BIS Innovation Hub

Lessons learnt on CBDCs

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Content

Introduction

Central bank money has unique advantages – safety, finality, liquidity and integrity (BIS (2021)). As economies go digital, they should continue to benefit from these advantages. Given that money sits at the heart of the financial system, it must continue to be issued and controlled by trusted and accountable institutions that have public policy – not profit – objectives (Cœuré (2021), Carstens (2022)).

The world's central banks are stepping up efforts to prepare the ground for central bank digital currencies (CBDCs) either as digital cash (retail) or tokenised reserves (wholesale). A well designed CBDC will be a safe and neutral[1] means of payment and settlement asset, serving as a common interoperable foundation upon which the new payment ecosystem can develop. It will enable an open and integrated finance architecture, while fostering competition and further innovation.

To build a CBDC for the public, a central bank must understand what users need, and work closely with other authorities and stakeholders to deliver it. With its Innovation Hub, the BIS has focused on the practical details of CBDC designs. CBDCs will take years to be rolled out widely but stablecoins and cryptoassets are already here. This makes it even more urgent to start such research efforts.[2] In our centres around the world, the Hub already has 12 CBDC-related proofs of concept (PoCs) and prototypes either completed or under way, with more to come.

This report shows how the BIS Innovation Hub (BISIH) (Graph 1 and Box A) is helping central banks to embark on their CBDC journeys and discusses the lessons learnt so far. The report starts by introducing the BISIH and how it operates. It then presents the different CBDC projects, splitting them into retail and wholesale as well as domestic and cross-border use cases. For each category, the key insights and lessons learnt are presented from the perspectives of desirability, feasibility and viability. In conclusion, a gap analysis seeks to guide the Hub, central banks and other policy makers on what should come next in terms of CBDC experimentation. The individual projects are summarised in Annex A.

The CBDC projects of the BISIH

Over the last three years, the BISIH has started 29 projects, of which 12 are related to CBDCs. By combining the global focus of the BIS and the local scope of host central banks, the overall strategy is to lead on cross-border use cases while helping to shape domestic efforts. Under this umbrella, individual centres pursue projects tailored to their comparative advantages and individual capabilities. In addition, the Hub collaborates with central banks around the world, international financial institutions,

[1] Provided on an equal basis to all commercial parties with a commitment to competitive fairness.

[2] In addition, a well coordinated regulatory response and sound economic governance are important tools for managing the risks associated with cryptoassets.

the private sector and academia. The nascent implementations of CBDCs across the globe also feeds into the Hub's thinking and work.

The portfolio of completed and ongoing projects spans both wholesale and retail CBDCs and covers domestic as well as cross-border use cases (Graph 1). The majority of projects so far focus on either cross-border wholesale (four projects) or domestic retail use cases or challenges (five projects). Only one project (and its sequel) looks at domestic wCBDC, whereas a recent project was the first to tackle the challenge of the cross-border retail CBDC. Distributed ledger technologies (DLTs) were used in most of the experiments. While decentralised technologies offer many possibilities, a CBDC does not necessarily need to be based on DLT.

BIS Innovation Hub CBDC projects | Graph 1

Increased complexity[3] →

↓ Increased complexity[4]	Domestic use case	Cross-border use cases
Wholesale	**Helvetia I** (CH)① **Helvetia II** (CH)②	**Jura** (CH)③ **Dunbar** (SG)④ **mBridge** (HK)⑤ *<u>Mariana</u>* (CH, SG, EU)⑥
Retail	**Aurum** (HK)⑦ *<u>Sela</u>* (HK)⑧ **Rosalind** (UK)⑨ **Polaris** (SE)⑩ *<u>Tourbillon</u>* (CH)⑪	**Icebreaker** (SE)⑫

Bold font denotes project with a published report. *<u>Italic and underline</u>* denotes ongoing project. (.) denotes the BISIH Centre leading the respective project. ① Settling tokenised assets in central bank money ② Settling tokenised assets in wholesale CBDC. ③ Cross-border settlement using wholesale CBDC. ④ International settlements using multi-CBDCs. ⑤ Connecting economies through CBDC. ⑥ CBDCs in automated market-makers. ⑦ A two-tier retail CBDC system. ⑧ A cyber-secure retail CBDC architecture. ⑨ Application programming interface to distribute retail CBDC. ⑩ Secure and resilient CBDC systems, offline and online. ⑪ Cyber resiliency, scalability and privacy in a prototype CBDC (retail or wholesale). ⑫ Retail CBDC for international payments.

Source: M Bech, "BISIH project showcase: Using CBDCs across borders – lessons from practical experimentation" presentation at BISIH Innovation Summit, March 2023.

The first two projects were *Aurum* and *Helvetia*. Aurum prototyped a retail CBDC wallet that emulates the current two-tiered framework for bank note issuance in Hong Kong SAR while Helvetia tested how "tokenised" assets can be settled in

[3] Cross-border and multicurrency payment systems are more complex to set up and operate than domestic systems. On top of operational challenges, some complexities of domestic systems are amplified in a cross-border context (eg cross-border governance, conflict of laws issues, and adherence to multiple AML and CFT regimes (Bech et al (2020a)).

[4] Compared with wholesale CBDCs, the introduction of retail CBDCs is a more far-reaching innovation. Retail CBDCs modify the conventional two-tier monetary system in that they make central bank digital money available to the general public, just as cash is available to the general public as a direct claim on the central bank (BIS (2021)). The implications of a retail CBDC for the monetary system would depend on its operational architecture.

central bank money, leveraging a fully regulated digital platform based on DLT demonstrated in Switzerland as the SIX Digital Exchange (SDX).

A second wave of projects responded to the G20 cross-border payments programme and explored how to deliver faster, cheaper and more transparent cross-border payments (and securities settlement) using wCBDC. Projects *Jura*, *Dunbar* and *mBridge* demonstrated that common systems encompassing multiple wCBDCs are operationally feasible and can bring efficiencies.[5] Responding to demand from central banks, the work has recently pivoted to domestic retail CBDC. The Hub's efforts focus on specific design challenges and include how to use application programming interfaces (APIs) to distribute and settle retail CBDC (Rosalind), ensure cyber-secure open and accessible retail CBDC architecture (Sela), implement and operate CBDC platforms that are secure and resilient, offline and online (Polaris) and how to develop a CBDC system that preserves transaction privacy, is resilient to quantum computer attacks and can handle large transaction volumes (Tourbillon).

Projects often build on previous work either by host central banks or the Hub itself. For example, Dunbar built on the earlier project Ubin by the MAS, mBridge leveraged the *Inthanon LionRock* projects by HKMA and Bank of Thailand and Jura borrowed from Helvetia. Moreover, the ongoing cross-centre *Mariana* project, which looks at FX trading and settlement in a world with tokenised CBDC, used Projects Dunbar and Jura as starting points. Part of the Hub's value added is in leveraging the diverse experience of existing domestic CBDC experiments to help interlink systems and build international settlement platforms, and also compare them with non-CBDC based solutions (eg Project *Nexus*).

In accordance with the BISIH innovation process, the lessons learnt from the first CBDC projects have been handed over to central bank community via detailed reports (eg BISIH (2022a, 2022b)). In the case of Aurum, source code was also shared via BIS Open Tech for central banks to further build on.[6] Learnings also include insights on the "how" eg how to run tech/innovation projects, or how to identify good vendors.

Box A: The BIS Innovation Hub

The BISIH aims to be a global force for innovation. The Innovation Hub started in 2020 with three centres in Hong Kong SAR, Singapore and Switzerland, respectively. Last year saw the opening of two new centres in London at the Bank of England and in Stockholm together with four Nordic central banks. In May 2023, a centre for the Eurosystem with locations in Frankfurt and Paris saw the light of day and later in 2023, the plan is open a centre in Toronto together with the Bank of Canada. The Hub also has a strategic partnership with the Federal Reserve System through the New York Innovation Center at the Federal Reserve Bank of New York (Graph A1).

[5] See Using CBDCs across borders: lessons from practical experiments (bis.org).

[6] BIS Open Tech is a platform for sharing statistical and financial software to promote international cooperation and coordination. These software tools are developed according to international best practices and standards and can be reused and further developed in a wide variety of environments. See www.bis.org/innovation/bis_open_tech.htm.

BIS Innovation Hub centres | Graph A1

Source: BISIH Innovation Hub, Swiss Centre.

