single set of rules, a single technical system, and a single set of participants.

In this experimental set-up, commercial banks performed PvP with CBDCs issued by central banks on a single DLT system. There

FIGURE 5 – mCBDC ON MULTIPLE INTERCONNECTED DLTs

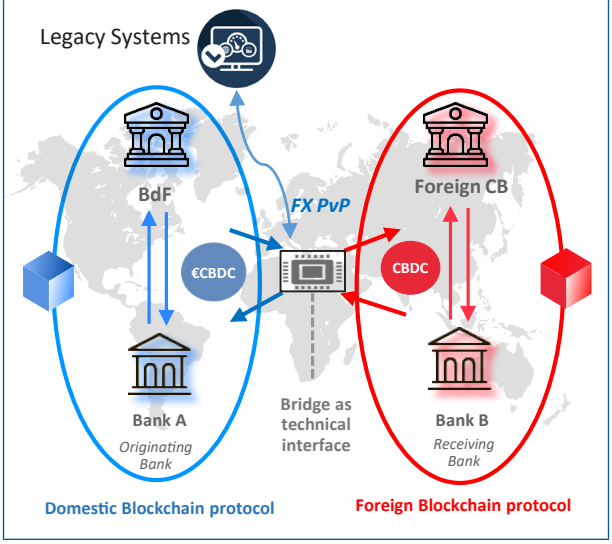


FIGURE 6 – mCBDC ON A SINGLE MULTI-CURRENCY SYSTEM

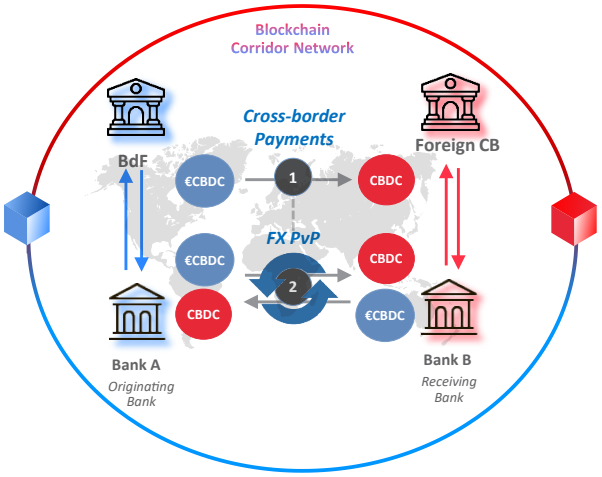
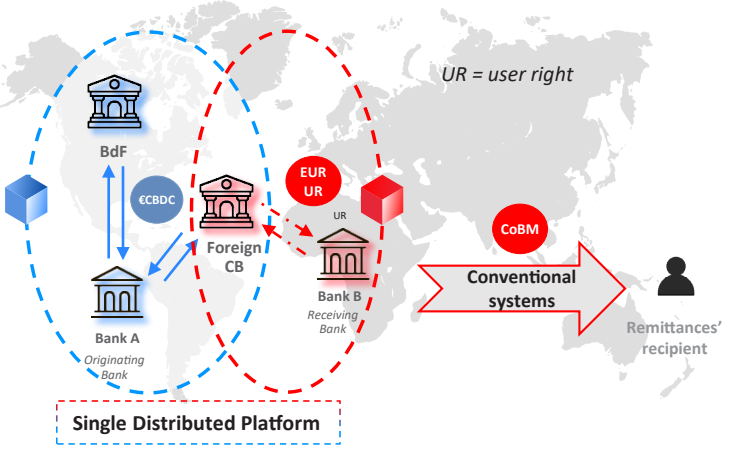


FIGURE 7 – ALTERNATIVE TO mCBDC TO ENSURE COMPATIBILITY WITH EXISTING SYSTEMS COMPATIBILITY BETWEEN CBDC AND CONVENTIONAL SYSTEMS



was a shared system of governance and a shared rulebook for payment rules, fees, etc. However, each central bank defined which participants could use its CBDC token.

