BIS Innovation Hub

# Using CBDCs across borders: lessons from practical experiments

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Morten Bech
Morten.Bech@bis.org

Codruta Boar
Codruta.Boar@bis.org

Daniel Eidan
Daniel.Eidan@bis.org

Philipp Haene
Philipp.Haene@snb.ch

Henry Holden
Henry.Holden@bis.org

Wee Kee Toh
WeeKee.toh@bis.org

# Using CBDCs across borders: lessons from practical experiments[1]

*Key takeaways*

- The BIS Innovation Hub (BISIH) is leading practical experiments to show how central bank digital currencies (CBDCs) could help deliver faster, cheaper and more transparent cross-border payments.
- These experiments demonstrate that common systems encompassing multiple CBDCs are operationally feasible and could bring efficiencies. Yet policy, legal, governance and economic questions remain.
- The BISIH is uniquely positioned to bring central banks together in the collaborative efforts that will be necessary to make further progress on this question.

## Introduction

Central bank digital currencies (CBDCs) could help to deliver better cross-border payments. Nine out of 10 central banks are exploring CBDCs, both conceptually and technically, either in retail or wholesale form or both. Work on wholesale CBDCs is increasingly driven by reasons related to cross-border payments efficiency (Kosse and Mattei (2022)). The G20 has made enhancing cross-border payments a priority and endorsed a comprehensive programme in the form of a set of 19 building blocks led by the Financial Stability Board (FSB) and the BIS Committee on Payments and Market Infrastructures (BIS CPMI) to address the key challenges (BIS CPMI (2020)). As part of the more forward-looking work of the roadmap, one building block (19) considers how to factor an international dimension into the design of CBDCs. In response to the G20 call for action, the BIS Innovation Hub (BISIH) is coordinating experiments on how this can be done. At present, three cross-border CBDC projects with central banks and private

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sector partners around the world have been completed (Inthanon-LionRock2 (ILR2), Jura and Dunbar), another is in progress (mBridge) and more are planned.[2]

Here, we outline the similarities and differences of these four projects with a view to setting out the insights and lessons learnt. Collectively, the projects show that platforms with two or more CBDCs are technically feasible and offer a range of benefits that can lead to faster, cheaper and more transparent payments across borders. While this is desirable, questions remain unanswered related to policy considerations, legal and regulatory frameworks, and basic operational economics that might call into question the viability of multi-CBDC platforms[3]. Hence, there are many avenues for future explorations by both the public and private sector, individually and in collaboration.

## Overview of experiments

The BISIH has conducted four cross-border CBDC experiments over the last 18 months. They are part of a broader portfolio of projects that examine different aspects of retail and wholesale CBDC (wCBDC) in both a domestic and cross-border context (BISIH et al (2022)).

### Inthanon-LionRock2

In September 2021, the BISIH Hong Kong Centre completed **Project Inthanon-LionRock2 (ILR2)** together with the Hong Kong Monetary Authority (HKMA) and the Bank of Thailand (BoT) (BISIH et al (2021b)). ILR2 built on the original Inthanon-LionRock project by HKMA and BoT (Graph 1). The goal of the project was to explore the use of DLT for facilitating real-time cross-border funds transfers using an atomic payment versus payment (PvP) mechanism for foreign exchange (FX) transactions between the two jurisdictions.

The experiment demonstrated the potential of using digital currencies and DLT to deliver real-time, cheaper and safer cross-border payments and settlements. The common platform was able to complete cross-border transfers in seconds, as opposed to several days. It also demonstrated the potential to reduce several cost components of correspondent banking by up to half. It does so by using smart contracts and an algorithmic liquidity saving mechanism to reduce the nostro-vostro liquidity, treasury operation, FX and compliance costs.[4]