What does the BISIH do? It pioneers innovation. It seeks to move the technology frontier for central banks in their pursuit of monetary and financial stability. The mandate has three pillars (Graph A2, left-hand-panel). In the first pillar, the Hub scans the horizon for new technologies of relevance to central banks and the financial system at large. The Hub seeks to find solutions to pain points and challenges facing central banks and the financial sector. It does so in the second pillar by building and testing technological PoCs, prototypes and minimal viable products (MVPs). The BISIH shares what it learns and produces from its projects with the central bank community and beyond in the form of reports, code and outreach initiatives. Relevant and quality outputs make the Hub a focal point for central bank innovation – the third and final pillar.[7]

The BISIH has six strategic themes, as proposed by central bank governors. These are: (1) sup- and regtech; (2) next-generation financial market infrastructures (FMIs); (3) CBDCs; (4) open finance; (5) green finance; and (6) cyber security.

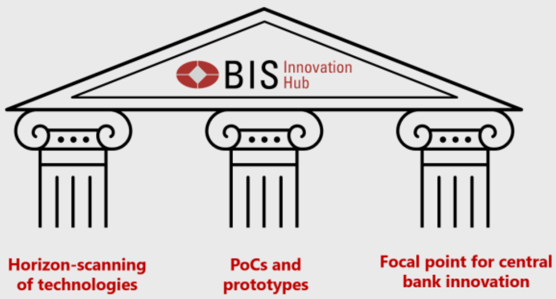
The work programme's[8] products – typically PoCs and prototypes – result from a structured innovation process consisting of three high-level phases (Graph A2, right-hand-panel). An example of such a process is based on established innovation processes (eg Burkus (2013), Gartner (2019)) but it is tailored to specific central bank needs and adapted to the context of the BIS Innovation Hub.

[7] The BIS Innovation Network's role is to support the Innovation Hub's priorities, share knowledge about technology projects and discuss innovative answers to problem statements relevant to central banks.

[8] Every year the BISIH publishes a work programme laying out its priorities: www.bis.org/about/bisih/about.htm.

The BIS Innovation Hub | Graph A2

The three pillars of the BISIH mandate



BISIH innovation process

Source: BISIH Innovation Hub, Swiss Centre.

- **Phase I – Discovery**: During the discovery phase, approaches such as design thinking and foresight thinking are employed to identify potential areas of opportunity for central bank innovation efforts and to create tangible use cases. This phase takes a systemic approach, considering the technology trends and emerging needs that are relevant to the financial sector in relation to central bank policy objectives.

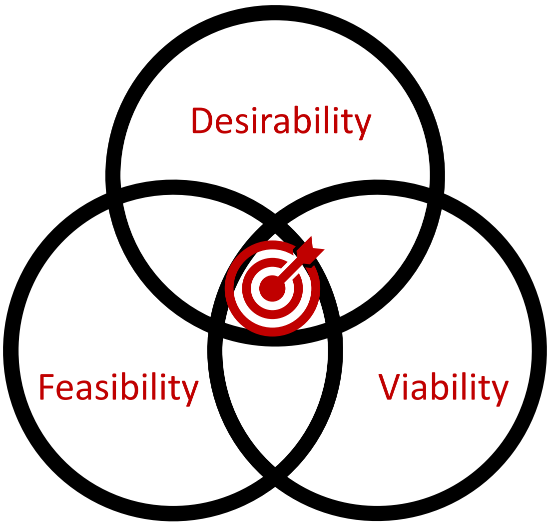
- **Phase II – Exploration**: The exploration phase combines lean startup and agile methods. Early-stage explorations evaluate the potential value of selected use cases. Project scopes are developed and adjusted iteratively in collaboration with the relevant stakeholder community. This phase may involve the development, modification and testing of specific technical components that could be used in subsequent PoCs or prototypes. The aim is to enhance the assessment of potential value added and reduce lead time. The subsequent build phase typically employs the Scrum methodology for iterative development of the PoC or prototype.

- **Phase III – Sharing**: The final phase of the innovation process focuses on evaluating outcomes and disseminating products to a broader community. The assessment of outcomes involves measuring the value of the solution, taking into account the three dimensions: innovation, policy and work processes. This phase serves as a decision point regarding the future course of action, including whether to continue exploring the current work or pivot towards new use cases. The product handover entails transferring knowledge and solution outcomes to relevant stakeholders. The product may consist of various elements such as reports, videos, technical documentation, blueprints, code and/or technical documentation. If necessary, the Innovation Hub may provide support in deploying a solution led by a central bank.

Lessons learnt

Meaningful innovations bring together what is *desirable* with what is *feasible* and *viable* (Graph 2). The discovery phase of the BISIH innovation process seeks to identify challenges where solutions are desirable from both individual and societal perspectives. Given the BISIH's mandate, the focus of projects is on demonstrating technical feasibility. That said, other forms of feasibility such as legal and regulatory may also be considered. Some projects also try to look the potential economic viability of the proposed solutions, but this is difficult given the early-stage nature of many BISIH projects. Ultimately, the best viability test here is whether or not the learnings from the BISIH prototypes or MVPs are being used and deployed at central banks and elsewhere.

Desirable, feasible and viable innovation — Graph 2



Source: BIS Innovation Hub, Swiss Centre.

Wholesale CBDC for domestic use cases

Desirability

By underpinning the future monetary system, CBDCs would be the foundation upon which further innovations build. Their desirability depends to a large degree on where private and public sector stakeholders take payments, clearing and settlement in the future (Bech et al (2020b)). For example, if financial institutions and market infrastructures move towards tokenised securities and such platforms become systemic, then introducing a wCBDC will be core to the functioning of a tokenised environment.[9] Moreover, there is currently much discussion around the concept of unified ledgers and tokenised deposits and, depending on their design, wCBDCs could have great potential (Carstens (2023), BIS (2023b)).

Feasibility

The feasibility lessons on domestic use cases of wCBDC come from Project Helvetia. The project was a multi-phase investigation by the BISIH, the SNB and the Swiss financial infrastructure operator SIX. The project leveraged the test system of SIX Digital Exchange (SDX), a regulated platform for the trading and settlement of tokenised assets.[10]

Via two PoCs, the first phase of Helvetia demonstrated the functional feasibility and legal robustness of settling tokenised assets with a wCBDC as well as by linking SDX to the existing Swiss real-time gross settlement (RTGS) system, SIC. On the other hand, phase II showed that a wCBDC can be integrated with the existing core banking systems and processes of commercial and central banks to provide an end-to-end solution.[11] The legal assessments of Helvetia found that that issuing and transferring wCBDC on a DLT platform operated and owned by a private sector company is feasible and permissible under applicable Swiss law. For other jurisdictions, such a setup might not be permissible.

Both approaches to settling tokenised assets in central bank money were shown to be feasible in a near live setting.[12] From a central bank perspective, the RTGS link is operationally simpler, as it requires no changes to existing central bank operated systems and raises fewer policy questions. The Helvetia analysis also suggests, however, that the wCBDC approach provides more scope for future innovation and efficiency gains in the settlement process[13].

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9 Tokenisation potentially has several benefits. It can reduce the complexity in securities settlement by facilitating simpler, more direct holding systems. It can also facilitate increased automation through the use of smart contracts. For example, FX trading (especially in highly liquid currencies) is already highly automated and fast. However, the settlement layer could benefit from the DLT-related efficiency gains that could result in instantaneous 24/7 settlement. Moreover, tokenisation and programmability can be helpful in terms of shortening settlement cycles, provide alternatives to central clearing and introduce new forms of conditionality. Still many operational and regulator aspects of payment and securities transactions remain the same and liquidity and settlement risks do not disappear.

10 In September 2021, FINMA (the Swiss financial market authority) licensed SDX to operate a fully regulated stock exchange and central securities depository (CSD) based on blockchain technology.

11 The ability of tokenised systems to interoperate with account-based systems will be key to their success. Currently, transfers are largely conducted across account-based systems. Tokenisation introduces new types of arrangement, depending on whether the security or the cash leg or both are tokenised. Tokenisation is likely to occur at different times for different assets.

12 By leveraging SDX, a fully regulated live digital platform based on DLT.

13 The wCBDC issued in the experiment (i) existed overnight, making it easier to implement and execute overnight or longer-term smart contracts, and (ii) supports atomic settlement with no time lag, as it can be blocked by the notary node on the DLT platform simultaneously with trading orders.

Viability

At this point, no central bank has introduced a wCBDC for domestic or other use cases, but they are inching closer, based in part on the learnings from the BISIH projects.