The Banque de France also tested a set-up where only one jurisdiction issued a CBDC, as an alternative to the aforementioned mCBDC arrangements in the context of remittances.

Instead of a traditional cross-border transfer in commercial money, the experiment leveraged an existing banking relationship between central banks to enable near real-time EUR transfers between end-users from different jurisdictions. In this set-up, there was a single system set-up, with common protocols, allowing CBDC to be exchanged between the two jurisdictions.

2.2.2 Key takeaways from the cross-border experiments

The Banque de France's cross-border experiments showed the technical feasibility of ensuring interoperability between different jurisdictions' systems where settlement of cross-border and cross-currency transactions can occur in CeBM thanks to CBDC (including in the case where only one jurisdiction issues a CBDC).

The experiments indicated that, from a technical perspective, interoperability can be achieved in multiple ways. One experiment showed how interoperability between CBDC systems could be implemented despite the lack of common protocols, and with conventional systems, through a single technical interface (Figure 5). Other experiments indicated how interoperability between CBDC systems could be implemented on a single network or through common protocols (Figures 4 and 6). In addition, one experiment indicated how CBDC could help to streamline cross-border payments even if the receiving jurisdiction has not issued a CBDC (Figure 7), without granting access to CBDC to non-residents. In all of these cross-border experiments, each jurisdiction's central bank could fully control its CBDC, including determining which entities have access to it.

The experiments also provided several insights into a W-CBDC's potential to improve cross-border payments. In particular, they showed how mCBDC arrangements could (i) improve current correspondent banking models, and (ii) enhance the security and flexibility of cross-border settlement. However, further investigations are necessary before deploying such set-ups live, in particular to better evaluate the international macro-financial implications of cross-border CBDC use.[36]

The experiments highlighted how mCBDC arrangements could facilitate cross-border transactions by optimising current correspondent banking models. One experiment indicated how DLT could increase transparency and reduce both processing times and costs. This was, in part, achieved because the DLT set-up offered transaction traceability and visibility to all participants involved, including post-trade intermediaries, thereby reducing the need for reconciliation. Another experiment showed how the number of correspondent banks involved in a PvP could similarly be optimised by allowing banks to have multi-currency wallets. In this particular case, however, each central bank would still retain full control over its own CBDC.

The experiments also showed that mCBDC arrangements could address current frictions in cross-border payments, in particular by providing more security and flexibility in cross-currency payments:

- Firstly, mCBDC arrangements could help to secure settlement in emerging FX markets. On the one hand, capital flows to emerging markets have significantly increased in the last ten years, leaving a growing share of FX flows prone to settlement fails in the absence of mechanisms to ensure

36 *Central bank digital currencies for cross-border payments: Report to the G20*, July 2021.

settlement finality. On the other hand, DLT can prevent settlement fails as margin calls are programmed on the DLT and PvP can only occur if both wallets are sufficiently provisioned, reducing counterparty risks.

- Secondly, mCBDC systems could help to improve cross-border payments by addressing existing frictions related to the closing times of each jurisdiction's systems, which require many transactions to be initiated in advance, and mean that same-day settlement is rarely possible. CBDC systems could make settlement of cross-border transactions in CeBM more available by adding new intraday settlement possibilities. Further investigations would be needed to understand how the new infrastructure on which multiple CBDCs circulate (regardless of arrangement) can interoperate with existing infrastructures.

3. Two additional key technical findings

3.1 Central banks can retain control over a wholesale CBDC issued on distributed ledger technology

In current conventional payment systems (such as the TARGET services), central banks directly operate an infrastructure where CeBM accounts are opened for a limited number of participants (T2 participants in Europe) who are subject to specific and stringent regulatory requirements. As owner and operator of the system, only the central bank exercises control over its settlement asset. In distributed systems, there is not necessarily a single operator of the system, for instance on a public DLT.

The Banque de France's experiments explored how central banks can exercise similar controls on a DLT environment, without having to be operators of the DLT themselves. In this case, W-CBDC tokens are issued through smart contracts (computer programs embedded in the DLT). The experiments tested different mechanisms through which central banks can keep control over their settlement asset circulating on a DLT.