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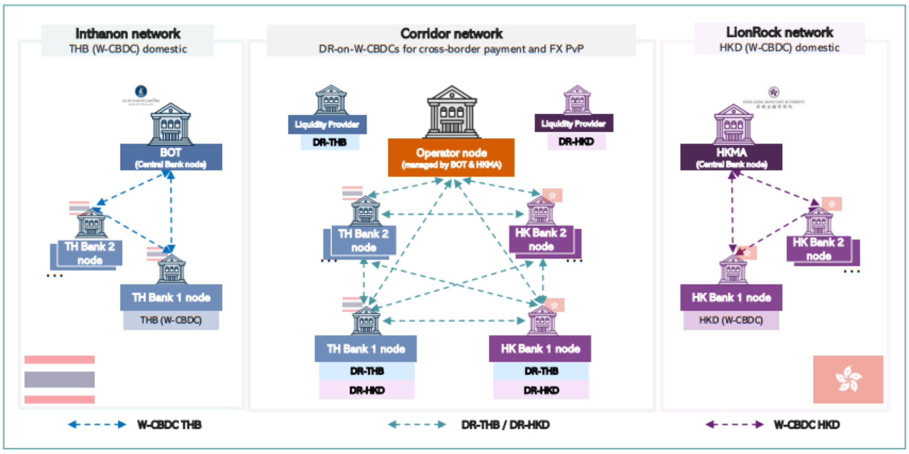
2 Full details of the design and findings of the individual experiments based on distributed ledger technology (DLT) are available on the BIS website.

3 See Auer et al (2021) for a description of three high-level approaches to form multi-CBDC arrangements.

4 See BISIH et al (2021b) at page 33.

Experimental architecture: ILR2 Graph 1




The proposed model of the corridor network comprised of the corridor operator node, the participating bank nodes and the foreign currency liquidity providers. The first one is a joint BoT and HKMA body that enables the issuance and redemption of wCBDC and ensures compliance with regulation. The second initiates and settles cross-border payments, and the third one provides foreign currency liquidity when gridlock occurs.

## Jura

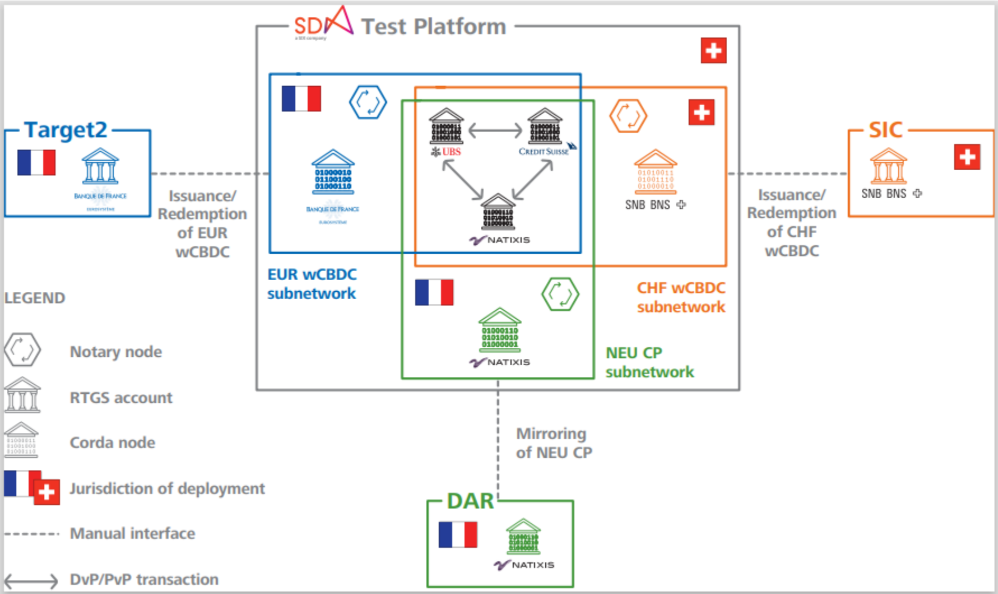
The Swiss Centre, together with the Bank of France, the Swiss National Bank and a private sector consortium, including the SIX Digital Exchange (SDX), published the findings of **Project Jura** in December 2021 (Graph 2) (BISIH et al (2021a)).[5] Project Jura explored the direct transfer of euro and Swiss franc wCBDCs 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,[6] using real-value transactions and complying with current regulatory requirements.