The SNB is currently taking forward the Helvetia investigation and is exploring three models for settling tokenised securities in central bank money (Maechler and Moser (2023)). One model advances the "RTGS link" by exploring whether adjustments can be made to either the link itself or the SIC RTGS system to mitigate the identified disadvantages. Another model explores the introduction of a private Swiss franc "stablecoin" that is protected under bankruptcy laws and backed one to one by reserves (sight deposits) held at the SNB. The final model explores in depth the operational basis for using a Swiss franc wCBDC for integrated settlement on private sector platforms, including the issuance of a real wCBDC on SDX for a limited time and testing selected transactions with market participants.

Another example[14] of a central bank inching closer to a wCBDC traces back to the BISIH Project *Genesis*. Genesis did not experiment with CBDCs but rather prototyped two digital platforms for tokenised green bonds. In February 2023, the HKMA assisted the Hong Kong SAR government in issuing a tokenised green bond based in part on the learnings from Genesis (HKMA (2023)). The live deployment puts the full lifecycle of the bond on a DLT platform, including issuance, settlement of secondary trading, coupon payment and redemption. In order to facilitate these processes, the payment leg was also tokenised. Specifically, the HKMA mints HKD cash tokens in exchange for HKD fiat provided by banks. These "single-purpose" cash tokens are akin to a wCBDC (Yue (2023)).

Retail CBDC for domestic use cases

Desirability

Today, central banks provide bank notes to the public and settlement balances (or reserves) for interbank payments. Some central banks are also involved in the clearing and settlement of cheques and other forms of retail payments. The systems are working, and years of development as well as economies of scale and scope have made them fairly efficient. Nonetheless, most agree that central bank money and payment services need to evolve to be fit for the digital future. The question is how central banks can best support retail payments in the future. This is debated not only by stakeholders in the financial sector but increasingly by the public too, and in many countries rCBDCs are at the centre of this debate.

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14 Other examples include the Reserve Bank of India, which launched a wholesale pilot in November 2022 with nine banks to explore the settlement of secondary market transactions in government securities: see pib.gov.in/PressReleaseIframePage.aspx?PRID=1882883.

Proponents of rCBDCs[15] point to the need to preserve the trust of public money and the many issues that can potentially be addressed, such as financial inclusion, cross-border payments, payment efficiency, safety and innovation. Moreover, central bankers as well as politicians highlight the need to maintain *monetary sovereignty*[16] as well as *strategic autonomy* (Villeroy de Galhau (2022)).[17] In contrast, opponents often stress that private sector is doing a good job in many cases and rCBDC is "a solution in search of a problem". Moreover, opponents point to privacy concerns and fear that an rCBDC will usher in a surveillance state. In addition, many note the potential risk of disintermediating the banking sector.

The desirability of an rCBDC as well as the timing of a decision is likely to vary across jurisdictions. Countries where the use of cash is rapidly declining may need to consider alternatives sooner rather than later. Also, countries where financial inclusion is lacking or the banking system is underdeveloped may see larger benefits. According to the latest BIS survey on CBDC, 93% of countries are engaged in some form of CBDC work, with almost a quarter of central banks piloting a retail CBDC. In addition, more than 80% of central banks see potential value in having both an rCBDC and a fast payment system (Kosse and Mattei (2023)).[18] The BISIH is responding to this demand and has, over the last three years, led five projects on rCBDC focused on domestic use cases (Table 1).

Critical to the success of an rCBDC is to have banks and payment service providers (PSPs) on board. The benefits of an rCBDC cannot be realised if there is insufficient uptake or adoption. However, too much adoption may disintermediate banks and PSPs (BIS (2023c)), especially in financially underdeveloped systems. A significant shift from bank deposits into CBDCs (or other new forms of privately issued digital money) could have implications for lending and intermediation by the banking sector. Flight to CBDC safety could increase in stressed conditions. Central banks might consider measures (eg limits on CBDC's holdings, choices around CBDC remuneration) to manage such risks. Careful design and implementation can help to ensure that the financial system comes to "no harm", as discussed in Group of Central Banks (2021)).

Feasibility

Designing an rCBDC system is a major undertaking, involving a multitude of requirements and stakeholders that might lead to conflicting demands. The BISIH projects do not aim to provide a complete end-to-end solution and have not tested

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15 For a discussion on how rCBDC compares with other payment methods, see [III. CBDCs: an opportunity for the monetary system (bis.org)](#).

16 The power of the state to exercise exclusive control over its currency.

17 The ability of a state to pursue its national interests and adopt its preferred policy without depending heavily on other foreign states.

18 Central banks may want to assess the case for an rCBDC on top of other alternatives such as a fast payment system (FPS). FPS may be easier and cheaper to put in place in the short term but only in jurisdictions where the financial system is already well developed and able to accommodate such an initiative with minimal disruption. Countries with limited financial infrastructures may choose an rCBDC, recognising that the introduction of either an FPS or an rCBDC will be a major undertaking involving several phases of work. Some central banks may consider not consider it a binary choice, as an FPS and an rCBDC can be integrated into the same ecosystem (BIS (2023a)).

the feasibility of such an rCBDC system. Rather they seek to unpack the complexities to individual challenges in the design of an rCBDC. By doing so, BISIH experiments on rCBDC help inform policy and operational decisions, and gain clarity on specific requirements, trade-offs and solution vendor options before an rCBDC is implemented.

The projects tested different use cases. Beyond issuance and redemption, different types of payment (eg peer-to-peer transfers and micropayments), devices (point-of-sale payment, e-wallet in mobile phone) and solutions (online and offline) have been explored. Specific challenges investigated so far include (i) how to distribute an rCBDC with the private sector in charge of customer-facing activities (Aurum and Sela); (ii) how to use application programming interfaces (APIs)[19] to design new payment solutions, support an innovative ecosystem and achieve interoperability with the broader payment system (Rosalind); (iii) how to build a cyber-secure, open and accessible rCBDC architecture (Sela); (iv) how to make secure and resilient, online and offline payments with an rCBDC (Polaris); and (v) how to develop an rCBDC system that preserves transaction privacy, resists quantum computer attacks and handles large transaction volumes (Tourbillon).

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[19] An API is a set of rules and specifications followed by software programmes to communicate with each other, serving as an interface between different software programmes to facilitate their interaction.

BIS Innovation Hub rCBDC projects focused on domestic use cases — Table 1

	Aurum (HK)	**Rosalind** (UK)	**Polaris** (SE)	*Sela* (HK)	*Tourbillon* (CH)
Problem statement	How tiered architectures can be used for the distribution of rCBDC (using intermediated CBDC and stablecoins backed by CBDC)	How to use API to distribute and settle rCBDC, to explore interoperability with the broader payment system, and to support innovation	How to implement and operate CBDC platforms that are secure and resilient, offline and online	How to ensure cyber-secure open and accessible rCBDC architecture	How to develop a CBDC that preserves transaction privacy, is resilient to quantum computer attacks and can handle large transaction volumes
Output	Prototype	Prototype	Handbook	Prototype	Prototype
Use cases tested in addition to issuance, redemption and distribution	Transfers payment using e-wallet in mobile phone and QR code	30+ use cases (eg, online, in-store and offline payments, DvP, micropayments parent and child wallet)	Analysis of offline payment considerations, security and resilience framework, cyber threat modelling gaps	Transfers using technical service providers	Withdrawal, PoS payment, payment over the internet, peer to peer payment
Main trade-off identified (to date)	Security vs performance	Privacy vs ecosystem data sharing. API extensibility vs consistency in user experience	Risk managements vs privacy vs user experience	Cyber risk vs distributing responsibility	Cyber security vs scalability
Main lesson learnt (to date)	The intermediated CBDC model, allows for decoupling the wholesale and e-wallet systems which could strengthen cyber resilience	Privacy model for an open API is fundamental and should be decided from the outset	Offline solutions are complex and need to be designed from an early stage, even if not implemented until later	The addition of new types of intermediary can lead to a more robust, distributed and resilient system that eliminates single points of attack	It is challenging to reconcile privacy, scalability and quantum security
Technology used	Hyberledger Fabric	Open API, FAPI, Hyperledger Besu and Fabric	Hardware and software solutions, including tamper-resistant devices	M10 Digital Currency Platform	Blind signature, mixed networks, post-quantum cryptography

Bold font denotes project with a published report. Italic and underline denotes ongoing project. (.) denotes the BISIH Centre leading the respective project.

