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Joint Report to the G20:

Options for access to and interoperability of CBDCs for cross-border payments

July 2022

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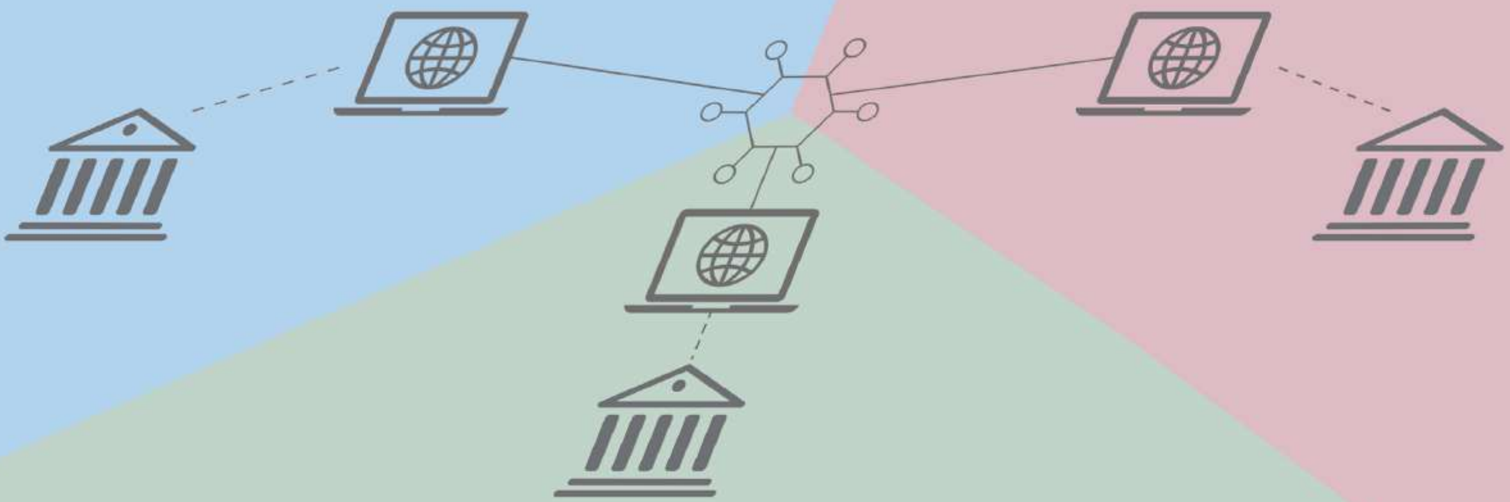

Options for access to and interoperability of CBDCs for cross-border payments

Report to the G20

July 2022

BIS | Committee on Payments and Market Infrastructures | Innovation Hub

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Executive summary

In October 2020, the G20 endorsed a roadmap to enhance cross-border payments, developed by the Financial Stability Board (FSB) in coordination with the Bank for International Settlements' Committee on Payments and Market Infrastructures (CPMI) and other relevant international organisations and standard setters. The G20 cross-border payments programme aims to address long-standing challenges in the cross-border payments market, including high costs, low speed, limited access and insufficient transparency. This programme comprises the necessary elements of a globally coordinated response in the form of a set of 19 building blocks (BBs), based on a CPMI report to the G20 (CPMI (2020a, 2020b)). BB 19 is tasked with factoring an international dimension into central bank digital currency (CBDC) design to explore how CBDCs could potentially enhance cross-border payments. As mandated under Action 1 of this building block, in July 2021 the CPMI, BIS Innovation Hub, International Monetary Fund and World Bank published a stocktake of provisional domestic CBDC designs and experimentations and their potential to enhance cross-border payments (CPMI et al (2021)).

The current report is a response to Action 2 of BB 19 and presents different options for access to and interoperability of CBDC systems to facilitate cross-border payments. It assesses these options based on five criteria: do no harm, enhancing efficiency, increasing resilience, assuring coexistence and interoperability with non-CBDC systems, and enhancing financial inclusion. Also, leveraging experiences from existing CBDC projects, the report discusses the key implementation challenges of each of the access and interoperability options. Central banks have different motivations for exploring or developing CBDC systems, and the demand for improved cross-border payment rails differs across jurisdictions. Therefore, this report serves as a tool for central banks to assess different cross-border CBDC design options given their objectives.

When identifying access options, the report distinguishes between, on the one hand, access by foreign banks and other payment service providers (PSPs) to wholesale CBDC (wCBDC) systems and retail CBDC (rCBDC) systems in case of a two-tier model, and, on the other hand, access to rCBDCs by non-residents. Access by PSPs may be *indirect* (ie via an intermediary) or *direct* (ie without an intermediary). These models are similar to the access models of traditional payment systems as discussed in BB 10 of the G20 cross-border payments programme (CPMI (2022b)). In a third model – *closed access* – only domestic PSPs are granted access to the CBDC system. The discussion on access to rCBDCs by non-residents focuses on whether and under what conditions (eg transaction and holding fees and limits) non-residents are granted access.

Well calibrated access to CBDCs by foreign PSPs and non-residents may facilitate cross-border payments, though it is not a silver bullet. A complementary approach is ensuring interoperability between CBDC systems. Building on the BB 19 Action 1 work, the current report presents three ways to achieve this: compatibility, interlinking and a single system. *Compatibility* refers to individual CBDC systems using common standards, such that the operational burden on PSPs for participating in multiple systems is reduced. *Interlinking* refers to establishing a set of contractual agreements, technical links, standards, and operational components between CBDC systems allowing participants to transact with each other without participating in the same system. Similar to the interlinking of traditional payment systems (see CPMI (2022c)), CBDCs could be interlinked via different models – via a single access point, bilateral link or "hub and spoke" model. A *single system* refers to an arrangement that uses a single common technical infrastructure hosting multiple CBDCs.

Each of the CBDC access and interoperability models has different implications in terms of macro-financial risks, efficiency, resilience, coexistence and interoperability with non-CBDC systems, and financial inclusion. At the same time, as with traditional cross-border arrangements, CBDC cross-border arrangements raise a number of implementation challenges, which differ depending on the type of access and interoperability model used. A number of CBDC projects have been completed as one-off experiments and others are still in an exploratory stage (see Annex 6). Yet, these initiatives provided useful insights for the analysis of cross-border CBDC access and interoperability options. Potential challenges of broader access to CBDC systems range from governance, decision-making and risk management to operational, technical and financial aspects. Many of these are fairly similar to the challenges of broadening access to traditional payment systems (see CPMI (2022b)). Each interoperability model also faces different challenges, eg in terms of investment and maintenance cost, scalability, legal and regulatory frameworks and governance.

There is no "one size fits all" model for access to and interoperability of CBDC systems. For example, while compatibility might be the least costly form of interoperability, it may not achieve similar efficiency benefits to interlinking multiple systems or developing a single system. Combining compatibility with a direct access model would go a long way, but given the challenges of achieving direct access, such a solution might be difficult to realise in the short run. Similarly, while interlinking via a single access point may not necessarily require direct access or the establishment of new technical components, it has scalability limitations. Overall, interlinking of CBDC systems through a hub and spoke or single system might bring more improvement to the cross-border payments market than compatibility or single access points, and the same holds for direct access models compared to closed or indirect access. Yet, given the elevated challenges of these solutions, they are most likely to be implemented where the benefits of enhanced cross-border payments exceed the challenges, such as between countries with large trade volumes, or between countries with similar CBDC objectives and designs. This inherently might entail the risk that the interoperability and access models with the highest potential to alleviate current cross-border payment frictions are not implemented for the use cases that are currently heavily impacted by these frictions, such as remittances.

For CBDCs to enhance cross-border payments, jurisdictions working on a CBDC must take the cross-border functionality into account at an early stage to avoid unintended barriers later. CBDCs are new to all, and those central banks who choose to explore one need to go through design and development phases. Although each jurisdiction is likely to be bound by certain constraints when designing a CBDC, eg in terms of ensuring coexistence and interoperability with current systems and complying with existing legal and regulatory frameworks, many design features are still undecided which allows central banks to start with a "clean slate". To use this opportunity, international cooperation and coordination is needed in the early stages of CBDC design. More structured and broader international coordination on domestic CBDC designs would be beneficial to lower barriers to cross-border compatibility and could serve as a launching pad for interoperability. In addition, jurisdictions must keep in mind to build CBDC ecosystems that are flexible enough to account for different forms of interoperability and coexistence as well as inclusivity and accessibility needs – both with the payment methods we have today and with potential future types of money. Other considerations that are relevant to the design of cross-border CBDC solutions and that may warrant coordination include ensuring compliance with rules on anti-money laundering (AML) and combating the financing of terrorism (CFT) while safeguarding privacy and promoting competition.

To avoid domestic CBDC work unintentionally creating barriers to cross-border CBDC payments, further work is required in the short-term within the central bank community to identify the stages of domestic CBDC planning and development when decisions should be taken on cross-border CBDC access and interoperability models. Further work is also required on the standards to which domestic CBDC designs would need to adhere to support cross-border payments. Even jurisdictions not planning to issue a CBDC ought to be involved in this work as they will still be part of this new potential cross-border payments landscape. To inform such work, further technology experimentation on cross-border payments between rCBDCs is essential, since to date, most cross-border CBDC experiments have focused on wCBDCs. Also, it would be beneficial to broaden the diversity of countries involved in the CBDC experiments and dialogues, especially to better understand the implications and requirements to enhance currently underserved cross-border corridors. To the extent that cross-border use of CBDCs for these corridors relies on the quality of and features in national payment system infrastructures, it is essential to continue dedicating resources to improving and strengthening these infrastructures and regulatory, supervisory, and oversight practices. More work is also required on the trade-offs between different assessment criteria and between different access and interoperability models. Macroeconomic implications, eg of limiting CBDC holdings to certain participants and of large-scale issuance to non-residents, would also require further consideration.

While CBDCs can enhance cross-border payments in various ways, eg by extending the availability of central bank money settlements around the clock and by eliminating the need for PSPs to act as liquidity providers, they will come with implementation challenges. Some of these are common to all types of money or traditional payment systems, yet some are specific to CBDCs, eg in terms of the required legal authority to issue CBDCs, macro-financial implications, controlling and monitoring CBDC holdings, and, depending on the technology used, different technical and operational challenges. The "clean slate" advantage of CBDCs, however, will allow central banks to address these challenges at an early stage.

Other building blocks of the G20 cross-border payments programme focus on measures to improve existing payment systems, eg via extended operating hours, broader access, interlinking of fast payment systems or adoption of harmonised message formats. Improvements in these areas could complement and in some cases (eg facilitating comprehensive application of AML/CFT rules) also be directly beneficial to improve cross-border payments with CBDCs.

1 Introduction

1.1 Background

In October 2020, the G20 endorsed a roadmap to enhance cross-border payments, developed by the Financial Stability Board (FSB) in coordination with the Bank for International Settlements' Committee on Payments and Market Infrastructures (CPMI) and other relevant international organisations and standard-setting bodies. The G20 cross-border payments programme aims to address long-standing challenges in the cross-border payments market, including high costs, low speed, limited access and insufficient transparency. This programme comprises the necessary elements of a globally coordinated response in the form of a set of 19 building blocks (BBs), based on a CPMI report to the G20 (CPMI (2020a, 2020b)).[1]

BB 19 is tasked with factoring an international dimension into central bank digital currency (CBDC) design to explore how CBDCs could potentially enhance cross-border payments. As mandated under Action 1 of this building block, in July 2021 the CPMI Future of Payments Working Group (FoP) published a stocktake of provisional domestic CBDC designs and central bank experimentations and their potential to enhance cross-border payments (CPMI et al (2021)). This report also provided a conceptual framework for how CBDCs could be connected via multi-CBDC (mCBDC) arrangements and an analysis of international macro-financial implications of cross-border CBDC use.[2]

The current report constitutes a response to BB 19 Action 2 of the G20 cross-border payments programme, which invited the CPMI in collaboration with the BIS Innovation Hub (BISIH), the International Monetary Fund (IMF) and the World Bank to identify and analyse options for access to and interlinking of CBDCs that could improve cross-border payments, covering different CBDC design, access and interlinking options, including interoperability with non-CBDC payment arrangements. Access and interlinking are two key features through which CBDCs can be made available to banks and other payment service providers (hereafter collectively referred to as PSPs) from different systems or jurisdictions and through which end users can seamlessly transact with each other regardless of their geographic location or choice of PSP.[3] In addition to covering interlinking options, the report takes a broader approach by considering interoperability options in general.

The remainder of Section 1 provides the definitions used in this report and summarises the potential role of CBDC in improving cross-border payments. Section 2 presents five evaluation criteria for assessing different cross-border CBDC arrangements taking the CBDC principles defined by the Group of Central Banks (2020) and the G7 (2021) as a starting point. Section 3 presents potential options for access to and interoperability, including interlinking, of CBDCs and maps completed and ongoing CBDC projects accordingly. Section 4 assesses the identified options against the five evaluation criteria and discusses their implementation challenges based on lessons from existing CBDC projects. Section 5 concludes and presents recommendations for future work.

[1] The 19 building blocks are arranged into five focus areas, four of which (focus areas A to D) seek to enhance the existing payments infrastructure. Focus area E, comprising BBs 17 (multilateral platforms), 18 (stablecoins) and 19 (CBDCs), is more exploratory and covers emerging payments infrastructure and arrangements. See FSB (2020a) for an overview of the G20 roadmap to enhance cross-border payments.

[2] See also Auer et al (2021) for more details on the conceptual mCBDC arrangements.

[3] The CPMI report on best practices for jurisdictions and payment system operators conducting a self-assessment with the aim of expanding access to key payment systems (CPMI (2022b)) also refers to payment infrastructures, beyond banks and non-banks, as possible payment system participants. In the current report we consider non-banks and payment infrastructures, and also other central banks, as part of "other PSPs".

1.2 Definitions and scope

CBDC has generally been defined as central bank money in a digital format, denominated in the national unit of account, that is a direct liability of the central bank and can be used for retail payments and/or wholesale settlement.[4] Based on this definition, traditional central bank reserve or settlement accounts currently held by commercial banks and certain other financial institutions at the central bank can also be seen as CBDC. As an analysis of these traditional accounts is out of the scope of this report, we apply a narrower definition of CBDC by defining it as *a new form of central bank money* in a digital format, denominated in the national unit of account, that is a direct liability of the central bank. This report will consider both retail and wholesale CBDCs. *Retail CBDCs* (rCBDCs) are meant to be held and used by individuals and firms for day-to-day transactions, including purchases of goods and services, whereas *wholesale CBDCs* (wCBDCs) are held by eligible financial institutions only and used for financial market payments (eg interbank payments and the settlement of securities and currency transactions).[5] Financial institutions with access to wCBDC can, however, offer retail services to individuals and firms that build on the wCBDC, such as cross-border transfers of non-CBDC money. Further, a CBDC relies on many different components to be circulated. This report considers a *CBDC ecosystem* to encompass the underlying payment system, information and communications technology (ICT) infrastructure, governance and business arrangements, and participants involved in CBDC payments. Participants in CBDC ecosystems may include different service providers, such as payment interface providers onboarding customers and offering wallets. Further, the term cross-border CBDC arrangement is used in this report to refer to the design choices made regarding access and interoperability.

Cross-border CBDC payments, as described in this report, cover the following cases: (i) a payment between residents, including resident financial institutions, of two separate jurisdictions where at least one entity is using a CBDC; or (ii) a transfer of a CBDC by a resident or non-resident of the issuing jurisdiction to a wallet or account maintained in another jurisdiction or vice versa. Many, but not all, are also cross-currency payments where the payer and payee are respectively debited and credited in different currencies (see Box 1). As such, cross-border CBDC payments could also include payments made by tourists and business travellers, either when they use their home country's CBDC when abroad or when they acquire the CBDC of the country they are visiting. For the purpose of this report, cross-currency cross-border payments will be in focus.[6]

Interoperability refers to technical, semantic and business compatibility that enables a system to be used in conjunction with other systems. Interoperability allows PSPs from different CBDC systems to make payments across systems without participating in multiple systems (Boar et al (2021)). As discussed in Section 3, for CBDCs, interoperability could be achieved between different CBDC systems.

1.3 How can CBDC mitigate challenges and frictions in cross-border payments?

Cross-border payments face four particular challenges: high cost, low speed, limited access and insufficient transparency. These challenges arise from a series of frictions, including fragmented and truncated data formats, complex processing of compliance checks, limited operating hours, legacy technology platforms, long transaction chains, high funding costs, and weak competition. Legal, technical and commercial

[4] See eg BIS (2021b). This definition also applies to currency unions, as long as the CBDC is a liability issued by a central bank that is in its own currency (ie where it does have the monetary authority), such as a digital currency issued by the European Central Bank.

[5] In line with our definition of CBDC and the approach used in CPMI-MC (2018), a wCBDC is defined as a new form of digital central bank money that is different from balances in traditional central bank reserve or settlement accounts. For one of the first papers on wCBDCs, see www.mas.gov.sg/-/media/MAS/ProjectUbin/Cross-Border-Interbank-Payments-and-Settlements.pdf.

[6] Cross-border payments within a monetary union typically encounter fewer challenges and frictions. Therefore, cross-border payments between jurisdictions using the same CBDC will not be a focus of this report.

changes are necessary in a number of areas to overcome these frictions. These changes include harmonisation of regulatory, supervisory and legislative frameworks (eg for anti-money laundering and combating the financing of terrorism (AML/CFT); see also Box 2 in Section 2), improvements in existing payment infrastructures and arrangements (eg operating hours, participation requirements, funding and interlinking arrangements) and harmonisation of market practices and standards (eg messaging standards; see FSB (2020a)). There are ongoing projects to relieve the traditional cross-border payment system of some of these frictions, such as the introduction of a common messaging standard. However, such improvements on an already existing and complex structure can be costly and difficult.

Box 1

Currency conversion – a vital element of cross-currency payments

Cross-currency payments are payments where the payer's and payee's accounts are respectively debited and credited in two different currencies. Hence, a vital element of cross-currency payments is the currency conversion: somewhere along the payments chain, the currency of the payer has to be converted into the currency of the payee.

The currency conversion can be provided by different entities; typically, it could be provided by the PSP of the payer, by the PSP of the payee or by an intermediary which stands in between both PSPs, such as an international bank or even a central bank. If it is the payer's PSP doing the conversion, the payer basically purchases the foreign currency (B) from its PSP against the home currency (A) prior to sending it to the payee. By contrast, if the payee's PSP is offering the exchange, it is the payee who purchases currency (B) from its PSP against currency (A) after receiving it from the payer. In the intermediary example, the payer's and payee's PSPs sell and buy, respectively, the two currencies to and from the intermediary.

To enact a cross-currency payment, the entity responsible for the conversion must have sufficient balances of the different currencies. The treasury departments of the involved entities monitor their holdings of each currency and determine when they must buy and sell currencies to cover their transactions. They do so at the foreign exchange (FX) market. These FX transactions are ideally settled on a payment-versus-payment (PvP)[7] basis to reduce settlement risk. Major currencies are commonly settled on a PvP basis, eg via CLS, whereas other, eg emerging market currencies are more often settled on a non-PvP basis. BB 9 of the G20 cross-border payments programme is about facilitating increased adoption of PvP.[8]

CBDCs can help to enhance cross-border payments in various ways. First, as with any new system, one key advantage of both retail and wholesale CBDC is the opportunity to start with a "clean slate". CBDC is new to all, and those central banks who choose to explore one must go through design and development phases. This provides an opportunity for central banks to take the cross-border dimension into account when designing their domestic CBDCs. Cross-border payment markets are bound by a number of issues, including the structure of existing domestic payment systems, currency exchange issues, the demand for cross-border payments, and the legal and regulatory aspects of these payments. As such, each jurisdiction will face certain constraints when designing a CBDC, eg in terms of ensuring coexistence and interoperability with current systems and complying with existing legal and regulatory frameworks. Nevertheless, many design features and technical specifications are still undecided, which allows central banks to start with a "clean slate". For example, CBDC infrastructures could be made available 24/7, allowing for instant cross-border settlement and overcoming mismatches of operating hours between different jurisdictions.[9] More broadly, the fact that a significant number of central banks are now simultaneously looking into the issue of CBDCs (see Kosse and Mattei (2022)) allows them to increase their coordination efforts and to achieve interoperability between their CBDCs from the outset. Interoperability of CBDC systems could facilitate cross-border CBDC payments between financial institutions, corporates

7 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.

8 For full details of the actions under BB 9, see FSB (2020a, Annex 1).

9 See CPMI (2022a) for a discussion on extending operating hours to enhance cross-border payments.

and consumers by reducing the costs for PSPs and shortening transaction chains, which might eventually result in a higher transaction speed and lower end user fees.[10] Achieving interoperability once systems have been fully designed and employed can be more complicated.[11]

Second, cross-border CBDC arrangements would improve the safety of cross-border payments because payments are made using a direct liability of the central bank, which is the safest and most liquid settlement asset (especially when compared to stablecoins and other cryptoassets). Moreover, since CBDCs are a direct liability of the central bank, there is no need for PSPs (as wallet providers or payment validators) to act as liquidity providers, which could increase the number of PSPs. However, those PSPs acting as FX providers must have CBDC accounts with the central banks to hold and transact both currencies. A common FX trading venue could enhance competition and bring additional benefits. An increased number of PSPs and direct access to central bank money could then shorten cross-border transaction chains, simplify processes and address current frictions in cross-border funding arrangements.

Third, CBDCs, as a new means of cross-border payment, are commonly meant to coexist with and complement existing cross-border payment options. In this case, CBDCs would increase payment diversity, thereby stimulating resilience, competition and efficiency in a cross-border context. The potential programmability features of CBDCs enabled by smart contracts and APIs could facilitate faster and better interoperability with other CBDCs and non-CBDC systems. This would allow payments to be tightly linked to business processes enabling self-triggered and conditioned transactions, leading to vast improvements to payment speed, and hence promote efficiency. CBDCs could also specifically be designed to improve individuals' and businesses' access to affordable cross-border payment products and services, for example through simplified onboarding allowing remote registration or electronic know-your-customer (e-KYC) processes and through low-cost and easy-to-use instruments, especially when these aspects are explicitly taken into account in the domestic design of CBDCs.

Measures to improve cross-border payments in general and involving other types of money are discussed in other building blocks of the G20 payments programme. Improvements in these areas could complement the effort to ensure interoperability of CBDC systems for cross-border payments.[12] Moreover, there might be circumstances where the desired interoperability requirements for improving cross-border payments conflict with those for achieving domestic interoperability. In such a case, jurisdictions might face a trade-off between making their CBDC interoperable with existing domestic payment infrastructures and achieving international interoperability with other CBDCs. These and other challenges will be discussed in Section 4.

2 Evaluation criteria for analysing cross-border CBDC arrangements

The establishment of a new CBDC ecosystem allows jurisdictions to take the cross-border dimension into account at an early stage. There are several aspects to consider when designing a cross-border CBDC arrangement and different ways in which these can be accommodated. This section presents five

[10] See Boar et al (2021) for a discussion of the benefits and trade-offs of interoperability between payment systems across borders and Oliver Wyman and J.P. Morgan (2021) for an estimation of the transaction cost implications of moving from traditional correspondent banking arrangements to an mCBDC solution.

[11] For example, BB 13 of the G20 cross-border payments programme is currently working on interlinking existing payment systems (see eg CPMI (2022c)).

[12] Indeed, harmonisation of regulatory, supervisory and legislative frameworks is not only important for facilitating cross-border payments through existing systems but would also be important for cross-border CBDC payments. Such harmonisation requires concrete legal changes and strong international cooperation. Important work on this is being done in BBs 4 (regulatory, supervisory and oversight frameworks) and 5 (AML/CFT) of the G20 cross-border payments programme, which aims to align regulatory, supervisory and oversight frameworks for cross-border payments and to further harmonise the application of AML/CFT rules among countries.

evaluation criteria that will be used in Section 4.1 to analyse the potential options for access to and interoperability of CBDCs which will be identified in Section 3.

The five evaluation criteria below are based on the CBDC principles developed by the Group of Central Banks (2020)[13] and the G7 (2021).[14] When designing their CBDCs, central banks may want to ensure that all these principles are properly observed for cross-border CBDC transactions. Some of these principles have a direct impact on the way in which central banks achieve their mandated objectives, eg do no harm to macro-financial stability or interoperability and coexistence of payment systems. By contrast, other principles require central banks to comply with prevailing laws, rules and guidelines developed outside of their usual remit, eg AML/CFT regulations (see Box 2 at the end of this section and Annex 3) and provisions regarding data and privacy protection. In this report, we assume that CBDC ecosystems are developed in accordance with all these relevant laws, rules and guidelines. The analysis in Section 4.1 will focus on those principles that commonly fall within the mandate or public policy objectives of central banks. For the purpose of this report, we have grouped these into five overarching criteria: do no harm, enhancing efficiency, increasing resilience, assuring coexistence and interoperability with non-CBDC systems, and enhancing financial inclusion. For each of these, the remainder of this section describes its relevance in the context of cross-border CBDC payments. The potential challenges faced when complying with the prevailing rules and regulations will be further discussed in Section 4.2.

2.1 Do no harm

Do no harm in the context of CBDCs refers to designing CBDC ecosystems that support public policy objectives and do not impede central banks' ability to carry out their mandates (Group of Central Banks (2020), G7 (2021)). For example, apart from the benefits discussed above, cross-border use of CBDCs could increase macro-financial risks (G7 (2021), IMF (2020)). First, cross-border availability of CBDCs can foster currency substitution in countries with weaker economic fundamentals. Second, capital flows could increase, leading to the benefits of increased market integration, but also increasing synchronisation and intensification of global financial cycles and contagion risks, and potentially also heightening capital flow volatility. Both currency substitution and increased capital flow volatility and synchronicity could have negative implications for financial stability and the ability of countries to conduct independent monetary policy.[15] While most of these risks are more pronounced for recipient countries, swings in the external demand for a CBDC could also affect the implementation of monetary policy of the issuing country if its financial markets are relatively small or shallow. Third, cross-border payments with CBDCs could help circumvent existing capital flow management measures (CFMs), which could undermine countries' efforts to maintain macro-financial stability. However, CFMs could also be an integral part of CBDC design, directly embedded into the CBDC software, for instance by ensuring that digital wallets have caps on how many cross-border transactions a user can make in a certain time period. This could increase CFMs' efficiency.[16] Finally, cross-border availability of CBDCs may in some cases contribute to a reconfiguration of reserve currency holdings, which, while not a risk, could require a change in regional and global backstops (eg a change in multilateral lenders and regional FX reserve pooling arrangements).

[13] The Group of Central Banks (2020) outline three common foundational principles for domestic retail CBDC issuance: do no harm, coexistence, and innovation and efficiency. In addition, they discuss several core features that support these foundational principles, eg convertibility, convenience, resilience, interoperability, availability, low cost, security, instant settlement, scalability, flexibility and robust legal framework.

[14] The G7 (2021) discuss 13 principles for retail CBDCs: monetary and financial stability, legal and governance frameworks, data privacy, competition, operational resilience and cyber security, illicit finance, spillovers, energy and environment, digital economy and innovation, financial inclusion, payments to and from the public sector, cross-border functionality, and international development. A comparison shows that most of the G7 principles were also covered by either the three common foundational principles or the core features of the Group of Central Banks (2020).

[15] For more on this, see IMF (2020) and CPMI et al (2021).

[16] See He et al (forthcoming) on CBDC and CFMs.

Many of these risks, such as currency substitution, are not new, but the availability of CBDCs across borders could reinforce them and their impact, including by making it more difficult to implement monetary policy and capital control measures. Therefore, it is crucial for cross-border CBDC arrangements to be designed in such a way that negative spillovers to the macroeconomy and risks to financial stability are limited, in both the domestic and cross-border context. Examples of design features that could be employed for this purpose may include restrictions on holdings of CBDCs by non-residents, caps and fees on flows, and specific risk monitoring systems.

2.2 Enhancing efficiency

Efficient payments, both wholesale and retail, are characterised by low cost and high speed, without compromising other relevant aspects, such as ease of use, accessibility, availability and safety. CBDC ecosystems could enhance efficiency in the overall payments market by adopting cutting-edge technology compared to legacy systems, and fostering a level playing field and competition, for instance through increased product diversity and enhanced interoperability (see also Section 2.4) between other means of payment in a domestic and cross-border context (Group of Central Banks (2020), G7 (2021)).

Efficiency sits at the core of the G20 cross-border payments programme that aims to address the challenges of high costs, low speed, limited access and limited transparency. For CBDCs to promote efficiency in the broader payments market, it is crucial that CBDC payments themselves are as efficient as possible. Encouraging broad-based private sector participation and the supply of innovative payment services as well as technologies and technical standards/procedures that minimise risks and lower costs in CBDC ecosystems would be essential in achieving efficiency in CBDC payments. Several design choices will also have an impact on the efficiency of CBDC payments, such as choices related to fee structure, access policy and interoperability arrangements.

2.3 Increasing resilience

Resilience is the ability to identify, protect against and recover from adverse shocks and other disruptive events. An ecosystem can be said to be resilient at the system level if weaknesses of its individual participants do not undermine the resilience of the entire ecosystem. CBDC ecosystems with their own payment instruments and infrastructures could provide an independent alternative to existing payment instruments and systems, contributing to the general resilience of the overall payment landscape in the domestic and cross-border context (Group of Central Banks (2020), G7 (2021)).

The ability of CBDC ecosystems to contribute to the resilience of the overall payment landscape would depend crucially on interlinkages with existing payment systems as well as the overall resilience of these ecosystems. CBDC ecosystems should be secure (eg resist cyber attacks and fraud) and resilient to operational risks, such as loss of network communication, electrical outage, and natural disasters (Group of Central Banks (2020)). The resilience of CBDC ecosystems would also depend on the resilience of arrangements used for interlinking CBDCs, the presence of a sufficient number of intermediaries to reduce risks from single points of failure and the cross-border coordination and supervision of resilience-related activities and policies. There are several international sets of guidance that would be relevant to ensure resilience of cross-border CBDC arrangements, such as the CPMI-IOSCO guidance on cyber resilience for financial market infrastructures (CPMI-IOSCO (2016)), the CPMI report on reducing the risk of wholesale payments fraud related to endpoint security (CPMI (2018)), and the FSB report on regulatory and supervisory issues relating to outsourcing and third-party relationships (FSB (2020b)).

2.4 Assuring coexistence and interoperability with non-CBDC systems

Different types of central bank money – new (CBDC) and existing (banknotes and balances in reserve or settlement accounts) – should complement each other and coexist in a wider payment landscape that supports public policy objectives and includes and supports private money (just like commercial bank accounts and cash issued by central banks currently coexist; see Group of Central Banks (2020)). In addition to coexistence, interoperability between the different forms would enable end users to seamlessly transact with each other regardless of their geographic location, choice of PSP or type of money and support the convertibility at par.

CBDC systems that coexist and are interoperable with domestic as well as other cross-border transfer arrangements avoid fragmentation and inefficiencies in payment systems (eg the need for separate card acceptance terminals for CBDC payments), ensure competition and facilitate adoption of CBDCs. Given that the payments market is constantly changing, a cross-border CBDC system should also be flexible enough to interoperate with future payment services, systems, schemes and arrangements. This requires carefully considered design choices, eg regarding the involvement of foreign PSPs or the type of interoperability model used.

2.5 Enhancing financial inclusion

Financial inclusion means that individuals and businesses have access to affordable financial products and services that meet their needs – transactions, payments, savings, credit and insurance – delivered in a responsible and sustainable way. CBDCs should not impede and, where possible, should enhance access to payment services for those currently excluded from or underserved by the existing financial system, while also complementing the important role that will continue to be played by cash (G7 (2021)).

Financial inclusion aspects explicitly factored into the domestic designs of CBDC ecosystems may also enhance financial inclusion in a cross-border context. CBDCs could be designed to ensure access to a basic, trustworthy means to pay and store value in situations where PSPs do not offer transaction accounts that effectively meet the needs of the unbanked and/or have failed to instil trust (CPMI-WB (2020)). As part of CBDC design, the use of third-party agents, person-to-person payments at little or no cost, different user interfaces, simplified KYC and e-KYC processes, offline payments and cross-border interoperability, among others,[17] can address multiple barriers related to geography, institutional factors or market structure. These design features can contribute to meeting the needs of specific groups, such as those without ID credentials or international migrants. While these features are not unique to CBDCs, the opportunity to deploy them through one public sector-led initiative may present a unique and novel approach for tackling financial exclusion going forward (BIS-WB (2022)).

[17] For instance, time-tested measures such as simplified KYC and e-KYC, accessible, low-cost and easy-to-use payment instruments and extended access points to and from cash could facilitate individuals' access to cross-border CBDC arrangements (eg for making and receiving remittances and cross-border e-commerce payments).

Box 2

AML/CFT compliance in cross-border CBDC arrangements

Illicit activity undermines financial integrity, national security and economic development. As with any value transfer system, CBDCs could be used by criminals and terrorists for illicit activity. An important part of global efforts to combat illicit finance is national implementation of sound anti-money laundering and combating the financing of terrorism (AML/CFT) regimes in line with the international standards set by the Financial Action Task Force (FATF). Central banks are expected to design CBDCs in line with AML/CFT requirements.[18]

The exact financial integrity implications of a CBDC arrangement will vary depending on the design choices taken. In particular, central banks, in coordination with relevant AML/CFT bodies, should consider the following aspects when designing a CBDC arrangement:

- **CBDC ecosystem and scope:** While a wide and varied user base may be desirable for a CBDC, the number and jurisdiction of residence of users will affect money laundering and terrorism financing (ML/TF) risks. Similarly, the number, type and location of intermediaries involved in the issuance, distribution and use cases of the CBDC will have regulatory and supervisory implications, particularly as service providers may be located abroad in the context of a cross-border arrangement.
- **Level of intermediation and allocation of AML/CFT responsibilities:** In a one-tier model (see Section 3.1.2), the central bank would have a direct relationship with end users, and, as a result, would have AML/CFT obligations. This model could create conflicts of interest if the central bank is also the AML/CFT supervisor. In a two-tier model, AML/CFT obligations would remain with intermediaries. Ensuring that all relevant actors are subject to the AML/CFT regime and supervised would be key in this model.
- **User identification and due diligence:** A critical component of AML/CFT is identifying the customer and source of funds. Due diligence challenges might differ between account-based or token-based CBDC arrangements,[19] and as with traditional financial services, these challenges are likely to be magnified in a cross-border context. Some rules pertaining to "traditional" financial transactions (eg the wire transfer rule) may require further thought in the context of a CBDC arrangement.
- **Oversight of AML/CFT compliance:** The evolution of new service providers and/or services may require adaptation of AML/CFT laws and regulations, supervisory models, and organisational structures of AML/CFT supervisors. Coordination with other key AML/CFT agencies as well as foreign counterparts (in the case of cross-border arrangements) will also be important.

As with the traditional forms of money and financial services, the implementation of AML/CFT measures for CBDCs will be more challenging in a cross-border context, calling for global harmonisation and collaboration.

See Annex 3 for further elaboration and discussion of the key design considerations.

3 Potential options for access to and interoperability of CBDCs

The potential uptake and use of CBDCs for cross-border transactions strongly depend on the access and interoperability choices made by central banks when designing their CBDCs. There are two main ways to enable cross-border payments using CBDC. First, national CBDCs can be made available to non-residents (for rCBDCs) and to foreign PSPs (for both rCBDCs and wCBDCs) for direct use. Second, cross-border CBDC transactions can be facilitated through interoperability between different countries' CBDC systems.

[18] See FATF (2020, Annex B) for further information on CBDCs in the AML/CFT context.

[19] Account-based and token-based CBDC arrangements are not always fully distinct from each other and, indeed, many CBDC arrangements are hybrid systems. For the purpose of this discussion, the critical distinction is whether authentication is primarily focused on the user or the object of payment.