[5] The Jura Mountains are a subalpine mountain range that run parallel to part of the French–Swiss border.

[6] 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.

Experimental architecture: Jura

Graph 2




The experimental architecture comprised four infrastructure elements: (i) TARGET2; (ii) the SIC system; (iii) the Digital Asset Registry (DAR); and (iv) the SDX test platform (Graph 2). The first three enabled the issuance and redemption of wCBDC and tokenised commercial paper and final settlement of instruments. The SDX test platform was where the PvP and DvP exchanges of these tokens took place.

Issuing a wCBDC on a third-party platform and giving non-resident financial institutions direct access to central bank money raises intricate policy issues. Jura explored a new approach including subnetworks and dual-notary signing. This may give central banks comfort to issue a wCBDC on a third-party platform and to grant non-resident financial institutions access to wCBDC.

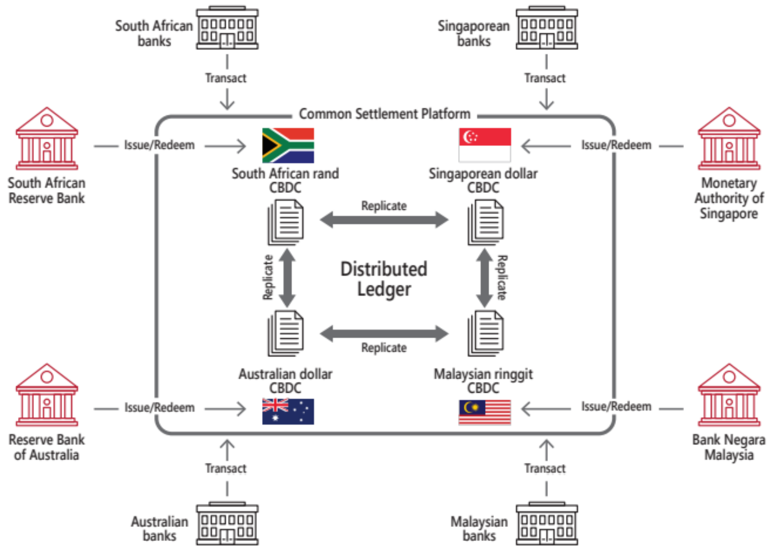
## Dunbar

In March 2022, the Singapore Centre released a report on **Project Dunbar** (Graph 3) (BISIH et al (2022)). Dunbar brought together the Reserve Bank of Australia (RBA), Bank Negara Malaysia (BNM), the Monetary Authority of Singapore (MAS) and the South African Reserve Bank (SARB) with the BISIH to test the use of multiple wCBDCs for international settlements.

The project developed two prototypes, based on different DLTs, for a shared platform that could enable international settlements using digital currencies issued by multiple central banks. The platform was designed to facilitate direct cross-border transactions between financial institutions in different currencies, with the potential to cut costs and increase the speed of settlement.

The experiment was organised in three workstreams: one focusing on high-level functional requirements and design, and two concurrent technical streams that developed prototypes on different technological platforms (Corda and Partior). The project identified three critical challenges in implementing a multi-CBDC platform shared across central banks: access, jurisdictional boundaries and governance. It proposed practical design solutions to address them.