Several key learnings have emerged. These include:

- A well designed API has benefits. First, it could facilitate retail payments in CBDC. This would allow an rCBDC to interoperate with other payment systems (eg a fast payment system or global card networks), and other forms of money (eg commercial bank money and stablecoins) while supporting a diverse range of use cases (eg online shopping platforms). Second, it could be applied to a wide range of central bank ledger types and third-party applications and systems. Such broad compatibility will be important in a world where central banks are experimenting with a range of ledger designs and technologies. Meanwhile, private sector systems may be based on many different ledger technologies and systems.
- Balancing privacy with desired features such as financial integrity and security is challenging, but the technology shows promise. For example, privacy-enhancing technologies such as "blind signatures" can allow the central bank to issue rCBDCs without knowing the identity of the holder and could be improved to provide resistance to quantum computer attacks without compromising scalability.
- CBDCs with offline payment functionality could be a powerful digital payment instrument. However, providing offline payments is complex and involves a number of technology, security and operational considerations. Offline payment solutions could operate in three modes,[20] which refer to how the solution would connect online if and when required. They could be based on tamper-resistant hardware, software or a combination of both.

In sum, the BISIH projects on rCBDC are experimenting with (i) the most promising CBDC model: a two-tier model with public-private partnership; (ii) the most fundamental feature: privacy; and (iii) the greatest challenge: cyber security.

Viability

So far only four jurisdictions have introduced live rCBDC pilots: the Central Bank of The Bahamas with the *Sand dollar*, the Eastern Caribbean Central Bank with *Dcash*, the Central Bank of Nigeria with *eNaira*, and the Bank of Jamaica with *JAM-DEX*. Several pilots such as the PBoC with the *e-cny* and RBI with *e-rupee* are under way (updated data set of Auer et al (2020)).[21] So far adoption has been mixed across these pilots, but lessons are being learnt and it is still early days.[22] Big open questions around rCBDCs remain before they can be deployed at scale. These include challenges around

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20 The three modes of operation are fully offline, intermittently offline and staged offline. See [Project Polaris: Handbook for offline payments with CBDC (bis.org)] for a more detailed discussion.

21 Another example of experimentation comes from Hungary. The central bank recently launched an app to improve the financial literacy of students. The app includes electronic money accounts, which are a direct central bank liability, jointly managed by the students and their parents. This is a limited-use CBDC for retail purposes (MNB (2023)).

22 For example, Ree (2023) assesses the eNaira's first year of performance. The paper observes that: (i) despite the laudably undisrupted operation for the first full year, the CBDC project has not yet moved beyond the initial wave of limited adoption; (ii) network effects suggest the initial low adoption spell will require a coordinated policy drive to break it; (iii) its potential in financial inclusion requires a strategy to set the right relationship with mobile money, given the former's potential to either complement or substitute for the latter; and (iv) cost savings from integrating CBDC—as a bridge vehicle—in the remittance process may also be substantial.

rCBDC demand and adoption, concerns around privacy, legal and regulatory implications, communication with and education of the public, solution vendor dependencies, maturity of technology stacks suitable for critical infrastructures and the use of open-source components.

CBDC across borders

The G20's efforts to enhance cross-border payments envision a potential role for CBDCs to help reduce costs and increase speed, while improving transparency as well as inclusiveness. In particular, the FSB-CPMI roadmap stresses the importance of factoring international dimensions into CBDC designs. In response, the BISIH has put significant resources into exploring cross-border use cases for CBDCs.

In the wholesale space, working with different constellations of central banks, the BISIH has analysed many aspects of how CBDC can support cross-border and cross-currency transactions. The lessons learnt are detailed in the individual reports of Projects Jura, Dunbar and mBridge.[23] In addition, the BISIH has conducted a comparative study of the three projects, highlighting commonalities and differences in both design and the lessons learnt (BISIH (2022), Bech et al (2023)). The Mariana project looks to the future. It envisions a world where central banks have issued wCBDC and asks how FX trading and settlement might look. Specifically, Mariana investigates whether so-called automated market-makers (AMMs) could be the answer. AMM stems from decentralised finance, where they allow users to go from say one stable coin to another based on a pool of liquidity and an algorithmic protocol that more or less automatically determines the exchange rate based on the relative shares of coins in the pool.

In the retail space, the BISIH has conducted only one experiment across borders. Using a hub-and-spoke model, Project Icebreaker connected different retail CBDC systems across borders to explore how they can be used for international retail and remittance payments.

Desirability[24]

Better and cheaper cross-border transactions are universally desirable. In addition to cross-border or offshore payments,[25] the three completed wCBDC projects focus on use cases where CBDCs were transferred against either another CBDC (payment versus payment (PvP)) or tokenised securities (delivery versus payment (DvP)). While systems exist to cater to both cross-border PvP and DvP, coverage is not ubiquitous in terms of currencies and jurisdictions, and costs are often seen as being high.

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[23] These projects have focused on settlement only with FX trading done off-platform. Project Mariana is expanding on this work to explore joint trading and settlement in wCBDCs.

[24] Given the futuristic nature of Mariana, desirability and viability are hard to ascertain at this juncture. Feasibility is still being explored. The report is expected to come out by end-November 2023.

[25] Payments in a currency different from the ones of the jurisdictions of the payer and payee.

BISIH cross-border CBDC projects

Table 2

		Jura	**Dunbar**	**mBridge**	**Icebreaker**	*Mariana*
Experiment design	**BISIH centres**	CH	SG	HK	SE	EU, SG, CH
	Central banks	BdF, SNB	MAS, SARB, RBA, BNM	HKMA, BoT, PBoC, CBUAE	CBs of SE, NO and IS	BdF, MAS, SNB
	Output	Prototype	Prototype	Pilot	PoC	PoC
	Type of CBDC	Wholesale, Intraday	Wholesale, O/N w/o interest	Wholesale, Intraday & O/N	Retail	Wholesale
	Currencies	EUR, CHF	AUD, MYR, SGD, SAR	HKD, CNY, THB, AED	ILS, NOK, SEK	EUR, SGD, CHF
	Transaction type	Real value	Simulated	Real value	Simulated	Simulated
	Interoperability model	Common plat. w subnetworks	Common platform	Common platform	Hub and spoke	Common platform for FX
	DLT	Corda	Corda, Quorum	mBridge Ledger	Corda, Hyperledger Besu, Ethereum Quorum	Ethereum
	Operator	Private	Central banks	Central banks	Central banks	Central banks
	Extra use cases	PvP,[1] DvP,[2] offshore	PvP,[1] offshore	PvP	PvPvP	FX trading, PvP

Bold font denotes project with a published report. Italic and underline denotes ongoing project. (.) denotes the BISIH Centre leading the respective project.

[1] A settlement mechanism that ensures that the final transfer of a payment in one currency occurs if and only if the final transfer of a payment in another currency or currencies takes place. [2] A securities settlement mechanism that 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.

Sources: Bech et al (2023); BISIH (2023a).

Feasibility

The three completed wCBDC cross-border projects share two key features. First, all the projects opted to build a common DLT platform, as this was seen as easier and with more upside than, say, interlinking separate domestic platforms.[26] Second, all the projects assumed that central banks would allow access to their wCBDC by *non-resident financial institutions*.[27] Such direct access to wCBDC from abroad allows cross-border payments to be made on a single system without intermediaries such as

[26] Jura implemented subnetworks for the two currencies that allowed the central bank on issuers to control and monitor all transactions in their respective currencies or securities via their roles as so-called notaries. In addition, conditional transfers (PvP or DvP) required approval by both relevant notaries.

[27] The policy decision of broadening access arrangements to non-resident financial institutions could also be undertaken without CBDC.

correspondent banks. However, the projects also differ in several aspects (Table 2). These aspects include:

1) The *number of currencies*/central banks involved. Dunbar (AUD, MYR, SGD, SAR) and mBridge (HKD, CNY, THB, AED) involved four currencies or central banks whereas Jura involved only two (EUR, CHF).[28]

2) The *transaction types* employed. The testing of Jura and mBridge settled real-value transactions whereas Dunbar relied on simulated transfers. Real-value transactions helped to focus the minds of test participants.[29]

3) The *form of wCBDC*. The wCBDCs of Jura existed only during the business day (ie intraday) and the monies were returned to the central bank reserve accounts of the participants prior to close of business. In contrast, the wCBDCs of Dunbar and mBridge were kept overnight on the platform (at least in some jurisdictions).[30] For mBridge, central banks can tailor the time frames during which their CBDCs are allowed to exist on the platform. In neither case did the CBDCs accrue interest.