To exercise control over CeBM, central banks must have some form of access to the DLT infrastructure to authenticate transactions at the protocol level without facing risks of false impersonation. Access can be achieved either by direct operation of a node or by using another node. Although technically feasible, intermediated access to a node exposes the central bank to possible outage or even censorship from the access provider.

The controls implemented during the experiments via smart contracts include, for instance:

- Making central banks the sole issuers of W-CBDC tokens;
- Letting central banks set the perimeter of circulation of the W-CBDC through whitelisting: this involves identifying all permitted users of the W-CBDC tokens, and checking participants' authorisation for every transaction;
- Checking for debit and credit consistency at the transaction level;
- Allowing central banks to freeze the circulation of W-CBDC tokens, preventing them from being used in transactions.

These mechanisms highlight two main avenues for further investigation:

- To what extent do they help mitigate the risk of outsourcing the management of settlement accounts in CeBM, possibly implied by the use of distributed ledgers to process and validate transactions?
- To what extent could they provide central banks with more control over their settlement asset, for instance through real-time monitoring, or intraday restriction capacities?

This question of control over the CBDC is all the more relevant as a W-CBDC could trigger a demand from financial actors that do not currently have access to CeBM but want to settle financial instruments in W-CBDC. This question could also be relevant in if a retail CBDC is issued in addition to a W-CBDC.

The Banque de France's experiments explored how CBDC and its programmability allow market participants to be granted access to CeBM without necessarily giving them access to a specific

infrastructure managed by the central bank (such as T2). In addition, central banks can exercise some controls on how these market participants use the W-CBDC. For instance, in some experiments with a cross-border dimension, some entities which do not have access to T2 had the possibility of using the CBDC. This was achieved in the context of the experiments in the following ways:

- The entities had correspondent banking arrangements with T2 participants. The W-CBDC was issued to the T2 participants, which then used it on behalf of their clients;

- The entities were regulated in other jurisdictions and had access to these jurisdictions' RTGS systems.

However, the experiments did not go beyond demonstrating the technical feasibility of making a CBDC accessible beyond current central banks' eligible counterparties (T2 participants in the case of the Eurosystem). In particular, the implications and potential risks for the transmission of monetary policy should be investigated, as widening access to CeBM could have important implications for the role of intermediaries in today's financial markets and raise legal issues that are not in the scope of this report. Additionally, in the context of the experiments, payment finality was achieved in T2 and the use of W-CBDC tokens was simulated on DLT environments, as CBDC is not yet legally qualified. As a result, before issuing a CBDC, it is essential to clarify where finality of payments occurs and which entities could have access to the CBDC.[37]

3.2 Different technical options are available for efficiently implementing a wholesale CBDC on distributed ledger technology

The Banque de France's experiments involved the use of various technologies, including private DLTs and public DLTs. This variety highlights the technological choices available through the use of DLT with respect to (i) confidentiality and traceability of transactions, (ii) resilience, and (iii) ecological footprint. While assessing performance and scalability was not directly within the remit of the experiments, their results nonetheless provided insights into the potential of various DLTs in this regard (iv).

3.2.1 Confidentiality and traceability of transactions

The experiments explored different options to implement differentiated privacy where market participants' transaction data can be pseudonymous, while the Banque de France could have more visibility over transactions. Two main techniques were investigated: data encryption and data segregation. One experiment highlighted that both techniques can be combined.

The first strategy is data encryption, where specific cryptographic keys are required to decrypt and read specific data. These keys are distributed in order to determine which participants can access which data. Even if market participants can only have access to their private key, allowing them to see their transactions, the central bank could have a copy of all private keys, thus giving it visibility over all transactions (differentiated privacy). The experiments highlighted that differentiated privacy can be implemented through data encryption on both public blockchain and private blockchain through technologies such as Zero-Knowledge Proof. However, conducting encryption on public blockchain generates overall fees as much as ten times higher than for an identical transaction on the same blockchain without the encryption technology. Although fees are less of a constraint on private DLTs, encryption also requires additional computing resources.