3.1 Options for access to CBDCs

3.1.1 Access to wCBDC by foreign PSPs

When designing a wCBDC, central banks must decide whether and how foreign PSPs can access the system and use their wCBDCs. In general, the following choices can be made (see Graph 1):[20]

- *Closed access – domestic PSPs only:* only domestic institutions can access, hold and use the wCBDC. In this model, central banks issue (redeem) wCBDCs to (from) the participants upon receiving (transferring) central bank reserves from (to) them in their traditional settlement accounts, or upon receiving (transferring) collateral, similar to the issuance of central bank reserves. In this model, foreign PSPs are not direct or indirect participants in the wCBDC system. Yet, the wCBDC could still be used in a cross-border setting through various interoperability and/or interlinking arrangements as discussed in Section 3.2 (see Table A.1 in Annex 4 and projects HSBC, Jasper-Ubin, Prosperus, MAS and Aber in Annex 6).
- *Indirect access – foreign PSPs can access the wCBDC network via an intermediary.* As with indirect access to traditional payment systems, indirect access to wCBDC systems may take various forms. For example, foreign PSPs might be required to rely on a direct (domestic) participant for payment instruction, clearing and settlement. In this case, the direct participant transacts on the wCBDC ledger on behalf of the foreign PSP. An alternative indirect access model would be one in which foreign PSPs are allowed to hold a wCBDC directly and to submit their own transactions, but still rely on a direct (domestic) participant for the onboarding and possibly also transaction processing. Project Dunbar Phase I (Annex 6.9) is an example of a wCBDC using such an indirect access model.[21] This report focuses on forms of indirect access that are formalised in the system rules and that dictate some or all of the terms of such access. Thus, correspondent banking is not considered a formal indirect access model.
- *Direct access – foreign PSPs can directly hold and transact in wCBDC issued by a central bank without an intermediary participant.* In this model, foreign PSPs, upon satisfying certain access criteria, can hold and transact directly without the need for an intermediary (see Table A.1 in Annex 4 and projects Helvetia Phase II, mBridge and Jura in Annex 6). This model would generally require mutual reliance by the central banks on the supervision of these entities by their home supervisors.[22]

Each of the above options will have different implications, eg in terms of efficiency (length of transaction chain, processing speed, costs and fees), competition and innovation (barriers to entry, creation of level

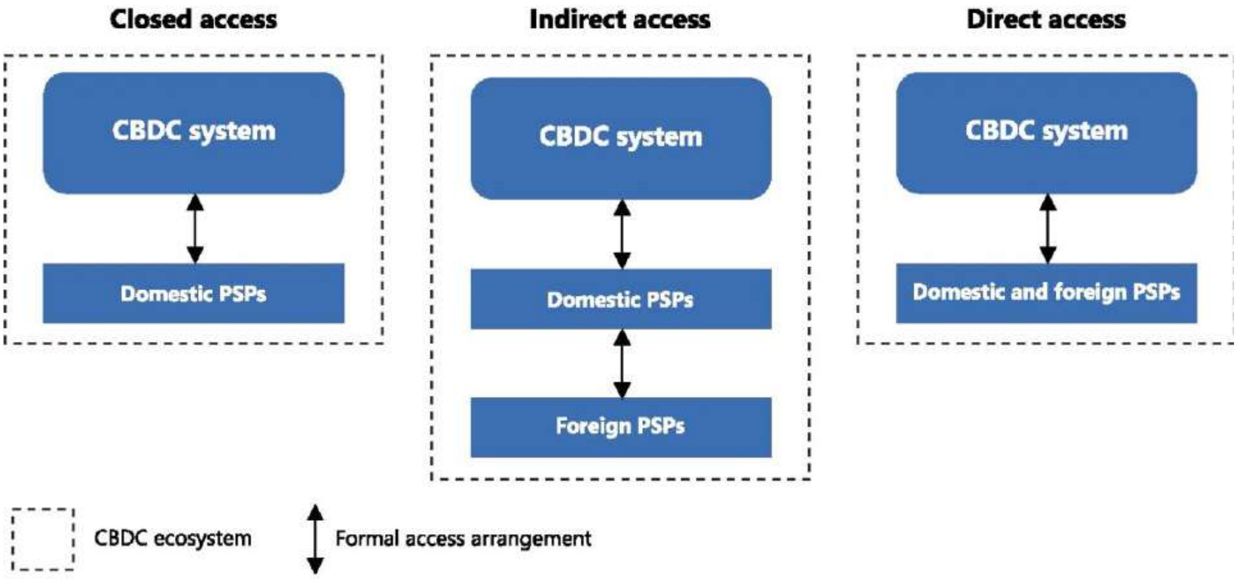
[20] The access choices presented in this report are similar to the access options for non-CBDC systems presented and discussed by the CPMI as part of the work conducted under BB 10 of the G20 cross-border payments programme (CPMI (2022b)). The BB 10 report distinguishes between direct access, indirect access and agent-only access. Since there is some variation in agent access models and the types of entities that may use or offer them (such as payment infrastructures or non-bank PSPs) depending on the settlement needs of the participant, agent access models may be considered direct or indirect access depending on the jurisdiction and the perspectives of the system operators. Therefore, in the current report, we only distinguish between direct and indirect access.

[21] Prototypes were developed to flexibly support both indirect and direct access models. In jurisdictions where the regulatory frameworks allow direct access to the CBDC by non-resident banks, approval routing to "sponsoring" banks could be disabled to move from a sponsored to direct CBDC access model.

[22] Even if foreign PSPs are given direct access, central banks might limit the issuance (redemption) of CBDCs to domestic PSPs. In this case, foreign PSPs would have to buy (sell) the CBDC in the secondary market from (to) domestic PSPs. So the provisioning of direct access to wCBDC raises the question of how to issue wCBDC to non-local banks or other PSPs. While most wCBDC projects propose the issuance of wCBDC through the RTGS system, another option proposed by BISIH, SIX and SNB would be for the central bank to issue wCBDC via monetary policy operations, such as standing facilities, directly on the wCBDC network (see project Helvetia Phase II in Annex 6.5).

playing field), resilience (settlement/liquidity/credit risks, concentration risks) and financial inclusion. Also, the challenges and feasibility of each access option differ. These will be discussed in Section 4.[23]

High-level options for access to wCBDC systems by foreign PSPs — Graph 1



This report does not consider a correspondent banking arrangement as a formal access model. Yet, in each of the CBDC access models presented here, direct and indirect participants could establish correspondent banking relationships with other PSPs that are neither direct nor indirect CBDC system participants. Such arrangements might especially occur in a cross-border arrangement based on closed access and in which interoperability with other CBDC systems is achieved via compatibility.

Source: Authors' elaboration.

3.1.2 Access to rCBDC by non-residents and the role of PSPs

When designing an rCBDC, central banks will also have to find an answer to the following two questions, each of which will impact the flow of cross-border CBDC transfers:

- *Who will be able to hold and transfer rCBDCs and under what conditions?* A key issue is to what extent non-residents of the issuing jurisdiction will be granted access to the rCBDC. There is a spectrum of options, starting with granting access to tourists and business travellers visiting the country. Broadening this out somewhat, access could also be granted to refugees, asylum seekers, foreign entrepreneurs, and resident branches of foreign corporates, as well as to expatriates and relatives living abroad so that they could use the rCBDC to send and receive remittances and cross-border transfers. The flow of cross-border rCBDC payments can further be influenced by

[23] On top of determining who can access wCBDC, central banks will have to decide which rights each of the participants will have in the system. In case of, for example, a DLT, the various options might differ depending on the type of DLT used, but generally speaking the role of participants in such a network might vary from validating transactions within the network, to reading and writing information (ie submitting transactions) to reading own transactions only. These choices too will have different implications.

the conditions set for holding and using rCBDCs. CBDC holdings and payments by non-residents, when allowed, could be limited through caps or fees.[24]

- *If access to rCBDC is allowed for non-residents, how will they be able to access it?* For rCBDCs to be accessible to non-residents, either when visiting the issuing country or when abroad, they would need to be able to open and hold an rCBDC account. This requires the rCBDC ecosystem to be designed such that rCBDCs can be acquired by non-residents through transfers or in exchange for their home currency. As with the distribution of domestic rCBDCs, these account and exchange services can be provided either directly by the issuing central bank (one-tier rCBDC model) or indirectly via private sector intermediaries (two-tier rCBDC model).[25] One- and two-tier architectures might have different implications, both in terms of the five criteria discussed in this report and in terms of their implementation challenges. However, as most central banks are considering a potential domestic rCBDC architecture that involves a role for the private sector (see Kosse and Mattei (2022)), this report focuses on two-tier architectures.

If non-residents are not allowed to hold rCBDCs, one way to still transact using them is for the end user to have a non-CBDC account with an intermediary who has access to rCBDC and who can make an rCBDC transfer on the end user's behalf. However, from the end user's perspective, this would constitute a claim on the PSP even if the rCBDC would still be a liability of the central bank. Alternatively, if multiple CBDC systems are interlinked (see Section 3.2), non-residents, provided that they have access to a domestic CBDC, could still make CBDC payments to someone in another CBDC system in the presence of an intermediary PSP acting as a CBDC conversion provider. Similar to the wCBDC access options presented in Section 3.1.1, foreign PSPs may be granted access to the rCBDC using an indirect or direct access model.

3.2 Options for interoperability of CBDC systems

As mentioned earlier, cross-border payments with CBDC can also be enabled through ensuring interoperability between different CBDC systems as well as between CBDC and non-CBDC systems. In this section, we explore different types of interoperability, while accounting for the fact that somewhere along the payments chain, one currency (regardless of its form, whether CBDC or non-CBDC) must be exchanged for another, just like traditional cross-currency transactions (see Box 1).[26] Domestic interoperability between a jurisdiction's CBDC and non-CBDC systems will be briefly discussed in Section 3.3.

There are three broad models of mCBDC arrangements that can be used to achieve interoperability (see CPMI et al (2021)[27] and Graph 2):

- *The compatible model* – refers to individual CBDC systems that use common standards, such as message formats, cryptographic techniques, and data requirements, that reduce the operational burden on PSPs for participating in multiple systems. Hence, compatibility might be achieved, for example, through the use of common messaging standards and data formats, such as ISO

[24] Remuneration is another tool that central banks could use to influence holdings and use of rCBDC (see eg Bindseil (2020)), which could be considered as a negative fee.

[25] In a two-tier model, the issuing central bank and trusted private sector intermediaries would work together in a complementary way (see Auer and Boehme (2021)). The central bank could focus on issuing the CBDC, providing the core CBDC infrastructure, and ensuring its stability and security, whereas the majority of the operational tasks and consumer-facing activities would be delegated to the intermediaries. These intermediaries could be located either within or outside the country of issuance depending on the jurisdiction's policy and regulation.

[26] As is the case with traditional cross-currency transactions, foreign currency providers for cross-border CBDC transactions must hold enough balances in the respective currencies. This requires them to hold CBDCs either directly or indirectly and necessitates domestic interoperability between the CBDC systems and traditional central bank reserves. This type of interoperability to facilitate FX transactions is out of the scope of this report's analysis.

[27] The three models of mCBDC arrangements were first presented in Auer et al (2021).

standards.[28] Cross-border CBDC payments in the compatible model could be achieved with the various access models presented in Section 3.1. If a CBDC system allows for direct access, a foreign PSP could directly access the system to facilitate a cross-border payment using that CBDC. In that case, the foreign PSP would likely have to obtain the currency of the CBDC system on its own accord. Alternatively, a foreign PSP could access the CBDC system via a direct participant that probably performs the currency conversion (see Graph 3).

Although the compatible model does not link different CBDC systems, it has the potential to improve current cross-border payments by enhancing efficiency of payment processing and compliance protocols and by facilitating participation in different systems and different jurisdictions. Depending on the access model, some frictions may however remain, such as the need for individual PSPs to establish correspondent banking relationships. See project Helvetia Phase II (Annex 6.5) for an example of a compatible model with direct access.

- *The interlinked model* – links different CBDC systems with a set of technical and contractual agreements that not only facilitate communication and exchange of data, but could also facilitate compliance, foreign currency provision and settlement.[29] These common arrangements would allow participants in the interlinked CBDC systems to transact with each other without the need to become a direct participant in each of them or to establish bilateral arrangements with an intermediary for each of them. Interlinking arrangements could include common technical functionalities between CBDC systems (such as PvP settlement) and a common set of currency providers connected via a common trading venue. For the interlinked model, a question is how exactly the CBDC systems involved are linked. Work on interlinking of non-CBDC payment systems is being taken forward under BB 13 of the G20 cross-border payments programme (see eg CPMI (2022c)). For the purposes of this report, we build our analysis on the ways of interlinking systems identified in that work, which can also be applied to CBDC systems (see Graph 3):

    - *A single access point* – where participants in one system have access to another system through a single "gateway" entity, such as a PSP acting as a single correspondent bank for all and participating in both systems. This model differs from the compatible model above in that the single gateway entity is a formalised part of the arrangement and acts as a gateway to all other participants;

    - *A bilateral link* – where two individual CBDC systems are directly linked so that participants in one system can directly transact with participants in the foreign system (see projects HSBC and Jasper-Ubin in Annex 6);

    - *A hub and spoke solution* – where 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.[30]

- *The single system model* – refers to CBDCs that use a single common technical infrastructure and potentially also a common rulebook.[31] While the rulebook over the platform will apply to all participants, the rulebook for each CBDC might still differ between jurisdictions with regard to, for example, holding and transaction limits, participation requirements, and issuance and redemption of CBDCs. Hence, this model is not connecting separate CBDC systems, but rather

[28] There could be trade-offs between promoting international interoperability of CBDCs using commonly implemented standards and achieving domestic interoperability with existing forms of money within jurisdictions; this should be carefully assessed.

[29] The BIS Innovation Hub's Project Nexus is an example of an interlinked model applied to fast payment systems. This project provides a blueprint for a scalable cross-border payment network that would connect fast payment systems in multiple countries. Detailed information about the project is available at www.bis.org/about/bisih/topics/fmis/nexus.htm.

[30] Project Nexus is an example of a hub and spoke model even if not focused on CBDC. See nexus.bisih.org/.

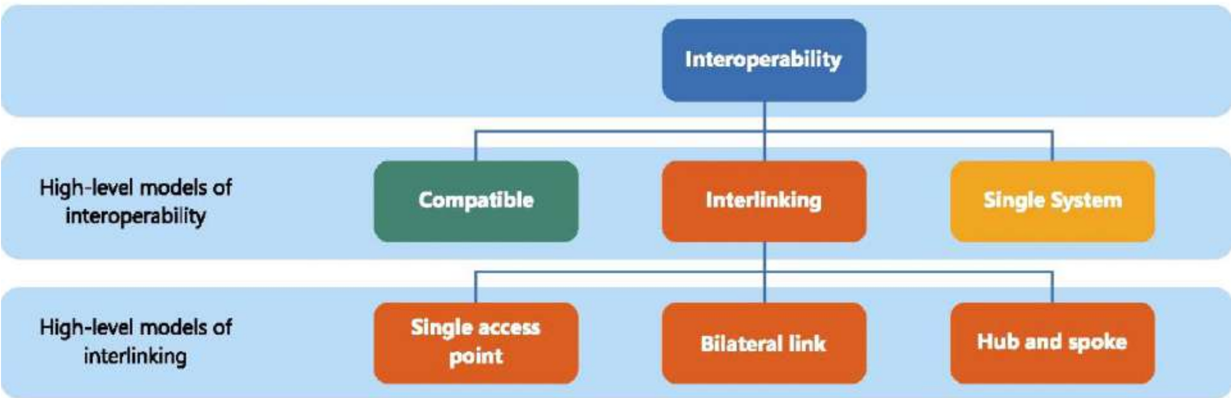
[31] A single system model may qualify as a "common platform" and a "multilateral platform" as defined by BBs 13 (interlinking) and 17 (multilateral platforms) of the G20 cross-border payments programme.

establishing a common platform to achieve interoperability between CBDCs. The single system model may offer the same services as the interlinked model (eg PvP functionality and common currency trading venue), but could also establish common participation requirements for all jurisdictions involved. If establishing such requirements, the single system model could bring additional benefits as compared to the interlinked model by further stimulating competition (see Graph 3 and projects Prosperus, MAS, Aber, Dunbar, mBridge and Jura in Annex 6).

The design of the interlinked model and the single system model raises the question of which entities provide the common services. For instance, central banks could act as common settlement agents or foreign currency providers, but these services could also be left to the private sector. The role of the public sector in that case could be to specify requirements for private actors to offer certain common services. Currency providers could in principle be anyone that is willing to engage in currency exchange, but if they are not themselves settlement agents in the respective CBDC systems, they would have to rely on common settlement agents. Common technical functionalities allowing for PvP settlement would eliminate credit risk exposures in the settlement process. This would stimulate competition in the provision of these intermediary services, as PSPs in different systems could act as settlement and foreign currency providers to each other without exposure to credit risks in the settlement process.[32]

All models described in this section can be implemented with different access options and using different technical solutions. When analysing the different access and interoperability arrangements in the remainder of this report, we remain agnostic regarding the technical solutions used. Moreover, it should be noted that the interoperability and interlinking options presented above should be taken as stylised models that aim to facilitate our understanding of the high-level distinctions and key considerations. In practice, hybrid solutions may arise that have characteristics of different models. Also, systems may be classified in multiple ways depending on their reach and access criteria. For example, a single system implemented by a group of countries could act as a hub to other countries outside this group.

High-level models of interoperability and interlinking of CBDC systems — Graph 2

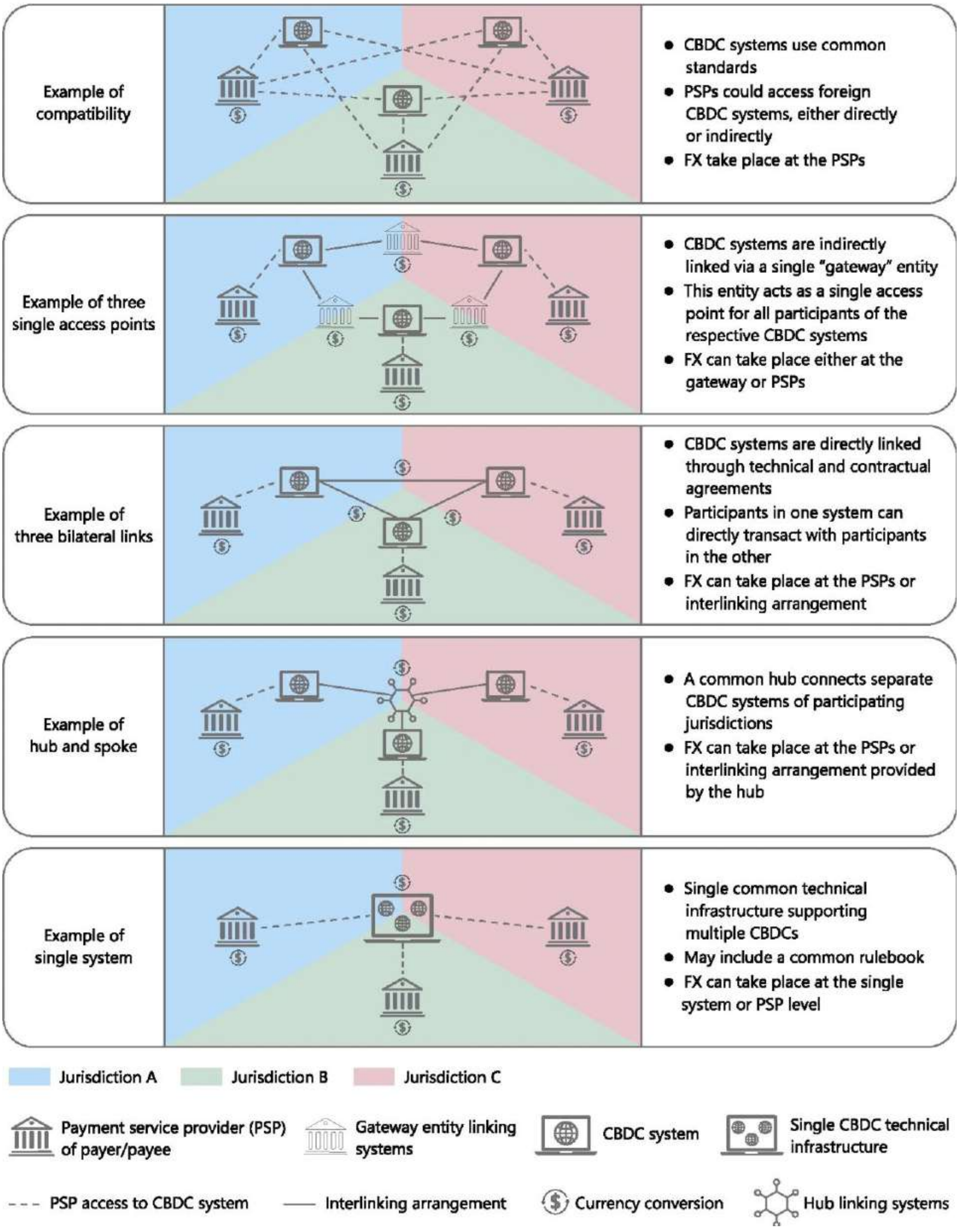


Source: Authors' elaboration leveraging CPMI et al (2021) and CPMI (2022c).

32 Payments from one CBDC system to the other would in this case involve two payments as in the compatible model where one intermediary is acting as settlement agent and currency provider. As a first step in cross-border payment, a domestic PSP would enter into a foreign currency trade via a common trading venue. After the foreign currency exchange rate is established via the foreign currency trade, the cross-currency payment would be settled by two synchronised payments in respective currencies. The foreign currency provider (or its settlement agent) would settle the payment to the ultimate receiver in the currency of the receiver, while the originating PSP would settle the payment to the foreign currency provider (or its settlement agent) in the domestic currency.

Key features of interoperability and interlinking of CBDC systems

Graph 3



The PSP access to the CBDC system could be based on any of the models discussed in Section 3.1.1.

Source: Authors' elaboration leveraging CPMI et al (2021) and CPMI (2022c).

3.3 Interoperability of CBDC and non-CBDC systems

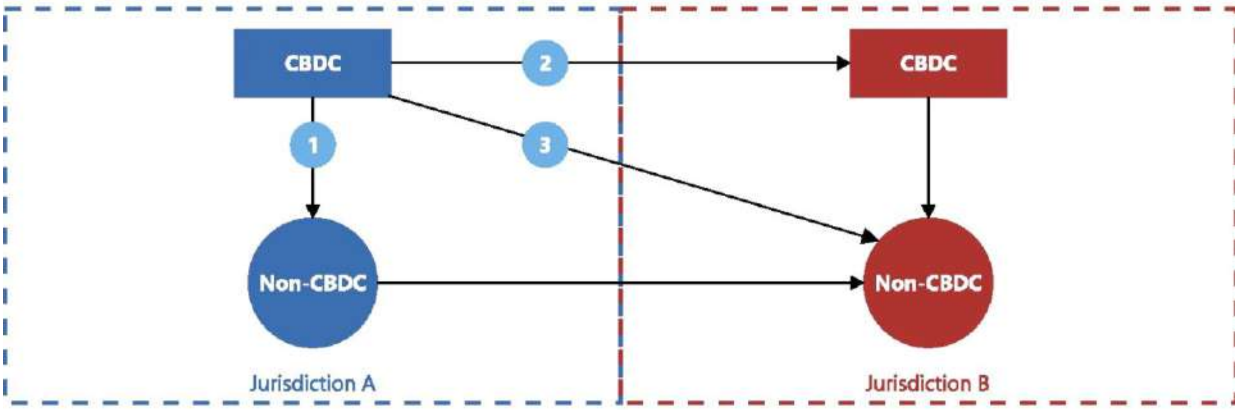
Interoperability between CBDC and non-CBDC systems, such as fast payment systems, RTGS systems or other (future) systems, is key to ensuring that end users can seamlessly transact across borders regardless of the payment instrument chosen. For example, arrangements among wCBDC systems might require linking to the non-CBDC systems in each jurisdiction to facilitate cross-border transfers and wCBDC arrangements could act as the settlement system for linked domestic retail payment systems. In addition, there might be cases in which a payer wants to send money using a CBDC to a country without a CBDC.

To achieve interoperability between CBDC and non-CBDC systems, it should be considered at an early stage – both within and between jurisdictions. There are three general options to attain such "universal" interoperability. As an illustration, let us consider the example where someone in Country A would like to use a CBDC account to transfer money to someone in Country B who does not have a CBDC account. Such a payment could, in principle, take three different routes (see Graph 4):

1. From the CBDC system to the non-CBDC system in Country A and then to the non-CBDC system in Country B via a cross-border interoperability arrangement between the two non-CBDC systems;
2. From the CBDC system in Country A to the CBDC system in Country B using the cross-border interoperability arrangement between the two CBDC systems and subsequently to the non-CBDC system using domestic interoperability between the CBDC and non-CBDC systems in Country B;
3. From the CBDC system in Country A directly to the non-CBDC system in country B via a cross-border interoperability arrangement between the domestic CBDC and foreign non-CBDC systems.

The first two routes are similar in the sense that they both build on domestic interoperability between a CBDC and non-CBDC systems and a cross-border arrangement connecting two systems of the same type. However, the first option would rely on the traditional cross-border arrangement, whereas the second would rely on a CBDC cross-border arrangement, which could be more efficient, for example for the reasons mentioned in Section 1. The third route only requires one type of interoperability, ie cross-border interoperability. Provided that more than one cross-border connection exists, different routes would be available for end users. Factors such as cost and speed will then influence the selected route, which in turn will be affected by which of the interoperability models from Section 3.2 is used for each "link".

Interoperability of CBDC systems with non-CBDC systems — Graph 4



Source: Authors' elaboration.

4 Analysis of access and interoperability options

4.1 Analysis of access and interoperability options for meeting the criteria

Tables A.1 and A.2 in Annex 4 map a selection of completed and ongoing CBDC projects against the access and interoperability options identified above. The majority of the wCBDC projects have been completed as one-off experiments, while a few are still in an exploratory stage (see Graph A.1 in Annex 4). Regardless of their status, most cross-border wCBDC projects use a single system to facilitate CBDC transactions between jurisdictions, and all except one apply a closed or direct access model. This might suggest that central banks perceive these interoperability and access options either to have the highest potential to add value in the long run or to be the easiest to start from in the short run. In this section, we analyse the access and interoperability options identified in Section 3 through the lens of the five criteria presented in Section 2 (see also Graph 5 at the end of this section for a summary).

4.1.1 Do no harm

As discussed in Section 2.1, macro-financial risks of cross-border use of CBDCs derive mainly from potential capital volatility and currency substitution. Thus, limiting harm in this context implies maintaining the option of implementing CFMs to control flows. Cross-border use of CBDC will require an interface, such as a digital wallet, to access and transfer the CBDC. This interface could be exploited to control flows regardless of the interoperability model used. Control measures could also be applied directly to the connection between CBDC systems. In this case, the implementation of such controls depends on the different choices regarding interoperability of and access to CBDCs.

At the interface level, different access controls and limits can be used to mitigate risks. Here it is relevant to distinguish between rCBDC and wCBDC. For rCBDC, controls could potentially be "hard-coded" in the wallet to limit the amount of foreign holdings or the size and frequency of cross-border transactions. The access choice will set the scope for such controls. Allowing non-residents, such as tourists, access to rCBDCs when physically within the borders of the issuing country probably has limited macro-financial consequences compared to allowing access to non-residents who are not physically in the issuing country. Controls such as GPS geolocation and transaction limits could be used to limit the use and holdings of rCBDC by non-residents after leaving the issuing country. Similarly, for wCBDC, controls could be applied to the foreign intermediaries' accounts. If the issuing country allows indirect access (see Section 3.1.1), the account held by indirect participants may be set up in such a way that transactions related to foreign banks are flagged, which would allow for real-time reporting to both domestic and foreign central banks – assuming that they are cooperating on surveillance flows – and for potential blocking of foreign transactions. Control at the interface level could thus be used with any interlinking option. It would, however, require: (i) effective KYC procedures; (ii) wallet design that allows control parameters to be set; and (iii) close cooperation among central banks, as the wallet issuer or overseer (ie the issuing central bank) must be willing to set those parameters to take international effects into account. Compliance of all actors involved would also be key for effective controls.

In the compatible model, countries would rely primarily on regulation and supervision of the domestic financial service providers providing the connection between jurisdictions. This would be similar to the current CFMs setup, in which financial intermediaries are responsible for implementing controls. Both the model for cross-border payments and the method to control them would thus be an updated version of the present system. Effects of increased use of digital money on the possibility of enforcing regulation and CFMs need to be analysed, and possibly updated for the digital age.

Both the interlinked model and the single system model allow the system operators to monitor and control transaction flows more directly, as flows are channelled through either a single access point, a bilateral link, a central hub, or a single system. However, a key challenge with these models is the governance of the link, hub or system, especially if there are competing country requests for controls and stops on flows. Governance must allow for a process to resolve different requests and, at the very least, provide the option of detaching unilaterally from the cross-border arrangement if the control of flows would not meet the needs of a certain jurisdiction.

4.1.2 Enhancing efficiency

The efficiency implications of different access and interoperability options depend on a large number of factors, such as the number of systems or intermediary PSPs involved, the development and maintenance costs of the arrangements, and whether such factors result in speedier and cheaper payments. All else equal, the single system model with common infrastructure and a single rulebook may lead to shorter transaction chains and hence speedier transactions than a single access point, bilateral link or hub and spoke model, as the latter involve multiple systems.

Also, integrating currency trading platforms and technical PvP functionalities in different interlinking solutions or in a single system may generate efficiency improvements, as such arrangements would reduce principal and currency exchange risks and potentially increase competition in the FX market. The compatible model would rely on policies and design to ensure an increase in competition. There is a risk that this model could be dominated by a few large PSPs for whom it is viable to participate in multiple CBDC systems and act as a currency provider and settlement agent.

Although the compatible model, the single access point model and bilateral links model can be established with relatively low costs, the adoption of a hub and spoke or single system would allow the costs of a technical solution for CBDCs to be shared among multiple participating jurisdictions. This would facilitate low fees and the internalisation of network effects that would bring added benefits to the users. Both aspects are crucial for encouraging sufficient adoption and private sector participation. At the same time, adopting a single system would save the costs of establishing and maintaining separate links or hubs necessary in the interlinking options. A single system (if operated on a cost-recovery basis similar to traditional payment systems operated or governed by the public sector) may be especially attractive in regions with smaller jurisdictions that may otherwise lack the scale that is required to sufficiently lower the unit cost of CBDC payments. Achieving low fees is especially important in the context of remittances and other low-value cross-border payments.

The use of a common rulebook may further increase the efficiency of a single system, as this may lead to additional harmonisation of payment messages, compliance and data processing. This in turn could result in faster payment processing, eg due to faster pre-checks and compliance. It could also promote harmonisation among other payment systems, especially if the CBDC system interoperates with other, domestic, payment systems. A single system with a common rulebook may also contribute to lowering legal uncertainty around settlement finality, and hence increase speed. This is particularly important in the context of time-critical large-value cross-border payments.

CBDC systems which would offer direct access to a broad range of institutions could contribute to efficiency. This could enhance competition, reduce risk and shorten transaction chains, but as highlighted elsewhere, it could also bring changes to the risk profile of the direct participants, potentially undermining the integrity of the existing settlement process (see eg CPMI (2022b)). Provided that risks relating to the direct access policy can be controlled, this policy could further enhance efficiency in cross-currency payments.

4.1.3 Increasing resilience

Resilience as defined in Section 2.3 is a broad term that covers the management of various risks. In addition to implementing general guidance on resilience, the different arrangements used for connecting CBDCs may have varying implications for resilience. Implications may differ according to how centralised or decentralised arrangements are. Both can offer potential advantages and disadvantages for resilience.

As the single system model is centralised, consequences could be large if it is disrupted. However, such a system would allow pooling of knowledge and resources from multiple jurisdictions, which could support more extensive measures, such as mirroring of crucial components and sophisticated cyber security measures, and more extensive incident management and reporting.

The resilience of the compatibility model depends on the access model implemented. An indirect access model might result in a few large domestic PSPs through which foreign PSPs access multiple CBDC systems. By contrast, compatible models allowing for direct access might increase resilience by reducing concentration of risk in a single or a few crucial entities.

The various interlinking models also differ in terms of their potential resilience. In the bilateral link or single access point model, a disturbance to the link or gateway entity between two jurisdictions would disrupt all transactions between the two respective jurisdictions, but not that of other countries. However, multiple jurisdictions could be connected through bilateral links or single access points which could increase resilience through redundancy: if the link between country A and B is disrupted but both countries also have a link to country C, then payment between A and B could potentially be rerouted via C. Similarly, in a hub and spoke model, a disturbance to one jurisdiction's link to a hub would only disrupt the transactions to and from this jurisdiction, while leaving transactions between other spokes unaffected. However, disruptions to the hub would affect all payments in the system, similar to a disruption of a single system and thus increase concentration risk.

While a bilateral link model could reduce the concentration risk of a hub and spoke or single system, maintaining a high level of resilience for all links and systems could be costly. Using a hub and spoke or a common platform, in contrast, allows pooling of resources (eg knowledge and budgets) that could be employed for increasing resilience compared to a more decentralised approach.

The choice of interoperability model might also have longer-term implications for development of resilience, as entities develop strategies to cope with risks. More centralised models might entail larger resources to develop new risk management tools. But on the other hand, a compatible model – provided that sufficient competition can be achieved – could provide a diversity of experimentation with new approaches, as different actors strive to adapt to changing risk landscapes, which could benefit the development of resilience.

Overall resilience of cross-border payments would also depend on the resilience of the individual CBDC systems. To protect domestic CBDC systems from operational failures of individual intermediaries or third parties (eg wallet providers or critical service providers), strict eligibility and compliance requirements for participants (eg sufficient operational and technical ability, sound risk management) could be established. A jurisdiction would have greater autonomy in establishing regulatory compliance requirements and supervising intermediaries with a less integrated model. However, establishing a common rulebook between jurisdictions would probably increase resilience, since everyone would abide by the same rules which would minimise the risks arising from divergent or inconsistent requirements. This is especially important if access is broadened to foreign PSPs that are not under the purview of the domestic regulator. In this case, some degree of coordination between the different jurisdictions is needed (eg to exclude a participant from the arrangement in case of misconduct or insolvency).

4.1.4 Assuring coexistence and interoperability with non-CBDC systems

To promote coexistence with other forms of money and payment instruments and a reasonable level of adoption of CBDC, interoperability with non-CBDC systems, both domestically and cross-border, is fundamental. Users benefit from having a choice of different payment methods. To fully achieve this, users must have the ability to effortlessly go from one method to another.

For end users to make and receive rCBDC payments, they must be able to domestically exchange CBDC to cash or commercial bank money. One way to achieve this is to use a two-tier model in which PSPs are allowed to hold and transact the rCBDC. Extending this to a cross-border setting, PSPs could be allowed to hold and transact both domestic and foreign CBDC and commercial bank money. In such an arrangement, an access model giving PSPs direct access to both the CBDC and non-CBDC systems would be the best option to enhance interoperability across borders as it would reduce the number of intermediaries involved.

Coexistence with non-CBDC systems is best promoted via a level playing field. Ensuring that different forms of public money (eg cash and traditional reserves) and private money (eg commercial bank accounts and e-money) can coexist and sustain sound business models is best achieved by access models promoting competition between PSPs and payment types. Establishing interoperability between different forms of payment types across borders would promote coexistence as it provides users with more options.

Section 3.3 presents three potential routes for connecting a domestic CBDC system with a foreign non-CBDC system. The first route (utilising domestic interoperability and then non-CBDC cross-border arrangements) requires improvements in non-CBDC payment infrastructures and arrangements (eg messaging standards, opening hours, participation requirements, funding and interlinking arrangements) and domestic interoperability between CBDC and non-CBDC. For the second route (connecting domestic and foreign CBDC systems and then utilising domestic interoperability in the foreign country), the CBDC connection could be established using either compatibility, interlinking, or a single system model. The third route (connecting a CBDC system directly with non-CBDC systems) would be important in cases where a recipient country does not have a CBDC. Potentially, all the models of interlinking could be used to link a domestic CBDC to a foreign non-CBDC system.

4.1.5 Enhancing financial inclusion

As noted in Section 2, simplified onboarding (eg via remote registration), ease of use, and access through a wide range of interoperable access points are likely to have a direct impact on how a CBDC supports financial inclusion objectives. These aspects largely depend on domestic CBDC design choices. Furthermore, the greater the level of harmonisation of regulations and alignment of technical standards and business practices, the broader the range of potential CBDC use cases supported and the greater the potential impact on financial inclusion. It is also worth noting that financial inclusion also depends to a great extent on the domestic arrangements of each jurisdiction. Factors such as foreign exchange policies, and the level of development of ICT infrastructure could dramatically affect the ability and willingness of users to use formal channels to send and receive remittances.