4) The *platform operator*. For Dunbar and mBridge, one or more of the involved central banks were the operator whereas for Jura the operator was a private sector firm (SDX).

5) *The DLT employed*. Jura used Corda, Dunbar tested Corda and Quorum and mBridge relied on new native blockchain custom-designed and developed by central banks (mBridge ledger).

Every experiment showed that a multiple-wCBDC platform is operationally feasible, allowing multiple currencies and assets to be settled and various access policies to coexist. Beyond meeting core requirements, however, the experiments highlighted potential operational efficiencies compared with current arrangements. Notably, bringing multiple currencies and assets into a single system with participants directly transacting reduced overheads,[31] made settlement faster[32] and increased operational transparency.[33]

Still difficult feasibility questions remain about how (i) new DLT platforms and existing systems will interact; (ii) what kind of scalability challenges might lie ahead;

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28 The EUR/CHF pair is, however, the only bilateral pair covered by the experiments that shows up in the BIS Triennial Central Bank Survey on foreign exchange turnover, with about 1% of global turnover.

29 All transactions were real value, with terms, conditions and prices (rates) agreed ex ante on an over-the-counter (OTC) basis. Significant legal and regulatory preparations were needed for the experiment to take place including rulebooks, contingency procedures and monitoring capabilities.

30 An intraday CBDC means that there is a mandatory conversion of CBDC into reserve balances before the value date change in the real-time gross settlement (RTGS) system. An alternative approach is to have a CBDC exist indefinitely on the DLT platform. This is referred to here as “overnight” CBDC to emphasise that there is no end-of-day conversion, and it remains on the holder’s balance sheet overnight. Nonetheless, an overnight CBDC can still be converted into reserves at any time at the holder’s request.

31 A common DLT platform allows smart contracts to automate rules and processes at a system and participant level (eg having sufficient liquidity or meeting business requirements). This can lower the costs associated with compliance or manual interventions.

32 Reducing the need for intermediaries and enabling direct transactions between participants removes the need for correspondent payment chains that can slow down settlement.

33 In a common platform, payments are recorded on a single ledger in one step and participants have full real-time visibility of their holdings.

and (iii) how resilience and security could best be guaranteed now and in the future. Likewise, once technical designs are shown to be feasible, analysis and simulations of financial stress can be designed far more accurately to highlight potential systemic issues, the need for further policy tools, or how far the global targets set for cross-border payments in terms of cost, speed, transparency and access are being met.

In contrast, project Icebreaker uses a hub-and-spoke model to connect three DLT-based rCBDC systems located in Sweden, Norway and Israel.[34] As none of these jurisdictions have a live CBDC, each rCBDC in the experiment was a limited-scope prototype. Project Icebreaker demonstrated that central banks have a large degree of flexibility when designing their "domestic" systems to support cross-border rCBDC payments through a minimum set of requirements. These include implementing a form of digital escrow (known as a hash time-locked contract) and communicating with a central hub via a standard set of technology-agnostic APIs.

The project also investigated different options in terms of effecting foreign exchange (FX) conversions among the three currencies. For example, the project found that the automated use of bridge currencies[35] can promote competition and may reduce costs for end users. Many of the policy and operational challenges (eg governance, sanctions screening) for a cross-border rCBDC network are, however, common to those of interlinking fast payment systems, as exemplified by Project Nexus.

Viability

The BISIH projects show that central banks have several options in terms of making CBDC work across borders. Common platforms are likely to have more upside but hub-and-spoke designs provide more flexibility for domestic systems and are thus easier to contemplate at least in the short run.[36] Throughout the experiments, DLT was found to provide new solutions to many "old" operational challenges and policy questions. For example, in Project Jura, subnetworks allowed the platform to respect jurisdictional boundaries and data location requirements while (dual) notaries allowed central banks to control and monitor their currencies both in terms of payment and PvP settlement. Moreover, programmability allows for new types of conditional or chained payment, and certain policy controls (eg capital controls) can be built in from the start.

Although systems with multiple CBDCs are technically feasible, further work is needed to assess viability considering policy, legal and regulatory, governance and economic issues, including macro-financial implications (Box B).

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[34] In designing a hub-and-spoke model for rCBDCs, Project Icebreaker drew many lessons from Project Nexus (Singapore Centre), which has developed a hub-and-spoke model to connect the domestic fast payment systems of different jurisdictions at scale.

[35] A currency that is used as an intermediate step in an exchange between two currencies for which there is no direct foreign exchange rate, or where the direct rate is unfavourable.

[36] There is no "one-size-fits-all" model. While CBDC cross-border arrangements could provide an advantage compared to traditional cross-border arrangements, several challenges arise. For example, a common platform would require greater protection than interlinking system due to the "single point of failure" problem. See CPMI-BISIH-IMF-WB (2022) for a discussion of the benefits and challenges of each interoperability model.

The legal implications arising from cross-border CBDC arrangements will be highly dependent on their design. FMIs should have a robust legal basis for their activities in all relevant jurisdictions (CPMI-IOSCO (2012)). Traditional cross-border arrangements have to manage multiple legal and regulatory frameworks, which can add complexity. Cross-border CBDC platforms are no different. Changes related to the issuance and transfer of a CBDC, and the finality and validity of the settlement may have idiosyncratic challenges. Developing rulebooks, contingency procedures and monitoring capabilities can all help highlight challenges or areas where more clarity might be needed.

Governance is potentially complex. Any cross-border CBDC arrangement will need to be supported by a commonly agreed governance framework that determines the rules, rights and obligations of all parties. A common ownership and governance model for multiple central banks in individual but overlapping (digital) realms is novel territory. However, CLS and SWIFT provide several decades of lessons on cooperative oversight of private companies. And the existence of these arrangements shows the possibility of successful cross-border collaboration where there are common incentives[37].

Further experimentation could help. A new phase of the mBridge project is testing additional business cases and transaction types, exploring interoperability with domestic payment systems, and introducing liquidity management tools. Forthcoming projects will do more work to tease out legal and regulatory issues in a cross-border context.[38]

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[37] Governance arrangements for a DLT platform could include "levels" of rules to balance flexibility with standardisation. For example, they could feature (i) rules applicable to all (eg access to the system); (ii) jurisdiction-specific rules (eg access to a CBDC); and (iii) currency-specific rules (eg FX controls).

[38] For example, a forthcoming project in the Singapore Centre aims to develop a common protocol layer that embeds a set of policy and regulatory measures relevant in cross-border payment arrangements.

Box B: Economic implications of cross-border use of CBDCs

CBDCs that can be used across borders bring benefits as well as challenges. The potential of CBDCs to enhance cross-border payments depends on their access configurations. At a retail level, non-resident individuals could be allowed to hold a CBDC issued by another jurisdiction, with access allowed for a limited period, such as a tourist visit, or indefinitely. In a wholesale context, non-resident financial institutions could be allowed to hold a wholesale CBDC issued in another jurisdiction either directly or indirectly. An additional approach to facilitating cross-border payments with CBDCs is by ensuring interoperability between CBDC systems, either by facilitating their compatibility, interlinking them, or establishing a common platform (Auer et al (2021)).

Regardless of the access or interoperability model, cross-border CBDC arrangements need to be designed in such a way that negative spillovers to the macroeconomy and risks to financial stability are limited (CPMI-BISIH-IMF-WB (2022)). One potential concern is that cross-border use of CBDCs could hamper monetary sovereignty by spurring currency substitution, exchange rate volatility and tax avoidance (Chen et al (20222)), especially in countries with weaker economic fundamentals. Of course, private sector developments such as cryptoassets and stablecoins may also increase such risks (BIS (2023d)). Emerging markets and developing economies may face a set of additional risks which include capital flow and exchange rate volatility, macroeconomic policy challenges, loss of monetary sovereignty, regulatory perimeter collapse, and illicit activities (Prasad (2023)). International cooperation is key to limiting cross-border spillovers.

Careful design of CBDCs could help mitigate potentially adverse macro-financial implications of cross-border use of CBDC. Examples include design features such as restrictions on holdings of CBDCs by non-residents, caps and fees on flows, and specific risk monitoring systems (CPMI-BISIH-IMF-WB (2022)). These design choices are ultimately policy decisions, and there are technological ways of addressing them that central banks can employ.