Experimental architecture: Dunbar — Graph 3



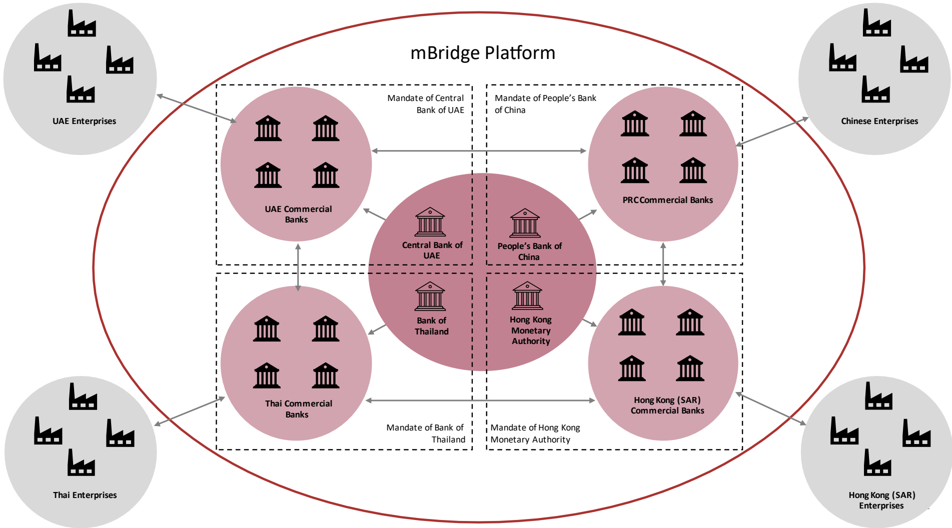

Each participating central bank issues its own CBDC in its domestic currency. Participating commercial banks are then able to hold these CBDCs directly, gaining access to foreign currencies without the need for accounts with correspondent banks. As all participating banks could potentially hold the different CBDCs directly, they would be able to transact directly with each other in the participating currencies.

## mBridge

In February 2021, the People's Bank of China and the Central Bank of the United Arab Emirates joined the original members of ILR2 to create a third phase of the project under the umbrella of BISIH Hong Kong Centre, renamed **Project mBridge**. The work of the previous ILR2 proof of concept (PoC) was extended to explore multi-currency cross-border payment capabilities built on DLT. It envisages the development of a DLT platform through which multiple central banks can issue their own CBDC and distribute it to participants. These participants can in turn conduct peer-to-peer payments and redeem the CBDC for reserves at the issuing central bank.

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 (Graph 4). Focus areas in the current phase include further work on the technology stack, and deeper dives into legal and governance aspects. An upcoming pilot aims to provide data-driven insights to optimise the different architecture components and their ability to scale to more participants and to a production volume of transactions.

Experimental architecture: mBridge Graph 4




The architecture enables a fully connected network of issuing central banks to validate transactions on behalf of their domestic commercial bank participants. The platform consists of three distinct components with different levels of controls: (i) the common network enables identity, connectivity and discovery; (ii) the wallets enable jurisdictional self-custody of all tokens; and (iii) the tokens represent CBDCs that circulate offshore on the network.

## How are the experiments similar?

The BISIH's four experiments all focus on *wholesale* environments in which *multiple* CBDCs are transferred either individually or against another CBDC or a tokenised security. These trials involved cross-border access to CBDC, were based on DLT and featured similarities in the tested use cases conducted among regional partners. Common key features include:

- *Access to wCBDC by non-resident financial institutions*: system participants in all experiments could access the CBDCs of jurisdictions where they were not themselves resident. This broadens direct access to central bank money, as compared with today's systems, where access is often conditional on local supervision or licensing. Direct access to CBDC from abroad allowed cross-border payments to be made without intermediaries on a single system. By giving participants from one jurisdiction access to the CBDCs issued by another jurisdiction, settlement of cross-border payments was demonstrated to be possible.
- *Platform design*: DLTs were used to build the platforms used in every experiment, enabling the novel "multiple currencies within a single system" approach. This model represents the biggest change from today's payment systems and theoretically offers the greatest efficiency gains (See box on

technology considerations and implementations). Previously, to achieve efficiency gains in traditional systems and allow the central bank to maintain control over access to its currency and settlement, it was necessary to interlink discrete centralised systems. Yet, this approach presents some serious challenges (eg operational and technical interoperability) (Bech et al (2020)).

- *Teams:* finally, all experiments were/are major undertakings between (broadly) regional partners, involving public-private sector cooperation. On average, the projects took around 18 months to complete. The assembled teams included at least 40 people, with (on average) two thirds coming from the public sector and a third coming from the private sector (eg technology providers, banks, consultancy firms and law firms).