37 The Settlement Finality Directive (Directive 98/26/EC of the European Parliament of the Council of 19 May 1998 on settlement finality in payment and securities settlement systems) only covers the finality of payments within "systems" in the meaning of that text. Either the infrastructure on which the CBDC circulates is considered as a system, in which case the definition of «participant» excludes the participation of several actors; or the infrastructure is not considered as a system, which may have consequences for the finality of payments.

The second strategy is data segregation. This implies that data be located on specific nodes of the blockchain. As a result, the transactions are stored in relevant databases only and made accessible to specific node owners, for instance the parties to a transaction. Differentiated privacy is implemented by ensuring that all transactions are also stored in the central bank's node, while only participants' transactions are stored in their nodes. This was implemented during the experiments on private blockchains and non-blockchain distributed systems

3.2.2 Resilience of the infrastructure depending on the consensus mechanism

In the experiments, different consensus algorithms, by which transactions are validated on the ledger, were tested, each with their own benefits and drawbacks.

In some experiments, the Banque de France was fully in charge of validating all transactions involving CBDC.[38] Transactions could not be recorded on the ledger without the consent of the Banque de France nodes. This level of centralised control over transactions by the central bank provides resilience in the face of some risks, such as software bugs, as the central bank can modify the ledger and rectify errors. Conversely, this same access to the ledger by the central bank can be problematic: if a central bank's node is compromised from a cybersecurity point of view, the ledger can also be modified and compromised.

In other experiments, the Banque de France's validation was not imperatively required for transactions to proceed. A simple majority of participants (on public blockchains) or two thirds of participants (on private blockchains) was enough to validate transactions. In this case, the ledger cannot be modified unilaterally by the central bank, which means that a level of consensus has to be defined among the participants in order to rectify any software errors. However, this need for a consensus among nodes in order to validate a transaction also implies that the ledger will keep working even if some nodes, such as the central bank's, are compromised (for instance because of a cyber-security attack). It should be noted that in the case of public blockchains, the simple majority rule (51%), while lower than two thirds, can be harder to achieve given the very large number of participants in the network.

3.2.3 Ecological footprint

As the ecological criticism against blockchains becomes a pressing issue, the use of these technologies by central banks must be consistent with their efforts to green up their activities, as highlighted by the G7.[39]

Criticism of blockchains' ecological footprint stems first from the exorbitant amount of energy that is consumed in the validation process of some prominent public blockchain networks and their consensus algorithms, for instance proof of work (PoW) for Bitcoin and Ethereum 1.0. This algorithm implies that miners compete, in terms of processing power (and thus energy consumption), to validate transactions first and be rewarded with newly mined cryptocurrencies. However, the validation of transactions using a W-CBDC would probably involve a smaller number of actors and computers, and other consensus algorithms have been and are being developed which could be more energy-efficient, such as proof of stake (PoS)[40] or proof of authority (PoA).[41]

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38 In any case, the Banque de France had a view of the euro cash leg of transactions. In the case of the DvP, the Banque de France did not have any visibility over the securities leg. In the case of cross-border payments, the Banque de France did not have any visibility over transactions in a foreign CBDC.

39 G7 Finance Ministers and Central Bank Governors' Communiqué, July 5th 2021.

40 With PoS, the transaction validators pledge the amount required of their assets, as collateral to have the right to validate transactions. If the transaction is not valid, they would lose their pledged assets (partly or fully).

41 With PoA, some participants have the authority to validate transactions.

Seven out of the nine experiments relied on private blockchains or other distributed systems, with no PoW. Two experiments used public blockchains (Ethereum). Ethereum currently relies on PoW and consumes a large amount of energy; however, it is currently performing an upgrade where PoS will replace the current PoW, reducing its energy consumption by a factor of 10,000. The lack of volume in the experiments meant it was not possible to measure the energy efficiency of distributed systems in comparison with conventional systems, but the experiments nonetheless showed that options, in terms of consensus algorithms, are available to limit a CBDC's ecological footprint.