A common platform model for wCBDC can be designed from a technical perspective to support different access policies. The information design about CBDC holdings can allow for monitoring the currency flows outside a jurisdiction. Control measures that restrict the circulation of CBDC under certain conditions can be programmed into the technology or a payments platform.[39] These tools could provide central banks with the ability to broaden access, while mitigating macro-financial vulnerabilities. Moreover, one design option could be to embed policy measures (eg capital flow management, macroprudential, AML/CFT) into smart contracts governing CBDC in a common protocol layer. This could ease the general policy and regulatory compliance burden by automating compliance procedures, providing real-time transaction monitoring, and increasing transparency and visibility around country-specific policies.

A crucial prerequisite for obtaining the greatest benefits from cross-border CBDC arrangements is the need for cooperation between jurisdictions. Partnerships with the private sector[40] could also help to further develop technology solutions for the use of CBDCs across borders.

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39 A CBDC does not necessarily equal programmable money. This would be a policy/design choice to be made by each jurisdiction.

40 See [Press release: Reserve Bank of India and Bank for International Settlements invite cross-border payments solutions for G20 Techsprint (bis.org)].

A path forward

Work on CBDCs by any jurisdiction can benefit from the lessons learnt in the experiments of other central banks and the BISIH. BISIH projects are helping to inform the work of central banks and other policymakers and legislators on the technological choices underlying a CBDC. Experimenting under the BISIH umbrella allows projects to build iteratively on one another with a view to gaining a richer understanding for the entire central bank community. Looking to the future, the BISIH will work further on the "what" and the "how" of CBDCs.

One way to assess "what" the BISIH (and others) should work on in future is to relate the essential CBDC features, and evaluation criteria listed by eg the Group of Central Banks (2020) and (CPMI-BISIH-IMF-WB (2022) with the learnings from the BISIH's CBDC project so far (Annex B). This gap analysis shows that work has been progressing on instant payments, interoperability and privacy for all types of CBDC and use case. More work is still needed to explore technical aspects such as scalability and performance, the coexistence of DLT-based and traditional infrastructures, cyber security and resilience as well as legal arrangements. Complex trade-offs between these features will also need be addressed, including how to balance scale, speed and open access with security, and how to balance offline functionality with complexity and security. Sandboxes and pilots with real-value transactions could help inject further realism.

The "how" could follow a modular approach. Projects could build components that can be bundled together. In this approach, different modules such as payment, foreign exchange, compliance can be decoupled and modularised to accommodate evolving needs. This would allow the central banking community to adapt and extend different functionalities to their technical, business and regulatory requirements. For example, the Hub has developed an in-house DLT experimentation platform, known as Arena, which offers the option of privacy via so-called stealth accounts. Arena is being used in Project Mariana, which is looking at foreign exchange trading and settlement in a future where central banks have issued wholesale CBDC, applying concepts developed in decentralised finance (DeFi). Features developed in other non-CBDC BISIH projects could be used in a CBDC context. For example, the synchronous settlement model developed by Project *Meridian* could be used for a foreign exchange transaction. An alternative could be the Nexus model, which allows the payment service to be decoupled from the FX service such that smaller banks and non-bank PSPs who do not want to incur the cost and complexity of managing FX and liquidity risk can reach out to a competitive market of FX providers. Such a solution may facilitate business processes in a CBDC context too.

Collaborative efforts are necessary to answer the questions ahead and the BISIH is uniquely positioned to bring central banks and private sector together to explore the future for CBDCs.

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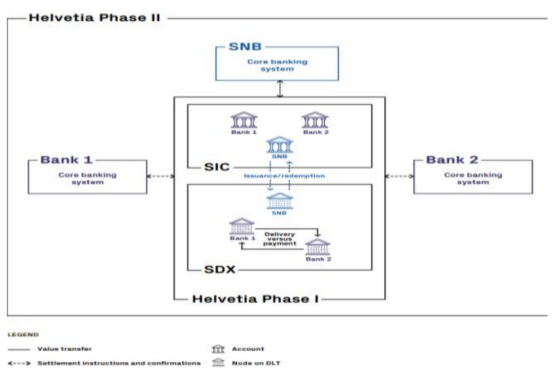
Annex A: Overview of experiments

<table>
<tr><th>Description</th><th>Graph</th></tr>
<tr><td>Project Helvetia, together with the BIS Innovation Hub Swiss Centre, the Swiss National Bank and the financial infrastructure operator SIX, explored how central banks could offer settlement in central bank money with more tokenised financial assets based on DLT, focusing on operational, legal and policy questions in two phases. Phase I built on the test environments of the Swiss real-time gross settlement system and SIX Digital Exchange (SDX), a platform for the trading and settlement of tokenised assets. Phase II expanded on the work carried out in Phase I by (i) adding commercial banks to the experiment; (ii) integrating wholesale CBDC into the core banking systems of the central bank and commercial banks; and (iii) running transactions from end to end.</td><td>
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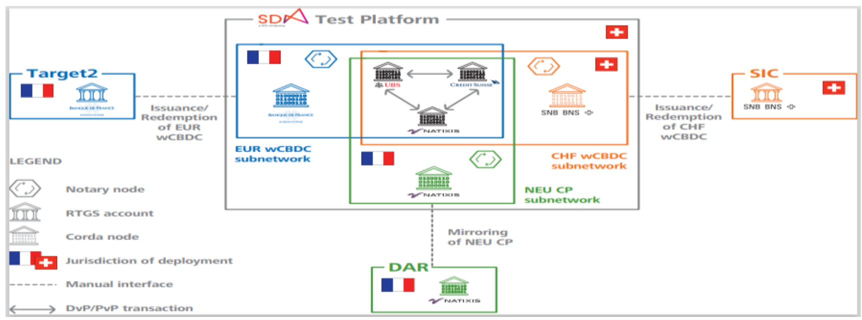
<tr><td>Project Jura, together with the BIS Innovation Hub Swiss Centre, the Bank of France, the Swiss National Bank and a private sector consortium, including the SIX Digital Exchange (SDX), explored how to use wholesale CBDC for cross-border payment and settlement of tokenised financial instruments using a common multi-CBDC platform with separate subnetworks. Project Jura explored the direct transfer of euro and Swiss franc wholesale CBDCs between French and Swiss commercial banks on a single DLT platform operated by a third party. Tokenised asset and FX trades were settled using PvP and delivery-versus-payment (DvP) mechanisms. The Jura experiment was conducted in a near real setting, using real-value transactions and complying with current regulatory requirements.</td><td>
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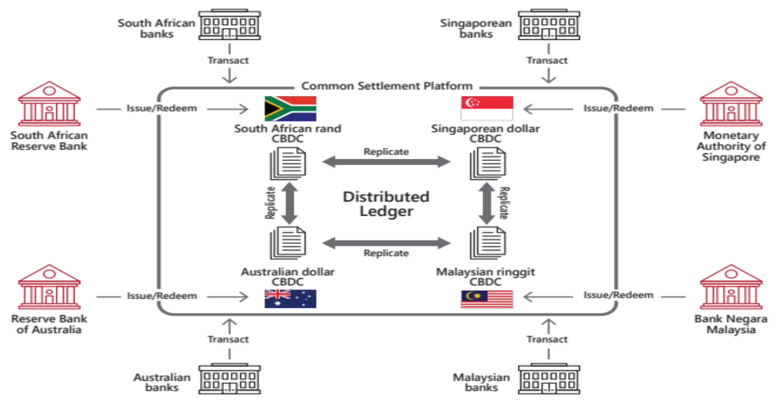
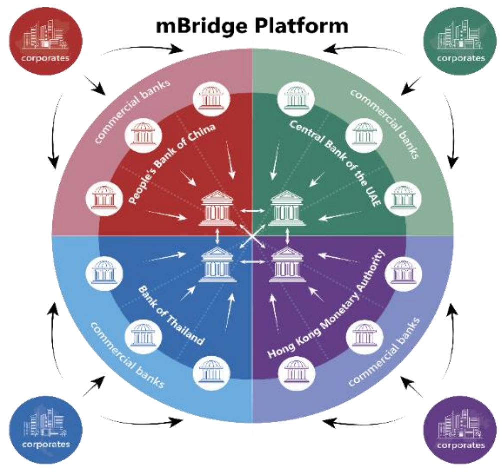
Project Dunbar, in collaboration with the BIS Innovation Hub Singapore Centre, the Reserve Bank of Australia, Central Bank of Malaysia, Monetary Authority of Singapore and the South African Reserve Bank, explored how a common platform for multi-CBDCs could enable cheaper, faster and safer cross-border payments. It identified the challenges of implementing a multi-CBDC platform shared across central banks and proposed practical design approaches to address them. These approaches were validated through the successful development of technical prototypes on Corda and Quorum, proving that the concept of multi-CBDCs was technically viable.	
Project mBridge is being developed by the BIS Innovation Hub Hong Kong Centre, the Hong Kong Monetary Authority, the Bank of Thailand, the Digital Currency Institute of the People's Bank of China and the Central Bank of the United Arab Emirates. It explores how wholesale CBDCs can be used for cross-border payments using a common multi-CBDC platform. The mBridge platform is built in a modular "Lego bricks" approach to enable flexibility of implementation and the inclusion of features that apply across participating members. Focus areas in the current phase include further work on the technology stack, and deeper dives into legal and governance aspects. mBridge demonstrates that it is realistic to aim for a tailored multi-CBDC platform solution to tackle the limitations of today's cross-border payment systems.	