## How do the experiments differ?

The four cross-border CBDC projects differ in several dimensions. These include the degree of realism, the number of currencies and the use cases tested. This resulted in variations of both technical and experimental design (Table 1).

- *Output*: ILR2 was a PoC while Jura, Dunbar and mBridge were prototypes.[7] Jura was also conducted in a near-real setting for a better understanding of regulatory requirements.
- *Currencies*: the projects all involved a variety of currencies. ILR2 experimented with the Hong Kong dollar and the Thai baht. Jura settled real-value transactions in euros and Swiss francs. Dunbar and mBridge each involved four currencies. ILR2, and Jura CBDCs were all intraday, and CBDCs issued in Dunbar were overnight.[8] mBridge will test with both intraday and overnight CBDCs.
- *Use cases*: all four experiments settled a variety of cross-border payment types (see box on international payments).[9] For example, all projects tested cross-border and offshore payments. Moreover, a significant risk in wholesale markets is FX settlement risk (Bech and Holden (2019)). Hence, all experiments included payment versus payment (PvP) protection to remove this risk. However, Jura differed from the other three experiments by including tokenised commercial paper (ie a financial asset), which broadened the settlement use cases.

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7 While a PoC focuses on one or just a few aspects of a product, a prototype is a working model of several aspects of the product. A PoC focuses on whether something can be done, whereas a prototype demonstrates how something can be done.

8 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.

9 FX trading for all projects is done off-platform. ILR included FX trading also on-platform (“posted board rate” and “request for quote”).

- *Technical design*: in terms of interoperability, wCBDCs were made interoperable with each other using a common platform (ILR2, mBridge or Dunbar) or a common platform with separate subnetworks (Jura) so that each central bank maintains individual control over its wCBDC. The platforms are operated by the central banks who have issued CBDCs into the system. The exception is Jura, which explicitly looks at a central bank's requirements for issuing CBDC onto a private third-party platform.

Project scope and experiment design

Table 1

| | | Inthanon LionRock2 | Jura | Dunbar | mBridge |
|---|---|---|---|---|---|
| Experiment design | **BIS Innovation Hub Centre** | Hong Kong | Switzerland | Singapore | Hong Kong |
| | **Central banks** | HKMA, BoT | BdF, SNB | MAS, SARB, RBA, BNM | HKMA, BoT, PBoC, CBUAE |
| | **Output** | PoC | Prototype | Prototype | Prototype |
| | **Type of wCBDC** | Intraday | Intraday | Overnight w/o interest | Intraday and overnight |
| | **Currencies** | HKD, THB | EUR, CHF | AUD, MYR, SGD, SAR | HKD, CNY, THB, AED |
| | **Transaction type** | Simulated | Real value | Simulated | Real value |
| | **Interoperability model** | Common platform | Common plat. w. subnetworks | Common platform | Common platform |
| | **DLT** | Hyperledger Besu | Corda | Corda, Quorum | mBridge Ledger (MBL) |
| | **Non-resident banks can ... wCBDC** | Hold and transfer | Hold and transfer | Hold and transfer (ok from sponsor) | Hold and transfer |
| | **Platform operator** | Central banks | Private | Central banks | Central banks |
| Use cases | **Domestic payments** | (✓) | (✓) | (✓) | (✓) |
| | **Cross-border payments** | ✓ | ✓ | ✓ | ✓ |
| | **Offshore payments** | ✓ | ✓ | ✓ | ✓ |
| | **Domestic payment in foreign currency** | × | ✓ | ✓ | × |
| | **PvP**[1] | ✓ | ✓ | ✓ | ✓ |
| | **DvP**[2] | × | ✓ | × | × |

✓ = Tested; (✓) = possible but not tested/out of scope; × = not possible;

[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.