Access options to wCBDC are relevant to financial inclusion insofar as they may have a bearing on the ability of PSPs to serve a wide range of customers, including segments that most incumbents may consider unprofitable or difficult to reach. wCBDC systems act as a bridge for the PSPs' customers to transfer funds among themselves. Although customers will not hold CBDCs, the wCBDC could be used to switch, clear and settle customer transfers initiated from non-CBDC systems. Options that facilitate direct access to wCBDC accounts by foreign PSPs would appear to be most supportive of financial inclusion objectives, as foreign PSPs might have a better traction with certain customer segments like diaspora and their families. An indirect access model would make foreign PSPs reliant on domestic banks acting as correspondents, and closed access models would be the least supportive. Cross-border CBDC arrangements could be well placed to replace the existing correspondent banking relationships provided there is a large number of direct participants, thereby cutting down the number of intermediaries and multiple steps that weigh on costs and disproportionately affect small-value payments such as remittances (BIS-WB (2022)).

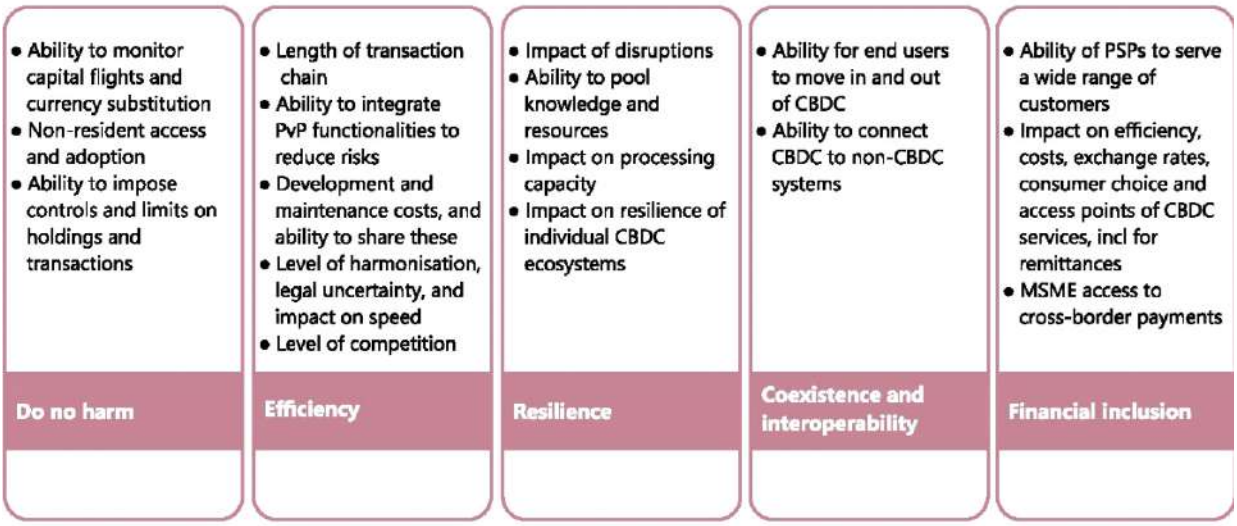
Cross-border CBDC arrangements that have small local and regional banks as direct participants would enhance micro, small and medium-sized enterprises (MSMEs)' access to cross-border payments (WTO et al (2021)). MSMEs – both as exporters and importers – could benefit from greater access to international markets and from digital tools and services for furthering their business. These opportunities are dependent on MSMEs having access to cross-border payment services. As MSMEs tend to be served by smaller local or regional banks, the de-risking phenomenon affecting these banks' correspondent banking relationships may result in hindering their ability to connect MSMEs to cross-border markets. Cross-border CBDC arrangements could provide or restore this connection. Another aspect of relevance is MSMEs' limited access to trade finance facilities, where new approaches based on technologies such as blockchain and tokenisation could be relevant. Such approaches could integrate better with CBDC-based payment services.

Allowing carefully calibrated non-resident access to domestic CBDC ecosystems may enhance financial inclusion, eg by enabling citizens working abroad to transfer funds to their family members' CBDC accounts domestically. This would have a positive impact on financial inclusion, both domestically and across the border, if it leads to a higher adoption and use of formal payment accounts. However, risks associated with, for example, currency substitution would increase.

In addition to access policies, the specific cross-border CBDC interoperability models may also have implications for financial inclusion insofar as greater levels of harmonisation may contribute to greater efficiency, lower end user costs, increased consumer choice or better access points. However, there may be certain trade-offs between harmonisation and the prerequisites for a model:

- CBDC cross-border arrangements based on a compatible model could be the least complex way to achieve cross-border interoperability. However, for compatibility to enhance financial inclusion, there should be strong harmonisation on such aspects as fee structure, speed of payment processing, AML/CFT arrangements, exchange rates and dispute resolution.
- For interlinked models, it would be the role of the system operators to ensure alignment. Compared to the compatible model, interlinking will typically reach a higher degree of harmonisation, and thus enable financial institutions and users to select among a larger (or common) set of providers, possibly leading to fewer fees and better services.
- The single system arrangement in principle provides the governance to ensure the highest degree of alignment across several aspects of CBDC operations. However, some jurisdictions may lack the incentives or eligibility criteria to participate in a common governance arrangement.

Factors that influence the impact of access and interoperability models on each of the five assessment criteria — Graph 5



Source: Authors' elaboration.

4.2 Assessment of implementation challenges

4.2.1 Challenges of interoperability of CBDC systems for facilitating cross-border payments

While CBDC cross-border arrangements could provide an advantage compared to the traditional cross-border arrangements, several challenges are common to all types of payments.[33] For example, in order to be successful, interoperability options for CBDC systems need to address challenges related to investment and maintenance cost, scalability, legal and regulatory frameworks, governance, AML/CFT and privacy protection, technology standardisation, risk management, operational and information-sharing concerns. In addition, other issues arise, such as network governance arrangements, data warehousing and choice of custody model, as CBDC business model questions remain to be answered. However, novel technologies, for instance DLT, potentially open up new options (eg subnetworks, control of nodes)[34] for addressing some of these challenges. Some of these challenges are universal across the different interoperability models, while others are more specific and should be taken into account in evaluating interoperability options (see Annex 5).

Investment and maintenance cost

Cost sharing and incentive mechanisms are key to the sustainability of all interoperability models. The compatible model, the single access point model and bilateral links can be established with relatively low costs. With the hub and spoke model, a hub must be set up from scratch, with the costs varying depending on the functions offered. A single system with a common platform requires a fully fledged mCBDC system and would be the costliest upfront, inter alia because of the importance of ensuring operational resilience and to avoid having a "single point of failure". However, once the hub or common platform was in place, costs could be shared among a larger number of participants, and the marginal cost on an ongoing basis could be the lowest.

The initial and ongoing investment might cover system software development, hardware infrastructures, system operation and maintenance, business monitoring, etc. For hub and spoke models and single systems with a common platform, it is essential to weigh who shoulders the development work, how to build it, who maintains it and how to ensure business sustainability in an international cooperative context.

Scalability

The compatible model using common standards would result in extensive scalability if the common standards truly removed country-by-country variation. However, its scalability would be limited if different detailed standards were still permitted. Despite simplicity in terms of having fewer attributes to harmonise and low costs, the single access point model and bilateral links have obvious scalability limitations compared with the hub and spoke model or the single system using a common platform. This is because a multitude of bilateral links between single access points, payment systems and other systems results in complex processes and requires a myriad of interoperability arrangements to be maintained. By design, a hub or common platform could more easily accommodate new participants and, by limiting the number of access points, reduce the costs associated with accommodating each new participant.

Legal and regulatory framework

Divergent, restrictive and not sufficiently harmonised legal and regulatory frameworks can pose challenges for mCBDC arrangements. Rules and regulations like CFMs, tax and payment laws, data-sharing and privacy treatment differ across jurisdictions. Interlinkage between infrastructures located in different

[33] BBs 10 (access), 13 (interlinking) and 17 (multilateral platforms) of the G20 cross-border payments programme address in more detail interlinking and access questions for traditional payment systems.

[34] See Annex 6 for a technical overview of how interoperability and access questions are being addressed in current experiments.

jurisdictions may therefore be regulated by divergent regulatory frameworks, which could result in important legal uncertainties. However, legal certainty is necessary in terms of applicable laws. Legal certainty is also required for any financial market infrastructure (CPMI-IOSCO (2012)), whatever the interoperability model chosen. However, complexities could increase in a bilateral link model, because there are a multitude of links. The hub and spoke model and the single system with a common platform would bring added complexity upfront, as they require broader legal and regulatory policies to be determined, to which the platform and its participants must adhere. Yet, after such consensus is reached among the participating jurisdictions, the hub and spoke model and single system with a common platform would show greater efficiency in terms of accomplishing compliance duties on an ongoing basis and could reduce the aforementioned legal uncertainty. Finally, it is important that the issuance of CBDC is legally feasible in the issuing country[35] and that issued CBDCs are fully recognised as currency by recipient countries' laws.

Governance arrangements

Cross-border CBDC arrangements require governance structures and frameworks, such as system rules, clear goals, effective decision-making processes, risk management policies and procedures, and clear rights and obligations – as with any interoperability arrangement. While traditional governance aspects and agreement on a rulebook are complex issues in all the interoperability models, challenges could be even more difficult for a single system with a common rulebook, since all participants would in essence have to accept the same rulebook and the risk of dissension increases with the number and heterogeneity of the participants. However, this single system model could potentially be less challenging in the longer term once the rulebook is agreed upon. How a governance model would fit with multiple central banks that share a common mCBDC platform and involve multiple commercial stakeholders remains a key consideration. Individuality that allows a sufficient level of autonomy and control has to be balanced with universality and standardisation. To address this challenge, governance structures and decision-making frameworks could be designed.[36]

Domestic versus cross-border interoperability

As discussed in Section 3.3, ensuring domestic interoperability would also be crucial in a CBDC ecosystem. As CBDC efforts progress in each jurisdiction, potential trade-offs might arise between promoting international interoperability of CBDCs using commonly implemented standards on the one hand and achieving domestic interoperability with existing forms of money on the other. For example, creating a single system and rulebook for cross-border CBDC payments could shift the interoperability challenge from between CBDCs (internationally) to between CBDCs and other forms of payment (domestically). This could impact the different priorities of central banks.

The balance between addressing illicit finance and privacy protection

Regardless of the model chosen, an mCBDC arrangement requires strong coordination among participating central banks to address illicit finance and to strike a balance between protecting privacy and combating illegal activities. AML/CFT processes are more challenging in a cross-border context. Different jurisdictions might have different thresholds to identify significant transactions that require enhanced due diligence. In a single mCBDC system, participants may collectively agree to adopt the lowest threshold to comply with the most stringent regulatory requirements, and, in the specific case of sanctions screening, this model as well as hub and spoke could facilitate the implantation of automated verification of sanction enforcement. However, it might be complex to agree on a single set of rules that allows individual countries to have the variations tailored to their ML/TF risk profile and other country-specific contexts (see also Box

[35] Kosse and Mattei (2022) show that 26% of the 81 respondent central banks have the legal authority to issue a CBDC and another 10% of jurisdictions are currently changing their laws to allow for it.

[36] See BIS (2021a, Section 6) for considerations related to the governance structure and conceptual decision-making framework of a common CBDC platform.

2). Customised privacy solutions that satisfy AML/CFT requirements also should be determined, eg who can access which parts of a cross-border transaction and under what circumstances.

Technology standardisation

One challenge relates to technological coordination. Insufficient technical standardisation in areas such as message formats, data elements, cryptographic algorithms and numbering and coding systems would cause frictions and inefficiencies when attempting to achieve interoperability between CBDC systems. Adopting the same technical standards requires high initial effort in each interoperability model. Another aspect relates to technological infrastructure and implementation. Greater challenges would appear in the steady state phase because remaining differences between systems would create inefficiencies. With a single system with a common platform, it would be easier to have baseline technological compatibility. In addition, a common platform model could enable greater technological efficiency for settlement and other processes.

Risk management, operational and information-sharing challenges

Given the currency conversion involved in most cross-border CBDC payments, challenges arise with respect to the choice of entities to provide the conversion service and bear the associated FX risk, and the choice of a reasonable exchange rate determination mechanism that minimises the risk of FX arbitrage. A single system with a common platform has the potential to streamline the payment process by performing both FX trading and settlement on the platform.[37]

Market and liquidity fragmentation issues could be less challenging for a hub and spoke or single system model considering that liquidity would be centralised on one platform for several jurisdictions. If central banks were to issue CBDCs on several platforms, this could induce liquidity and market fragmentation, unless it is feasible to seamlessly transfer funds across systems or platforms.

From a cyber security perspective, it would be essential to ensure the resilience of all the systems and models. However, the hub and spoke and single system models would require greater protection against cyber attacks and extreme conditions due to the "single point of failure" problem.

Other questions related to data warehousing rules[38] and custody models[39] should also be carefully considered to ensure data safety. Data warehousing would be complex to address in hub and spoke and single system models, because data localisation requirements could prove challenging to implement. One solution is to store data with a mutually trusted party. For the compatible, single access point and bilateral link models this would be easier to handle, since data can be stored within each jurisdiction's borders if necessary. The custody relationships would depend on the CBDC system design.

4.2.2 Challenges related to access to wCBDC by foreign PSPs

The potential challenges of broadening access to wCBDC systems are the same as those for broadening access to traditional RTGS systems.[40] These range from governance, decision-making, and risk management to operational, technical and financial aspects. In addition, as a new tokenised financial ecosystem emerges that brings increased market choice and competition, specific challenges related to CBDC system adoption might arise.

[37] For example, automated market-making protocols could be deployed on the common platform.

[38] For example, what countries' data and privacy rules apply? Do geographic data warehousing rules apply?

[39] For example, who actually owns the CBDC, the end user or the PSP? What is the custody relationship? Can it be different across countries?

[40] See CPMI (2022b) for a discussion on access to non-CBDC systems for cross-border payments.

Governance, decision-making and risk management

Broader access can entail greater challenges in terms of governance, decision-making and risk management practices. A closed model would be the least challenging due to the familiarity with governing the participating PSPs. An indirect access model would pose a challenge for commercial models and incentives for PSPs to take on the role of direct/indirect participant. The direct model would be the most challenging as the system could be opened up to many new types of participants. As mentioned above, this could be especially challenging upfront if paired with the single system model, as there could easily be disagreements during the development phase over what types of PSPs to allow, or it could be viewed as difficult to implement due to the need for harmonisation of and changes in regulation. Although the question of direct access is more complex in a single system model and requires further study to understand the specific differences, their consequences and the actual regulatory changes that might be required, it also has the highest potential to unlock efficiency gains.

Operational and technical scalability aspects

More direct access may increase the operational burden on the system, as it is essential to ensure that it can handle the increased load of participants. From a technical scalability perspective, there may be a limit to the optimum number of financial entities allowed to connect directly to the network. A large number of participants may affect network performance and scalability. Tiering of system access is a possible option for resolving this issue. Also, expanding access may raise pressure on central banks' and payment system operators' resourcing needs. It could also increase reputational risks in the event of a problem with an entity that had been granted access.

Adoption

To be truly successful for cross-border payments, a cross-border CBDC arrangement would need to attract a sufficiently large mass of end users, PSPs, countries and currencies. Adoption challenges would be larger where there are already well functioning alternatives in place. Arrangements with broader PSP access would probably be adopted more easily, because end users would be more likely to already be a customer of one of the participating PSPs. At the same time, a challenge of an indirect access policy may be its commercial viability from the perspective of the domestic PSPs on whom the indirect participants would rely. The willingness to take on such a role and the potential fees charged for it may vary depending on the roles and responsibilities required from these direct participants.

4.2.3 Challenges related to access to rCBDC by non-residents

While many of the challenges related to access options for rCBDC systems overlap with the ones for wCBDC systems, identity management and enabling offline payments would be specific to an rCBDC system.

Identity management

In order to facilitate cross-border payments, there two options for identity management: either jurisdictions develop and use a coordinated identification (ID) system or they each accept the ID systems of the jurisdictions of their foreign participants. Identification is important for the implementation of AML/CFT, as well as for the enforcement of any caps or limits imposed on payers and/or account holders (see also Box 2). Passport information can be gathered from non-resident visitors to the domestic country, but non-residents while abroad may not have the appropriate ID documents to be properly onboarded – this might be especially relevant in case of massive population displacement caused by war, political instability or a natural disaster. Getting agreement on the appropriate ID requirements will be less challenging for the more decentralised interoperability models. The single system model would be the most challenging, as it would require agreement across all countries involved, which could lead to a sense of unfairness if the requirements are set too high for some jurisdictions.

Offline payments and technology

Many countries are pursuing the possibility of enabling domestic offline payments, for example for crisis scenarios (often paired with lower ID requirements). This could pose potential challenges, especially if they also want the CBDC in general to be open to foreign use. Unfettered use of an offline payment system outside the issuing jurisdiction could pose risks of currency substitution and heightened money laundering (if the offline system also enables anonymity), while at the same time it could prove challenging to restrict offline use to domestic users only.

5 Conclusions and considerations for future work

5.1 Conclusions

Many central banks around the world are currently exploring, both conceptually and technically, the possibility of issuing a CBDC, either in retail or wholesale form or both. Most of this work focuses on exploring or developing a CBDC to meet domestic policy objectives, such as improving domestic payments efficiency, financial inclusion or payments resilience (Kosse and Mattei (2022)). Yet, various CBDC experiments have also been conducted with the aim of making cross-border payments faster, cheaper and more efficient. For CBDC to be an effective enhancer of cross-border payments, international collaboration is needed to coordinate and incorporate cross-border functionalities at an early stage, so as to avoid unintended barriers later. Although each jurisdiction may be bound by certain constraints when designing a CBDC, eg in terms of ensuring coexistence and interoperability with current systems and complying with existing legal and regulatory frameworks, many design features are still undecided, which allows central banks to start with a "clean slate".

To use this opportunity, the central banking community should work closely together from the outset of CBDC explorations in order to make timely decisions around cross-border access and interoperability. Concrete steps for central banks could take different shapes, such as agreements on common standards for clearing and settlement, identification, and data and messaging, as well as interlinking of different CBDC systems or even developing a single system for cross-border CBDC payments. This could build on, or consider the role of, existing institutional arrangements for regional integration and cooperation. More structured and broader international coordination on domestic CBDC designs would be beneficial to lower barriers to cross-border access and compatibility and may serve as a launching pad for interoperability. With the right design and governance structure, as well as international collaboration, CBDCs for cross-border payments could provide a basis for further competition and innovation in this market.

Central banks have different motivations for exploring or developing CBDCs. Also, the demand and need for improved cross-border payment rails differ across jurisdictions. Central banks are therefore likely to adopt different CBDC designs, and jurisdictions may take different decisions as to how to arrange cross-border payment flows between them. This report presents several options for access to and interoperability of CBDCs for cross-border payments and evaluates these options based on five criteria: do no harm, enhancing efficiency, increasing resilience, assuring coexistence and interoperability with non-CBDC systems, and enhancing financial inclusion. By doing so, the report serves as a tool for central banks to assess different options given their objectives.

This report presents three general ways to achieve interoperability between two or more CBDC systems: via compatibility, interlinking or a single system. Compatibility of CBDC systems, eg via common standards, might be easiest and least costly to implement in the short run. In fact, at a minimum, compatibility is required to enable cross-border payments. However, interlinking of CBDC systems, and even more so a single system, might deliver larger benefits, for example as it could allow for PvP settlement and centralised FX services which may yield additional efficiency benefits. Given the governance challenges and relatively high upfront costs of the interlinking and single system models, it is likely that such solutions will only be implemented in the long run, and there where the benefits of enhanced cross-border payments exceed the challenges, for example between countries that currently have large bilateral or multilateral trade volumes, or that have similar CBDC objectives and designs. This inherently might risk that the interoperability and access models with the highest potential for alleviating current frictions in cross-border payments are not necessarily implemented for the use cases that currently face large cross-border payments frictions, such as remittances.[41] Importantly, the three models of interoperability need not mutually exclude each other. For instance, some countries might develop a single system with primary trading partners, while still promoting cross-border payments to other countries using the compatible model.

Interoperability of CBDC systems is one way to enhance cross-border CBDC payments – another and complementary way is to broaden access to CBDC systems by foreign PSPs and to allow non-residents to use rCBDCs. The challenges of broadening access to CBDC by foreign PSPs are similar to those of broadening access to traditional large-value systems (BB 10 of the G20 cross-border payments programme). When identifying different cross-border CBDC access options for PSPs, this report presents three stylised models: closed access, indirect access and direct access. Allowing for direct access would reduce the number of intermediaries and shorten the transaction chain. The discussion on access by non-residents focuses on who will be able to transfer and hold CBDCs, and under what conditions. A key decision is to what extent non-residents are granted access and whether such cross-border access will be subject to certain conditions, eg in the form of transaction and holding fees and limits. Challenges and risks related to access by non-residents could be more uncertain than those related to access by PSPs and require careful consideration. This further underlines the need for international coordination and cooperation.

Implementation of new payment systems takes time, while digital innovations are accelerating faster than ever. This, even when collaborating and coordinating on the design of their CBDCs, requires jurisdictions to build a CBDC ecosystem that is flexible enough to account for different forms of interoperability – interoperability and coexistence with the payment methods we have today, such as cash and commercial bank money, as well as interoperability with potential future types of public or private money, such as properly regulated and well designed stablecoins. Any CBDC ecosystem must be built with the flexibility to adapt to a changing future. Other relevant considerations in the design of cross-border CBDC solutions, which may warrant cross-sectoral coordination, including ensuring compliance with AML/CFT rules, while safeguarding privacy and promoting competition.

Other building blocks of the G20 cross-border payments programme focus on measures to improve existing payment systems, eg via extended operating hours, broader access, interlinking of fast payment systems, or adoption of harmonised message formats. These work streams could complement and in some cases (eg facilitating comprehensive application of AML/CFT rules) also be directly beneficial to improve cross-border payments with CBDC.

5.2 Considerations for future work

The "clean slate" advantage of CBDCs has an expiry date. By the end of 2021, more than a quarter of central banks were developing or running concrete CBDC pilots. To help central banks in the planning and development of their CBDCs and to make sure that cross-border functionalities are considered in time, the central bank community should identify the stages in the design process when access and interoperability decisions must be taken. Having open and regular dialogues between central banks about their CBDC journey and experiences so far would be instrumental here. Further work is also required on the standards to which domestic CBDC designs would need to adhere to support cross-border payments.

[41] See Project Prosperus (Annex 6.3) for an encouraging example of a CBDC project focusing on the use of CBDC for remittance transfers.

Even jurisdictions not planning to issue a CBDC ought to be closely involved in this work as they will still be part of this new potential cross-border payments landscape.

While many central banks are exploring rCBDC issuance, presently most cross-border experiments involve wCBDC.[42] The BISIH conducted a deep-dive into the experience gained across its mCBDC projects, focusing on key functional and technological considerations, and lessons learnt for using wCBDC for settling across borders (BISIH (2022)). While many lessons from wCBDC experiments could apply to CBDCs more generally, an rCBDC is different in that it contains an additional set of participants, consumers and businesses, and that retail systems will likely process and settle a larger number of payments, which has implications for which technology can be used. Further work focusing on rCBDCs is essential to better understand the implications of such a cross-border CBDC arrangement.[43] Different rCBDCs could also be connected through wCBDC cross-border payment arrangements, and the interaction between retail and wholesale CBDC should therefore be further explored. Also, the opportunities and implications of offline capabilities for cross-border payments require further analysis.[44]

The analysis in this paper has pointed out several potential trade-offs between criteria and between choices of different cross-border CBDC arrangements. For example, there could be a trade-off between offering freedom to access CBDC cross-border services and minimising negative spillovers from capital outflows or currency substitution. Going forward, central banks ought to consider how to manage such trade-offs. However, at least in principle, technological advances make it possible to embed some CFMs in the design of CBDCs and allow central banks to strike a balance between efficiency gains and risk reduction.

While current experiments can help provide insight into technological feasibility, questions remain about their viability and the challenges of moving from a prototype to a production setting. Further assessment of the non-technological dimensions, such as legal, regulatory (eg AML/CFT compliance), governance, and policy issues is essential. In addition, actions to broaden the diversity of countries involved in CBDC experimentations and dialogues would be beneficial, especially to better understand the implications and requirements of cross-border CBDC arrangements to enhance the currently underserved cross-border corridors.

More work is also required regarding the macroeconomic implications of CBDCs. This report has highlighted potential risks, such as increased currency substitution and heightened capital flow volatility. In addition, some jurisdictions might choose to impose holding limits on rCBDCs in order, for example, to mitigate risks to monetary and financial stability from high rCBDC holdings, eg the risk of runs from the banking system into rCBDC. However, such holding limits might hamper the ability of PSPs to perform the currency conversion in cross-border CBDC payments if they are expected to do so. Such issues, in addition to the macroeconomic and monetary policy implications of potentially issuing CBDC to a large set of non-domestic participants, should be studied further.

[42] Kosse and Mattei (2022) show that central banks presently perceive wCBDC to be more capable of addressing cross-border frictions than rCBDC and that enhancing cross-border payments is a more important motivation for wCBDC than for rCBDC. See also Bank of France (2021) and the BIS Innovation Hub (BISIH) website (www.bis.org/about/bisih/projects.htm) for an overview of several wCBDC projects.

[43] A two-tier rCBDC distribution model is being studied in Project Aurum, run by the BIS Innovation Hub Centre in Hong Kong SAR and the Hong Kong Monetary Authority (HKMA) in collaboration with the Hong Kong Applied Science and Technology Research Institute. More details are available at www.bis.org/about/bisih/topics/cbdc/rcbdc.htm.

[44] The BISIH, via Project Polaris, is about to embark on work on this, to provide a deeper and holistic insight into the design, architecture and infrastructural requirements of offline payments as well as the operational impacts.

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Annex 1: Glossary

Access: As used in this report, this means 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.

Application programming interface (API): a set of rules and specifications for software programs to communicate with each other that forms an interface between different programs to facilitate their interaction.
See www.bis.org/bcbs/publ/d486.pdf

Central bank digital currency (CBDC): a new form of central bank money in a digital format, denominated in the national unit of account, that is a direct liability of the central bank and can be used for retail payments and/or wholesale settlement.

Central bank money: A liability of a central bank which can be used for settlement purposes. The widespread use of central bank money for large and critical settlements is pivotal to the functioning of the global financial system, offering safety, availability, efficiency, neutrality and finality.
See www.bis.org/cpmi/publ/d101a.pdf

Clearing: The process of transmitting, reconciling and, in some cases, confirming transactions prior to settlement, potentially including netting of transactions and establishment of final positions for settlement.
See www.bis.org/cpmi/publ/d101a.pdf

Correspondent banking: An arrangement whereby one bank (correspondent) holds deposits owned by other banks (respondents) and provides those banks with payment and other services. Correspondent banking networks are critical for firms and households that conduct business or send payments internationally.
See www.bis.org/cpmi/publ/d147.htm

Distributed ledger technology (DLT): DLT refers to the processes and related technologies that enable nodes in a network (or arrangement) to securely propose, validate and record state changes (or updates) to a synchronised ledger that is distributed across the network's nodes. In the context of payment, clearing, and settlement, DLT enables entities, through the use of established procedures and protocols, to carry out transactions without necessarily relying on a central authority to maintain a single "golden copy" of the ledger.
See www.bis.org/cpmi/publ/d157.pdf

Financial inclusion: Universal access to, and frequent use of, a wide range of reasonably priced financial services, in particular transaction accounts.
See www.worldbank.org/en/topic/financialinclusion/brief/achieving-universal-financial-access-by-2020 and www.bis.org/cpmi/publ/d191.pdf

Fragmented and truncated data formats: Data standards and formats vary significantly across jurisdictions, infrastructures and message networks and the amount of data that is carried in most cross-border messages is extremely limited. This prevents high rates of automated "straight through processing", leads to delays in processing and releasing cross-border payments, and increases technology and staffing costs.
See www.fsb.org/wp-content/uploads/P090420-1.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

Retail CBDC (rCBDC): A CBDC for use by the general public.
See www.bis.org/publ/arpdf/ar2021e3.pdf

Settlement: The discharge of an obligation in accordance with the terms of the underlying contract.
See www.bis.org/cpmi/publ/d101.htm

Settlement account: An account containing money and/or assets that is held with a central bank, central securities depository, central counterparty or any other institution acting as a settlement agent, which is used to settle transactions between participants or members of a commercial settlement system.
See www.bis.org/cpmi/publ/d101.htm

Settlement asset: An asset used for the discharge of obligations as specified by the rules, regulations or customary practice for a financial market infrastructure.
See www.bis.org/cpmi/publ/d101.htm

Settlement finality: Settlement finality is defined as the point when the irrevocable and unconditional transfer of an asset occurs. Final settlement is a legally defined moment.
See www.bis.org/cpmi/publ/d101.htm

Smart contract: Protocol or code that self-executes when certain conditions are met.
See www.bis.org/publ/qtrpdf/r_qt2003i.pdf

Wallet: Electronic wallets are payment arrangements that enable end users to securely access, manage and use a variety of payment instruments issued by one or more PSPs via an application or a website. The electronic wallet may reside on a device owned by the holder, eg a smartphone or a personal computer, or may be remotely hosted on a server but still under the control of the holder.
See www.bis.org/cpmi/publ/d191.pdf

Wholesale CBDC (wCBDC): A CBDC for use by financial institutions (wholesale transactions). A wCBDC is a new form of digital central bank money that is different from balances in traditional bank reserves or settlement accounts.
See www.bis.org/publ/arpdf/ar2021e3.pdf

Annex 2: Acronyms and abbreviations

AML	anti-money laundering
API	application programming interface
BB	building block
BIS	Bank for International Settlements
CBDC	central bank digital currency
CFM	capital flow management measure
CFT	combating the financing of terrorism
CPMI	BIS Committee on Payments and Market Infrastructures
DLT	distributed ledger technology
FATF	Financial Action Task Force
FSB	Financial Stability Board
FX	foreign exchange
G7	Group of Seven
G20	Group of Twenty
ICT	information and communications technology
ID	identification
IMF	International Monetary Fund
IOSCO	International Organization of Securities Commissions
IP	intellectual property
IPS	instant payment system
KYC	know-your-customer
LVPS	large-value payment system
MC	Markets Committee
mCBDC	multi-CBDC
MSMEs	micro, small and medium-sized enterprises
PSP	payment service provider
PvP	payment versus payment
rCBDC	retail central bank digital currency
RTGS	real-time gross settlement
wCBDC	wholesale central bank digital currency

Annex 3: AML/CFT compliance in cross-border CBDC arrangements

Illicit activity undermines financial integrity, national security and economic development. As with any value transfer system, CBDCs could be used by criminals and terrorists for illicit activity. An important part of global efforts to combat illicit finance is national implementation of sound anti-money laundering and combating the financing of terrorism (AML/CFT) regimes in line with the international standards set by the Financial Action Task Force (FATF). While AML/CFT requirements may not be the primary motivation for central banks to issue a CBDC, central banks are expected to design CBDCs in line with AML/CFT requirements.[45]

The exact financial integrity implications of any given CBDC arrangement will vary depending on the particular design choices taken. Regardless of the design choices made, countries must: assess and mitigate the money laundering and terrorism financing (ML/TF) risks associated with a CBDC; ensure that relevant CBDC activities (eg the exchange of assets, transfer of value, and management of assets) are regulated and supervised for AML/CFT purposes; and pursue criminal cases involving CBDC. In particular, central banks, in coordination with relevant AML/CFT bodies, should consider the following aspects when designing a CBDC arrangement:

- **CBDC ecosystem and scope:** While a wide and varied user base may be desirable for a CBDC and many countries identify financial inclusion and cross-border payments as motivation for CBDC development, the number and jurisdiction of residence of users will affect ML/TF risks that need to be managed. For example, wCBDC arrangements that can only be accessed by eligible PSPs will probably present fewer ML/TF risks than a retail arrangement widely available to users from multiple countries. Similarly, the number and type of intermediaries involved in the issuance, distribution and use cases of the CBDC will have regulatory and supervisory implications, particularly in the cross-border context where service providers may operate outside of the issuing jurisdiction.
- **Level of intermediation and allocation of AML/CFT responsibilities:** In a one-tier model (see Section 3.1.2), the central bank would have a direct relationship with the end user. This necessitates central banks assuming AML/CFT obligations that are currently generally assigned to intermediaries and with which central banks are likely to have limited experience or expertise. This model could potentially create conflicts of interest if the central bank has AML/CFT obligations (and is therefore a regulated entity) and at the same time is a supervisor overseeing implementation of these obligations. A two-tier model would preserve the current structure – in which intermediaries have AML/CFT obligations – but might be more difficult to supervise. Regardless of the model chosen, gaps should not exist in the implementation of AML/CFT preventive measures, such as customer due diligence, monitoring of transactions and business relationships, record-keeping, and reporting of suspicious transactions. The cost of AML/CFT compliance may offset some of the purported benefits accrued to CBDCs in a cross-border context, including speed, lower cost, and convenience. However, these trade-offs are necessary to ensure the integrity of the financial system and the reputation of the CBDC.
- **User identification and due diligence:** Critical components of AML/CFT include identifying the customer and source of funds. Due diligence is an important part of ML/TF prevention. Additional preventive measures include transaction monitoring, suspicious transaction reporting, and implementation of targeted financial sanctions. This consideration would be particularly important in a retail context, as users in the wholesale context would be regulated financial institutions. In a CBDC arrangement that has more account-based attributes, identification of parties and transaction authentication naturally arise as part of account management. User

[45] See FATF (2020, Annex B) for further information on CBDCs in the AML/CFT context.

identification[46] is not inherent in a pure token-based system,[47] in which case the necessary due diligence would probably have to be built into a precondition to receiving the token, for instance at the stage of wallet opening. Regardless of the model chosen, countries must consider how fulfilment of AML/CFT obligations, including due diligence, will be carried out within the particular CBDC system. Uncertainties as to how to apply some rules relating to "traditional" financial transfers (eg the wire transfer rule, whereby information on both parties to a transaction must be obtained/held by service providers on both ends) will have to be answered. Key considerations, such as how and when due diligence will be conducted, who will be responsible for carrying out due diligence, and whether the legislative and institutional frameworks require an adjustment, should occur prior to a CBDC launch and keep up with the evolution of the CBDC system. In terms of user identification, a well advanced digital ID system could be a mitigating measure.[48] As with traditional financial services and products, due diligence challenges (eg knowing your customer and understanding a customer's business, identifying and verifying the beneficial owners and accounts) are likely to be magnified in a cross-border context.

- **Oversight of AML/CFT compliance:** The evolution of new service providers and/or services/products may require adapting of AML/CFT laws and regulations, supervisory models, and organisational structures of AML/CFT supervisors. Any new supervisors would have to develop the requisite expertise and avoid any conflicts of interest that may arise. Coordination with other financial sector supervisors and key AML/CFT agencies (such as financial intelligence units and law enforcement) will also be important. Supervisors should keep in mind that overseeing entities located in a different jurisdiction could pose challenges (eg conducting on-site inspections).

As with the traditional forms of money, financial services and activities, the implementation of AML/CFT measures for CBDC is difficult in a cross-border context, from the perspective of both service providers/ other regulated entities, and competent authorities. To facilitate the provision of cross-border services and supervision of such activities and to prevent regulatory arbitrage, harmonisation of AML/CFT frameworks at a global level would be vital. Information-gathering and -sharing may require common technological solutions to be developed between countries. Competent authorities will have to stay abreast of developments and ensure that they are able to adjust their policies and frameworks to account for changes in the financial landscape.

46 User identification refers to customer due diligence measures to identify a customer and verify their identity through independent and reliable sources, not to the extrapolation of other identifying information on users, such as IP addresses.

47 Account-based and token-based CBDC arrangements are not always fully distinct from each other and, indeed, many CBDC arrangements are hybrid systems. For the purpose of this discussion, the critical distinction is whether authentication is primarily focused on the user or the object of payment.

48 For further information on digital ID in an AML/CFT context, see: www.fatf-gafi.org/media/fatf/documents/recommendations/Guidance-on-Digital-Identity.pdf.