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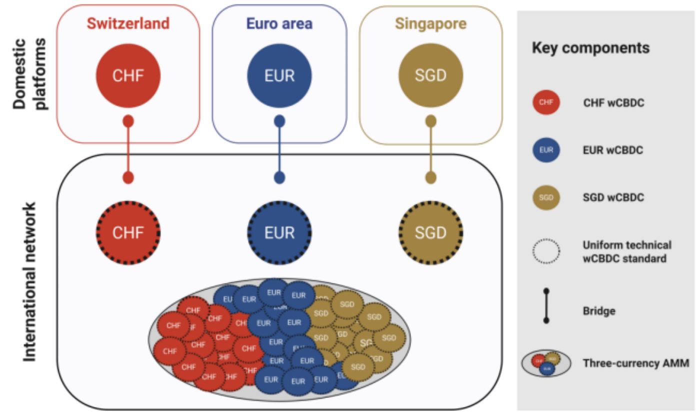
<tr>
<td>Project Mariana is a joint proof of concept between the Switzerland, Singapore and Eurosystem BIS Innovation Hub Centres, the Bank of France, the Monetary Authority of Singapore and the Swiss National Bank. The project expands on previous wCBDC experiments by the BISIH, exploring concepts developed in decentralised finance (DeFi) applications. It set out to investigate whether so-called automated market-makers (AMMs) using wCBDCs could improve the effectiveness, safety and transparency of FX trading and settlement, eliminating some of their associated risks in FX markets. The project also examined cross-border interoperability using wCBDC based on a uniform technical standard, as a way to future-proof CBDC developments.</td>
<td>
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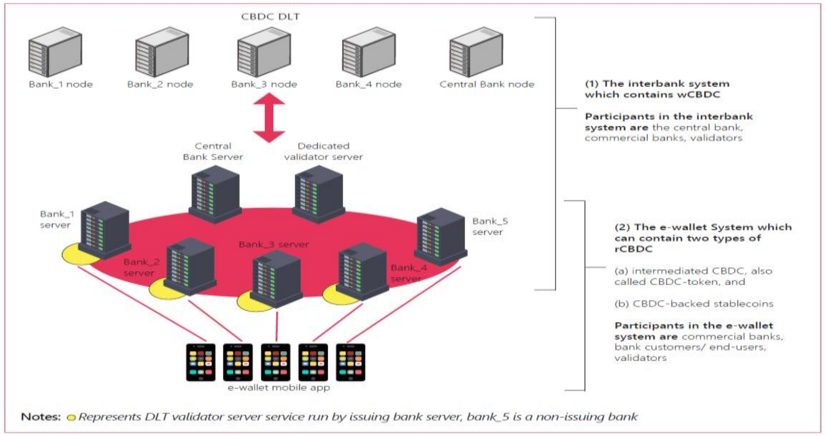
<tr>
<td>Project Aurum, in partnership with the BIS Innovation Hub Hong Kong Centre, Hong Kong Monetary Authority and the Hong Kong Applied Science and Technology Research Institute, explored how tiered architectures can be used for the distribution of retail CBDC. It is a full-stack (front-end and back-end) CBDC system comprising a wholesale interbank system and a retail e-wallet system. The aim was to bring to life two very different types of token in the interbank system: intermediated CBDC and stablecoins backed by CBDC. The Project Aurum prototype is designed to prevent over-issuance and to be flexible for different CBDC models. The technical manuals together with the source code are accessible to all BIS member central banks on <u>BIS Open Tech.</u></td>
<td>
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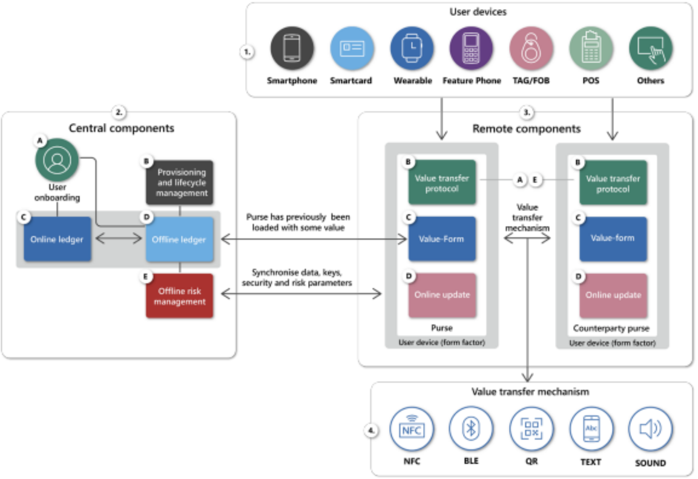
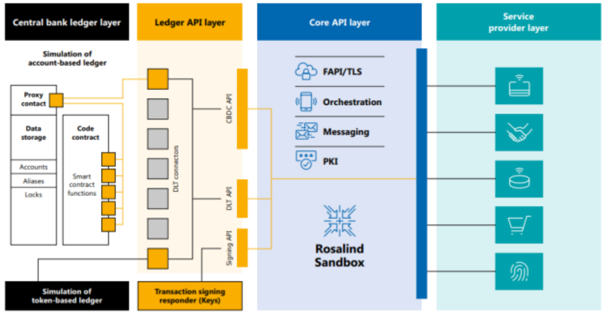
Project Polaris, launched by the BIS Innovation Hub Nordic Centre, explores how to implement and operate end-to-end secure and resilient CBDC platforms, including provisions for offline functionality. A key focus of the project is on the provision of offline payments functionality for CBDC, which could address requirements for resilience, crisis robustness, financial inclusion, cash resemblance, accessibility and other desiderata. Another key focus area is on the practical aspects of security and resilience, taking a risk-based approach, to build a security and resilience playbook to inform the work of central banks. This would build on existing industry frameworks and apply them to CBDCs, incorporating state-of-the art practices to put together a set of fundamental capabilities and associated processes for a central bank to consider when implementing a secure and resilient CBDC system.



Project Rosalind, a joint experiment with the BIS Innovation Hub's London Centre and the Bank of England, investigated how to use API) functions to distribute and settle retail CBDC payments. Based on a two-tier distribution model, the project explored how this interface could best enable a central bank ledger to interact with private sector agents to safely provide retail payments. It also explored some of the functionalities required to enable a diverse and innovative set of use cases to be developed by the private sector. Project Rosalind demonstrated a set of API functionalities that could enable a close collaboration between the public and private sector in developing a retail CBDC system as well as supporting a robust ecosystem to spur innovation. Project Rosalind completed a TechSprint in April 2023.