### International payments

All four BISIH cross-border CBDC experiments explored settling different kinds of "international payments". For this purpose, these experiments distinguished between "cross-border payments" and "offshore payments". Cross-border payments take place between a payer and a payee who are residents of different jurisdictions; the payment may be made in the currency of the payer's jurisdiction or in another currency.

"Offshore payments" take place between two institutions, neither of whom is resident in the jurisdiction in which the payment is being made; the payment is typically made in the currency of that jurisdiction. Finally, it should be noted that some jurisdictions permit their residents to make "domestic payments" between each other in a foreign currency. All projects tested cross-border and offshore payments, and some also included domestic payments made in a foreign currency.

| | | **Currency** | |
|---|---|---|---|
| | | **Domestic** | **Foreign** |
| **Residence of financial institutions** | **Both domestic** | Domestic payment | Domestic payment in foreign currency |
| | **Domestic and foreign** | Cross-border payment | |
| | **Both foreign** | Offshore payments | NA |

Source: Authors' elaboration

International payments in different currencies often involve the settlement of FX trades. To remove settlement risk, PvP is necessary. All experiments incorporated this. Beyond payments, Jura also included tokenised commercial paper. This meant that cross-border settlement of tokenised assets using DvP settlement could be explored.

## What are the key insights?

The four CBDC projects are practical experiments that focus on the technical feasibility of these novel multi-currency systems. Nonetheless, they also provided a vehicle for considering wider policy, legal and systemic issues.

### Technical feasibility

Every experiment worked ie they each showed an mCBDC platform is operationally feasible, allowing multiple currencies and assets to be settled and various access policies to co-exist.[10] Yet beyond meeting core requirements, the experiments highlighted potential operational efficiencies compared with the current arrangements. Bringing multiple currencies and assets into a single system with

[10] While DLT is still a nascent area, multiple projects are in production, eg SDX, Partior and the eCNY. The BISIH mCBDC projects use technology platforms developed in these projects. While the mCBDC projects are still largely experiments in the form of PoCs and prototypes, the use of in-production platforms may make it easier to identify a viable pathway to live deployment.

participants directly transacting lowered costs, made settlement faster and increased operational transparency.

1. **Lower costs**. 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.
2. **Faster settlement**. Reducing the need for intermediaries and enabling direct transactions between participants removes the need for correspondent payment chains that can slow down settlement.
3. **Operational transparency**. In an mCBDC system, payments are recorded on a single ledger in one step and participants have full real-time visibility of their holdings.

## Broader issues

Although mCBDC systems might be operationally feasible, designs also need to explore the viability of mCBDC models, taking into account policy, legal, governance and economic issues. Experimentation can help. Multiple requirements quickly emerge as central banks collaborate and compare their needs.

1. **Policy**. The BISIH experiments have shown that, from a technical perspective, a common platform model can be designed to support different access policies. Transparency of CBDC holdings means that monitoring currency flows outside a jurisdiction is possible. And control measures that restrict the circulation of CBDC under certain conditions can also be programmed into a platform. These tools could provide central banks with the ability to broaden access.
2. **Legal**. A robust legal basis is required for any financial market infrastructure (FMI) (CPMI-IOSCO (2012)). Yet legal changes related to the issuance and transfer of a specific CBDC, and the finality and validity of the settlement may face idiosyncratic challenges depending on the jurisdictions and currencies involved. Developing rulebooks, contingency procedures and monitoring capabilities can help highlight these challenges or areas in which more clarity might be needed.
3. **Governance.** Any mCBDC 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.
4. **Systemic issues.** A necessary prerequisite for launching an mCBDC system is an assessment of the economic implications. Interlinkages with existing domestic money markets, foreign exchange markets and securities trading (where a system includes asset settlement) could contribute to the financial resilience or vulnerability of the broader financial system. For example, participants' access to liquidity and credit in one currency (or lack of it) could spill over to other

currencies or markets at significant speed. Simulation using realistic payment data can help identify risk areas.