Annex 4: Access and interoperability choices in existing CBDC projects

Tables A.1 and A.2 map a selection of completed and ongoing CBDC projects against the access and interoperability options identified in the report. Annex 6 provides for a more detailed description of some of the projects. Table A.2 contains the rCBDCs which are, at the time of writing, circulating among the public, either as a "live" CBDC or in the form of a pilot. While these rCBDCs are mainly developed for domestic purposes, their designs shed light on the choices made regarding their use by non-residents. Table A.1 maps existing cross-border wCBDC projects. It also contains non-CBDC cross-border arrangements that provide useful insights into how different combinations of access and interoperability options can be employed for cross-border payments. The majority of wCBDC projects have been completed as one-off experiments, while a few are still in an exploratory stage (see Graph A.1). Regardless of their status, most of these wCBDC projects use a single system to facilitate CBDC transactions between jurisdictions and, all except for one, apply a closed or direct access model. This might suggest that central banks perceive these interoperability and access options either to have the highest potential to add value in the long run or to be easiest to start from in the short run.

Mapping of existing cross-border wCBDC projects and non-CBDC arrangements[1] Table A.1

	Compatibility	Interlinking			Single system
		Single access point	Bilateral link	Hub and spoke	
Closed access			**HSBC** **Jasper-Ubin** *Directo a Mexico*	*Nexus* *REPSS*	**Prosperus** **MAS** **Aber** *Buna*
Indirect access					*TIPS* **Dunbar**[2]
Direct access	**Helvetia Phase II**	*euroSIC*			**mBridge** **Jura**

The font type of the project name indicates whether it is a wCBDC (**bold**) or a non-CBDC arrangement (*italic*).

[1] See Annex 6 for the descriptions of the wCBDC projects indicated in bold. [2] In jurisdictions where the regulatory frameworks allow direct access to CBDC by non-resident banks, approval routing to "sponsoring" banks could be disabled to move from an indirect to direct CBDC access model.

Source: Authors' elaboration.

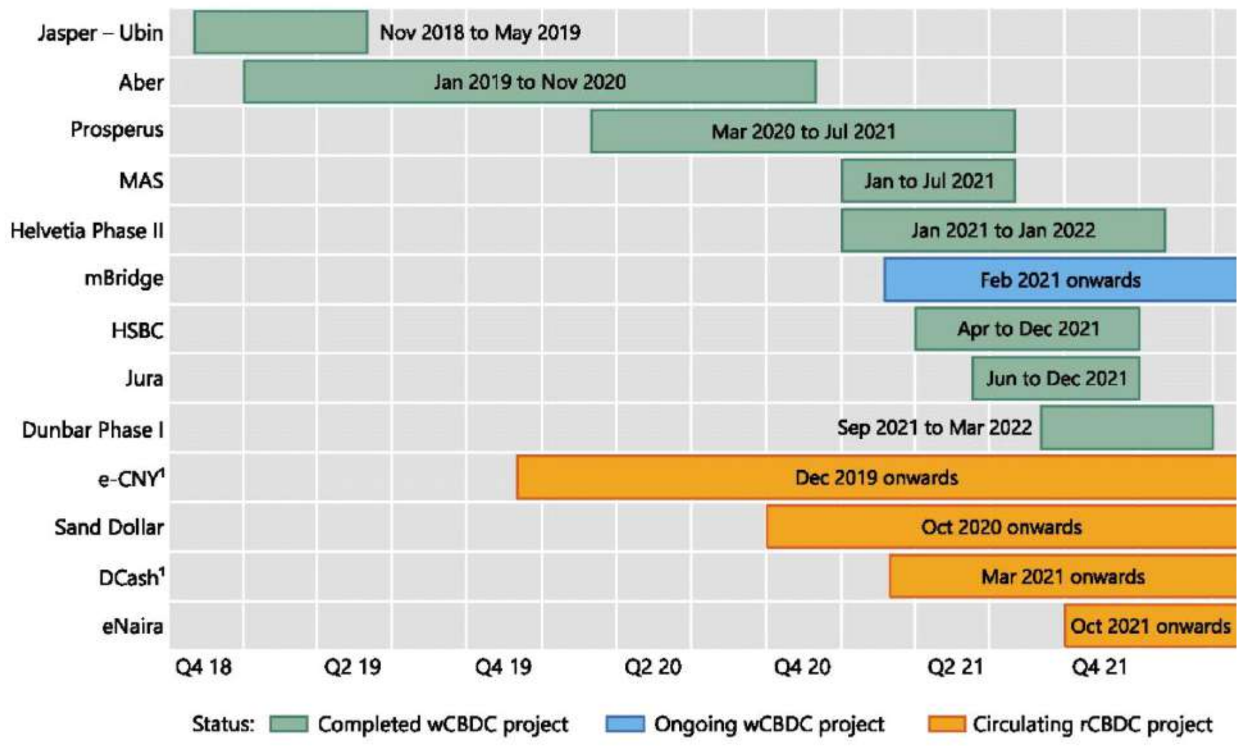
Mapping of the current status of circulating rCBDCs[1] Table A.2

	No caps or fees on transactions or holdings	Caps or fees on transactions	Caps or fees on holdings	Caps or fees on transactions and holdings
Domestic residents only				eNaira DCash
Non-residents visiting the country				Sand Dollar e-CNY
Non-residents when also abroad				

[1] These are either formally issued or circulating as a pilot. As they progress, restrictions might be added or removed. See Annex 6 for descriptions of the rCBDC projects.

Source: Authors' elaboration.

Timeline of cross-border wCBDC projects and circulating rCBDCs Graph A.1



[1] The project is still ongoing in the form of a pilot.

Source: Authors' elaboration.

Annex 5: Summary of challenges of high-level interoperability options

Interoperability options for CBDC systems for facilitating cross-border payments

Challenges related to: Table A.3

	Compatibility	Interlinking			Single system
		Single access point	Bilateral link	Hub and spoke	
Investment and maintenance cost	Relatively low cost	Relatively low cost	Relatively low cost	Costs vary depending on functions offered	Costliest upfront; requires a fully fledged system
Scalability	Extensive scalability if common standards truly remove country-by-country variation; limited if different standards are still permitted	Limited scalability; would require multitude of links	Limited scalability; would require multitude of links	Extensive scalability	Extensive scalability
Legal, regulatory and oversight frameworks	Complex	Complex	Increased complexity if it requires multitude of links	Added complexity upfront to determine a clear delineation of jurisdictional boundaries, adherence to regulatory policies of different jurisdictions; less challenging on an ongoing basis	
Governance arrangements	Complex	Complex	Increased complexity to manage multitude of links	Increased complexity in a system with additional integration	Added complexity on how a common ownership and governance model would fit with multiple central banks in individual but overlapping dimensions
Domestic vs cross-border interoperability	Potential trade-offs might arise between promoting international interoperability of CBDCs using commonly implemented standards and achieving domestic interoperability with existing forms of money				
Balance between addressing illicit	All models require strong coordination among participating central banks to address illicit finance and to strike a balance between protecting privacy and combating illegal activities				

finance and privacy protection					
Technology standardisation: technical coordination vs technical infrastructure and implementation	High complexity for technical coordination; added challenges for technical implementation if systems are different	High complexity for technical coordination; added challenges for technical implementation if systems are different	Increased complexity if it requires multitude of links for both technical coordination and requirements	High complexity for technical coordination; added complexity for technical implementation if different systems are permitted	High complexity for technical coordination; low complexity for technical implementation
FX model	Challenges arise with respect to the choice of entities to provide the conversion service and bear the associated FX risk, and the choice of a reasonable exchange rate determination mechanism that minimises the risk of FX arbitrage				Potential to streamline the payment process by performing both FX trading and settlement on the platform; automated market-making protocols could be deployed on the common platform
Resilience	Essential to ensure the resilience of all the systems and models			Would require greater protection against cyber attacks and extreme conditions due to the "single point of failure" problem	
Market and liquidity fragmentation	Not applicable as liquidity stays on the home account	Potentially more fragmentation	Potentially more fragmentation	Less fragmentation considering that liquidity is centralised on one platform for several jurisdictions	Less fragmentation considering that liquidity is centralised on one platform for several jurisdictions
Data warehousing	Easier to handle, as data can be stored within jurisdiction border if necessary	Easier to handle, as data can be stored within jurisdiction border if necessary	Easier to handle, increased complexity in case of multitude of links	Complex to implement; data localisation requirements could prove challenging to implement	Complex to implement; data localisation requirements could prove challenging to implement
Custody model	Depends on the CBDC system design				

Annex 6: Descriptions of existing CBDC projects

6.1 Jasper-Ubin (project completed in May 2019)[49]

6.1.1 Context

The Jasper-Ubin project was an experiment to test and explore the benefits of distributed ledger technology (DLT) for cross-border payments. This work undertakes a line of enquiry emanating from the paper "*Cross-border interbank payments and settlements*," authored by the Bank of Canada, the Bank of England, the Monetary Authority of Singapore, HSBC and a group of other commercial banks in the United Kingdom, Canada and Singapore.[50] Jasper-Ubin explores the architecture of token-based wCBDC proposed in the paper by building a cross-border payment proof of concept solution.

6.1.2 Participants

The experiment was led by the Bank of Canada (BoC) and Monetary Authority of Singapore (MAS) in collaboration with Accenture and JP-Morgan as technology partners.

6.1.3 High-level design of the experiment

The Jasper-Ubin solution was based on different DLT networks in different jurisdictions, without requiring any trusted entity (but replacing it with trust in the technical solution), with the intention of reflecting a potential future world of heterogeneous networks aimed at increasing the efficiency of and reducing risks for cross-border payments. The cross-border (between Canada and Singapore), cross-currency (CAD and SGD) payment use case was implemented by building and linking two DLT platform networks (using R3's Corda for Canada and ConsenSys' Quorum for Singapore).

The hash time-locked contracts (HTLC) protocol was used to connect the two networks and allow an atomic PvP settlement transaction without the involvement of a trusted third party acting as an intermediary. HTLC is a reliable way of passing messages between the two systems and the distributed ledger platforms used supported the basic constructs of HTLC: locking or encumbering the asset to be transferred, secret disclosure to the counterparty to complete the acceptance process, and a timeout mechanism to release the encumbrance should the counterparty fail in its acceptance process. The project successfully demonstrated atomic transactions between two different DLT networks.

6.1.4 Key considerations around interoperability and access

In terms of interlinking, each country managed their own DLT-based RTGS network and interoperability was achieved by implementing the HTLC protocol in both networks. HTLC performed well to achieve atomic PvP settlement. However, there were rare circumstances where challenges and some complications arose, especially when large numbers of networks or jurisdictions were assumed.

With regard to access, commercial banks in each of the jurisdictions had access to their local network and were able to settle multicurrency cross-border wholesale payments with their counterparties in the other jurisdiction without the need for a trusted intermediary. The central bank in each jurisdiction was in full control of access criteria for its local commercial banks. Commercial banks did not need direct access to both platforms to fully use the system. After the project, the BoC and MAS declared that it remains to be seen whether they will eventually use blockchain technology for high-value cross-border payments.

[49] See www.mas.gov.sg/-/media/Jasper-Ubin-Design-Paper.pdf.

[50] See www.mas.gov.sg/-/media/MAS/ProjectUbin/Cross-Border-Interbank-Payments-and-Settlements.pdf.

6.2 Aber (project completed in November 2020)[51]

6.2.1 Context

The aim of the initiative was to study, understand, and evaluate the feasibility of a single dual-issued wCBDC as an instrument for domestic and cross-border settlement between two countries.

6.2.2 Participants

The experiment was a cooperation between the Saudi Central Bank (SAMA), the Central Bank of the United Arab Emirates (CBUAE) and six commercial banks (three from each jurisdiction).

6.2.3 High-level design of the experiment

The participants agreed upon the following three key principles that guided the execution of the project:

- Commercial banks had to be active participants, running local nodes on the network, and be fully engaged from a technical and business perspective throughout the lifecycle of the project.
- Real money was used in the project. This was important because it forced greater consideration of the non-functional aspects, including security and the interaction of the system with existing payment systems, such as the domestic RTGS system.
- The project sought to explore how such systems can leverage the unique characteristics of DLT to drive greater levels of distribution.

The project was structured into three distinct phases or use cases:

- Cross-border settlement between the two central banks;
- Domestic settlement between three commercial banks in each country;
- Cross-border direct transactions between the participating commercial banks.

6.2.4 Key considerations around interoperability and access

Since Aber is an interbank payment system, its requirements were naturally derived from the features of traditional RTGS systems but extended to cover cross-border payments. The main difference with the traditional implementation was its decentralised nature. The system allowed payment and settlement between commercial banks without the central bank(s) nodes being available. The key property of irrevocable transactions can be achieved as long as transaction validity requires a quorum of participants that do not necessarily include the central bank(s).

The commercial banks had complete knowledge of their own nodes and transactions, but did not know about other nodes (ie their overall DLT balances) or transactions between other nodes. The two central banks had visibility on everything regarding the nodes and transactions in their own jurisdictions. In addition, they also knew about all cross-border transactions. As a result, the central banks did not know the overall DLT balances and the domestic transactions of participants in the other jurisdiction. However, central banks had full visibility on the money supply, including of the digital currency issued to the other country.

The project confirmed that a cross-border dual-issued CBDC was technically viable and that it was possible to design a distributed payment system that offered the two countries significant improvement over centralised payment systems in terms of architectural resilience. The project also confirmed the viability of DLT as a mechanism for both domestic and cross-border settlement.

[51] See www.sama.gov.sa/en-US/News/Documents/Project_Aber_report-EN.pdf.

6.3 Prosperus (project completed in July 2021)[52]

6.3.1 Context

Project Prosperus covered the issuance and distribution of EUR wCBDC and usage rights to operate near real-time remittance transfers between individuals from France to Tunisia.

6.3.2 Participants

The experiment involved the Bank of France (BdF) and the Central Bank of Tunisia (BCT) in collaboration with a group of private sector firms comprising ProsperUs, the French bank Wormser Frères, the Tunisian bank BIAT and its French subsidiary BIAT France.

6.3.3 High-level design of the experiment

In this experiment, the cross-border funds transfer for a customer in Tunisia was operated from a French bank to the BCT. The payment flow contained details about the sender, the beneficial owner and his Tunisian banking coordinates. While the design is similar to the scenario in which the BCT acts as the remittance EUR correspondent bank for all Tunisian banks, it has the benefit of a near immediate release of funds to the remittance recipient.

The process relied on both central banks' infrastructures: T2 and TOPAZE for the BdF, and the BCT's core banking system. To bridge them, the distributed ledger Instaclear allowed the creation of "wallets" to enable the receipt of EUR CBDC and EUR CBDC "usage right". This ledger, although it is not a blockchain, allows its administrators to authorise and supervise participants and transactions. The experiment allowed the BdF to issue intraday EUR wCBDC on Instaclear against blocked balances on a central bank's technical account in T2. The BdF had exclusive rights to create and destroy the EUR wCBDC.

The experiment showed that wCBDC is an effective means to lower remittance costs while also reducing the delays in crediting the remittance recipient's bank account. Although other experiments had already demonstrated all or some of these basic functionalities, the Prosperus experiment showed that a DLT involving central banks could be a viable core system of a remittance channel.

6.3.4 Key considerations around interoperability and access

Interlinking was achieved by using a common technical distributed platform, Instaclear, which relies on an account-based system that grants each institution a node. Each node's parameters, including whether it could hold, mint, transfer or destroy a wCBDC token, were set up by a trusted authority.

In terms of access, any T2 participant is eligible to access EUR wCBDC as long as it operates a node in the system. Although the BCT is not a T2 participant, it has a EUR central bank money account with the BdF and therefore was able to operate a node. In addition, any Tunisian commercial bank can set up a node and be informed, through the BCT and within the Instaclear platform, of an incoming credit to its account at the BCT and therefore credit its clients' balances accordingly.

[52] See www.banque-france.fr/en/communique-de-presse/banque-de-france-cooperation-banque-centrale-de-tunisie-successfully-conducts-experiment-use-central.

6.4 MAS (project completed in July 2021)[53]

6.4.1 Context

The MAS experiment covered cross-border payment and cross-currency PvP transactions in EUR wCBDC and SGD wCBDC issued and exchanged on a single corridor network.

6.4.2 Participants

The experiment involved the Bank of France (BdF) and Monetary Authority of Singapore (MAS) in collaboration with JPMorgan as technology partner.

6.4.3 High-level design of the experiment

In the shared corridor network, the BdF and MAS are jointly controlled operators. They share the management of the rulebook and the governance arrangements. Additionally, commercial banks are admitted to the network as participants.

Fictitious commercial banks located in France and Singapore settled multicurrency cross-border wholesale payments. This included a cross-border payment with currency conversion, and settlement of an FX trade in PvP. In order to reduce intermediaries and optimise costs, these cross-border transactions were managed by smart contracts, one for order orchestration, and the other for the automatic liquidity and FX rate management.

Automated market-making (AMM) and liquidity management capabilities were incorporated into the overall design. The use of AMM could seemingly be a viable alternative to traditional order book infrastructures. AMMs allow permissionless and automatic ways of trading digital assets and use liquidity pools instead of a traditional market with buyers and sellers.

6.4.4 Key considerations around interoperability and access

In terms of interlinking, each country maintained only a single connection to a shared common platform for cross-border features. In practice this experiment involved the respective central banks issuing their CBDC tokens to the commercial banks' wallets. The commercial banks could then initiate transactions on the network if they had sufficient CBDC tokens for such transactions.

The single DLT platform reduced the complexity of bank-to-bank integration and simplified the business process through a single standardised governing rulebook.

With regard to access, the experiment used the principle of sharing data on a need-to-know basis. The CBDC balance of each commercial bank was known only to itself and the central bank issuing the CBDC token. To achieve this, at the node level, the state database is split into a public state and a private state. A public state is always in sync across the network through the consensus algorithm. The private state is updated based on the private transactions that a node is part of, and thus is unique only to that node. This also means that the private state will be divergent across nodes.

[53] See www.banque-france.fr/sites/default/files/media/2021/11/15/bdf-mas-onyx_liquidity_management_in_a_multi-currency_corridor_network_vfinal_-_12112021_0.pdf.

6.5 Helvetia Phase II (project completed in January 2022)[54]

6.5.1 Context

Helvetia Phase II looks towards a future with more tokenised assets and DLT-based financial market infrastructures. It addresses the question of whether and how settlement in central bank money would be feasible in such infrastructures.

The Helvetia Phase II experiment covers domestic and cross-border DvP and payment settlement in wCBDC issued and exchanged on a private permissioned DLT platform. Use cases are investigated end to end, ie from entering the settlement instructions, via the matching and settlement on the DLT platform to booking and reconciliation in core banking systems.

6.5.2 Participants

Helvetia Phase II is a joint project by the BIS Innovation Hub Centre in Switzerland, the Swiss National Bank (SNB) and SIX. It leverages the DLT-based central securities depository (CSD) of SIX Digital Exchange (SDX), a subsidiary of the main Swiss financial market infrastructure provider SIX. Five commercial banks participated in the experiment: Citi, Credit Suisse, Goldman Sachs, Hypothekarbank Lenzburg and UBS.

6.5.3 High-level design of the experiment

The solution design consists of three components: (i) the SDX test platform; (ii) the Swiss RTGS test system; and (iii) the core banking test systems of commercial banks and that of the SNB. Interoperability across these systems is achieved through ISO messaging. This form of integration is compatible with existing core banking systems and back office processes of commercial banks and central banks.

The wCBDC in Helvetia is designed to be a tokenised form of central bank money. Access criteria, remuneration and the value date rules of wCBDC are identical to those for reserve balances held in today's RTGS system. Furthermore, the central bank retains similar control and monitoring capabilities over wCBDC as over reserve balances.

6.5.4 Key considerations around interoperability and access

In Helvetia Phase II, eligible resident and non-resident financial institutions have direct access to wCBDC, facilitating cross-border DvP and payment settlement in wCBDC. The wCBDC can either be issued through the one-to-one conversion of RTGS balances into wCBDC or monetary policy transactions on the DLT platform, ie the direct issuance of wCBDC by the central bank. The latter approach could be one way to provide direct access to wCBDC to financial intermediaries without access to the RTGS system.

Helvetia Phase II investigates single-currency cross-border settlement. Cross-currency settlement and currency conversion would require some form of compatibility with arrangements outside the DLT platform. As shown in Project Jura, the solution design of Helvetia could be broadened to a single system with direct access to multiple wCBDCs.

[54] Links to report and video: www.bis.org/publ/othp45.pdf and www.youtube.com/watch?v=R5TF3xB5J88.

6.6 mBridge (project ongoing)

6.6.1 Context

The mBridge project aims to build a prototype for an mCBDC platform for cross-border payments. Earlier versions of mBridge[55] have shown that using a CBDC arrangement for cross-border payments can be cheaper, faster and more transparent than today's existing systems.

6.6.2 Participants

The project involves the BIS Innovation Hub Centre in Hong Kong SAR, the Hong Kong Monetary Authority, the Digital Currency Institute (DCI) of the People's Bank of China, the Central Bank of the United Arab Emirates, the Bank of Thailand and private sector partners.

6.6.3 High-level design of the experiment

In the current iteration of the project built on mBridge Ledger, all central banks can issue their respective CBDCs on the platform. All commercial bank participants can receive this issued CBDC in return for reserves and transact directly with each other regardless of jurisdiction.

The currencies issued on the mBridge platform are the Hong Kong dollar, renminbi, Thai baht and UAE dirham. They are settled using a single logical ledger. The leading use case of the current pilot is to settle cross-border payments for international trade. Advanced atomic PvP, liquidity management and privacy features are all in scope. The consensus model is inspired by the "HotStuff" consensus protocol. The participants share encrypted messages peer-to-peer and use RocksDB for persistent storage.

6.6.4 Key considerations around interoperability and access

Several key considerations around interoperability and access options still need to be decided for the current iteration of the project. The project is currently gathering requirements to provide connectivity with other DLT-based CBDC systems, RTGS and traditional payment integrations.

Access to the platform as a private DLT is achieved by successfully completing the onboarding process. The onboarding criteria for each jurisdiction are the responsibility of the corresponding central bank. The technical platform onboarding is still in discovery. The project aims to onboard a few commercial banks for a pilot to better understand these requirements. With respect to platform controls, each issuing central bank can control which participants are allowed to have custody of its currency, the maximum custody and transaction limits. All issuing central banks can see transaction and balance sheet details for all banks within their jurisdiction. Commercial banks can only see their own custody and transaction details.

[55] See www.bis.org/publ/othp40.htm.

6.7 HSBC (project completed in December 2021)[56]

6.7.1 Context

The HSBC PoC was designed to cover an end-to-end transactional lifecycle, covering eBonds (issuance, ISIN dissemination, DvP across primary issuance and secondary trading, coupon payments), CBDCs (issuance and allocation), and foreign exchange between two CBDCs (pricing and PvP).

6.7.2 Participants

The experiment involved the Bank of France (BdF) and HSBC in collaboration with IBM as a technology partner.

6.7.3 High-level design of the experiment

In this experiment, a virtual issuer sold a virtual eBond to HSBC on the primary market. This transaction was settled in EUR CBDC. HSBC then sold the asset in EUR CBDC to one of its corporate clients (DvP). A coupon was paid to HSBC and cascaded to its client in EUR CBDC. The corporate client converted the EUR CBDC into another CBDC (XXX, a fictitious currency from a simulated central bank X).

The experiment tested a novel PvP/cross-border model. To achieve this, two main use cases were explored: (1) interoperability between systems using different DLTs (Fabric and Corda); and (2) control of the usage of the CBDC by the issuing central bank through programmability features.

The technical interface ("Bridge") developed as part of the experiment allowed for interoperability, transfer of data and information and exchange of assets. The experiment leveraged on four multi-chain technologies: (1) DLT for the settlement of securities transactions and their cash legs on the primary market (DL3S); (2) DLT where T2 participants and their clients can use EUR CBDC to settle specific transactions in a secure way (Euro-NET); (3) DLT where participants in a simulated central bank and their clients can use CBDC in a secure way (XXX-NET); and (4) DLT custody platform (HSBC Vault).

6.7.4 Key considerations around interoperability and access

The interlinking of both CBDCs and the fictitious digital bond was conducted in a multi-cloud environment that incorporated public and private clouds. For the wholesale CBDCs to circulate, two issuer nodes on each subnetwork – controlled by the BdF for EUR wCBDC and by the simulated central bank for XXX wCBDC – allowed for the issuance of tokens on the DLT test platforms. Each issuer node had sole and exclusive rights to create and destroy the respective type of wCBDC. In this experiment, the CBDCs issued by the BdF and the other central bank were intraday.[57]

In terms of access criteria, the experiment made no assumptions on the rules and usage rights the simulated central bank would establish for its participants. On the BdF side, under specific usage protocols managed through programmability, the experiment extended the use of CBDC to non-T2 participants.

[56] See www.banque-france.fr/en/communique-de-presse/banque-de-france-has-successfully-completed-first-tranche-its-experimentation-programme-central-bank.

[57] An intraday wCBDC means that there is a mandatory conversion of wCBDC into reserve balances before the value date change in the RTGS system.

6.8 Jura (project completed in December 2021)[58]

6.8.1 Context

Project Jura explored DvP and PvP use cases between euro and Swiss franc wCBDCs and a tokenised French commercial paper (CP) in a near-real setting.

6.8.2 Participants

The experiment involved the Bank of France (BdF) and the Swiss National Bank (SNB) in collaboration with the BIS Innovation Hub and a group of private sector firms comprising Accenture, Credit Suisse, Natixis, R3, SIX Digital Exchange and UBS.

6.8.3 High-level design of the experiment

The experiment took place over three days and explored two use cases: (1) settlement of EUR-CHF FX transactions with EUR and CHF wCBDC between French and Swiss financial institutions; and (2) issuance and redemption of a tokenised French CP and settlement of the tokenised CP with EUR wCBDC between French and Swiss financial institutions (cross-border) and Swiss financial institutions (offshore).

On the technical side, Jura explored a new approach including subnetworks and a dual-notary signing mechanism. The cross-border settlements conducted used three subnetworks on a single privately operated DLT platform developed under Corda technology: one subnetwork dedicated to the French tokenised asset, one dedicated to the EUR wCBDC and one dedicated to the CHF wCBDC. The dual-notary signing capability allowed tokens to be exchanged atomically while residing on different subnetworks and jurisdictions.

Having sub-networks on a single platform with dual-notary signing validation involves fewer institutions in the payment process, which could improve efficiency and reduce cost, while enabling transparent pricing and a simplified fee structure. Settlement speed is likely to be increased.

6.8.4 Key considerations around interoperability and access

Project Jura combined the advantages of the model where two platforms are linked (BIS model 2) and the single platform model (BIS model 3). The project also explored the interlinking between traditional infrastructures (RTGS systems, Target2 and SIC) and DLT (SDX testing platform).

The EUR and CHF wCBDCs in Jura had two key access features: they were intraday, and directly available to non-resident banks. In the experiment, the BdF and SNB provided direct access to intraday wCBDC for regulated financial institutions domiciled in France and Switzerland which had access to reserves at the respective domestic central bank. Subnetworks on the SDX test platform allowed the central banks to maintain control over who had access to their wCBDCs. While having direct access to hold and transact the wCBDC, non-resident regulated financial institutions that did not have access to the RTGS relied on correspondents to make the RTGS funds transfers – a prerequisite for the issuance of wCBDC.

[58] See www.bis.org/publ/othp44.htm.

6.9 Dunbar (Phase I completed in March 2022)[59]

6.9.1 Context

Project Dunbar enabled international settlements on a common platform that enabled issuance of multiple CBDCs by different central banks.

6.9.2 Participants

The experiment involved the BIS Innovation Hub Centre in Singapore, the Reserve Bank of Australia, the Central Bank of Malaysia, the Monetary Authority of Singapore and the South African Reserve Bank, in partnership with R3, Partior, DBS Bank, JP-Morgan, Temasek and Accenture.

6.9.3 High-level design of the experiment

Project Dunbar developed two prototypes of an mCBDC shared settlement platform on the Corda and Quorum DLTs. The prototypes proved the technical feasibility of implementing a shared mCBDC platform. With respect to governance, the common platform guarantees autonomy for participating central banks in the issuance of their CBDC, within a framework of uniformly applied rules.

On this common shared platform, multiple central banks issue their CBDCs, which can be used by participating commercial banks for payments. Participating commercial banks will be able to hold and transact in the CBDCs issued. This includes CBDCs in local as well as foreign currencies. Banks that are connected to the domestic payment system can exchange their central bank balances for CBDCs. Non-local banks (banks licensed as banks in other jurisdictions, but not in the local jurisdiction) which are not connected to the domestic payment system can exchange CBDCs with other banks.

6.9.4 Key considerations around interoperability and access

In this common platform participants transact using common functions (smart contracts on DLT) and messaging formats. Interlinking with legacy systems was not part of the experimental scope.

In designing the access framework, two models were explored: direct and indirect (sponsored/hybrid) CBDC access. A "sponsored" indirect CBDC access model is applied that allows banks to hold CBDCs from jurisdictions where they do not have a presence. With this CBDC model, non-local banks hold CBDCs representing a direct liability of the issuing central banks. The banks that have direct access and on which the indirect participants rely are called "sponsoring" banks. These banks are subject to local regulations and perform customer due diligence processes on the non-local banks. This includes onboarding and know-your-customer (KYC) processes as well as suspicious transaction monitoring and AML/CFT processes. This allows application of control processes without the need for changes to existing regulatory policies. While the need for an intermediary is eliminated in the settlement process, intermediaries, in the form of "sponsoring" banks, continue to play a role for control processes such as KYC and AML/CFT. This represents a limitation on the efficiency gains of eliminating intermediaries and poses a challenge with regard to commercial models and incentives for banks to play such "sponsoring" roles. Various possibilities exist, including reciprocal arrangements, obligations imposed as conditions of access, and fees, and require further evaluation. Dunbar's prototypes were developed to flexibly support both sponsored and direct access models. In jurisdictions where the regulatory frameworks allow direct access to CBDC by non-resident banks, approval routing to "sponsoring" banks could be disabled to move from a "sponsored" to a "direct" CBDC access model.

[59] See www.bis.org/about/bisih/topics/cbdc/dunbar.htm. Phase II of the project is being scoped.

6.10 e-CNY (project ongoing)[60]

6.10.1 Context

E-CNY is the digital version of fiat currency issued by the People's Bank of China (PBC). It is designed mainly for domestic retail usage, and aims to improve efficiency, the resilience of the central bank payment system and financial inclusion.

6.10.2 Participants

The PBC, eligible commercial banks, PSPs, telecoms operators and end users.

6.10.3 High-level design of the experiment

The e-CNY project has adopted a two-tier model, whereby the PBC issues e-CNY to authorised operators, including eligible commercial banks, PSPs (in the name of their commercial bank arms) and telecoms operators (grouping with commercial banks). The authorised operators are responsible for providing exchange and circulation services to the general public. With the two-tier model, the general public can still access e-CNY through traditional financial intermediaries, which would not be crowded out in the process of digitalisation of the fiat money.

In terms of design features, the system provides tiered wallets with different thresholds in order to achieve synergies between anonymity, risk reduction and financial inclusion. Following the principle of "anonymity for small value and traceable for high value", wallets with lower thresholds allow greater anonymity. As a result, e-CNY can more easily be rolled out into rural or disadvantaged areas where identification can be difficult. Wallets with higher thresholds follow respective customer due diligence procedures that ensure AML/CFT compliance. The e-CNY does not pay interest on its holdings because of quantitative restrictions, but also to avoid competition with bank deposits and to foster financial inclusion.

In terms of technology, the project uses a "hybrid architecture" with both distributed and centralised design, which enhances the resilience and scalability of the system and supports rapid growth in e-CNY transactions. Also, it has adopted a "long-term evolution" approach without any prescriptive technology path in advance, so new technological features can continuously contribute to the system. In terms of legal foundations, a general revision of the People's Bank of China Law (draft) stipulates that Chinese currency includes both physical and digital forms, and thus will confirm the legal tender status of the e-CNY.

6.10.4 Key considerations around interoperability and access

The e-CNY system broadens the accessibility of payment services, providing fiat money for a large population in various scenarios. Offline payment capacity and hardware-based wallets facilitate access for the underbanked population as well as foreign visitors.

The project is being carried out primarily with a view to domestic considerations, while the PBC also explores how CBDC can be used for enhancing cross-border payments. To this end, the PBCDCI[61] has partnered with the BISIH and three other central banks in the mBridge project (see Annex 6.6). The PBCDCI is also exploring interlinking with the fast payment system in Hong Kong SAR, in order to facilitate cross-border consumption of both mainland and Hong Kong SAR residents. As emphasised by the PBCDCI, cross-border payments should involve interoperability across domestic CBDCs or domestic CBDCs and incumbent payment systems, and domestic CBDCs should be converted to other currencies as payments cross borders, so as to avoid potential adverse macroeconomic implications such as currency substitution.

[60] See www.pbc.gov.cn/en/3688110/3688172/4157443/4293696/2021071614584691871.pdf.

[61] The Digital Currency Institute of the PBC, which undertook the e-CNY project.

6.11 Sand Dollar[62]

6.11.1 Context

The Sand Dollar was launched in October 2020 as the world's first CBDC, issued by the Central Bank of The Bahamas (CBB). Its main policy goals are financial inclusion, improved access to payments, efficiency of payments, resilience, and to reduce illicit use of money. In late 2021, the number of users of the Sand Dollar was around 20,000, or roughly 5% of the population. It is continuously being developed, and new functions are being added.

6.11.2 Participants

The CBB, supervised financial institutes including banks, credit unions, money transmission businesses, PSPs and end users.

6.11.3 High-level design

The Sand Dollar is issued by the CBB and circulated in a network consisting of private sector intermediaries that interact with the end users of Sand Dollars. The intermediaries develop and operate electronic wallets where end users store their Sand Dollars and the graphical interface that they use to make and receive payments. They also carry out the required KYC controls but do so using a common infrastructure that is operated by the central bank.

Technologically, the Sand Dollar makes use of DLT. Intermediaries offer end users wallets that are available with different caps on transactions and holdings. This arrangement is intended to relieve bank deposits from competition from CBDC and thus mitigate the risk of both bank disintermediation and digital bank runs. The lower tier wallets do not require formal proof of identity in order to ensure ease of access in areas in which identification can be difficult. Basic user information including a phone number is necessary, however. With higher caps the need for identity and KYC/AML compliance increases.

Recently, the CBB finished connecting the Sand Dollar to its banking sector, which allows payments from Sand Dollar wallets to bank accounts. The connection also enables automatic transfers between a Sand Dollar wallet into a linked bank account in case money transferred to the wallet exceeds the cap.

6.11.4 Key considerations around interoperability and access

The Sand Dollar does not currently have a cross-border function, but the CBB has stated that it intends to explore its international usage in the coming years.

[62] See https://www.sanddollar.bs.

6.12 DCash[63]

6.12.1 Context

DCash is the CBDC issued by the Eastern Caribbean Central Bank (ECCB) in the context of a pilot. The pilot started in March 2021 in some countries of the Eastern Caribbean Currency Union (ECCU) and will progressively extend to all countries. The pilot is expected to last at least until the summer of 2023, one year after the last country is planned to join the pilot. DCash is designed mainly for retail use, with the aim to improve efficiency and resilience of the payment system and financial inclusion. No decision has been made regarding a launch of the CBDC after the pilot ends.

6.12.2 Participants

The ECCB, financial institutions and end users (for the latter two, voluntary participation).

6.12.3 High-level design of the experiment

DCash uses a two-tier CBDC distribution model. The ECCB issues, redeems, and validates transactions, as well as updating the ledger. The CBDC is distributed through the banking system, which performs the onboarding of customers (KYC/AML/CFT), manages users' data and provides customer service. Currently, the ECCB offers banks a ready-made application for users to interact with DCash, but the expectation is that, in a formal launch, banks would develop their own applications.

In terms of design features, DCash does not bear interest, and there are quantitative limits to DCash holdings in place. These were put in place to limit the potential disintermediation of the banking system. The ECCB also wanted to keep control of the overall amount of DCash issued, by setting an aggregate limit on issuance. This, however, has not been put in place yet. To manage the trade-off between anonymity/financial inclusion and AML/CFT compliance, the system offers a tiered selection of wallets with different levels of thresholds. Wallets with lower limits allow for greater anonymity.

The ECCB has been relying on third-party vendors for the technology. The system is based on a DLT, considered by the central bank secure and apt for its needs. In terms of legal foundations, the ECCB has prepared a draft amendment to its central bank act. This will extend the definition of "currency" to "digital currency" and clarify the central bank's sole right to issue digital currency. The amendment also gives the status of legal tender to digital currency.