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<tr>
<td>Project Sela, in partnership with the BIS Innovation Hub Hong Kong Centre, the Hong Kong Monetary Authority and the Bank of Israel, explores how to ensure cyber-secure two-tiered retail CBDC architecture. The focus of the project is investigating the cyber security and technical feasibility of a two-tier retail CBDC architecture that allows intermediaries, such as commercial banks, payment service providers and financial technology firms, to provide CBDC services without any related financial exposure. If reducing financial exposure for retail CBDC intermediaries proves feasible, this could lead to a more accessible CBDC system. With this wider access, however, comes heightened concerns surrounding preventative cyber security. Project Sela will therefore evaluate how cyber security can be enhanced while providing wider system access.</td>
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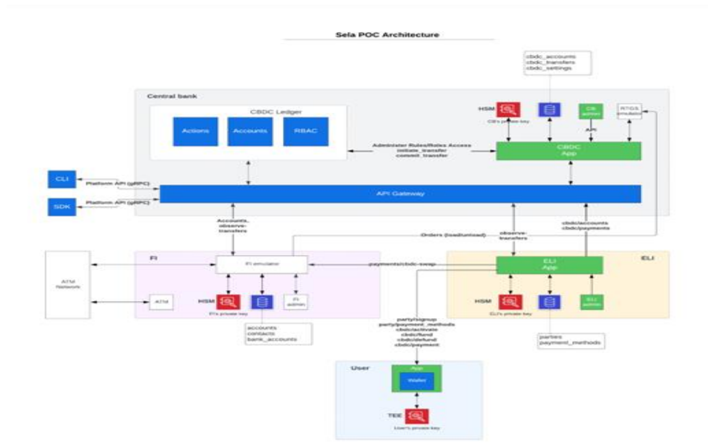

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<tr>
<td>Project Tourbillon, launched by the BIS Innovation Hub's Swiss Centre, investigates how to develop a CBDC system that preserves transaction privacy, is resilient to quantum computer attacks and can handle large transaction volumes. Central banks have identified cyber resiliency, scalability and privacy as core features of CBDCs. However, designing them involves complex trade-offs between these three elements. Project Tourbillon aims to reconcile these trade-offs by combining proven technologies such as blind signatures and mixed networks with the latest research on cryptography and CBDC design. The conclusions of this project will be relevant for both wholesale and retail CBDC systems.</td>
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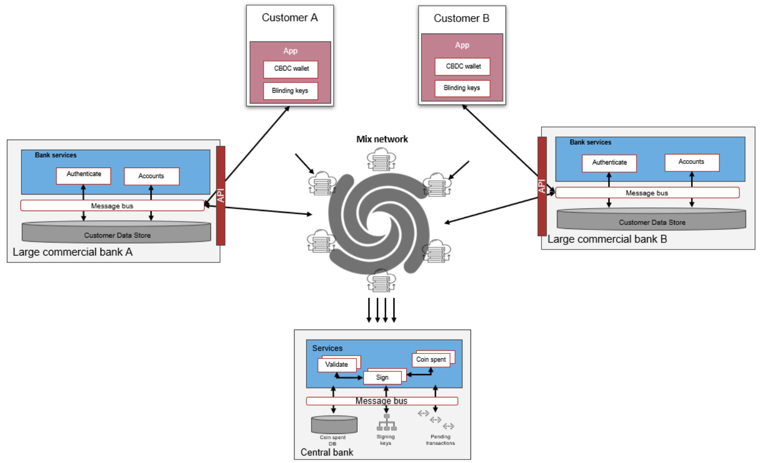

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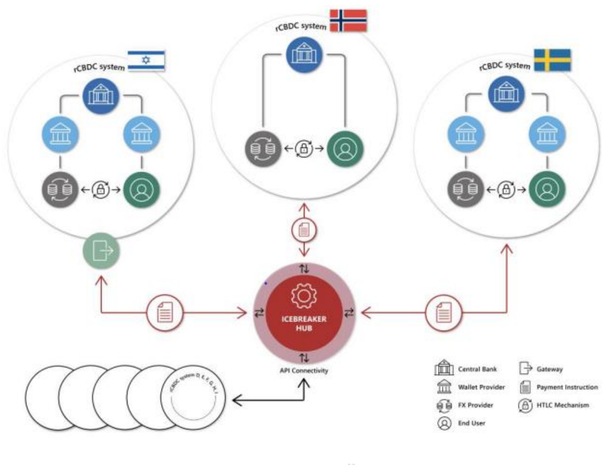
Project Icebreaker, a collaboration with the BIS Innovation Hub Nordic Centre and the central banks of Israel, Norway and Sweden, studied how retail CBDCs can be used for international retail and remittance payments using a hub-and-spoke model as a way to interlink domestic systems. Additional features promoted simplicity and interoperability, reduce settlement risk, and foster competition and transparency for cross-border retail CBDC payments. The project tested the technical feasibility of conducting cross-border and cross-currency transactions between different experimental retail CBDC systems. It shows that central banks can have almost full autonomy when designing their domestic retail CBDC system while still being able to participate in a formalised interlinking arrangement to enable cross-border payments.



Annex B: Selected CBDC features

Selected CBDC features — Table B1

	Domestic use case		Cross-border use case	
	Retail	**Wholesale**	**Retail**	**Wholesale**
Secure and resilient – the system should be extremely resistant to cyber attacks, operational failure, disruption or other threats.	*Tourbillon* *Sela* **Polaris**			
Instant – the system should offer instant or near instant system finality of settlement of transactions.	**All projects**			
Scalable – the system should be able to process large volume of transactions.	*Tourbillon*			
Interoperable – the system should offer sufficient interaction mechanisms with other payment systems and arrangements to allow easy flow of funds between systems.	**Aurum, Rosalind**	**Helvetia I** **Helvetia II**	**Icebreaker**	**Jura** **Dunbar** **mBridge** *Mariana*
Privacy – data governance arrangements should ensure users' privacy and control over data	**All projects**			
Inclusion – the system should enhance financial inclusion.	**Polaris, Rosalind**		**Icebreaker**	
Flexible and adaptable – the system should be adaptable to changing conditions and policy imperatives.	**Rosalind**			
Legal framework – the central bank should have clear authority underpinning its issuance of a CBDC.		**Helvetia I** **Helvetia II**		
Standards – system and participating entities should conform to the appropriate regulatory standards.				*Forthcoming project*

Bold font denotes project with a published report. Italic and underline denote ongoing project.

Source: combined features from *Executive paper – Central bank digital currencies: foundational principles and core features* (bis.org), *BIS Annual Economic Report 2022*, and *Options for access to and interoperability of CBDCs for cross-border payments* (bis.org).

Annex C: Glossary

Access: households' and businesses' access to payment services and the ability of banks, other PSPs and, where relevant, other market infrastructures to use the services of a CBDC system: see www.bis.org/publ/othp52.pdf.

Application programming interface (API): a set of rules and specifications followed by software programs to communicate with each other, and an interface between different software programs that facilitates their interaction.

Atomic settlement: instant exchange of assets, such that the transfer of each occurs only upon transfer of the others.

Blind signatures: cryptographic technique, as introduced by Chaum (1982), as a form of digital signature in which the content of a message is disguised (blinded) before it is signed.

Common platform: refers to CBDCs that use a single common technical infrastructure and potentially also a common rulebook. This model does not connect separate CBDC systems, but rather establishes a common platform to achieve interoperability between CBDCs: see www.bis.org/publ/othp52.pdf.

Decentralised finance (DeFi): a set of activities across financial services built on permissionless DLT such as blockchains.

Delivery versus payment (DvP): a settlement mechanism that links an asset transfer and a funds transfer in such a way as to ensure that delivery occurs if and only if the corresponding payment occurs: see www.bis.org/cpmi/publ/d101.htm.

Hub-and-spoke model: a common hub connects two or more separate CBDC systems of participating jurisdictions. The hub can be a payment system in itself, but does not necessarily have to be: see www.bis.org/publ/othp52.pdf.

Interoperability: the technical, semantic and business compatibility that enables a system or mechanism to be used in conjunction with other systems. Interoperability allows participants in different systems to conduct, clear and settle payments or financial transactions across systems without participating in multiple systems: see www.bis.org/publ/bisbull49.pdf.

Payment versus payment (PvP): a settlement mechanism that ensures that the final transfer of a payment in one currency occurs if and only if the final transfer of a payment in another currency or currencies takes place: see www.bis.org/cpmi/publ/d101.htm.

Programmability: a feature of programmable platform and other technologies whereby actions can be programmed or automated.

Programmable platform: technology-agnostic platform that includes a Turing machine with an execution environment and a ledger and governance rules: see www.bis.org/publ/arpdf/ar2023e3.pdf.

Smart contract: self-executing applications of programmable platforms that can trigger an action if some pre-specified conditions are met.

Tokenisation: the process of recording claims on real or financial assets that exist on a traditional ledger onto a programmable platform.

Tokenised deposit: a digital representation of a bank deposit in a programmable platform. A tokenised deposit represents a claim on a commercial bank, just like a regular deposit.

Quantum computer: refers to a device that uses the quantum behaviour of matter rather than the classical laws to make calculations. The quantum objects manipulated in a quantum computer are called "qubits", a contraction of the term "quantum bit". Quantum computers today are still an emerging technology and a research endeavour rather than an established engineering discipline: see www.bis.org/publ/othp67.pdf.

Quantum-resistant cryptography: also called quantum-resistant encryption or post-quantum cryptography, applies encryption algorithms that should resist to attacks based on quantum computers.