## Technology considerations and implementations

The mCBDC platforms used by the BISIH are all developed on various forms of DLT (Corda, Ethereum and custom built. See the Annex). Using DLT, it is possible to combine the efficiencies of a single system with the differing requirements of participating central banks. A common system uses uniformly applicable technical standards, enabling discoverability, communication and consensus. Many of the potential efficiency enhancing features are straightforward to implement on a DLT architecture. For example, direct peer-to-peer communication between participants can eliminate intermediaries, settlement risk can be reduced using atomic settlement and smart contracts can enable efficient, automated and integrated workflows. Some implementation considerations include:

- **Nodes:** all DLT architectures consist of so-called nodes which are interconnected to form a network. The nodes are run independently and represent participants on the platform. Nodes have their own data storage, can execute functions and can interact directly with other nodes. They can also share business logic functions – often referred to as smart contracts – and can do so in a coordinated and tamper-proof manner through consensus protocols. In Corda-based architectures (Jura and Dunbar) each central bank has an issuer node to create (or destroy) tokens; a notary node to validate transactions; and possibly an observer node to monitor CBDC activity. Using Ethereum-based architectures (ILR2 and Dunbar), the central bank has a validator node.
- **Networks:** a network is a collection of interconnected nodes. These networks standardise many technical aspects but can also be partitioned to give central banks control and sovereignty over their users and CBDCs. To do so, several techniques such as subnetworks, logical partitions or privacy groups can be used. For example, ILR2 and Dunbar – both Ethereum-based implementations – use privacy groups to ensure that transaction data are shared only with an ad hoc subset of participants. In Jura and Dunbar – both Corda-based implementations – the network can be split into subnetworks with separate notaries and specific asset types within them. These subnetworks can limit the circulation of a specific asset to a subset of participants on the network. In both examples, rules can also be associated with the currencies themselves, granting central banks control over their CBDC wherever the currency is allowed to circulate.
- **Data:** Corda-based architectures (Jura and Dunbar) assure the privacy of a transaction's existence vis-à-vis other members of the network by design since data is not broadcast to participants that are not counterparties to the transaction. In this case transparency becomes a challenge and special nodes (ie observer nodes) are needed for central banks to monitor activity for their CBDC. On Ethereum-based architectures (ILR2 and Dunbar), the transparency of a transaction's existence is natural because transaction data are broadcast to everyone on the network, but assuring privacy is a challenge since all members can see the transaction hashes.

# Conclusion

CBDCs may help to deliver better cross-border payments. Yet to achieve this, central banks need to understand how they should be built and how they contribute to a broader vision of the future monetary system (BIS (2022)). This requires combining practical and technological lessons from experiments, together with central banks' policies and understanding of systems and markets.

There is a lot more to do and experimentation can help to provide answers. The BISIH experiments build on earlier work and future projects will inject further realism and complexity. Advanced feasibility questions remain about how new DLT platforms and existing systems will interact; what scalability challenges might lie ahead; and how resilience and security are 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 or the need for further policy tools.

Experimenting under the BISIH umbrella allows projects to iteratively build on one another, developing a richer understanding for the entire central banking community. Collaborative efforts are necessary to answer the questions ahead and the BISIH is uniquely positioned to bring central banks together to explore how cross-border payments can be improved.

## References

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

Bech, M and H Holden (2019): "FX settlement risk remains significant", *BIS Quarterly Review*, December, pp 48–9.

Bech, M, U Faruqui and T Shirakami (2020): "Payments without borders", *BIS Quarterly Review*, March, pp 53–65.

Bank for International Settlements (BIS) (2022): "The future monetary system", *Annual Economic Report 2022*, Chapter III, June.

BIS Committee on Payments and Market Infrastructures (BIS CPMI) (2020): Enhancing cross-border payments: building blocks of a global roadmap – Stage 2 report to the G20, July.

BIS Innovation Hub (BISIH), Bank of France and Swiss National Bank (2021a): Project Jura: cross-border settlement using wholesale CBDC, December.

BISIH, 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 (2021b): *Inthanon-LionRock to mBridge: building a multi CBDC platform for international payments*, September.