6.12.4 Key considerations around interoperability and access

As the ECCU consists of eight different nations,[64] DCash is the first example of a cross-border CBDC, even though it is not cross-currency. Still, the focus for DCash has been on improving payments efficiency both within a country and across the countries forming the currency union. Further, the ECCB looks favourably on the possibility to use CBDC for cross-border payments with other countries, given the importance of trade and overseas remittances for ECCU countries. While the main priority for the ECCB is ensuring that DCash works smoothly for domestic purposes, it has begun discussions with other regional central banks regarding interoperability with legacy payment systems and platforms to enable remittances and trade in the region.

[63] See www.eccb-centralbank.org/p/what-you-should-know-1.

[64] The Eastern Caribbean Central Bank (ECCB) is the monetary authority of a group of eight island economies: Anguilla, Antigua and Barbuda, Dominica, Grenada, Montserrat, St Kitts and Nevis, St Lucia, and St Vincent and the Grenadines.

6.13 eNaira[65]

6.13.1 Context

The eNaira is the Nigerian CBDC issued by the Central Bank of Nigeria (CBN). It was launched as the world's second CBDC on 25 October 2021. The CBN lists several domestic policy goals for CBDC, including ensuring financial inclusion, improving the availability of and access to central bank money, and making payment systems more efficient and resilient. But the eNaira is also intended to improve cross-border payments and make remittances to Nigeria cheaper.

6.13.2 Participants

The CBN, financial institutions (FIs), end users, and government ministries, departments, and agencies (MDAs) (for receiving and making payments to citizens).

6.13.3 High-level design

eNaira uses a two-tier CBDC distribution model. The CBN administers the eNaira through the Digital Currency Management System (DCMS) to issue and mint the eNaira. The eNaira platform hosts the eNaira wallets for different participants. The eNaira stock wallets, which belong solely to the CBN, serve as the warehouse for all minted eNaira. FIs maintain a treasury eNaira wallet for holding and managing eNaira on the DCMS using the FI Suite. The FI Suite is the primary application the FIs use to manage their digital currency holdings, requests, and redemptions with the CBN. FIs may create eNaira Sub-Treasury Wallets for branches tied to them and fund them from their single eNaira treasury wallet with the CBN. An FI may also create an eNaira branch sub-wallet for its branches and fund them from the treasury eNaira wallet. There are also eNaira Merchant Speed Wallets used solely for receiving and making eNaira payments for goods and services, and eNaira Speed Wallets, which are available for end users to transact on the platforms.

Technologically, the eNaira relies on permissioned DLT, in which the intermediaries make up nodes in the network. The FIs also carry out onboarding of customers and AML/CFT controls. Users of eNaira are subject to a tiered structure of KYC requirements based on transaction and balance limits. Legally, the CBN is empowered to issue eNaira based on its mandate under the Central Bank of Nigeria Act and other financial institutions acts.

6.13.4 Key considerations around interoperability and access

Universal access to eNaira is a key goal of the CBN, and new forms of digital identification are being issued to the unbanked to help with access. The CBN also reports that the eNaira has been designed with international interoperability in mind. The eNaira, according to the CBN, could thus lead to cheaper remittances to Nigeria, and also improve cross-border payments in general, which could facilitate trade.

The individual and merchant wallets of the eNaira have different caps on daily transaction limits and the amount of eNaira that can be held in them, depending on their customer due diligence tier. The wallets with lower caps can be held by individuals that do not have a bank account, but a bank account is necessary to hold a wallet with higher caps. The caps are explained by the CBN as intended to ensure that the eNaira is primarily used for smaller retail payments and that competition between eNaira and bank deposits is limited. Similarly, the CBDC has been designed with a 0% interest rate, which is also intended to avoid competition with bank deposits. When it comes to anonymity, the CBN has opted to not allow anonymity even for lower-tier wallets. At present, a bank verification number is required to open a retail customer wallet, and going forward anyone whose identity can be verified at least with a phone number will be able to open lower-tier wallets.

[65] See enaira.gov.ng/ and www.cbn.gov.ng/Out/2021/FPRD/eNairaCircularAndGuidelines%20FINAL.pdf.

Annex 7: Composition of the Future of Payments Working Group (FoP)

Chair of the Working Group and Lead of the BB 19 drafting team

Sveriges Riksbank	Cecilia Skingsley
Bank of France	Valérie Fasquelle [until February 2022]

Members

Central Bank of Argentina	Luis D'Orio
Reserve Bank of Australia	Chris Thompson Cameron Dark (alternate)
National Bank of Belgium	Filip Caron [until October 2021] Axel Van Genechten [since October 2021]
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Board of Governors of the Federal Reserve System	David Mills Jackie Cremos (alternate) Jean Flemming (alternate)
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Bank for International Settlements	Raphael Auer*
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* Member of the drafting team.
** The access of the Central Bank of the Russian Federation to all BIS services, meetings and other BIS activities has been suspended.

Liaison and Coordination Committee on Central Bank Digital Currency

Interim Report

July 5, 2022

(English translation prepared by the Bank of Japan staff based on the Japanese original)

Contents

Introduction

Central Bank Digital Currency (CBDC) is a new form of digital money issued by a central bank.

In October 2020, the Bank of Japan (BOJ) publicly announced its approach to a general purpose CBDC intended for use by a wide range of entities, including individuals[1]. As mentioned then, "While the Bank of Japan currently has no plans to issue CBDC, from the viewpoint of ensuring the stability and efficiency of the overall payment and settlement systems, the Bank considers it important to prepare thoroughly to respond to changes in circumstances in an appropriate manner."

In line with the Approach, in April 2021, the BOJ started experiments relating to CBDC. "Proof of Concept (PoC) Phase 1" aimed at evaluating the basic functions of a CBDC was completed in March 2022, followed in April by a transition to "Phase 2," which investigates the feasibility of more complex additional functions. Also, in parallel, the BOJ has been investigating institutional arrangements, such as methods for ensuring financial stability and how a central bank should coordinate with the private sector.

Throughout the experiments, the BOJ recognizes the importance of staying in close contact with stakeholders in and abroad and leveraging a wide range of perspectives for further investigation. Toward that end, the Liaison and Coordination Committee on Central Bank Digital Currency ("Liaison Committee" hereinafter) was established in March 2021, with members coming from the private sector, the government, and the BOJ (Refer to Attachment for the member of the Liaison Committee), to share information on the progress of the PoC and to consult on future plans.

Summaries of the Liaison Committee's discussions are posted on the BOJ's website (available only in Japanese), and as experiments and investigations into institutional arrangements get fleshed out further, it becomes increasingly important to accurately communicate to a wide range of stakeholders and work closely with them to exchange ideas. With that in mind, the BOJ's Payment and Settlement Systems Department, which is the secretariat of the Liaison Committee, considers to publish this interim report so as to communicate the materials and discussions of the Liaison Committee in a comprehensive manner.

The BOJ or the Liaison Committee alone never intends to design the development of a payment

[1] See "The Bank of Japan's Approach to Central Bank Digital Currency," 9 Oct 2020. Referred to as "the Approach" in this paper.

system. The decision as to whether or not a CBDC should be issued will have to be a judgement by the Japanese people. We expect that this paper will serve as a foundation for further discussion among a wide range of stakeholders on whether to introduce a CBDC and what framework it should take.

1. Basic functions and core features of a CBDC

1.1 Basic functions of a CBDC

As mentioned above, CBDC is a new form of central bank electronic money[2]. Today, central banks issue money in the form of cash (banknotes). CBDC would be different from cash in that it is issued in digital format. Also, although central banks do issue electronic money to banks and other institutions in the form of central bank deposits (in the BOJ's case, these are "current account deposits at the BOJ"); CBDC would be different from this as well, in that it is a new form of electronic money unlike what exists now.

CBDC would be issued as central bank liabilities and would be held as assets by entities other than the central bank. CBDC is transferred between individuals and firms in exchange for goods and services, thereby functioning as a payment instrument. Also, by CBDC being issued denominated in their home countries' fiat currency, it would function as a unit of account in a nation's economy.

Figure 1: Types of money

		Form Digital ● Physical ○	Issuer Central bank ● Others ○	Balance JPY trillions (end Dec 2021)
Wholesale	Central bank deposits	●	●	543
	Wholesale CBDC	●	●	—
Universal	Bank deposits	●	○	1,630
	Cash	○	●	127
	General purpose CBDC	●	●	—

Note: Bank-deposit balances are the total of transferable deposits, time and savings deposits, and certificates of deposits at domestically licensed banks, foreign banks in Japan, financial institutions for agriculture, forestry and fisheries, and financial institutions for small businesses.
Source: BOJ

[2] The Bank for International Settlements (BIS) defines a CBDC as "a digital form of central bank money that is different from balances in traditional reserve or settlement accounts."

Money can be classified as "wholesale money" used by a limited number of entities, mostly financial institutions, for large transactions, or as "general purpose money" available for a wide range of entities including individuals and firms. Same classification is applicable to CBDC, and the BOJ currently explores general purpose one. The Liaison Committee's discussions and this paper are focused mainly on "general purpose CBDC."

Compared with bank deposits, which are one of general purpose money issued by private payment service providers (PSPs; e.g., banks and non-bank PSPs), CBDC, being issued directly by the central bank, will have concomitantly greater safety, and will impart finality to settlements. Also, as a public payment instrument, it incorporates neutrality and inclusiveness. In terms of its relationship to cash (banknotes), it is still central bank money, but CBDC has lower costs associated with transport, use, and storage. Unlike cash, the use of digital technology makes it possible to provide an array of additional functions and services to users. Taking these features into consideration, the Approach promotes the idea that CBDC in Japan should function as "a foundational payment instrument alongside cash," and points out the possibility that CBDC leads to "developing payment and settlement systems suitable for a digital society" as viewed from a wider range of perspectives.

Thus, many ways of utilizing CBDC can be conceivable. Still, that does not necessarily mean that CBDC should inherently be equipped with all convenient functions. In reality, even today, the fact that cash has "certain inconveniences" due to its being tangible (it is bulky and prone to theft) allows coexistence with deposits and other payment services, and strikes a right balance between convenience and stability in the payment and settlement system as a whole. In contemplating the introduction of CBDC, we need to consider so as not to interfere with the central bank's policy goals of price stability and financial stability. Taking these points into account, there might need to be a way to apply certain quantitative limits on CBDC holdings and/or transactions, and there needs to be a thorough investigation into how CBDC would work with private money and the division of roles with them. On that point, an opinion that "considering the potential effects that CBDC might bring, it might be appropriate to assign certain limits on the functions and features of CBDC at its initial rollout, and tweak these constraints gradually." was raised at the Liaison Committee.

For its own part, the BOJ is giving consideration to these points, and is proceeding with investigations into the features of CBDC and its institutional arrangements, from the perspective of ensuring the overall stability and efficiency of the payment and settlement system.

1.2 Core features required for CBDC

As a general purpose money issued by a central bank, CBDC must incorporate the following core features.

First, a point of discussion is how to ensure universal access—that CBDC is available to anyone as a foundational payment instrument. The typical scenario for CBDC usage would be, like private digital money, to operate that with a dedicated application on smartphones. For those users who would have some difficulty to use that, a topic for study is card devices. Retailers would have payment terminals to settle transactions with customers. In any case, there would need to be considerations in designs that provide convenience and portability in these endpoint devices.

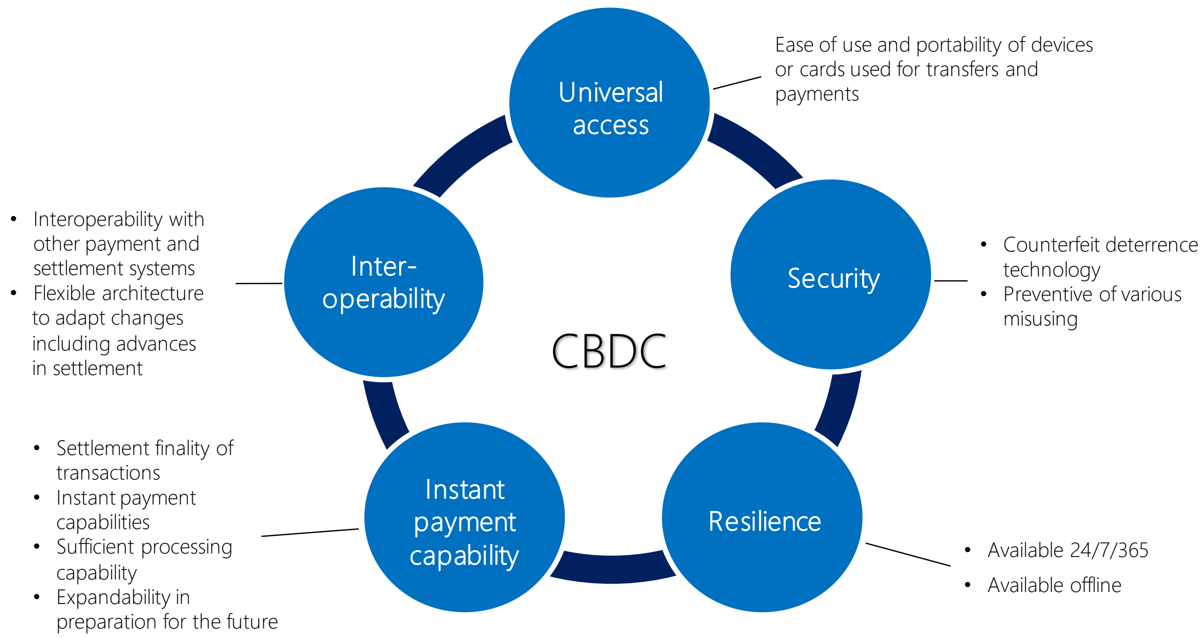
Second, for secure CBDC payments, sufficient security need to be ensured. If CBDC were to be issued, out of the need to protect user and transaction data appropriately, as well as risk of attacks aiming at counterfeiting or unauthorized use of CBDC, there would need to be appropriate measures in terms of technology and system operations regarding cybersecurity and information security. On this point, an opinion that "the security issues are not just matters of the BOJ's system. It is important that intermediaries address them as well." was raised at the Liaison Committee. Additionally, due consideration must be given to anti-money laundering and combating the financing of terrorism (AML/CFT).

Third, CBDC system must incorporate resilience so that it can be used anytime, anywhere. Specifically, there need to be efforts to improve availability (the capacity for constant 24/7/365 operation) that includes fault tolerance. There need to be studies of ways to support offline use in times of network disturbances as well as power outages (so that users can transfer CBDC or check balances with their personal devices), and ways to avoid going offline as much as possible.

Fourth, being central bank money, CBDC should offer settlement finality and instant payment capabilities, similar to cash. Because CBDC would be expected to be used by many people for daily transactions, the system also needs sufficient processing performance to enable settlement of frequent payments swiftly and safely, and attains expandability to meet future growth in usage.

Finally, it should ensure interoperability with private settlement systems. A CBDC system needs to smoothly connect to private sector so that the private sector can offer various services by using CBDC as a payment instrument; the system also needs a flexible architecture to adapt to changes including advances in private payment services in the future.

Figure 2: Core features a CBDC should incorporate



These are the core features required for CBDC. It is, however, difficult to fully incorporate all of them into CBDC when designing its institutional arrangements. For example, a CBDC that is a foundational payment instrument to the public would have adequate measures to resist security threats and system faults, but these measures would tend to impair the system's processing performance and convenience for users, or there may need to be certain restrictions on the scope of private settlement systems with which it could interconnect. These tradeoffs would be carefully balanced and dealt with thoughtfully for establishing stable and efficient payment and settlement systems.

Also, if a CBDC were introduced, the measures that ensure universal access and the functions that enable offline payments might be rolled out in a phased manner according to the use of cash. For example, as will be discussed later, if we assume a world in which a CBDC and cash coexist, it would be possible to fall back temporarily to cash settlements in a power outage, reducing the need for a system that can handle offline transactions at the initial CBDC rollout.

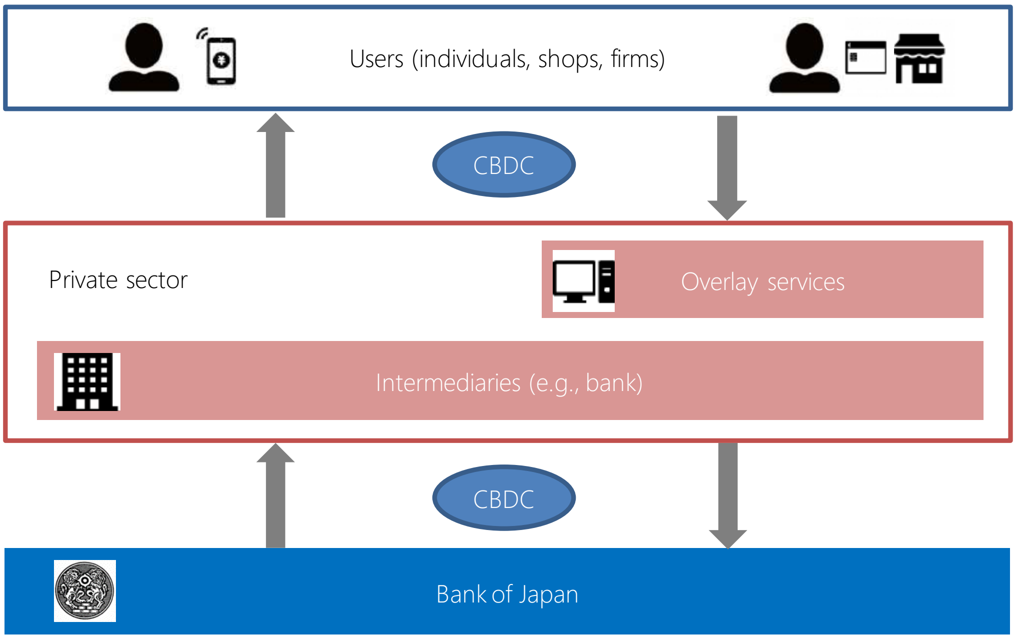
1.3 CBDC issuance and distribution

1.3.1 A two-tiered payment and settlement system

Many central banks, including the BOJ, would expect to issue CBDC through a two-tiered system comprising a central bank and the private sector (the indirect issuance model)[3].

The BOJ has no experience of having direct, daily transactions with firms and individuals, and recognizes that it would be hard to address elaborately the varied needs of all users. For this reason, the BOJ considers it appropriate to focus its efforts on providing CBDC as a foundational payment instrument, and having the private sector, as "intermediaries", fulfill the role of bringing CBDC to the public. This role-sharing makes good use of the private sector's experience and expertise, and will improve the stability and efficiency of the CBDC system as a whole.

Figure 3: Two-tiered CBDC system



Note that, as already mentioned, CBDC is issued by the BOJ and is not issued by intermediaries as their own liabilities. The "indirect" format means that intermediaries such as banks will stand between the BOJ and users, and act as middlemen for delivering or receiving CBDC[4]. As will be discussed in more detail in Chapter 3, for the operations of intermediaries, we expect the operations of intermediaries to include onboarding of CBDC users and payouts of CBDC to users in exchange for other forms of money (e.g., users' deposits) upon their requests.

[3] Conceptually, we can also conceive of the "direct issuance model" in which a central bank transacts directly with end users, without intermediaries, but there is no inclination toward this among developed countries at least.

[4] This is similar to the current way of cash in circulation: it is transported from the BOJ's main office, stored in the vaults and ATMs of financial institutions, and then provided to individuals and firms.

1.3.2 Offline services

There could be two variants of CBDC services: an online service provided over computer networks, and an offline service that is cut off from computer networks.

Assuming a case where CBDC is transferred between users, in the online mode each user with their smartphones or other devices transmit transaction requests via the systems of intermediaries to a geographically remote CBDC ledger (defined later). The ledger operator (e.g., the central bank) administers the amounts of CBDC held by users, which reduces each user's administrative overhead. Benefits of the online mode are that geographically distant users can easily exchange CBDC, and by connecting the CBDC system with systems of the private sector, it is easy to provide overlay services related to CBDC. In the offline mode, on the other hand, users use their endpoint devices to communicate directly with one another in order to directly transfer CBDC, and the information is stored locally on their respective devices. This requires that each user individually administer his/her own CBDC holdings. Like cash, this would be primarily for face-to-face transactions, and compared to online mode, it is limited in terms of the overlay services that could be provided via other systems.

We can expect two approaches to offline mode: 1) Online and offline mode coexist, and users can use either one at any time; 2) Availability of offline mode is limited for certain occasions such as natural disasters, while in normal times only online mode is available. The second approach, where the scope of offline usage is set more limited and temporal, might have more flexibility for adjusting service levels (e.g., setting lower limits on transactions while relaxing security requirements) than the first approach.

These points require further discussion, but hereinafter should be assumed that CBDC is being provided in online mode, except where otherwise indicated.

1.3.3 Basic transactions

Figure 4 describes the basic transactions relating to CBDC using five terms: issuance, payout, transfer, acceptance, and redemption. Here, end users A and B (individuals or firms) have beforehand linked to a certain private entity X or Y as their respective intermediary (the following description is concerned with the case where intermediaries are banks holding current account deposits at the BOJ).

The process begins with intermediary X asking the BOJ to debit the amount from its current account deposits at the BOJ and to credit an equivalent amount of CBDC to its account or to create an equivalent amount of CBDC tokens in exchange. This is how CBDC is issued, put into circulation.

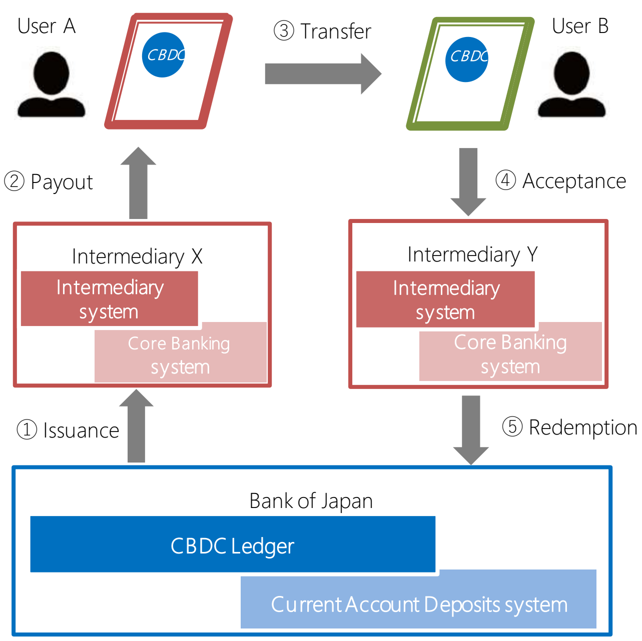
Next, CBDC is paid out to a user. User A uses a smartphone or other device to transmit instructions online to intermediary X requesting that their own deposits be debited from A's account and that they receive a payout of an equivalent amount of CBDC in exchange. Note that this is a matter for future design, but the CBDC payout to user A is not necessarily in exchange for the deposits at intermediary X. For example, facilitating user A to receive CBDC from intermediary X in exchange for cash or deposits at an intermediary other than X could ensure more effective CBDC distribution.

Third, the CBDC is transferred. A user transmits instructions online to convey CBDC to another user to make a payment to that user (shop, individual, etc.).

Fourth, acceptance reverses the action of payout. Intermediary Y receives CBDC from user B, and increases user B's deposited amount in exchange.

Fifth is redemption, which reverses the action of issuance. The BOJ receives CBDC from intermediary Y and credit the amount to intermediary Y's current account deposits at the BOJ in exchange.

Figure 4: Basic transactions using CBDC



Basic transactions	
① Issuance	The current account deposits of intermediary X are debited and CBDC is issued.
② Payout	User A's deposits are debited and CBDC is paid out.
③ Transfer	CBDC is transferred to accompany a transaction between users.
④ Acceptance	CBDC is accepted from user B and their deposits are credited.
⑤ Redemption	CBDC is redeemed from intermediary Y and its current account deposits are credited.

In this way, by converting with current account deposits at the BOJ and bank deposits, the movements that are exchanges of CBDC between the BOJ and financial institutions and between financial institutions and users wind up being similar to the way cash circulates today. The difference between the two is that in case of cash, banknotes or coins are physically delivered between the parties, while in the case of CBDC, records are changed in the CBDC ledger (described later) based on instructions transmitted online by intermediaries and users to effect transfers between the parties.

1.3.4 Balance-sheet changes

Figure 5 shows in simplified form the balance-sheet changes around CBDC issuance.

Step 1 on the upper left shows the state before CBDC is issued. When CBDC is issued, the central bank's and intermediary's balance sheets change, as shown in Step 2 on the upper right. From the intermediary's perspective, one asset— current account deposits at the central bank —is exchanged for another: CBDC.

Next, when CBDC is paid out by the intermediary to the end user, the balance sheet changes as shown in the lower pair of diagrams. First, the firm or individual obtains CBDC in exchange for cash, and the balance sheet changes as shown on the lower left in Step 3-1. Here, the user is bringing cash to an intermediary's counter or ATM, and the intermediary is paying out central bank–issued CBDC to the user in exchange. The intermediary brings the cash received from the user to the BOJ, and once that is credited to its current account deposits at the BOJ, the central bank's liability and the business/household asset complete the exchange from banknote to CBDC.

Next, in the case where a firm or individual obtains CBDC equivalent in value to money they have on deposit, the balance sheet changes as shown in Step 3-2 on the lower right. Here, the intermediary pays out central bank–issued CBDC to the firm or individual as requested by that user, and deducts an equivalent amount from their bank deposits. In this case, as long as no additional action is being taken, the intermediary's balance sheet is reduced by the amount of CBDC paid out[5].

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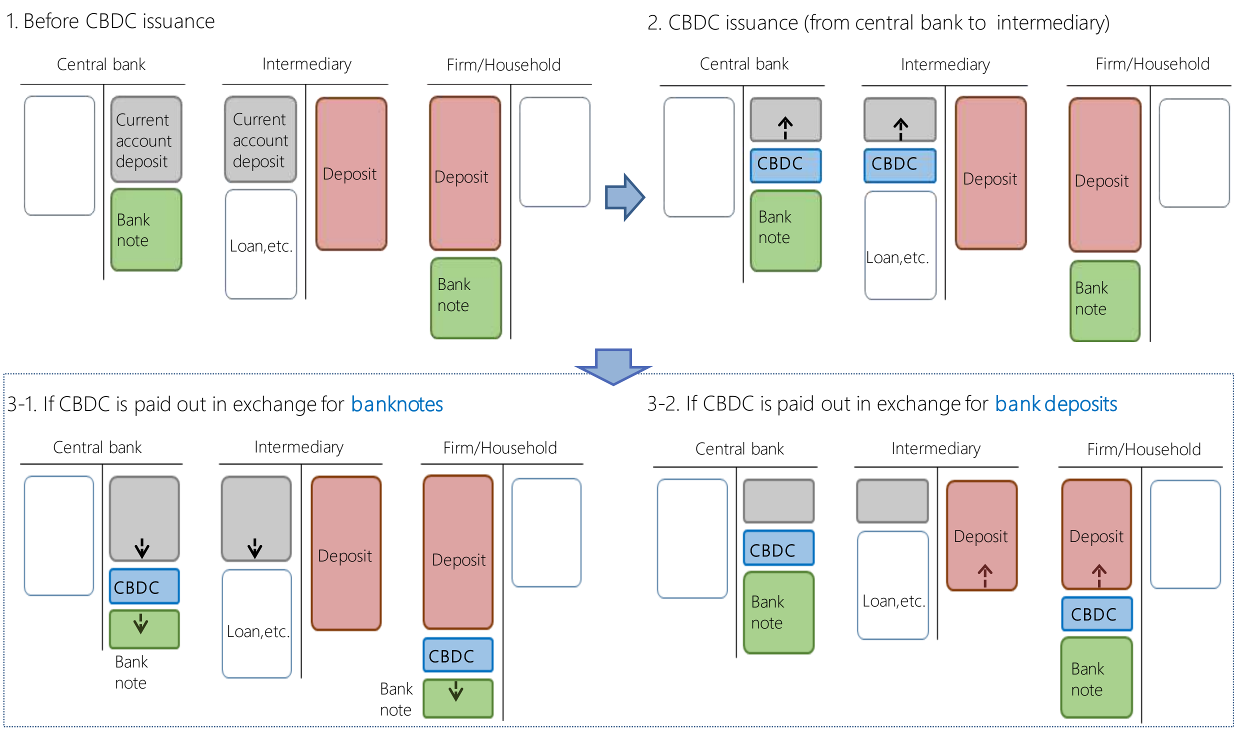
[5] In cases such as Figure 5 Step 3-2, when the current account deposits at the BOJ are reduced, if required by monetary policy, the BOJ will provide funds to the market through its market operation, and as a result, increase current account deposits at the BOJ. In this case, on the intermediary's side, government bonds are exchanged for current account deposits at the BOJ assets, or the current account deposits at the BOJ assets and the liabilities such as borrowing from the BOJ both increase in a straddle.

Figure 5: Balance-sheet changes accompanying the issuance and payout of CBDC



As mentioned above, CBDC is a liability of the BOJ and it serves as an asset to other entities. The role of intermediaries is to mediate between the BOJ and end users, mediating the exchange of CBDC assets. For this reason, an intermediary's solvency will have no direct impact on the value of CBDC, while there is a possibility that the distribution of CBDC will be affected if there is a failure in the intermediary's business operations. The stability in the value of CBDC is, same as for banknotes, backed by the confidence of the BOJ and its policies.

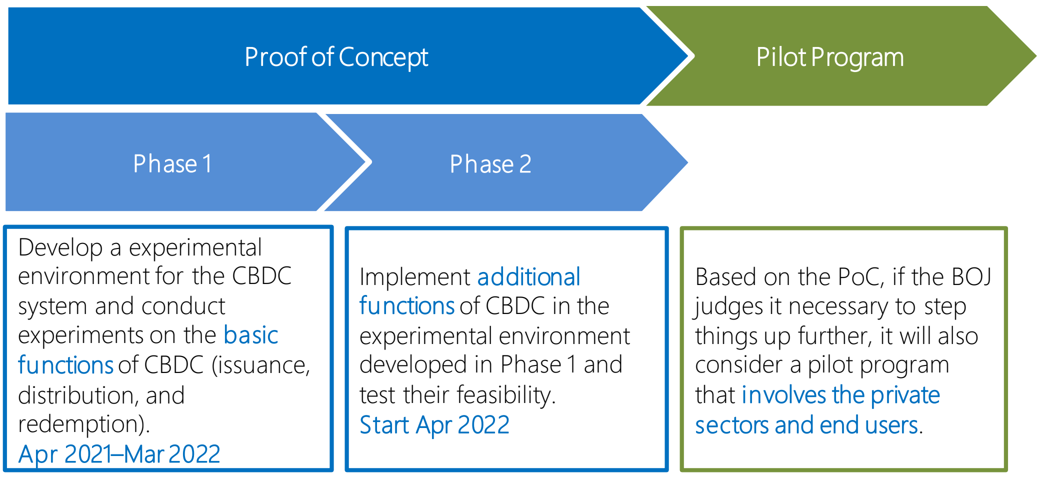
2. CBDC experiments

2.1 Proof of Concept Phase 1

2.1.1 Phase 1 overview

In line with the Approach, the BOJ has been conducting the planned technical experiments for CBDC. There are two stages to the experiments: Stage 1 is the PoC, and Stage 2 is the Pilot program involving intermediaries and end users. "Experiments" would arguably give some impressions of conducting the real-world payment experiments involving many consumers and retailers, but before these "experiments", the BOJ needs to build the experimental environment at the system level, and confirm whether the basic ideas for CBDC are technologically feasible. This process is what we call the PoC.

Figure 6: Experiment schedule



In addition to having two stages, the BOJ split the PoC into two phases, with Phase 1 starting in April 2021. In Phase 1, the BOJ built an experimental environment in the public cloud centered around a "CBDC ledger" as the foundation of a CBDC system, and evaluated whether the basic transactions relating to a CBDC (specifically, a series of transactions such as issuance, payout, transfer, etc., as described in Section 1.3.3) could be processed appropriately, and to evaluate the processing performance of the CBDC ledger and the functional aspects of reliability and ease of extension. The experiments are being conducted by the Payment and Settlement Systems Department of the BOJ, with a team of 15 people comprising the BOJ staff and staff of a contractor company selected through a bidding process.

The initial schedule for Phase 1 was for it to finish work in March 2022, and the intended goals have been achieved. Following is an overview on the experiment methods and related findings.

2.1.2 Three ledger designs

For the CBDC ledger in PoC Phase 1, the BOJ posted three design alternatives, based upon the discussions with internal and external parties. These three designs were mainly intended to analyze differences in processing performance stemming from those designs, inhered, and not necessarily to choose one of the three towards achieving a production-ready system.

The design alternatives can be classified according to two different facets. The first is whether the ledger is managed solely by the central bank or rather management is split between the central bank and intermediaries[6]. The second facet is whether the holding status is represented as "account-based" or "token-based": the former recognizes CBDC holdings as an intermediary's or user's account balance, whereas the latter assigns unique identifiers (IDs) to monetary data representing fixed value (tokens[7]) and recognizes CBDC holdings by linking these IDs to user IDs. Note that in all of these cases, payments assumingly take place online, by receiving online instructions from users and recording CBDC transaction or holdings data in the remote ledgers.

Design 1 deals with an account-based ledger system in which the central bank solely manages a ledger that records balances and transactions for all users and intermediaries. The payment of CBDC is handled as an account transfer between users.

Design 2 is an account-based ledger system, with intermediaries managing ledgers that record the balances and transactions of their respective customer users, and the central bank managing a ledger that records the balances and transactions of the intermediaries. In PoC Phase1, the every intermediary has two accounts at a ledger the central bank administers; one is its own accounts, recording the CBDC balances held by the intermediaries themselves, and the other is aggregated user accounts, meaning that it records the total CBDC balances held by their customer users. Here, when CBDC transfers between two end users under different intermediaries (see Figure 8, Step 4),

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6 Regarding the management entity of the ledger, the Bank for International Settlements (BIS) defines two models for a "Two-tier Retail CBDC": 1) a "hybrid model" in which the central bank centrally manages a ledger that records transactions for all users, and 2) an "intermediary model" in which intermediaries manage the ledgers that record the transactions for their respective customer users and the central bank manages a ledger that records transactions at the level of the intermediary. In Phase 1, Design 1 was an example of the first model and Design 2 was an example of the second.

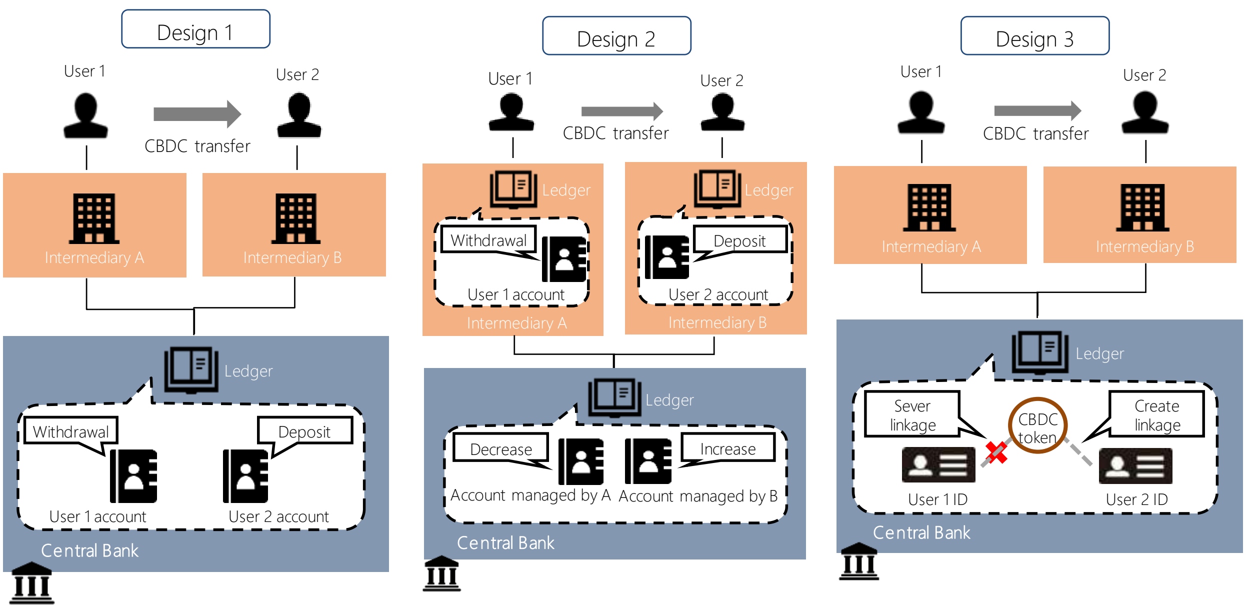
7 In this paper, we use the word "token" in the sense just described in the main text, but "token" and "tokenize" do not have formally established definitions and so may have other meanings, depending on the context.

the balances of the user's accounts managed by the intermediary and the intermediary's accounts managed by the central bank (aggregated user accounts) will rise or fall at the same time. However, with CBDC transfers within the same intermediary (see Figure 8, Steps 3 and 5), the user's account balances managed by that intermediary will rise and fall, but this will not result in any changes to the account balance for the intermediary managed by the central bank.