3.2.4 Performance and scalability

The Banque de France's experiments did not focus on technical prototyping but rather on unveiling innovative use cases for CBDC. This resulted in a relatively low number of total transactions being executed in each experiment: no more than 500 transactions for each of them. As a result, it was not possible to assess the scalability of the technologies used during the experiments or their performance if they were to be deployed in a production environment. However, due in particular to the diversity of technologies used during the experiments (public and private blockchains, other types of distributed systems), it was possible to draw some lessons on the scalability of DLTs. Conclusions could notably be drawn on transaction throughput (capacity to process a given number of transactions in a unit of time) and transaction latency (capacity to process one given transaction in a given time).

Some experiment were characterised by low transaction throughputs, attributable to:

- The use of first-generation public blockchain, with high transaction costs and high latency (from 20 seconds to multiple minutes);

- The implementation of multiple complex applications running on-chain on private blockchains.

On the other hand, latency in transaction processing was low in some experiments, suggesting that the technologies used could be scalable.[42] This can be explained by:

- The use of relatively centralized private networks, replicating performance features of conventional infrastructures;

- The use of a relatively decentralised private network made of several layers. Transaction data is stored on a first layer while some computations are made in a second layer (e.g. computations linked to the execution of a smart contract).[43] This boosts transaction speed as, comparatively, not all computations are carried out on a single system.

Regarding public blockchains, scalability could be improved thanks to changes to the consensus algorithm (see 3.2.3 above) and the implementation of layered architectures, for instance.

Overall, the Banque de France's experimentation programme indicates that the choice of the technology that would support the development of W-CBDC is definitely one of the challenges. Blockchain technologies are evolving rapidly, and even if they remain yet to be tested for large-scale applications in order to be used in a financial context, scalability is greatly improving thanks notably to the set-up of layered architectures for achieving appropriately expected computations, as experimented by the Banque de France.

42 This analysis excludes the case where low latency was explained by the use of a testing environment with less security constraints, boosting transaction speed.

43 An example of a layered architecture is the deployment of the Lightning network on the Bitcoin blockchain, which introduces netting and limits the use of layer 1 (Bitcoin blockchain with Proof of Work for validation transactions) to validating and storing netted transactions.

4. Conclusion

With many central banks around the world currently exploring, both conceptually and technically, the possibility of issuing a central bank digital currency, the Banque de France launched its own experimentation programme on the use of a wholesale CBDC. The programme explored how a wholesale CBDC would answer the demand for secure settlement on blockchains, expressed by market participants, and seeks to better understand the consequences of introducing a wholesale CBDC on the overall financial ecosystem and on the ways in which central banks carry out their mandate. In doing so, the Banque de France's experiments build on and complement previous and ongoing work conducted by other central banks and international organisations, including the Bank for International Settlements, the IMF, the World Bank, the G7 and the G20.

This report shows how a wholesale CBDC could be part of central banks' strategies to accompany the rise of tokenised finance. A wholesale CBDC would stand as a way to accompany innovation while maintaining current standards in terms of settlement safety, through the use of CeBM as a settlement asset for wholesale transactions. It could also play a unifying role for financial markets, preventing the fragmentation that could arise from the development of private settlement assets functioning in closed loops with only limited interoperability.

The Banque de France's experiments also concretely explored how cross-border payments could be enhanced by implementing various configurations for multi-CBDC arrangements. The experiments underline that a wholesale CBDC could contribute to faster, cheaper, more transparent and more inclusive cross-border payments, assuming central banks can efficiently cooperate in this matter.

The report also raises some open questions to be further investigated. First, the macroeconomic and monetary policy implications of issuing a wholesale CBDC potentially available to a larger set of participants need to be clarified, as well as the technical implications of controlling a wholesale CBDC in this case. Additionally, central banks must continue their assessment of the technology that could support the issuance and distribution of a wholesale CBDC, carefully weighing the implications of the various options available to them, in view of the imperatives of resilience, performance, energy-efficiency and scalability.

Finally, the experiments' findings highlight that a wholesale CBDC should be considered further, in particular in view of complementing the Eurosystem's ongoing work on a digital euro for retail purposes.

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