BISIH, Reserve Bank of Australia (RBA), National Bank of Malaysia (NBM), Monetary Authority of Singapore (MAS), and South African Reserve Bank (SARB) (2022): *Project Dunbar: international settlements using multi-CBDCs*, March.

CPMI and International Organization of Securities Commissions (IOSCO) (2012): *Principles for financial market infrastructures*, April.

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

# Annex: Distributed ledger technologies

**Corda**[11]

*Nodes*: each node runs an instance of Corda, a distributed operating system on a Java virtual machine, and one or more CorDapps, a Java-based application containing the business logic. While nodes do not contain the data within them, they manage it in a tamper-proof persistent database storage layer. Data is represented as unspent transaction output (UTXO) states and is shared between nodes on a need-to-know basis. This means that only transaction counterparties share data and there is no global broadcast to other members of the network. The nodes run correctness consensus in the form of smart contracts between them to ensure that data evolves in a consistent fashion. Because each node only sees data relevant to its own transactions, mitigation of double spending is outsourced to a permissioned notary function.

*Network*: a Corda network is enabled by three core services; an identity manager, a network map and a notary service. The identity manager acts as the gatekeeper to the network, and allows nodes onto the private network by providing signed certificates. These certificates represent the node's identity and are used to register the node on the network map. The network map service maps node identity certificates to IP addresses allowing nodes to discover and communicate with each other. It is the responsibility of the network maps to ensure that all nodes on the network have an accurate and up-to-date view of their counterparties on the network. The notary service provides uniqueness consensus to ensure that double spending does not happen on the network. The notary does so by providing a unique signature that effectively consumes a state on the ledger. This step is necessary to update the ledger and by ensuring the uniqueness of this signature, the notary eliminates a state being spent twice. Notaries can be operated by a single entity or in a coordinated fashion between network participants.

**Ethereum based**[12] (Quorum[13] and Hyperledger Besu[14])

*Nodes:* there are two types of nodes in Quorum and Hyperledger Besu architectures; participant nodes and validator nodes. Both types of nodes run on an Ethereum virtual machine – a mechanism that provides the ability to execute smart contracts, access stored data and look up accounts. Participant nodes focus on submitting transactions to a pending transaction pool to be executed and written to the ledger by validator nodes. Validator nodes share the same architecture but focus on executing transactions and writing blocks to the ledger. These blocks consist of a collection of transactions from the transaction pool. Once a block is created through the consensus protocol of choice on the network, the new block is broadcasted out to other nodes

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11 https://github.com/corda/corda

12 https://github.com/ethereum

13 https://github.com/ConsenSys/quorum

14 https://github.com/hyperledger/besu

on the network to verify and update their own state of the ledger. As such, each validator contains a full copy of the entire ledger. Both Quorum and Hyperledger Besu augment these functions with transaction privacy, permissioned validators, private key management and enterprise architecture tooling.

*Network:* an Ethereum network is any network of nodes that conform to the base Ethereum protocol specification. As such there can be many different Ethereum-based networks, both public and private (which are mutually exclusive). The Ethereum main net is the most public permissionless network where the publicly traded Ether token is traded. On Ethereum main net, anyone can join as a participant, and anyone can compete to validate transactions. Private permissioned versions of an Ethereum network are created by controlling access to a private network and implementing a permissioned validating service. Both Quorum and Hyperledger Besu create private networks by adding an administrator function for rule creation on inbound and outbound messages from nodes on the network. To create the permissioned consensus, they replace the permissionless proof of work or proof of stake found on main net with different forms of proof of authority or Byzantine fault tolerant[15] consensus mechanisms. The permissioned consensus mechanisms allow permissioned validators to take turns validating blocks for the network (approved by a super-majority of the other validators in most cases) to be written to the ledger. The several types of consensus mechanisms implement varying degrees of Byzantine fault tolerance to provide an array of different throughput and resiliency trade-offs for a given network.

[15] https://en.wikipedia.org/wiki/Byzantine_fault

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