Design 3 covers a token-based ledger system. Two token-based systems can be possibly conceivable: a fixed-value approach, in which the token ID assigned at issuance does not change until redemption, and a flexible-value approach, in which tokens can be split or merged in transfers, and token IDs will be reassigned at those times. The fixed-value approach was used in PoC Phase1. In this approach, the movements of all issued tokens are recorded in a ledger managed by the central bank, and CBDC transfers between users are effected by changing the linkages between token IDs and user IDs in the ledger. Note that, with the fixed-value approach, transfers become more complicated if a user does not have a set of tokens matching the value of CBDC to be transferred. In PoC Phase1, these cases were handled by the intermediary performing an exchange using tokens it had on hand.

Figure 7: Ledger design alternatives

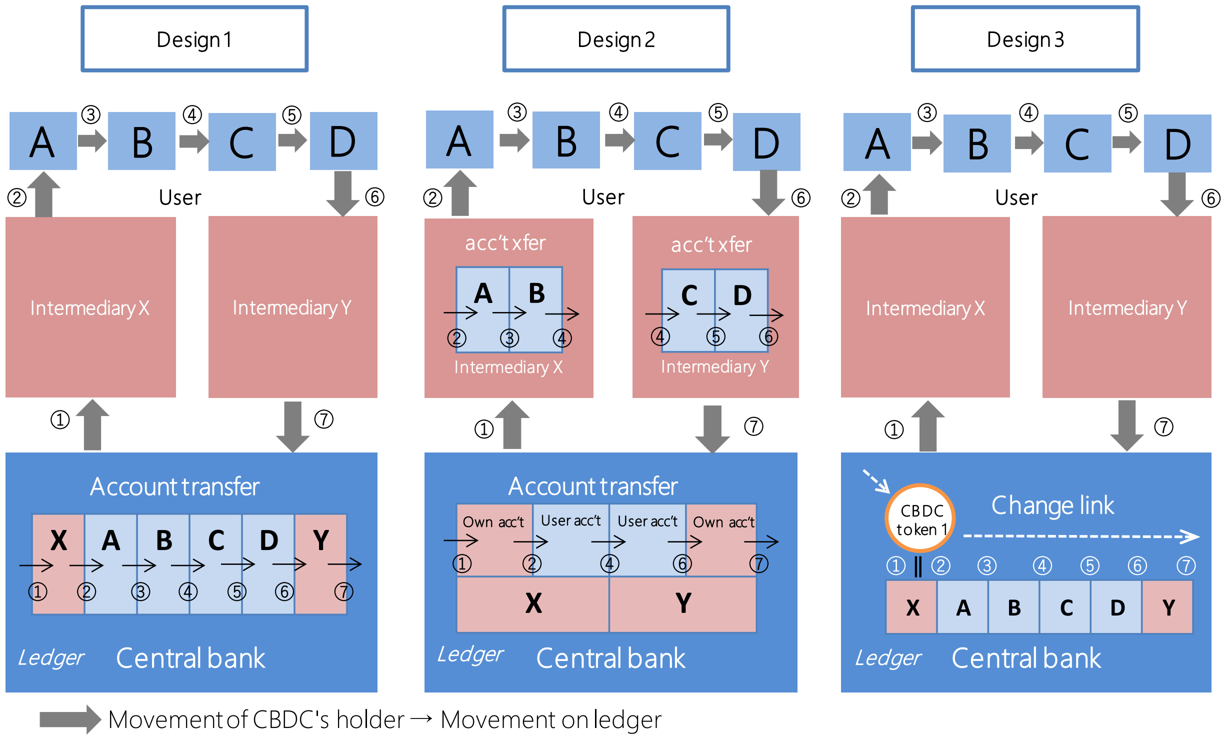
	Design 1	Design 2	Design 3
Ledger managed by	Central bank	Central bank & Intermediaries	Central bank
ID assigned to monetary data?	No (account-based)	No (account-based)	Yes (token-based)



As shown in Figure 7, the three design alternatives differ in terms of where the ledger is managed and the data model (account-based versus token-based), but what is unchanged is that the CBDC is issued by the central bank. Also, under the two-tiered payment and settlement system, intermediaries play similar roles in all of the designs in the sense that they stand between the central bank and users, and mediate the receipt of CBDC among other intermediary operations (see below). In the case of Design 2, these operations also include managing ledgers.

The ledger system in these three design alternatives has a "central management scheme" in all cases, managed either by the central bank or an intermediary, rather than a "distributed ledger scheme" where a single ledger is jointly managed by the participants in the transaction.

Figure 8: Ledger management entity and CBDC transfer recording methods



Note 1: ①: Issuance; ②: Payout; ③,⑤: Transfer within a single intermediary institution; ④: Transfer across intermediaries; ⑥: Acceptance; ⑦: Redemption.
Note 2: In Design 2, payouts (②), transfers across intermediaries (④), and acceptance (⑥) simultaneously increase and decrease account balances on the central bank's ledger and on intermediaries' ledgers. Movements of transfers within a single intermediary institution (③,⑤) are not reflected in the central bank's ledger.

2.1.3 Experiment methods and results[8]

The goals for PoC Phase 1 were to envision requirements towards achieving a production-ready system and, through experimental works and architecture evaluation to compare and evaluate

[8] For details on Phase 1 main results, see the "Central Bank Digital Currency Experiments Results and Findings from 'Proof of Concept Phase 1'" (May 2022, Payment and Settlement Systems Department, Bank of Japan).

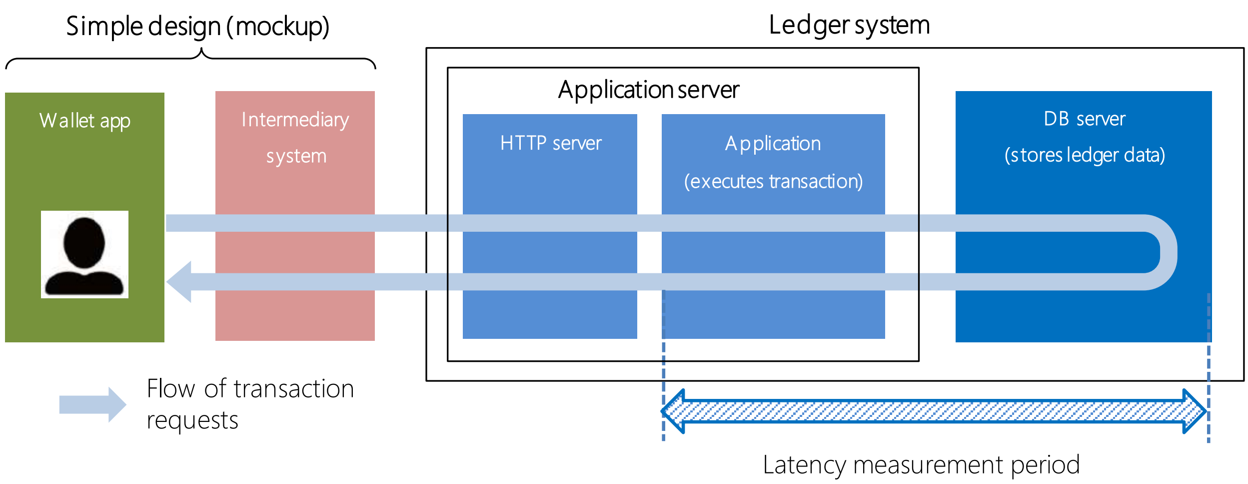
system performance and functionality using the three design alternatives.

(a) Performance evaluation

Performance evaluation methods

Performance evaluation was conducted in two stages. First, experimental works were run in which performance was measured using the experimental environment, assuming the required processing performance in introducing a CBDC in the future (production-ready system): typical throughput (the number of transactions requests that a CBDC ledger system could process per second) of several tens of thousands of transactions per second, peaks beyond 100,000 transactions per second, and latency (the time taken to process one transaction request) of within a few seconds. Second, based on those results, issues and strategies towards achieving a production-ready system were investigated in architecture evaluation. The experimental works ran each of the three design alternatives in a public cloud, using a ledger system consisting of application servers that execute the transaction requests and a database server that records and retains the resulting holding status. External to the ledgers are the wallet apps used by end users and the intermediaries' systems that would relay user instructions to the ledger; they have a simple design (mockup) that allows only the injection of transaction requests.

Figure 9: Overview of the experimental environment



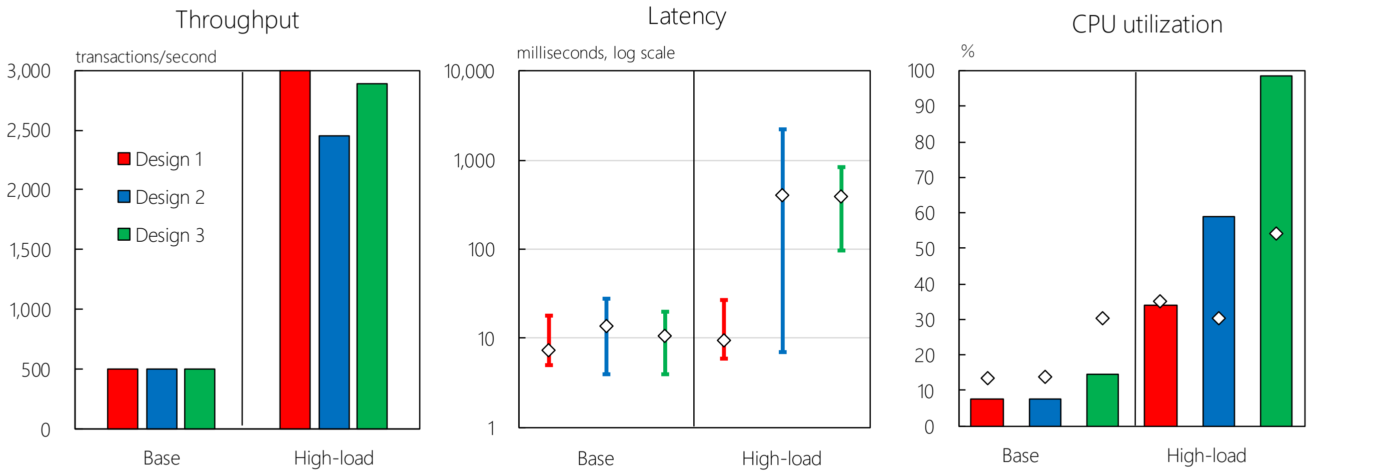
All three designs assume 100,000 end users and 5 intermediaries (2 large, 1 mid-sized, and 2 small, according to the number of end users). The breakdown of transaction requests requested via intermediary systems by type is as follows: 5% payouts, 30% transfers within a single intermediary, 60% transfers across intermediaries, and 5% acceptances. In addition, in Designs 1 and 2, each end user has their own account, and in Design 3, the total number of issued tokens is 25 million, and in a single iteration of a transaction request, the number of tokens that will be updated is 10.

To evaluate the processing performance of each design, experimental works were conducted using two scenarios: a "base scenario" in which 500 transaction requests were injected over a second, being a level each design should be able to handle without any delay of process, and a "high-load scenario" in which 3,000 transaction requests were injected over a second, being a level that should affect each design's processing performance. Three measurements were used in both scenarios to reveal differences in each design's processing performance and locate performance bottlenecks: 1) throughput (the number of transactions processed successfully per second by the application server's application), 2) latency (sum of application and database processing times), and 3) resource utilization (CPU utilization rates for the application server and database server).

Performance evaluation results

Results of the experimental works were as follows. In Design 1, even in the high-load scenario, throughput of 3,000 transaction requests per second, which was equivalent to the target rate set for transaction requests, was achieved and latency in both t base and high-load scenarios stayed about the same, at roughly 10 milliseconds. The database server's CPU utilization rate under the high-load scenario was about 30%, showing plenty of headroom.

Figure 10: Performance evaluation results



Note: Figures are average values for the measurement period. Latency shows ranges from the 1st to 99th percentiles,with averages indicated by ◇. CPU utilization is for the central bank's ledger, with bars indicating values for the database server and ◇ the application server.

In Design 2, the throughput dropped by 18% relative to the transaction requests under the high-load scenario, because of record locking accompanying concentration of processing in account-balance data. If there are multiple transaction requests that update account-balance data (record), records are locked so that a later transaction cannot be processed until the earlier transaction is complete (record locking). In Design 2, with requests for transfers across intermediaries (Figure 8, Step 4), there is a transfer between user accounts on the intermediary ledgers and at the same time, a transfer between intermediary accounts on the central bank's ledger (specifically, the aggregated user account), and we saw concentration of transaction requests on intermediary accounts, resulting in processing slowdowns. The processing delay incurred by this record locking increased latency for Design 2 (about 2,000 milliseconds for the 99th percentile) compared with Design 1, and database utilization rates climb to about 60% due to record-locking controls. Thus, Design 2 consumes more resources than Design 1.

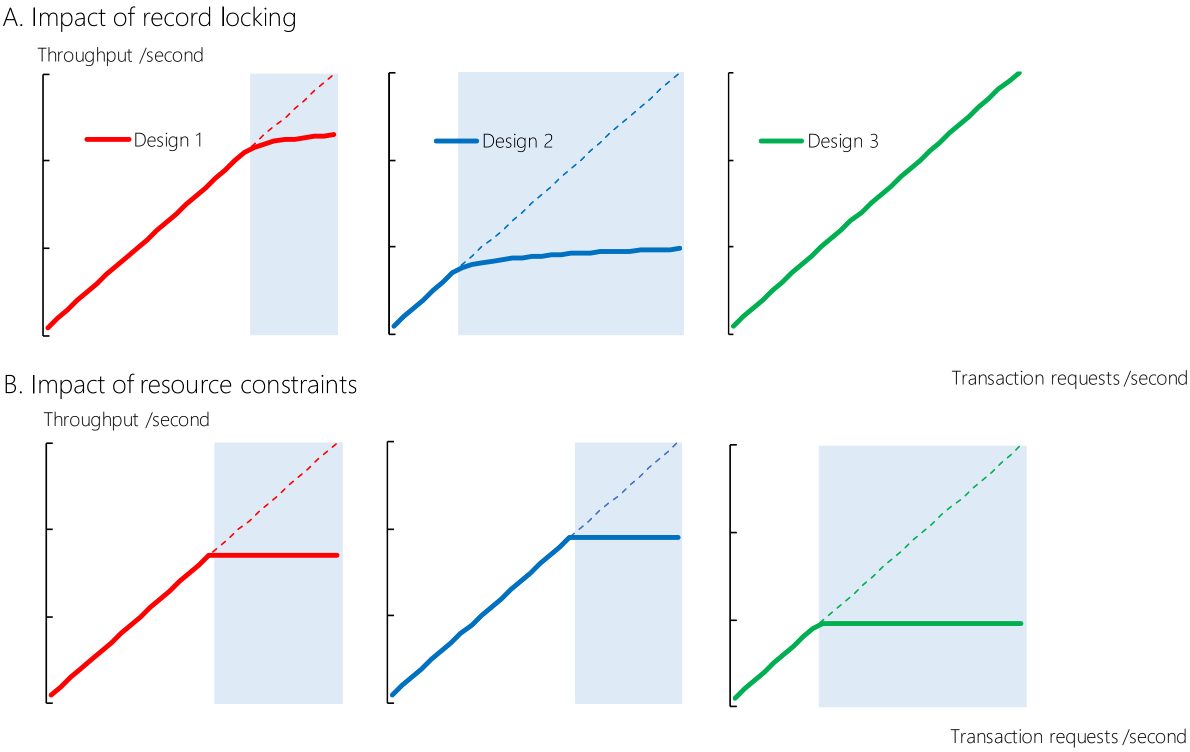
In Design 3, the high-load scenario raised CPU utilization to nearly 100%. The main factor behind this is that for each transaction instruction, holder ID updates were processed for multiple tokens, and because exchange processes happen for a constant fraction, the number of processes ballooned compared with other designs. Because of these resource constraints, the throughput dropped by 4% relative to the transaction requests, and the latency increased (about 800 milliseconds for the 99th percentile) compared with Design 1.

Performance issues towards achieving a production-ready system

The performance evaluation revealed two bottlenecks that would need to be addressed to achieve the processing performance necessary in a production-ready system (tens of thousands of transactions per second typically, 100,000 or more under peak load, and latency of no more than a few seconds): the impact of record locking and resource constraints.

The performance evaluation results showed that the record locking in Design 2 brought about performance bottleneck, but it could arise in Design 1, which is also account-based, depending on the number of transaction requests. One possible strategy for mitigating the impact of record locking is "record splitting," where the account-balance data recorded in the CBDC ledger are split into multiple parts. Another option is to redesign the business process flow (in Design 2, when processing requests for CBDC transfer across intermediaries, relaxing the simultaneity requirement of the central bank ledger transfer and the intermediary ledger transfer).

Figure 11: Effects of bottlenecks (simplified)



Note 1: The graphs approximate the relationship between transaction requests and throughput. Design 2 is for the central bank's ledger.
Note 2: The shaded areas indicate where a bottleneck is causing throughput to decline relative to the number of transaction requests. The dotted lines show the extrapolated curve without the bottleneck.
Note 3: All graphs for A and B exclude any reciprocal effects.

The impact of resource constraints was most apparent in Design 3, but Designs 1 and 2 could face the same problem, depending on the number of transaction requests. There are two ways to tackle this problem: scaling up (increasing server's processing performance) and scaling out (adding more servers). We can calculate that relying on scaling out alone to solve resource constraints in a production-ready system (assuming a throughput of 100,000 transactions per second) would require approximately the same number of database servers (for the central bank's ledger) for Designs 1 and 2, but two to three times as many for Design 3. When increasing the number of database servers, it is necessary to carefully optimize the design and layout of the databases, so as to avoid deterioration in throughput and latency due to transaction requests being concentrated in certain records.

In a production-ready system, there could be bottlenecks outside the scope of this experimental work (network bandwidth, storage I/O performance, etc.). There could also be scenarios unlike the ones we tested, such as temporary and localized extreme loads. Additionally, it would become necessary to meet additional needs such as implementing increasingly complex additional functions and sufficiently dealing with security risks. A production-ready system would need to fully account for all these factors in order to design and build a suitable system.

Summary of performance evaluation

The following summarizes the main results of performance evaluation for each design.

Processing perform lower in Design 2 compared with Design 1 due to the effects of record locking. That said, Design 1, which is also based on an account-based ledger system, could experience the similar lower performance depending on the number of transaction requests. In order to build a production-ready system, we would need to consider solutions such as split records and different business process flows to address these issues.

Design 3 required more resources than Designs 1 and 2 to process the same transactions. Designs 1 and 2 will be constrained by resources if the number of transaction requests is up significantly. In a production-ready system, Design 3 in particular would need greatly expanded resources with the additional optimizations.

(b) Functional evaluation

In addition to the performance evaluation described above in (a), functional evaluation of each design were also conducted as part of PoC Phase 1. Specifically, architecture evaluation was used to compare and evaluate each of the designs for the reliability (resistance to security risks, fault tolerance, and availability) and ease of extension that would be needed in a CBDC ledger system if it were built out as a production-ready system in the future. The results were as follows.

Regarding resistance to security risks (resistance to cyberattacks) and availability (the frequency and duration of system downtime), no significant differences were observed resulting from the differences between the design alternatives.

Regarding fault tolerance (the number of potential failure points and the scope of their impact), Design 2 is thought to have a relatively small expected impact area for faults, compared with Designs 1 and 3. However, it has more potential failure points, and the integrity of restored data is unlikely to be hold.

Regarding ease of extension (ease of implementing additional functions), each design has its distinct qualities, but whether major differences exist among them remains yet to be determined.

2.2 Proof of Concept Phase 2

2.2.1 Phase 2 overview

The BOJ began PoC Phase 2 in April 2022, following Phase 1. The purpose of Phase 2 is to implement more complex additional functions to the basic CBDC functions in Phase 1, as well as to explore their technological feasibility and processing performance. At the moment, Phase 2 is expected to last one year, ending in March 2023.

In Phase 2, an experimental environment will be developed on the CBDC ledger by adding-on some systems necessary for evaluating additional functions. Design 1 will be the primary scope in the experimental works for the ease of implementing additional functions to the CBDC ledger. Design 2 shares a number of aspects with Design 1 and we could supplement the experimental work with architecture evaluation to grasp the differences between these design alternatives. Additional studies related a token-based ledger including Design 3 will be underway if needed to explore its differences in terms of function and performance compared with an account-based ledger.

As in Phase 1, the experimental environment is built in a public cloud, and the systems that are external to the CBDC system, including those for current account deposits at the BOJ and the core banking systems of intermediaries, have simple functions (mockups) that only generate transaction requests to the ledger.

The members of the Liaison Committee have floated many ideas about what form a ledger system should take in a future where CBDC is introduced to Japan. For example, on the subject of comparing different ledger design alternatives, they have brought up whether there is a single point of failure, flexibility in the roles of financial institutions, load volume of building and operating the systems at intermediaries. Design 3 is intriguing from a technological standpoint, but has a lot of potential problems and seem to be relatively difficult to overcome.

The BOJ has made no decision about what sort of ledger system it might adopt. That choice will require consideration of a number of factors, including system processing performance and reliability, as well as the cost of developing and operating the ledger, and developments in other countries. In fact, many other countries are currently studying a number of different underlying technologies for CBDC ledgers. Work continues on exploring and acquiring information on hybrid of Designs 1 and 2, as well as token-based systems (including both flexible-value approaches and the fixed-value approach in Design 3), without any prejudice.

2.2.2 Experiment topics

In Phase 2, additional CBDC functions are being categorized into three blocks based on their affinity in IT system development. Specifically, functions are categorized as 1) functions that contribute to improving the convenience of payments; 2) economic designs for CBDC (limits on use that ensure the stability of the financial system); and 3) functions for coordination among intermediaries, or between the CBDC system and external systems. Experimental work is expected to proceed on these blocks accordingly (defining requirement, development, experimental work, and architecture evaluation). Note that none of these functions will necessarily be implemented in the future; one of the goals for Phase 2 is to prepare for future discussions of institutional arrangements by learning beforehand where the technological problems lie and what is technologically difficult or easy to implement.

Figure 12: Main experiment topics for Phase 2

	Functions being explored	Related systems built for experiment
Improving convenience of payments	1. Booking remittance instructions by users in advance 2. Batch remittances or "reverse lookup" remittances at user request 3. Ways to connect online CBDC and offline CBDC (charge/discharge)	• Accept and manage reservations for remittance instructions • Load distribution for batched remittances
Economic design (Safeguards ensuring the stability of the financial system)	1. Limits on CBDC holdings 2. Limits on CBDC transaction amounts (per transaction or per time period) 3. Limits on number of CBDC transactions (per time period) 4. Applying interest to CBDC holdings 5. Applying different limits based on user attributes	• Manage holdings history • Manage transaction history (amounts, iterations) • Calculate & pay interest • Manage details of per-user limits
Coordination among intermediaries/with external institutions	1. Providing multiple accounts to one user via multiple intermediaries 2. Name-based aggregation for multiple accounts 3. Ways to connect private settlement services, public system, etc. 4. Ways to exchange cash and CBDC	• Manage number of accounts held • Calculate holdings after name-based aggregation

In Phase 2, one of the goals is to evaluate whether the above functions are executed appropriately and what effect these functions—in particular holdings limits and transaction limits that can restrict CBDC processing of funds transfer—will have on system performance. Specifically, as in Phase 1, transaction request will be injected under a variety of scenarios and transaction throughput, latency, and resource utilization in the ledger system will be measured. Then, based on the results, the BOJ will investigate what strategies and methods of resource expansion would be needed to achieve the performance requirements of a production-ready system.

Additionally, on the assumption that multiple additional functions might be implemented, there will be a study (mostly through architecture evaluation) of problems and solutions relating to resistance to security risks, fault tolerance, and availability.

2.3 Next steps

The following points are issues that may need to be addressed in the future, in parallel with Phase 2.

2.3.1 Pilot program

As stated in the Approach, based on the PoC, if the BOJ judges it necessary to step things up further, it will consider a pilot program that involves the private sector and end users.

Assuming that it takes place, there are a number of possible ways that the pilot program could be conducted. Looking at examples from other countries, there are cases where test systems are designed with their utilization as production systems in mind, and from an early stage, the experimental environments were built at a large scale. However, there are also cases of starting with small-scale systems to focus on test objectives. In the latter cases, participants of the pilot program would be initially limited, then the scope and the participants would be expanded in a phased manner.

The BOJ will make a decision about whether to conduct the pilot program after exchanging opinions with other stakeholders on what topics should be considered in advance (for example, what the experiment topics are and what ledger technology is to be used), and, assuming it does decide to move forward, how intermediaries, other private businesses, private payment and settlement infrastructure, and end users such as retailers and individuals can be involved.

2.3.2 Research and study on elemental technology

In order for a CBDC to be widely used as a foundational payment instrument to the public, there are elemental technologies that it would need to incorporate: 1) cybersecurity and information security; 2) user authentication (including biometric authentication); and 3) endpoint devices (wallet apps and card-like devices). These technologies lie outside the implementation for the PoC, but the BOJ will conduct research into these in parallel and consider implementing these technologies in series in the future trials as needed. The BOJ sees it as important for that process to be informed by the technology and knowhow of companies in a range of businesses, through venues such as the Future of Payments Forum.

2.3.3 Follow-up of developments abroad

Looking at the developments in major economies on general purpose CBDCs, there are ongoing exchanges of views among stakeholders and technological testing, including a discussion paper laying out the topics for study in terms of policy in the United States (Jan 2022, The Federal Reserve) and a report on underlying technologies for CBDC ledgers (Feb 2022, The Boston Fed and MIT), as in China and the euro area.

Also, a CBDC Coalition[9], seven central banks including the BOJ participate, and has vigorously analyzed and investigated CBDC institutional arrangements and advanced technologies. Based on these activities among the major economies, the BOJ sees it as important to widely share findings on ways to build CBDC ledgers and elemental technologies and utilize these findings its own investigations.

[9] The member states are Japan, the United States, the Euro Area, the United Kingdom, Canada, Switzerland, and Sweden, and also is included the Bank for International Settlements, which in Jan 2020 formed a "group to evaluate the feasibility of central bank digital currencies by major economies." A report on the group's activities appears later in the Reference section.

3. Investigation of institutional arrangements

The Approach states that, in parallel with the CBDC experiments, the exploration of institutional arrangements will be conducted with four main themes: (1) how central banks and the private sector should cooperate and share roles, (2) the relationship with financial system stability, (3) ensuring privacy protection and handling of user information, and (4) the relationship with cross-border payments.

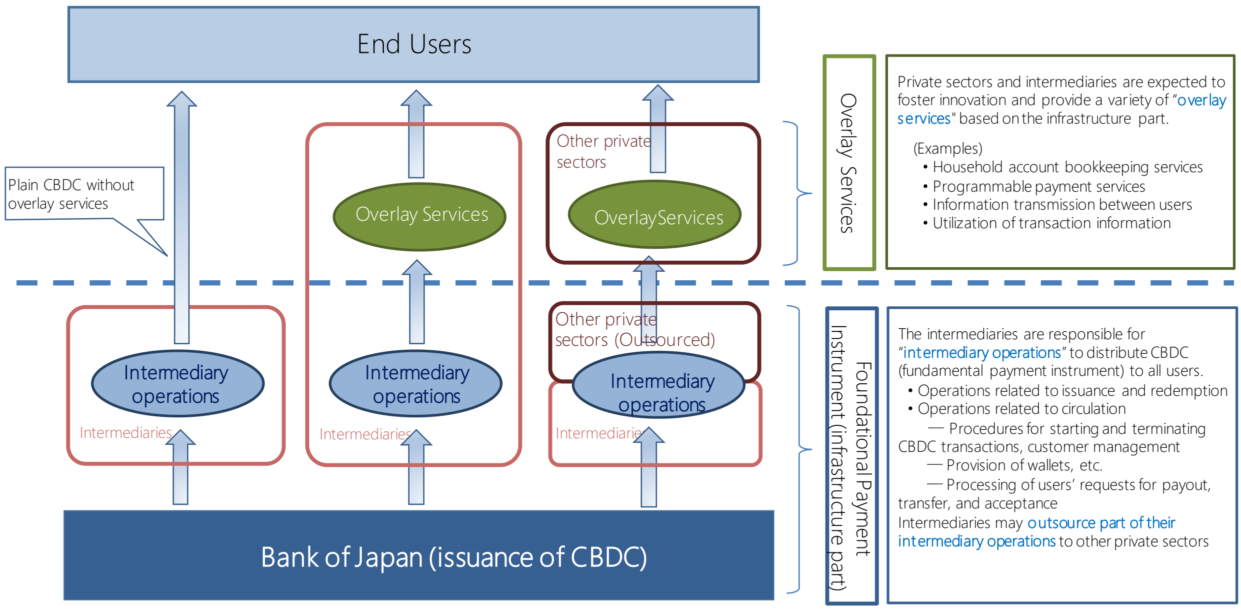
Of these themes, the Liaison Committee discussed (1) and (2) from the perspectives of "vertical coexistence" and "horizontal coexistence." This chapter introduces the BOJ's current understanding on these themes and the discussions at the Liaison Committee.

3.1 Entities constituting the CBDC system and their roles: vertical coexistence

3.1.1 "Foundational payment instrument" and "overlay services"

As a premise for exploring the relationship between a central bank and the private sector, it is helpful to divide the CBDC system into two areas: the infrastructure part to provide all users equally with CBDC as a "foundational payment instrument" and, the "overlay services" part that meet user needs on top of the infrastructure part in which CBDC works as a public good.

Figure 13: "Foundational payment instrument" and "overlay services"



The entities for infrastructure part consist of the BOJ and the intermediaries. While each intermediary is expected to exercise its ingenuity to expand the number of CBDC users (who could form its own customer base), it is required at the same time to conduct its "intermediary operations" under certain rules as an entity responsible for distributing CBDC as a public good. In this sense, such operations by intermediaries can be basically sorted out as being in a "non-competitive area." CBDC itself is expected to be a foundational payment instrument, available only for simple transactions with intermediaries and users.

In addition to the basic use of CBDC, the private sector could provide various "overlay services" in order to meet the needs of end users (e.g., household account bookkeeping services to record and manage the amount and use of CBDC). Such a service differs from the one for existing cash and is unique to the digital society. In such a "competitive area," private-sector innovation and the creation of new businesses and services would contribute to the convenience of the public, the efficiency of the payment and settlement systems, and the sustainability of the CBDC system as a whole.

From the user's perspective, the boundary between CBDC as a foundational payment instrument and overlay services using CBDC is likely to blur, as both are often provided integrally with a single app in smartphones. However, depending on whether the service falls under the category of intermediary operations (infrastructure part) or overlay services, its position in the CBDC system will vary, including its relationship with the BOJ, the degree of discretion the position has in providing services, how it handles user information, and how it bears the cost burden. An opinion was raised at the Liaison Committee that an appropriate division of roles between CBDC as a payment instrument and additional private payment services would lead to the creation of an efficient payment and settlement systems through avoiding overlapping investment. In light of these points, it is considered necessary to clearly distinguish between the two areas when designing CBDC's institutional arrangements onward.

In this way, rather than a "two-tiered structure" made up of the BOJ and the private sector, it may be more appropriate to view the CBDC system as a "multi-tiered structure" in which the operations and services of the private sector are further divided into an "infrastructure part" and an "overlay service part" and these parts are piled up. In any case, the "vertical coexistence" of the BOJ, intermediaries, and other private businesses will make it possible to achieve the functions and features required for CBDCs (see Section 1.1), namely, "a foundational payment instrument alongside cash" and "development of payment and settlement systems suitable for the digital society.”

The following outlines the main entities of the CBDC system and their roles.

3.1.2 Roles of the BOJ

The BOJ shall issue CBDC centrally as its own liabilities. It will also manage and operate the entire CBDC system as the issuer of CBDC or as the central bank responsible for the stable and efficient operation of Japan's payment and settlement systems. Specifically, in addition to establishing and administrating the system infrastructure (e.g., ledgers) necessary for the issuance and circulation of CBDCs, it is envisioned to formulate and implement basic rules for the administration of CBDCs, in cooperation with the government and other authorities.

3.1.3 "Intermediary operations" by intermediaries

(a) Concept of intermediary operations

Intermediaries are responsible for the "intermediary operations" necessary to provide CBDC to users. Specifically, the intermediaries will conduct operations related to the "issuance" and "redemption" of CBDC by the BOJ, and will also conduct operations related to the circulation of CBDC for the user. With regard to the latter, main tasks would include the following: (i) procedures for customers to start or terminate using CBDC; (ii) provision of wallets services for users (e.g., smartphone apps); (iii) processing of requests from users regarding "payout," "transfer," "acceptance," "balance inquiry," etc. (relaying online instructions to and from the BOJ); and (iv) daily customer management and support. In addition, as in Design 2 of the PoC Phase1, depending on the ledger design, the intermediaries may manage the ledger that records the transactions of its own end users for the BOJ, in which case the management and operation of the ledger would also be included among the intermediary operations.

While the intermediaries, along with the BOJ, will be responsible for providing CBDC to users, they may also benefit from being actively involved in intermediary operations by (i) maintaining and expanding their customer base, (ii) reducing cash handling costs, and (iii) providing overlay services by utilizing their position as intermediaries. In addition, although it depends on the relevant institutional arrangements, it may be possible to utilize the transaction information obtained through intermediary operations and overlay services for their own business and its expansion.

(b) Scope of intermediaries

Ensuring the quality of intermediary operations at an appropriate level is essential for CBDC to function as a foundational payment instrument to the public. Therefore, in order to become intermediaries, an institution must meet requirements to properly perform intermediary operations.

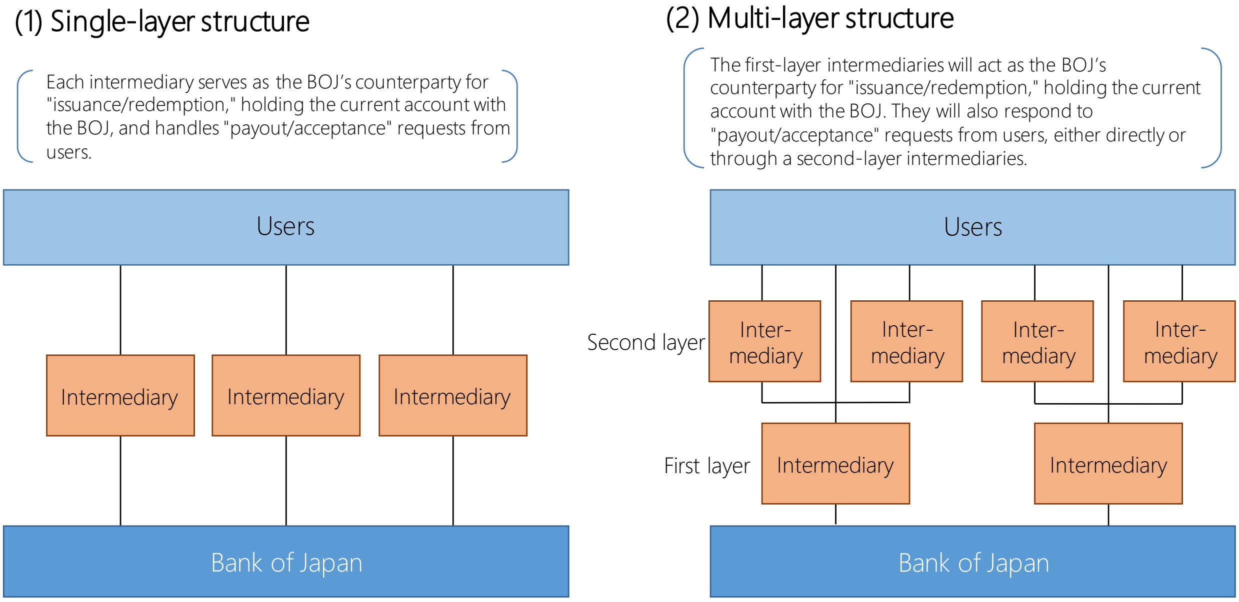
For example, providing assets that are to be exchanged for the "payout" or "acceptance" of CBDC and smoothly exchanging them with users is an important role required for intermediaries. In this regard, banks and other financial institutions are considered to be promising candidates for intermediaries, given that from a large number of customers they already accept deposits (which are exchanged for CBDC in payouts and acceptances) and their generally high administrative capabilities. In selecting eligible intermediaries, careful considerations would be required based on specific criteria related to administrative capabilities, business conditions, and IT system management and operation. Although dependent on the CBDC's institutional arrangements in the future, it is not necessary to require users to have a deposit account with their own intermediaries in order to use CBDC, as there are various possible assets that could be exchanged for CBDC payouts/acceptances. Therefore, the pros and cons of admitting non-bank PSPs such as fund transfer service providers as intermediaries will also be subject to future discussion.

(c) Structure of intermediaries

The left-hand side of Figure 14 shows a "single-layer structure," in which all intermediaries serve as the BOJ's counterparties for "issuance" and "redemption" while, at the same time, responding to requests from users for "payouts" and "acceptances."

Instead, there could be an alternative structure in which some intermediaries are solely responsible for "issuance" and "redemption" to and from the BOJ, whereas other intermediaries deal exclusively with users. This is the "multi-layer structure" shown in Figure 14 right. In this case, the "first-layer" intermediaries would be the "issued" counterparty for CBDC, and the "second-layer" intermediaries would receive CBDC from the first-layer intermediaries and payout the CBDC to its own users (in this case, the intermediaries that make up the infrastructure part shown in Figure 13 would be made further multi-layered).

Figure 14: Structure of intermediaries



With a variety of business types and sizes, a single-layer structure in which all intermediaries assume the identical operations and equal responsibilities might not be very workable. While governance related to intermediary operations may become more complicated with a multi-layer structure, it has the advantage that various types of private businesses can be involved in the circulation process of CBDCs based on their own businesses and preferences. Related to this, an opinion was raised at the Liaison Committee that, from the perspective of allocating the cost burden of intermediary operations and achieving universal access, it would be desirable to allow a multi-layer structure that includes intermediaries other than banks, instead of making only financial institutions holding BOJ current accounts perform all of intermediary operations.

Furthermore, in relation to the CBDC ledger design discussed in the PoC Phase 1, the intermediaries will not manage the ledger in the case of Designs 1 and 3, regardless of whether a single-layer or multi-layer structure is adopted. In the case of Design 2, it is assumed that the intermediaries manage part of the CBDC ledger, and, one idea should be that only the "first-layer" intermediaries undertake the ledger management and thereby record account balances and transactions for "lower-layer" intermediaries and end users, in light of their roles under a multi-layer structure.

Since the structure of intermediaries is foundational to the institutional arrangements for CBDC and will affect how the experiments are conducted in the future, the BOJ will give thorough consideration to this issue, taking into account the opinions of all stakeholders.

(d) Outsourcing of intermediary operations

In order to facilitate the smooth provision of CBDC to end users, intermediaries could outsource part of their intermediary operations as necessary. For example, outsourcing their operations such as "development and operation of end-point devices and applications for users" and "daily customer support" to other PSPs or business firms could enhance convenience for users and cost savings for the intermediaries. It is conceivable that multiple intermediaries could jointly outsource their operations to a single private business. Such outsourcing contractors could then leverage their own technology and knowledge to find their business opportunities with CBDC, a new payment system.

3.1.4 Provision of "overlay services" by the private sector including intermediaries

As mentioned above, in order to build stable and efficient payment and settlement systems suitable for the digital society, private businesses are expected to provide a variety of overlay services that meet the individual needs of users based on CBDC as a public good.

The starting point of the discussion is that overlay services can, in principle, be provided freely by any entities within the scope of relevant law and regulations. It is also possible for intermediaries, solely or jointly (e.g., as the financial industry as a whole), to provide overlay services apart from their intermediary operations.

While a variety of ideas are thinkable, the following list illustrates typical examples of overlay services which are currently discussed among stakeholders. In the meantime, an opinion was raised at the Liaison Committee that in order to explore an environment in which the public can take full advantage of the features of CBDC through the provision of such overlay services, it is necessary to consider the appropriate design of the operational scope of the private businesses, including a flexible application of the related laws on regulating their scope of business.

(a) Those that enhance customer convenience of use and handling of CBDC (e.g., household account bookkeeping services, setting lower upper limits on usable CBDC amounts for underage users)

(b) Those that assist CBDC payments (e.g., providing CBDC with "programmability").

(c) Those that enable CBDC payments with function of information transmission (e.g., EDI and bill relaying services)

(d) Those that utilize customer data acquired through CBDC transactions for new businesses and services (e.g., analyzing transaction information acquired with customer consent to develop value-added services that meet their specific needs).

Furthermore, in order to refer to the payment information necessary for providing overlay services or to retrieve such information to be utilized for other businesses, a mechanism to give access to and build smooth linkage with the CBDC's core system is required. API technology will play an important role in achieving such collaboration. In addition, "distributed ledger technology" might be useful for the private sector to provide overlay services, while depending on their contents. Thus, the introduction of CBDC might contribute significantly to the further development of related technologies.

3.1.5 Other issues

(a) Private payment infrastructure

Given that CBDC also has the aspect of a funds transfer platform in the retail field, it is necessary to make clear its relationship with the existing private payment infrastructure that processes retail funds transfer among banks in order to stimulate the discussion. An opinion was raised at the Liaison Committee that "it would be preferable to consider medium- to long-term collaboration between the CBDC system, the Zengin system (interbank clearing system for domestic funds transfers) and Cotra (small value funds transfer services) on the premise of their coexistence."[10]

In this regard, it would be appropriate to proceed with the following aspects.

First, from the perspective of ensuring the stability and efficiency of Japan's payment and settlement systems as a whole, it is necessary to consider adequate collaboration, taking into account that the next replacement of the Zengin system is scheduled for 2027.

Second, in order to achieve an appropriate division of roles between the private payment infrastructure and the CBDC system and to minimize investment costs, both of them would need to be built up as a flexible and efficient system respectively to accommodate various future options.

Third, if CBDC is introduced in the future, it will also be important to take an approach such that private payment infrastructures can support intermediary operations or provide "overlay

[10] At the 3rd Liaison Committee Meeting (April 13, 2022), a presentation was given by the Japanese Banks' Payment Clearing Network on next-generation of retail payment systems (initiatives related to upgrading the Zengin system).

services" to CBDC users, by utilizing its existing functions (confirmation of payee, EDI<Electronic Data Interchange> functions, etc.). Such approach can be seen as an example of "vertical coexistence," which would not only improve convenience for users but also contribute to the effective utilization of resources for private payment infrastructure.

In addition, a member of the Liaison Committee commented that, as an example of collaboration between the CBDC system and private payment infrastructure, CBDC could also be used for funds clearing among financial institutions that serve as intermediaries, which could lead to the utilization of existing infrastructure and reduction of investment burdens. In relation to this point, another member pointed out that from the viewpoint of promoting innovation, it is important to timely upgrade the basic infrastructure as necessary while ensuring transition period, as in the case of mobile communication systems whose standard setting and generational transitions are orderly planned and accordingly implemented, and that coexistence with CBDC will enable existing payment infrastructure such as the Zengin system to enhance its functions and restrain its costs.

(b) End users

As mentioned above, "universal access" is one of the core features that a general purpose CBDC should retain. Therefore, any discussion should start by assuming that every individual, firm, or shop in Japan that wishes to use CBDC may do so. The domestic use of CBDC by non-residents, such as sightseeing visitors to Japan, should also be discussed.

From the perspective of ensuring user convenience and the stable operation of the payment and settlement systems, it might be an option that the framework allows a single user to designate multiple financial institutions as his/her intermediaries. In addition, in light of approaches in other countries, it might be necessary to consider in the future differential setting in CBDC services (e.g., upper limit of holding and transaction amounts) based on the attributes of users (e.g., individuals or firms).

(c) Government

The government, being responsible for currency and financial supervision, needs to establish laws and regulations necessary for the operation of the CBDC system.[11] It is also necessary to

[11] According to the government's " Basic Policy on Economic and Fiscal Management and Reform 2021" (Honebuto-no Houshin, June 2021), "With regard to CBDC, the Government and the Bank of Japan will outline the system design based on the results of the Proof of Concept to be conducted by the end of FY2022, and will consider a pilot program and the

consider the specifics of how other public services are to be provided when CBDC is introduced.[12]

(d) IT firms, etc.

The CBDC system will be built up by combining various technologies available at the time, from ledgers to endpoint devices, and such efforts will continue incessantly into the future after the CBDC is introduced. It was pointed out in the Liaison Committee that there are numerous technical issues with the CBDC system, including the coordination between the infrastructure part and overlay services, the relationship with cross-border payments, and all stakeholders, including the IT industry hold a high level of interest in issues such as what kinds of architectures should be adopted to build up a computer system that connects all of central banks, intermediaries, and other relevant service providers.

The BOJ also recognizes that IT firms and experts to be involved in the administration and operation of the system infrastructure and in the provision of elemental technologies will play an important role in supporting the stable operation of the CBDC system in the future. Based on this recognition, the BOJ has established and regularly held the Future of Payments Forum to carry out discussions with a wide range of stakeholders. In the past year, we have held a Digital Currency Subgroup on the topic of "Technologies to Support CBDC," where the private sector, especially non-financial firms, have been invited as presenters to actively exchange opinions on the latest development of technologies for accomplishing the core features required for CBDC (see Section 1.2).[13]

3.2 Relationship with other types of payment instruments: horizontal coexistence

When considering the introduction of CBDC, it is necessary to aim for achieving "horizontal coexistence" as well as "vertical coexistence" as described in Section 3.1; i.e., CBDC and other types of payment instruments (cash, bank deposits, private digital money, etc.) should properly fulfil their functions and roles and thereby coexist with each other. In order to realize such horizontal

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feasibility and legal aspects of CBDC issuance"

12 The G7 report (October 2021) lists "payments to and from the public sector" as the topic of one of the public policy principles for retail CBDCs: "Any CBDC, where used to support payments between authorities and the public, should do so in a fast, inexpensive, transparent, inclusive and safe manner, both in normal times and in times of crisis."

13 Since June 2021, the BOJ has held three times Future of Payments Forum Digital Currency Subgroup meetings on the topic of "Technologies supporting CBDC" as follows. First session: June 11, 2021 ("Security," "Universal access," and "Standardization of information technology" as themes); second session: November 29, 2021 ("Resilience of payment infrastructure" and "Promptness in payment services"); third session: January 11, 2022 ("Digital currency and programmability" and "User devices supporting secure payment").

coexistence, it is important to ensure "interoperability" between CBDC and other types of payment instruments. It is expected that this will improve the convenience of each type of payment instrument, expand the range of user choice, promote competition in the field of payment services, and strengthen the resilience of the payment and settlement systems as a whole.

The following section outlines the relationship and interoperability between CBDC and other types of payment instruments.

Figure 15: "Vertical coexistence" and "horizontal coexistence"

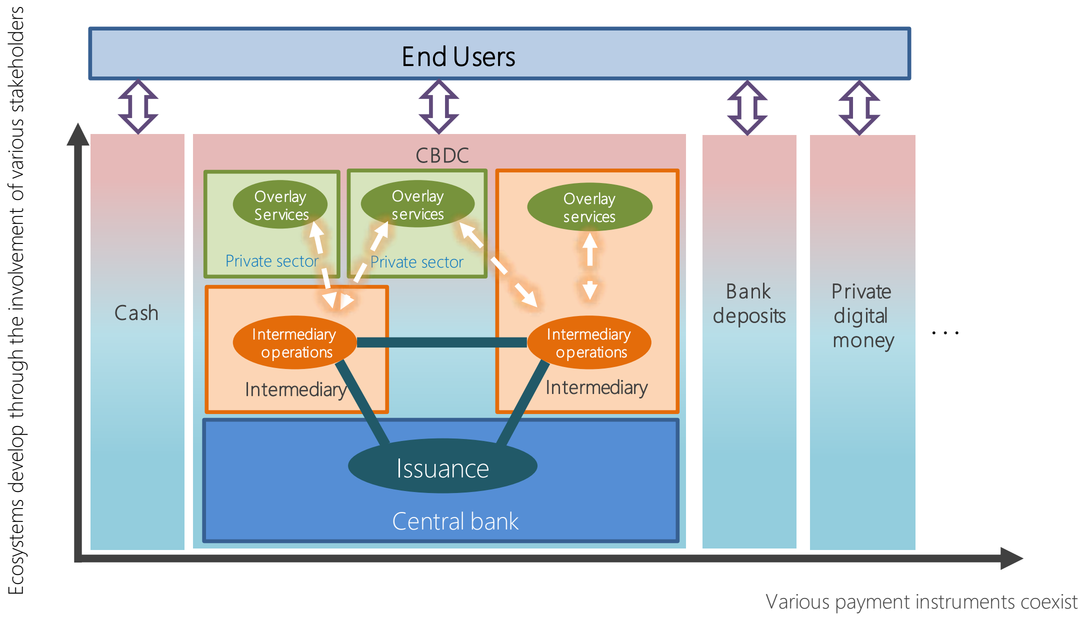
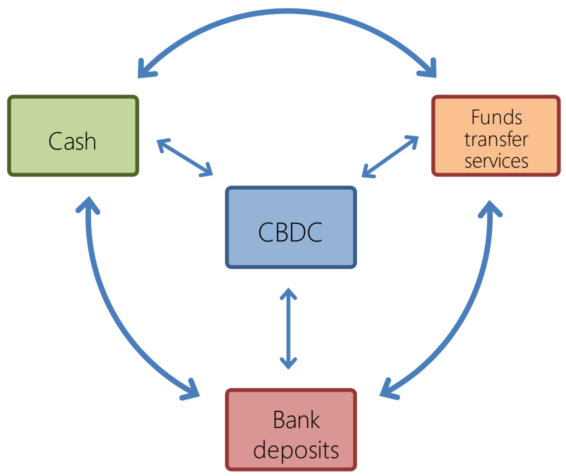


Figure 16: Horizontal interoperability



3.2.1 Relationship with cash

CBDC and cash (banknotes), both as the central bank money, complement each other. Based on this understanding, the BOJ will stay committed to supplying cash as long as there is demand from the public for it, even if it issues CBDC in the future, as indicated in the Approach. In Japan, where confidence in cash has always been strong, it is unlikely that the cash in circulation would drop significantly for the time being. Rather, it is expected that CBDC and cash will coexist for a considerable period of time, during which the optimal balance between CBDC and cash will be sought by individuals, firms, and financial institutions.

Institutional arrangements regarding CBDC should proceed on the basis of the situation described above. For example, ensuring interoperability between cash and CBDC is relevant. An opinion was raised at the Liaison Committee that, assuming that the two will continue to coexist for some time, it may not be necessary for CBDC to inherit, from its initial rollout, all the features for cash at present such as use in offline environments.

3.2.2 Relationship with bank deposits

Bank deposits currently play a wide variety of roles in terms of user attributes and size of amounts, including large value business-to-business payments, in addition to play a role as a store of value for the public. Furthermore, while banks, through providing their bank deposits, perform the credit creation functions essential for economic activities, CBDC, like cash, does not have such a function. Thus, bank deposits and CBDC play different roles, and one cannot completely replace the other.

In this context, potential attention should be paid to the substantive impact of the issuance of CBDC on bank deposits. Namely, depending on the CBDC product design, the "interoperability" between them may lead to a rapid or continuous shift in funds from bank deposits to CBDC. The situation where severe imbalance of money would have adverse effects on the financial system and economic activities must be avoided. In this regard, an opinion was raised at the Liaison Committee that "If the introduction of CBDC leads to the outflow of bank deposits above a certain volume and interrupts banks' credit creation functions, this could take a toll on the local economy. Taking such a negative impact into account, it is necessary to discuss effective measures such as setting caps on CBDC holding and transaction amount."

In a report released in September 2021,[14] the CBDC Coalition, consisting of seven central banks from Japan, the United States, and Europe, touched upon several potential "safeguards" to deal with this situation. The options listed include applying caps to the amount of CBDC held and/or

[14] "Central Bank Digital Currencies: Financial Stability Implications" (Group to evaluate the feasibility of central bank digital currencies, September 2021). For more information on the group's activities, see the Appendix.

transacted as a "quantitative" safeguard and applying a sufficiently low interest rate, including negative one, to CBDC or charging users a fee as a "price" safeguard. As mentioned above, the BOJ will also assess the technical feasibility and issues of setting caps on the amount of CBDC held and/or transacted as well as remunerations on CBDC in the PoC Phase 2, which started in April 2022.

On the other hand, an opinion was raised at the Liaison Committee that the shift in funds from bank deposits due to changes in people's preference for liquidity driven by the issuance of new money is not unique to CBDC and will not necessarily occur. For example, at present, "smooth exchange of cash and deposits" based on the establishment and expansion of ATM networks is one of important factors for individuals and firms when selecting a bank to do business with. In the same way, assuming a situation where CBDC will be widely used as a payment instrument in the future, "smooth exchange of CBDC and deposits" and "attractive services related to CBDC" could become new criteria for individuals and firms to choose their bank. As a result, deposit taking of banks that utilize CBDC may be more stable than by those that do not.

Keeping these various views in mind, the BOJ recognizes it is necessary to carefully analyze how much impact the introduction of CBDC will have on bank deposits and whether such impact is temporary at the time of CBDC introduction or continues as a long-term problem. In addition, in cooperation with stakeholders, the BOJ would like to design a scheme to ensure an appropriate balance between the convenience of CBDC and the stability of the financial system.

3.2.3 Relationship with private digital money

Over the past few years, many PSPs in Japan have issued digital moneys and competed with each other. Under these circumstances, users have raised such problems as different availability of payment services among different shops and no availability of funds transfers between individuals across different digital money services, leading to the inability to fully benefit from economies of scale and network externalities. In contrast, if CBDC is issued in the future, private money will be able to be easily exchanged with each other or to be obtained against other types of payment instruments via the public platform (i.e., CBDC), if the issuers of such private money so want. Thus, the successful coordination of CBDC with private digital money could greatly increase its convenience and improve the efficiency of the entire payment and settlement systems.[15]

[15] When a PSP issues private money backed by deposits with the central bank, the mechanism is sometimes referred to

In addition to such "horizontal coexistence" between private digital money and CBDC, private businesses could develop new businesses within the CBDC eco-system as outsourced entities for intermediary operations or overlay service providers, as described in Section 3.1.

3.3 Ensuring privacy and proper handling of user information

In considering the issuance of CBDC, it is necessary to prescribe the division of roles between the central bank and the private sector, i.e., who will acquire and control the data, to what extent, and under what conditions, while taking into account various requirements regarding the handling of user information. A member of the Liaison Committee also pointed out that, unlike cash, it is easy to obtain personal information and transaction history about CBDC, which might explore considerable potential for utilization of such data and at the same time control of information needs to be carefully considered.

How such user information should be protected and utilized needs to be examined respectively for (1) the infrastructure part for providing a "foundational payment instrument" and (2) the "overlay services" part that addresses individual user needs, as summarized in Section 3.1.

First, in the infrastructure part, in order for CBDC to be widely adopted by users as a foundational payment instrument, it is necessary to achieve robust privacy protection for the user information obtained and utilized by intermediaries and/or the BOJ, including the transaction information (ID/account number, transaction date and time, and amount) that is required for each payment.[16]

In relation to existing laws and regulations, information relating personal users is subject to protection under the Act on the Protection of Personal Information and other relevant laws and regulations. In addition, confidentiality obligations imposed on financial institutions would apply to user information which is not public. On the other hand, in the digital society, AML/CFT would become more important than ever, so CBDC must establish a framework to ensure appropriate compliance with it. In this sense, the same anonymity as cash is not always granted. It will be necessary to continue to consider the role of the BOJ and intermediaries regarding this area, as

as "synthetic CBDC" (the money in question is not a liability of the central bank and therefore not a CBDC).

16 The G7 report (October 2021) identified "Data privacy" as the topic of one of the public policy principles for retail CBDCs, stating: "Users of any CBDC should have a high degree of transparency regarding the use of their personal data, centred around the principles of data minimisation and control for the user (wherever possible). Access to individual users' data beyond the minimum required should be supported by a strong consent framework……."

well as the need for consequent legislative action.

Regarding "overlay services," information is transferred only between the private service providers and the users. The central bank is not in a position to obtain or utilize the user's transaction information. For the private service providers, the information provided by users can be a source of new services and businesses. From the perspective of user convenience and adding value of overlay services, how the private sector can effectively utilize user information will be an issue to be considered due course.

Such utilization of user information is obviously allowed subject to general laws, regulations and other rules for the protection of personal information. Private businesses are required to handle information appropriately, for example obtaining respective consent from users for the acquisition, utilization, and provision to third parties of information associated with the provision of overlay services.

3.4 Relationship with cross-border payments

In recent years, there has been an increasing demand for more convenient and inexpensive cross-border payment services, partly due to the influence of globalization and the worldwide stablecoin initiatives. Against this backdrop, international discussions are underway to improve the framework of international funds transfer, where the exchange of CBDCs among several countries is one of the options being considered for the future.

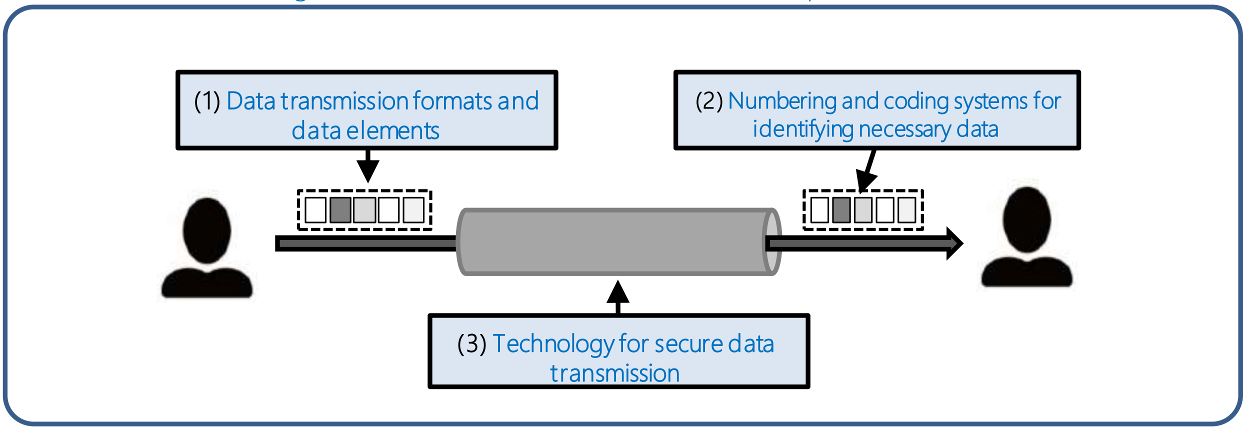
The priority for central banks in exploring CBDC is to improve the stability and efficiency of their own payment and settlement systems. On this basis, the BOJ recognizes that it is appropriate by taking this opportunity, at a time when many countries are accelerating their discussions on CBDC, to give a thorough consideration to the utilization of CBDC in cross-border payments as an extension of the considerations given in domestic context.

Figure 17: International discussions on cross-border payments

October 2020	Seven central banks and the BIS published "Central Bank Digital Currencies: Foundational Principles and Core Features," noting that "An interoperable CBDC...could play a role in improving cross-border payments."
October 2020	The FSB has published "Enhancing Cross-border Payments: Stage 3 roadmap" positioning CBDC as one of the new payment systems that could address the challenges faced by the existing remittance system.
July 2021	CMPI and others published joint report "Central bank digital currencies for cross-border payments" which analyzes the efforts in each country in line with the above "Roadmap".
October 2021	G7 Finance Ministers and Central Bank Governors Meeting released "Public Policy Principles for Retail Central Bank Digital Currencies," outlining the role of CBDC for cross-border functions. Principle 12: Cross-border functionality Jurisdictions considering issuing CBDCs should explore how they might enhance cross-border payments, including through central banks and other organisations working openly and collaboratively to consider the international dimensions of CBDC design.
to July 2022	CPMI and others analyze options for access and interlinking to CBDC of each jurisdiction to improve cross-border payments in line with the above "Roadmap".

If CBDCs are envisioned for cross-border payment usage, it is important to broaden consideration about how to ensure "interoperability" and "reliability" through standardization of information technology so that different CBDCs can be exchanged smoothly and securely. The "areas of standardization" that contribute to these objectives include (1) data transmission formats and data elements (e.g., ISO20022), (2) numbering and coding systems for identifying necessary data (identifiers), and (3) technologies for secure data transmission.[17]

Figure 18: Areas where standardization is expected



[17] Payment and Settlement Systems Report Annex Series, "Standardization in Information Technology related to Digital Currencies" (BOJ, Payment and Settlement Systems Department, June 2021) and "Interoperability and Standardization in Financial Services in the Digital Age" (ibid., April 2022).

The CBDC Coalition of seven central banks is continuing active discussions on international standards applicable to CBDC as one of the main issues to be considered. The BOJ will continue to be intently involved in the activities of ISO/TC 68[18] and contribute actively to international discussions on standardization.

3.5 Next Steps

Based on the discussions at the Liaison Committee, the following points should be considered going forward, in addition to the issues described in Sections 3.1 to 3.4.

The first is the CBDC system's own business model, i.e., the cost sharing for making the CBDC system sustainable as a whole. As mentioned above, the CBDC system can be divided into two areas: the infrastructure part to provide "foundational payment instrument" and the "overlay services" part that addresses individual user needs. For the latter, where PSPs are expected to compete with each other, the quantity and price of overlay services will be determined based on the supply and demand principles. Rather, the question is who should cover the cost of providing the foundational payment instrument (the infrastructure part), and in what manner.

In regard to this point, an opinion was raised at the Liaison Committee that "Cost design should be considered based on the characteristics of CBDC as a public good in order to ensure its smooth and stable circulation," and that "Cost efficiency should be pursued not only for the BOJ's system but also for society as a whole including intermediaries." The view that "Even after the introduction of CBDC, since the need to use cash is expected to remain strong, especially in rural areas, the administrative cost of cash and the adaptation cost related to CBDC may be incurred in parallel," was also presented in the Liaison Committee.

Approaches to covering the operating costs of the infrastructure part should be considered according to the specifics of institutional arrangements and product design, but in light of recent discussions abroad, various options (or a combination of these options) are possible, including (1) beneficiaries' burden (e.g., overlay service providers, shops, general users who benefit from the introduction of CBDCs), (2) coverage through benefits and cost savings received by intermediaries, and (3) public funding. In relation to this point, an opinion was raised at the Liaison Committee that "Attention should also be paid to ensuring economic rationalization of intermediaries and

[18] A technical committee responsible for international standardization in the field of financial services in ISO. The BOJ's Payment and Settlement Systems Department serves as the national secretariat.

maintenance of level playing field for diverse private businesses.", and that “Since CBDC plays a role as a public infrastructure, it might be reasonable to give further consideration to this issue putting an emphasis on the public funding.”

The second issue for consideration is the CBDC’s relationship with legal systems in various areas and the foundational contractual arrangements among relevant parties.

Ensuring the effectiveness and stability of CBDC from a legal perspective is essential for building a secure and efficient payment and settlement systems. A member of the Liaison Committee also expressed the view that it is necessary to consider many issues regarding currency laws, including highlighting the necessity to grant the legal tender status to CBDC.

Third, specific measures to enhance cooperation among stakeholders and external communication are also important issues to consider.

The scope of stakeholders will further expand as discussions regarding the issuance of CBDC progress and materialize. For this reason, consideration should be given to expanding the membership of the Liaison Committee, which currently consists mainly of financial industry representatives. In addition, an opinion was raised at the Liaison Committee that "if cost design based on public funding is to be brought into awareness, proper methods to incorporate the voices of end users such as consumers and small and medium-sized firms will be necessary in the future." In addition, efforts should be made to provide more easily comprehensible information to the public who will be the future users. One way to do this would be to give the CBDC project a specific name, following the example of other countries.

Concluding thoughts and next steps

As expressed in Introduction, while the BOJ "currently has no plan to issue CBDC, the BOJ considers it important to prepare thoroughly to respond to changes in circumstances in an appropriate manner". What is important is to envision "the future of payment and settlement systems suitable for a digital society", and in this sense, CBDC is only one means of achieving this goal. CBDC, as a public good, must complement and coexist with private payment services, and as a result of consideration, it might be concluded that approaches other than CBDC should be sought in order to achieve secure and efficient payment and settlement systems.

In fact, there are some cautiousness about the introduction of CBDC due to the strong preference for cash and high ratio of bank account holding in Japan. However, this situation is similar in other developed countries, and at this point, there are few countries that have a clear use case for CBDC. Nevertheless, the fact that CBDC is being seriously considered as a realistic future option in many countries must be taken seriously. Any of these countries is discussing, focusing on use cases and payment and settlement systems expected in the future, instead of those recognized in the present situation.

With the steady progress of digitization in all areas of society, sooner or later the time will come in Japan when how to deal with the social costs associated with cash circulation will have to be seriously considered. In addition, in the world of digital money, it is highly likely that new types of money, such as stablecoin and decentralized finance, will continue to emerge. In this context, one future direction is for the BOJ to provide broadly secure and neutral payment instruments called CBDC in order to avoid fragmentation and monopolization of payment services, and to enable private businesses to utilize these as a source for creating new services.

In addition, as payment services become more sophisticated, it will become increasingly difficult for existing payment and settlement systems alone to meet the diverse needs of end users, in terms of speed and cost. A new and highly flexible CBDC system may be able to respond quickly to future user needs. One idea is that through such a process, by carving out the infrastructure part (non-competitive area) and providing CBDC as a public good, the investment cost incurred by the private sector could be lowered. In any case, it is important to discuss the significance and role of CBDC from the perspective of "whether the problems we will face in the future can be solved without CBDC or whether CBDC would lead to better solutions," rather than discussing the need for CBDC based on the current situation.

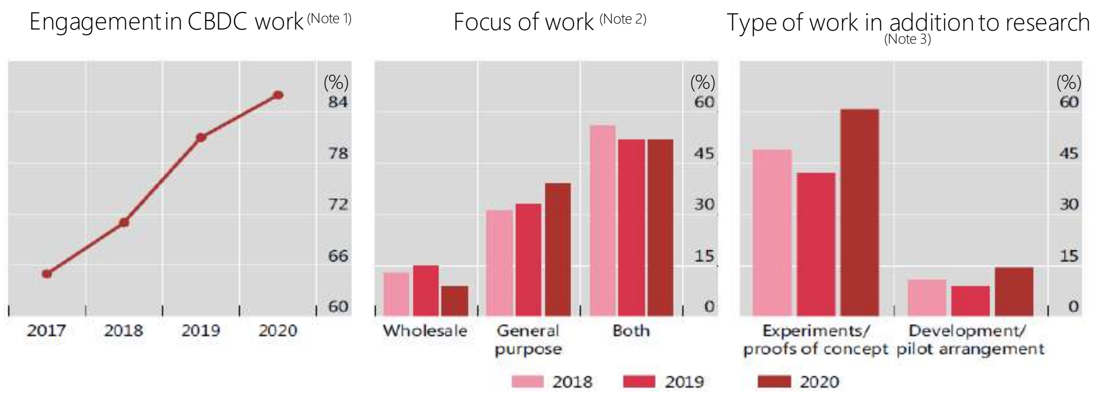
Whether CBDC is introduced or not will ultimately depend upon the public decision. Opinions such as, "Even if CBDC is introduced, it will not be fully utilized unless the public understanding is gained, including its necessity, as a basic infrastructure suitable for a digital society," and "It is necessary to build a consensus that the introduction of CBDC will bring positive added value to society as a whole, in parallel with institutional arrangements." were raised at the Liaison Committee. The BOJ will continue to make necessary preparations and external communication, while keeping these points in mind. Through these efforts, we expect the circle of discussion on the future of Japan's payment and settlement systems will be expanded.

Appendix: Status of works abroad

(1) Expansion of works in the world

In a survey conducted by the Bank for International Settlements (BIS) (October-December 2020), 86% of the 65 responding central banks have already been engaged in some kind of CBDC work. According to the survey, an increasing number of central banks have been considering general-purpose CBDC over wholesale CBDC in the past few years. Regarding their works, an increasing number of central banks are embarking on more concrete and practical initiatives such as "experiments or proof-of-concept" and "development or pilot arrangement," in addition to conceptual research activities.[19]

Figure 19: CBDC works by central banks



(Note 1) Share of respondents conducting work on CBDC in the 65 central banks that participated in the survey.
(Note 2) Share of respondents considering wholesale/general-purpose CBDC in the central banks who responded that they are considering CBDC.
(Note 3) Types of studies conducted in addition to the usual survey by respondents engaged in wholesale/general-purpose CBDC studies.
(Source) Boar, Codruta and Andreas Wehrli, "Ready, Steady, Go? – Results of the Third BIS Survey on Central Bank Digital Currency," BIS, January 2021.

(2) International "principles" for general purpose CBDCs

The growing consideration of CBDC in the world is due not only to the decline in the use of cash as a result of the development of cashless payments but also greatly to the emergence of the Libra initiative in 2019, intended as a global stablecoin. In response to these developments, a "Central bank group to assess potential cases for central bank digital currencies" was formed in January 2020, consisting of seven central banks (Japan, the United States, the Euro Area, the United Kingdom,

[19] According to the latest BIS survey published in May 2022 (October-December 2021), the number of central banks conducting CBDC research has increased to 90% out of the 81 responding central banks. Also, more than half of the central banks have conducted proof-of-concept or pilot arrangements for general-purpose CBDC and "about 68% of central banks consider that they are likely to or might possibly issue a retail CBDC in the short or medium term."

Canada, Switzerland, and Sweden) and the BIS (called herein the CBDC Coalition). Since then, the CBDC Coalition has been a driving force in international discussions on CBDC, and in October of the same year, the group compiled and published three "foundational principles" required for general purpose CBDC.[20]

The first foundational principle is "Do no harm" to monetary and financial stability: the issuance of a CBDC should not interfere with or impede a central bank's ability to carry out its mandate for monetary and financial stability.

The second foundational principle is "Ensure coexistence and complementarity of public and private forms of money": Different types of central bank money, i.e. CBDC and banknote, should complement one another. It is also important that private money, including commercial bank deposits, and CBDC, coexist and contribute to the financial system and real economy in an appropriate balance.

The third foundational principle is "Promote innovation and efficiency": public authorities and private sectors have their own roles to play in ensuring secure and efficient payment and settlement systems. In considering the issuance of CBDC it is also necessary to incorporate continuous innovation and competition from private sectors in order to promote its efficiency.

Figure 20: "Foundational principles" of the CBDC Coalition

Foundational principles	1. Do no harm to monetary and financial stability 2. Ensure coexistence and complementarity of public and private forms of money 3. Promote broader innovation and efficiency
Motivation for consideration	➢ The centrality of central bank money in a monetary system anchors public trust in money and supports public welfare. ➢ Our economies are becoming increasingly digital, user needs are rapidly evolving, and innovation is reshaping financial services. ➢ Many of our jurisdictions are seeing falling transactional use of cash, and new forms of digital money issued by the non-bank private sector (such as stablecoins) are emerging. ➢ A CBDC robustly meeting the foundational principles envisaged by this group could be an important instrument for central banks in such a future to enhance financial stability, harness new technologies and continue serving the public.. ➢ International cooperation on CBDC could provide an avenue for improving cross-border payments. From "Central bank digital currencies - executive summary" (Sep. 2021)

[20] "Central Bank Digital Currencies: Foundational Principles and Core Features" (October 2020)

The CBDC Coalition continued to conduct in-depth policy analysis and practical studies in line with the three foundational principles, and in September 2021, published three reports summarizing the discussions

Figure 21: Report of the CBDC Coalition (September 2021)

(1) System design and interoperability

- The central banks contributing to this report anticipate any CBDC ecosystems would involve the public and private sectors in a balance...
- For CBDC systems, domestic interoperability would need to be sufficient to achieve an easy flow of funds to and from other payment and settlement systems.
- Access to and treatment of payment data would play a significant role in any ecosystem design.

(2) User needs and adoption

- A CBDC would need to anticipate the needs of future users and incorporate related innovations..
- Central banks might accommodate evolving user needs by designing a flexible core system, supporting a diverse ecosystem of intermediaries delivering option, competition and innovation..
- Strategies for CBDC adoption would need to be tailored to the diverse economic structures and payment landscapes in individual jurisdictions.

(3) Financial stability implication

- A significant shift from bank deposits into CBDCs (or even into certain new forms of privately issued digital money) could have implications for lending and intermediation by the banking sector.
- Central banks are exploring safeguards that could be built into any CBDC to address financial stability risks. The design of any measures would likely need to balance moderating the risks from high and/or rapid take up of CBDC with other policy objectives...

In addition, the G7 Finance Ministers and Central Bank Governors have also been discussing CBDC, and in October 2021, the G7 released "Public Policy Principles for Retail Central Bank Digital Currencies (CBDCs)" consisting of 13 principles, including "monetary and financial stability" and "data privacy." The BOJ recognizes that these principles, which reflect sense of values shared by the G7 countries, will provide an important perspective for the BOJ in order to move forward CBDC experiments and investigations into institutional arrangements.

(3) Status of studies on general purpose CBDC in other jurisdictions

Figure 22: List of Public Policy Principles for Retail CBDCs

Foundational Issues

1. Monetary and financial stability
2. Legal and governance frameworks
3. Data privacy
4. Operational Resilience and Cyber Security
5. Competition
6. Illicit finance
7. Spillovers
8. Energy and Environment

Opportunities

9. Digital economy and innovation
10. Financial inclusion
11. Payments to and from the public sector
12. Cross-border functionality
13. International development

① China

Among major countries, China is the most advanced in its studies on general-purpose CBDC. In China, research on digital renminbi (e-CNY) started in 2014, and pilot R&D projects involving a large number of citizens and shops have been continuing since the end of 2019 onward, with an expansion of the areas covered taking place. Through the pilot projects, 260 million individual wallets (as of the end of 2021) and 10 million corporate wallets (as of the end of October 2021) have been opened. The People's Bank of China (PBOC), while stating that there is "no preset timetable for the final launch," has indicated that it intends to (a) forge ahead with the pilot R&D projects, (b) improve relevant institutional arrangements and rules, and (c) deepen analysis of the impact on financial and other related systems, and participate in international exchanges of views.

② The Euro Area

In July 2021, the ECB announced the launch of the "investigation phase" of a digital euro project, lasting till October 2023. President Lagarde also stated that "It is at the end of that investigation phase that the decision will definitely be made to launch the CBDCs and to make it a reality." Regarding the July 2021 decision, the ECB stated that it "will not prejudge any future decision on the possible issuance of a digital euro," but nevertheless, it is considered an important development that the Euro Area, following China, has clearly shown a positive attitude toward the introduction of CBDCs.

③ The United States

In January 2022, the FRB released a discussion paper outlining the benefits, risks, and policy considerations of CBDCs and soliciting the public comments, including on matters related to "CBDC design." Separately from this paper, the Boston Fed is continuing its collaboration with MIT on infrastructure technology (called “Project Hamilton”) beyond 2020, and in February 2022 published a whitepaper on the findings of Phase 1 (experiments in performance on a small-scale CBDC system. In addition, the Executive Order on Ensuring Responsible Development of Digital Assets, issued in March, placed the highest urgency on research and development of CBDC for the administration, and directed other federal government authorities in addition to the FRB to pursue CBDC research.

④ Other jurisdictions

Among developed countries, Sweden is ahead of other jurisdictions in the study; since 2020, experiments on general purpose CBDC (e-krona) have been conducted in phased approach, shifting to the third phase in February 2022. By the end of November 2022, the report of the committee formed at the request of Parliament on the necessity to issue e-krona will be submitted to the government.

Looking at emerging countries, several jurisdictions have already taken steps to issue general purpose CBDCs, and more recently, countries with large populations, such as Nigeria and India, are developing specific initiatives to do so.

Figure 23: Status of works in each country

United Kingdom	In November 2021, the Bank of England (BOE) announced the implementation of public consultation (in collaboration with the HM Treasury) on the general purpose CBDC in 2022. In March 2022, the BOE announced the implementation of a 12-month joint research with MIT in the United States.
Canada	In February 2020, the Bank of Canada (BOC) released a report on general purpose CBDCs. In March 2022, the BOC announced the implementation of a 12-month joint research with MIT in the United States.
Sweden	In February 2020, the Swedish Riksbank began pilot tests on general use CBDC (e-krona). By the end of November 2022, the report of the study committee formed at the request of Parliament on the necessity to issue e-krona will be submitted to the government.
Switzerland	In December 2019, the government released a report on CBDC, stating that "Universally accessible central bank digital currency would bring no additional benefits for Switzerland at present."
Cambodia	In October 2020, the National Bank of Cambodia announced the official launch of BAKONG The Next-Generation Mobile Payments .
The Bahamas	In October 2020, the Central Bank of The Bahamas announced the official nationwide issuance of general purpose CBDC (Sand Dollar).
Eastern Caribbean Currency Union (8 jurisdictions)	In March 2021, the Eastern Caribbean Central Bank announced the official launch of the general purpose CBDC (DCash) in four jurisdictions in the region. The remaining four jurisdictions are in the process of rolling out the system.
Nigeria	In October 2021, the Central Bank of Nigeria announced the official issuance of a general purpose CBDC (eNaira).
Jamaica	In December 2021, the Bank of Jamaica announced the official issuance of a general purpose CBDC for the first quarter of 2022.
India	In February 2022, the government proposed to issue a general-purpose CBDC (Digital Rupee) during FY2022.

(Attachment)

"Liaison and Coordination Committee on Central Bank Digital Currency" Members and others

As of April 13, 2022

Members	Japanese Bankers Association
	Regional Banks Association of Japan
	Second Association of Regional Banks
	International Bankers Association of Japan
	National Association of Shinkin Banks
	National Central Society of Credit Cooperatives
	National Association of Labour Banks
	Japan Securities Dealers Association
	Japan Payment Service Association
	Japan Association for Financial APIs
	Fintech Association of Japan
	Center for Financial Industry Information Systems
	Financial Services Agency
	Ministry of Finance
	Bank of Japan
Secretariat	Bank of Japan Payment and Settlement Systems Department

Past Meetings	First session: March 26, 2021
	Second session: October 15, 2021
	Third session: April 13, 2022

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Central Bank Digital Currency: Stability and Information

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Central Bank Digital Currency: Stability and Information*

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July 12, 2022

Abstract

We study how introducing a central bank digital currency (CBDC) would affect the stability of the banking system. We present a model that captures a concern commonly raised in policy discussions: the option to hold CBDC can increase the incentive for depositors to run on weak banks. Our model highlights two countervailing effects. First, banks do less maturity transformation when depositors have access to CBDC, which leaves them less exposed to runs. Second, monitoring the flow of funds into CBDC allows policymakers to identify and resolve weak banks sooner, which also decreases depositors' incentive to run. Our results suggest that a well-designed CBDC may decrease rather than increase financial fragility.

Keywords: CBDC, digital currency, financial stability, bank runs

JEL Codes: E43, E58, G21

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1 Introduction

There is growing interest in the possibility of central banks issuing an electronic form of currency that would be widely available to firms and households. The potential benefits and risks of such a central bank digital currency (CBDC) have been discussed by academics, market participants, and policymakers, and have been detailed in reports issued by central banks and other agencies. One of the primary risks raised in these discussions is that a CBDC might increase the fragility of the financial system. For example, a recent report by the European Central Bank (2020, p. 17) states "in crisis situations, when savers have less confidence in the whole banking sector, liquid assets might be shifted very rapidly from commercial bank deposits to the digital euro." Similarly, a report from the Federal Reserve (2022, p. 17) worries that "CBDC could make runs on financial firms more likely or more severe."[1] The logic of these arguments seems compelling: having access to a new safe, convenient form of money can make it more attractive for short-term creditors to pull funds out of banks and other financial institutions in periods of financial stress. Some observers, however, are optimistic that this concern can be mitigated through appropriate design choices.[2] Despite its clear importance, there has been relatively little formal analysis of this issue, and the effect of a CBDC on financial stability remains an open question.

We highlight two points that have been largely overlooked in this debate. First, the availability of CBDC will change the financial arrangements private agents make in normal times. We construct a model in which banks perform maturity transformation to insure depositors against idiosyncratic liquidity risk. The resulting maturity mismatch can create financial fragility in the form of runs by depositors following an adverse shock. We show that introducing a CBDC decreases the amount of maturity transformation performed by banks in the constrained-efficient allocation. Intuitively, having access to CBDC makes experiencing a liquidity shock less costly for depositors in our model, which leads banks to provide less insurance against this risk. When banks perform less maturity transformation, they are less exposed to the possibility of a run. In this way, the adjustments in private financial arrangements in response to a CBDC may tend to stabilize rather than destabilize the financial system.

Our second point is that observing the flow of funds into a CBDC can give policymakers more information about the state of the financial system and, in particular, about depositors' confidence in their banks. In periods of financial stress, banks and other financial

[1] This same concern is expressed in reports from the Bank for International Settlements (2018), Bank of England (2020), Danmarks Nationalbank (2017), Norges Bank (2018), and Sveriges Riksbank (2018).

[2] See, for example, Bindseil (2020), Kumhof and Noone (2021) and Bordo and Levin (2019).

intermediaries have private information about both the quality of their assets and their liquidity position, that is, the willingness of their depositors and other short-term creditors to continue to provide funding. A bank in a weak position will often have an incentive to hide this fact from regulators, at least for a while, to avoid triggering supervisory actions. The fact that this information remains hidden delays policymakers' response to an incipient financial crisis, making the crisis more severe. We show how observing the flow of funds into a CBDC can allow policymakers to infer when a run by a bank's depositors is underway more quickly and to place troubled banks into resolution sooner. When depositors anticipate this faster policy reaction, their incentive to join the run decreases. In other words, by allowing a quicker policy reaction to a crisis, this *information effect* is another channel through which CBDC may tend to improve rather than worsen financial stability.

To understand how this information effect operates, suppose a bank's depositors learn the quality of its assets has declined. If they wish to withdraw funding from the bank, they can currently shift their funds to another bank or other liquid assets (for example, government bonds). Regulators might not immediately observe these withdrawals and, even if they do, might have difficultly distinguishing them from the regular inflows and outflows generated by a bank's client transactions. Once a CBDC is introduced, policymakers have a new source of information: the flow of funds into the digital currency. The design features of this currency, including ease of access and any fees or interest paid on balances, will determine how attractive it is to potential users both in normal times and during a run. Policymakers can then evaluate whether or not the inflows into a CBDC are consistent with a bank's depositors maintaining confidence. We show that policymakers can infer when a run is underway more quickly by observing inflows into the CBDC than by simply observing withdrawals from the bank. In effect, observing inflows into the CBDC allows policymakers to make inferences about *why* depositors are withdrawing, which provides additional information beyond *whether* they are withdrawing.

We base our analysis on a model in the tradition of Diamond and Dybvig (1983). As is standard in this literature, private agents have an incentive to pool their resources in a bank to insure against idiosyncratic liquidity risk.[3] In our setting, this risk arises because some agents will be relocated before the investment technology has matured, as in Champ et al. (1996). Relocated agents must withdraw from their bank, and they earn an idiosyncratic return on goods they carry to their new location. Because depositors' relocation status is private information, banks give depositors the choice of when to withdraw. We study

[3] The *bank* in this type of model represents a variety of financial intermediation arrangements in practice where creditors have short-term claims against an intermediary holding longer-term assets. See Yorulmazer (2014) for a discussion of several such arrangements outside of the commercial banking system. Similarly, the depositors in our model represent all short-term creditors of such arrangements.

a situation in which some banks have suffered a loss in the value of their assets, but other banks have not. Depositors privately observe the value of their bank's assets at the beginning of the early period, before making their withdrawal decisions. Our focus is on whether the banking system is fragile in the sense that, in equilibrium, depositors with no immediate liquidity need withdraw from weak banks.

There is a government that can place weak banks into a resolution process and can bail out the depositors in those banks at the cost of providing less of a public good. However, the government only observes the value of a bank's assets at the end of the early period. Depending on the government's fiscal capacity, the resolution process may impose some losses (or "haircuts") on the remaining depositors. The government cannot commit to the details of a bailout policy in advance, which implies it will end up providing larger bailouts to banks in worse financial condition, as in Keister (2016). Anticipating this reaction, weak banks have no incentive to voluntarily restrict withdrawals or impose losses on their depositors before being placed in resolution. Instead, weak banks will continue operating as normal for as long as possible to avoid revealing their status to the government, as in Keister and Mitkov (2021). Depositors in a weak bank may be incentivized to withdraw during this period if they anticipate haircuts will be imposed on the remaining depositors during the resolution process. This incentive is the source of financial fragility in our model.

We introduce a CBDC into this environment as an alternative way for depositors to transfer funds across locations and periods. Because relocated depositors earn idiosyncratic returns on resources they hold directly, some will choose to use the CBDC and others will not. The fraction of relocated agents who use CBDC in normal times will depend on its design characteristics, which determine its effective return. In addition to serving this productive role, the CBDC can also be used by non-relocated depositors who choose to run on their bank. We first abstract from the information effect and show that introducing CBDC in this framework has an ambiguous impact on financial fragility. The effect highlighted in policy discussions is present in our model: because the CBDC offers a better way to hold resources outside the banking system, it increases the incentive for depositors in a weak bank to run. At the same time, however, the fact that depositors will have the option to use CBDC if they are relocated implies they have a lower demand for liquidity insurance. The banking contract optimally adjusts, therefore, to offer smaller payments for depositors who withdraw early and larger payments for depositors who wait. These changes decrease the incentive for depositors in a weak bank to run and tend to become stronger as the CBDC is designed to serve payment needs better. We use examples to illustrate how parameter values determine which of these two effects dominates, that is, whether introducing CBDC increases or decreases financial fragility when we abstract from the information effect.

We then turn our focus to CBDC as a new source of information for policymakers. One important determinant of depositors' incentive to run is how quickly weak banks are placed in resolution. Withdrawals made before resolution deplete a bank's resources and lead to larger haircuts for the remaining depositors. The later resolution occurs, therefore, the stronger the incentive becomes for depositors in a weak bank to run. The latest a weak bank will be placed in resolution is at the end of the early period, when the government observes the value of all banks' assets. However, resolution may occur earlier if the government can infer which banks are weak by observing two flows in real time: the withdrawals from each bank and the flow of funds from each bank into the CBDC. The government can infer a run is underway if the number of withdrawals from a bank goes above the normal level, in which case the bank in question must be weak and can be placed into resolution. With the introduction of CBDC, the government can also infer a bank is weak if the flows from the bank into CBDC go above the normal level. We show that this latter process is faster: policymakers can identify a run more quickly by monitoring flows into CBDC than by monitoring withdrawals. Weak banks can then be resolved sooner, which leads to smaller haircuts for the remaining depositors and decreases the incentive to run. In this way, the information effect associated with CBDC tends to decrease financial fragility.

This result can also be understood by thinking about the strategic interaction in depositors' withdrawal decisions. When there is no CBDC, these decisions are strategic complements for the standard reasons: early withdrawals by other depositors lead to larger haircuts for the remaining depositors, which increases the incentive for an individual depositor to withdraw early. Introducing a CBDC weakens this complementarity because early withdrawals also generate information that leads to a faster policy response, and this faster response tends to decrease the haircuts imposed on the remaining depositors. We show that, in some cases, the information effect is strong enough to dominate, meaning the net effect of early withdrawals by other depositors is to decrease the incentive for an individual depositor to withdraw early. In other words, introducing a CBDC can make depositors' withdrawal decisions *strategic substitutes* and thereby eliminate the multiplicity of equilibrium that typically appears in this class of models. In these cases, introducing a CBDC clearly improves stability in the banking system.

Related literature. A growing literature is developing formal economic models that can be used to study how the introduction of CBDC may affect banks, the broader financial system, and macroeconomic outcomes. Most of this literature focuses on the impact of CBDC in normal (non-crisis) periods; notable contributions include Barrdear and Kumhof

(2022), Chiu et al. (2021), Keister and Sanches (2022), and Williamson (2022b).[4] However, while the financial stability implications of CBDC have been discussed extensively in policy circles, fewer models focusing on this issue have been developed to date.

Two recent papers share our focus on how the introduction of CBDC would change the fragility of the banking system. Williamson (2022a) studies a model in which currency and bank deposits are used in decentralized exchange, in the tradition of Lagos and Wright (2005). Some banks experience a loss that will make deposits in those banks worthless, but depositors do not observe whether their own bank is weak and a run, if it occurs, will affect all banks. CBDC is more attractive than physical currency in this environment because it can be used in a more situations. This fact makes withdrawing from the bank more attractive when CBDC is introduced, increasing fragility. Williamson (2022a) emphasizes, however, that this fact also makes a banking panic less costly because agents can trade using CBDC even if bank deposits no longer circulate. As a result, introducing a CBDC can raise welfare even if fragility increases.

Kim and Kwon (2022) use a version of the model in Champ et al. (1996) to study how the introduction of CBDC would affect fragility through its impact on bank's asset portfolios. In their model, the introduction of CBDC leads to a decrease in bank deposits and raises the equilibrium real interest rate. This higher interest rate leads banks to allocate a smaller fraction of their portfolio to liquid assets and a larger fraction to loans. This portfolio shift, in turn, increases the probability that banks will have insufficient liquid assets to cover the fundamental demand for early withdrawals, an event that Champ et al. (1996) liken to historical banking panics. Kim and Kwon (2022) also show that this result can be reversed if the central bank deposits the funds raised by issuing CBDC into the banking system, as suggested by Brunnermeier and Niepelt (2019).

Our approach differs from these papers in several respects, two of which deserve emphasis. First, our model focuses on how changes in the *liabilities* side of banks' balance sheets affect their susceptibility to depositor runs. We identify a channel through which the introduction of CBDC leads banks to do less maturity transformation, which at least partially offsets the incentive for depositors to run into CBDC. Second, policymakers in our model endogenously *respond* to a banking crisis, which allows us to study how CBDC affects the timing of this response. The information effect we identify, which we believe is novel to both the formal literature and the policy debate, is another channel through which CBDC may help stabilize the banking system.

[4] See also Agur et al. (2022), Andolfatto (2021), Anhert et al. (2022), Davoodalhosseini (2022), Dong and Xiao (2021), Fernández-Villaverde et al. (2021), Monnet et al. (2021), Piazzesi and Schneider (2022) and Schilling et al. (2020).

Outline. In the next section, we present our baseline environment and analyze equilibrium when there is no CBDC. In Section 3, we introduce CBDC but assume policymakers make no inferences based on the flow of funds into CBDC, that is, we abstract from the information effect. We show that, in this case, introducing a CBDC may either increase or decrease financial fragility, depending on which of two competing effects dominates. We then introduce the information effect in Section 4 and show how this effect always tends to reduce fragility. We also highlight a tradeoff polcymakers face in choosing the design features that determine how attractive a CBDC is to users. Finally, in Section 5, we offer some concluding remarks.

2 A baseline model with no CBDC

Our baseline model is a version of the classic framework of Diamond and Dybvig (1983) that combines elements from Champ et al. (1996) and Keister and Mitkov (2021), among others. In this section, we present this baseline model and provide an analysis of equilibrium when there is no central bank digital currency.

2.1 The environment

There are two time periods, indexed by $t \in \{1, 2\}$, and a single private consumption good in each period. There is also a public good that can be produced at $t = 1$.

Depositors and banks. There is a continuum of depositors, indexed by $i \in [0, 1]$, in each of a continuum of locations, indexed by $j \in [0, 1]$. A depositor is initially endowed with one unit of the consumption good and desires private consumption only at $t = 2$. Preferences are given by

$$u(c_i^j) + v(g) = \frac{\left(c_i^j\right)^{1-\gamma}}{1-\gamma} + \delta \, \frac{g^{1-\gamma}}{1-\gamma}, \tag{1}$$

where c_i^j denotes private consumption of depositor i in location j and g denotes the level of the public good, which is common across locations. The parameter δ measures the relative importance of public consumption in depositors' preferences, and the coefficient of relative risk aversion satisfies $\gamma > 1$. Before period $t = 1$, depositors in each location pool their endowments to form a *bank*. The banking technology allows each depositor to contact their bank and withdraw goods in one of the two periods. Goods that are not withdrawn from the bank at $t = 1$ earn a gross return $R > 1$ between periods.

At the beginning of $t = 1$, a fraction $n > 0$ of banks lose a fraction $\sigma > 0$ of their assets, with each bank being equally likely to experience this loss. The parameters n and σ are common knowledge, but whether the bank in a particular location is "sound" or "weak" is observed only by the depositors in that location. Next, a fraction π of depositors in each location learn that they will be relocated to another location at the end of the period. Depositors cannot contact their bank after relocating and, therefore, must withdraw at $t = 1$. Relocating depositors earn an idiosyncratic return ρ_i on goods they carry with them to their new location between $t = 1$ and $t = 2$. This return is distributed according to a continuous cumulative distribution function F on the interval $\left[\underline{\rho}, \bar{\rho}\right]$, with $\bar{\rho} \leq R$. Non-relocating depositors earn a return of ρ^N between periods on any goods they withdraw from their bank at $t = 1$.

A depositor's risk of being relocated plays a similar role in our setting to the liquidity-preference shocks in Diamond and Dybvig (1983). Instead of withdrawing goods to consume immediately, however, relocated depositors withdraw from their bank to consume in the next period, as in Champ et al. (1996). We interpret the idiosyncratic return ρ_i as measuring how well existing payment methods serve the needs of each depositor. When we introduce CBDC in the next section, this approach will imply the CBDC is attractive to some withdrawing depositors, but not to others.

Both a depositor's relocation status and her idiosyncratic return on storage ρ_i are private information. After the relocation shocks are realized, each depositor chooses whether to withdraw from their bank at $t = 1$ or $t = 2$. Depositors withdrawing at $t = 1$ then arrive at their bank one at a time and must be served as they withdraw, as in Wallace (1988). At $t = 2$, the remaining resources in a bank are paid out to the bank's remaining depositors.

Government. The government plays two roles in our baseline model. First, it is endowed with $\tau > 0$ units of the private good at $t = 1$ and has a technology for converting these units one-for-one into the public good. We refer to τ as the government's *fiscal capacity*. Resources that are not converted into the public good can be transferred to weak banks. The government will choose these *bailout payments* without commitment, acting to maximize the sum of all depositors' utilities while taking past actions as given.

The government can also place weak banks into a resolution process. In this process, the government dictates how a bank's remaining resources, including any bailout payment, are allocated among its remaining depositors. However, the government observes bank-specific states with a delay; it knows at the beginning of $t = 1$ that some banks have experienced losses, but does not initially know which ones. We assume the government is able to directly observe which banks are weak at the end of period 1. However, it may be able to infer that a bank is weak more quickly by observing withdrawal behavior. This inference process varies across policy regimes and is discussed in detail below.

Once a bank is either observed or inferred to be weak, it is placed in resolution. If a run is underway and some non-movers have withdrawn early, we assume the run stops once the bank is in resolution. The government lacks commitment in the resolution process and will choose the allocation of the remaining resources to maximize the *ex post* sum of depositors' utilities. Our assumption that the government directly dictates this allocation simplifies the notation and exposition of the model, but is not necessary. In practice, the same allocation might be implemented in a variety of ways, including allowing banks to choose the allocation privately, perhaps as part of a living will. Because any bailout payments have already been made at this point, incentives are no longer distorted and private and public incentives are aligned. Any mechanism that allocates the remaining resources efficiently within a weak bank will lead to the same outcome as our approach.

2.2 The banking contract

A sound bank has one unit of the consumption good per depositor at $t = 1$. Suppose for the moment that only the fraction π of depositors who are being relocated withdraw at $t = 1$. Because the idiosyncratic storage returns of these depositors are private information, incentive compatibility requires that the bank in location j give a common amount x_1^j to each of them. Efficiency requires that the bank also give a common amount x_2^j to each of the fraction $1 - \pi$ of non-movers who withdraw at $t = 2$. The constrained efficient allocation of the resources in this bank then solves

$$\max_{\{x_1^j, x_2^j\}} \quad \pi \int_{\underline{\rho}}^{\bar{\rho}} u\left(\rho_i x_1^j\right) dF\left(\rho_i\right) + \left(1 - \pi\right) u\left(x_2^j\right) \tag{2}$$

subject to

$$\pi x_1^j + \left(1 - \pi\right) \frac{x_2^j}{R} \leq 1. \tag{3}$$

Let (x_1^*, x_2^*) denote the solution to this problem, which modifies the standard Diamond-Dybvig allocation problem to include the idiosyncratic return ρ_i on storage. The first-order condition

$$\int_{\underline{\rho}}^{\bar{\rho}} \rho_i u'\left(\rho_i x_1^*\right) dF\left(\rho_i\right) = Ru'\left(x_2^*\right) \tag{4}$$

characterizes this solution, which satisfies $1 < x_1^* < x_2^* < R$. We assume the return non-movers earn on resources held outside the banking system, ρ^N, is small enough that this allocation is strictly incentive compatible, that is,

$$\rho^N x_1^* < x_2^* \qquad \text{or} \qquad \rho^N < \frac{x_2^*}{x_1^*} \equiv \bar{\rho}^N. \tag{5}$$

We restrict the government's fiscal capacity to be small enough that the marginal value of public consumption is weakly higher than marginal value of private consumption in this constrained-efficient allocation,

$$v'(\tau) \geq \int_{\underline{\rho}}^{\bar{\rho}} \rho_i u'\left(\rho_i x_1^*\right) dF\left(\rho_i\right). \tag{6}$$

This condition ensures the government will not want to provide bailouts to sound banks. Let $\bar{\tau}$ denote the upper bound on fiscal capacity, that is, the value of τ for which equation (6) holds with equality.

We assume all banks offer their depositors a contract based on this constrained-efficient allocation. Because relocation status is private information, this contract gives depositors the option to withdraw at either $t = 1$ or $t = 2$. Depositors who withdraw at $t = 1$ are each given x_1^* unless the bank has been placed in resolution. We assume throughout the analysis that depositors do not run on sound banks, which implies all movers will receive x_1^* at $t = 1$ and all non-movers will receive x_2^* at $t = 2$. In other words, this deposit contract implements the constrained efficient allocation and, hence, is an optimal arrangement for depositors in a sound bank. We describe below how the anticipation of being bailed out makes this arrangement optimal for depositors in a weak bank as well, since choosing a different payment schedule would immediately reveal the bank's status to regulators.

While a weak bank initially follows this deposit contract, it will eventually be placed in resolution and the government will determine the payments made to its remaining depositors. While the banking contract is summarized by the promised payments (x_1^*, x_2^*), therefore, the payout a depositor receives from a weak bank will depend on the resolution process as well as on the withdrawal decisions of other depositors and her position in the withdrawal order. In the next subsection, we derive this payout and its implications for withdrawal behavior.

2.3 Resolution and withdrawal decisions

When a weak bank is placed in resolution, the government determines how its remaining resources are allocated. This allocation depends on how many depositors have already withdrawn and on how many of the remaining depositors are movers and still need to withdraw at $t = 1$. We begin by presenting a general specification of the resolution problem that applies to environments both without and with CBDC. We then specialize to the case without a CBDC and analyze the equilibrium withdrawal behavior of depositors. We focus throughout on symmetric equilibria, where the withdrawal behavior of depositors is the same in all weak banks.

Bailouts and resolution. Let θ denote the fraction of depositors who withdraw before the government is able to either observe or infer which banks are weak. Once these n weak banks are placed in resolution, the government will choose a bailout payment $\hat{b}$ to give to each of them, then use its remaining fiscal capacity to provide the public good. Within each weak bank, the government will give a payment $\hat{x}_1$ to each of the remaining movers at $t = 1$ and a payment $\hat{x}_2$ to each of the remaining non-movers at $t = 2$. Letting $\hat{\pi}$ denote the fraction of the remaining depositors who are movers,[5] these payments will be chosen to maximize

$$\max_{\{\hat{x}_1, \hat{x}_2, \hat{b}\}} \quad n(1-\theta)\left(\hat{\pi}\int_{\underline{\rho}}^{\bar{\rho}} u(\rho_i \hat{x}_1) dF(\rho_i) + (1-\hat{\pi})\, u\left(\hat{x}_2\right)\right) + v(\tau - n\hat{b}) \tag{7}$$

subject to the resource constraint

$$(1-\theta)\left(\hat{\pi}\hat{x}_1 + (1-\hat{\pi})\frac{\hat{x}_2}{R}\right) \leq 1 - \sigma - \theta x_1^* + \hat{b}. \tag{8}$$

The first term in the objective function is the sum of utilities of the $1-\theta$ depositors who remain in the n weak banks. The fraction $\hat{\pi}$ of these depositors who are movers each receive $\hat{x}_1$ at $t = 1$ and earn the idiosyncratic return ρ_i, while the remaining $1 - \hat{\pi}$ non-movers each consume the $\hat{x}_2$ they receive at $t = 2$. The final term in the objective function is the utility all depositors in the economy receive from the public good, which is produced using the government's fiscal capacity τ minus the bailout payments made to n banks of $\hat{b}$ each. The resource constraint in equation (8) says that the payments to each weak bank's remaining depositors come from the bank's remaining funds – the initial endowment of 1 minus the loss σ and the payment x_1^* made for each of the first θ withdrawals – plus the bailout payment $\hat{b}$. We assume $\sigma < 1 - \pi x_1^*$, which implies the loss in a weak bank is never so large that the bank runs completely out of resources before being placed in resolution.

When there is no CBDC, the government is able to determine which banks are weak after a fraction π of depositors have withdrawn. If there is no run on weak banks, the government directly observes their losses at the end of period 1, at which point the π movers have all withdrawn and the remaining depositors are all non-movers. If a fraction $\alpha > 0$ of non-movers run and attempt to withdraw at $t = 1$, the government will observe that a run is underway – and infer that the affected banks are weak – as soon as withdrawals go above π. In this case, some of the first π withdrawals will have been made by non-movers, and some of the remaining $1 - \pi$ depositors will be movers who still need to withdraw at $t = 1$.

The fraction of the remaining depositors who are movers when weak banks are placed in

[5] Note that our focus on symmetric equilibria implies $\hat{\pi}$ is the same in all weak banks.

resolution is

$$\hat{\pi}(\alpha) \equiv \frac{\alpha\pi}{\pi + \alpha(1-\pi)}. \tag{9}$$

When there is no CBDC, the resolution problem is given by equations (7) and (8) with $\theta = \pi$ and $\hat{\pi}$ given by equation (9). Let

$$\left(\hat{x}_1^N(\alpha), \hat{x}_2^N(\alpha), \hat{b}^N(\alpha)\right) \tag{10}$$

denote the solution to this resolution problem, where the N superscript indicates we are in the policy regime with no CBDC. This solution is characterized by the resource constraint in equation (8) together with the first-order conditions

$$\int_{\underline{\rho}}^{\bar{\rho}} \rho_i u'\left(\rho_i \hat{x}_1^N(\alpha)\right) dF(\rho_i) = Ru'\left(\hat{x}_2^N(\alpha)\right) = v'\left(\tau - n\hat{b}^N(\alpha)\right). \tag{11}$$

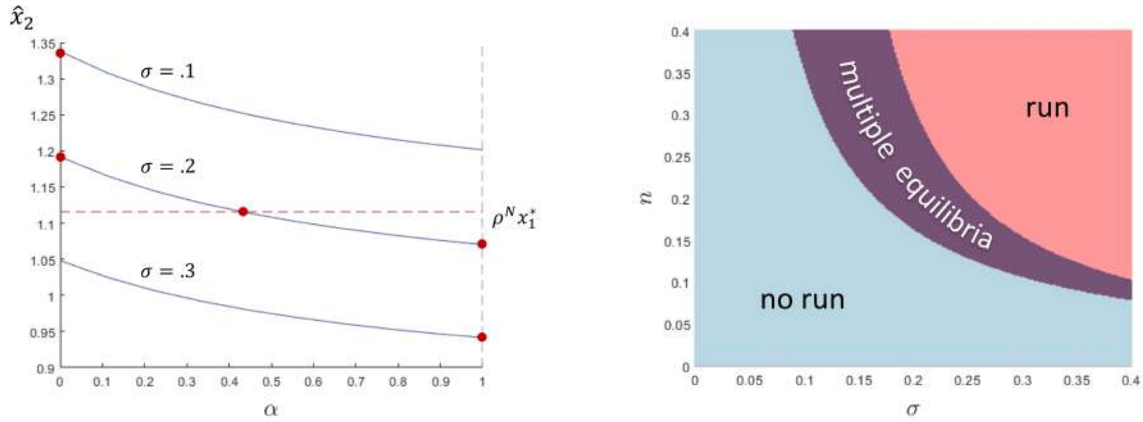
The withdrawal game. Depositors in a weak bank anticipate that their bank will be placed in resolution after π withdrawals. Movers will always withdraw at $t = 1$, since doing so is their only way to consume. For non-movers, the banking contract and the solution to the resolution problem together determine the payoffs of a game in which they each choose a withdrawal strategy.

If a non-mover chooses to withdraw at $t = 1$ and arrives before the bank is placed in resolution, she will receive x_1^* and store it at return ρ^N. If she arrives after the bank is placed in resolution or if she chooses to wait, she will receive $\hat{x}_2^N$ from the resolution allocation in equation (10) at $t = 2$.[6] Each non-mover chooses a strategy $\alpha_i^j \in [0,1]$ that corresponds to the probability of withdrawing at $t = 1$. If $\rho_N x_1^* < \hat{x}_2^N$, the best choice is to set $\alpha_i^j = 0$ and wait until $t = 2$ to withdraw. If $\rho_N x_1^* > \hat{x}_2^N$, the best choice is to run on the bank by setting $\alpha_i^j = 1$. We allow for mixed strategies, with $0 < \alpha_i^j < 1$, for reasons that will become clear below. We focus on symmetric equilibria of the withdrawal game, in which all depositors in weak banks choose the same value of α_i^j; we denote this common value by α. Such equilibria are characterized by a scalar $\alpha^N \in [0,1]$ satisfying

$$\alpha^N \begin{Bmatrix} = 0 \\ \in [0,1] \\ = 1 \end{Bmatrix} \quad \text{if} \quad \hat{x}_2^N\left(\alpha^N\right) \begin{Bmatrix} > \\ = \\ < \end{Bmatrix} \rho_N x_1^*. \tag{12}$$

In particular, an equilibrium exists in which all non-movers in weak banks wait until $t = 2$

[6] Note that the restriction on ρ^N in equation (5) implies implies the allocation in resolution is strictly incentive compatible and, since we assume the run stops, a non-mover will prefer to withdraw at $t = 2$.



(a) Payoffs with $n = 0.2$

(b) Fragility

Figure 1: Equilibrium with no CBDC
Source: Authors' analysis

to withdraw if $\hat{x}_2^N(0) \geq \rho_N x_1^*$. An equilibrium exists in which all non-movers run on weak banks and attempt to withdraw at $t = 1$ if $\hat{x}_2^N(1) \leq \rho_N x_1^*$.

2.4 Fragility

Figure 1 depicts payoffs and equilibrium in the withdrawal game for varying levels of losses in the banking system.[7] Panel (a) compares the payoffs available to a non-mover in a weak bank as a function of the fraction α of other non-movers who withdraw early. The red dots in the graph correspond to equilibria for different values of the loss σ. When σ is small, the payoff at $t = 2$ in resolution is larger than the payoff from withdrawing at $t = 1$ for all values of α. Withdrawing at $t = 2$ is a dominant strategy in this case, which implies $\alpha^N = 0$ is the unique equilibrium and no bank runs occur. When the loss σ is large, the payment $\hat{x}_2$ is smaller than the payoff from withdrawing at $t = 1$ for all values of α and withdrawing early is a dominant strategy. In this case, the unique equilibrium has $\alpha^N = 1$ and runs occur on all weak banks. For the middle value of σ in the figure, both of these equilibria exist, as does a mixed-strategy equilibrium with $0 < \alpha^N < 1$. The fact that the $\hat{x}_2$ curves are decreasing in α reflects the usual strategic complementarity in withdrawal decisions: as more depositors withdraw early, the bank is in worse shape when resolution comes and the payments available to depositors who wait become smaller.

Panel (b) of Figure 1 shows how the equilibria of the withdrawal game change as the parameters σ (the loss in each weak bank) and n (the fraction of banks that are weak) vary. The following two propositions give conditions under which the patterns illustrated in this

[7] The parameter values used in this figure are $R = 2$, $\pi = 0.5$, $\gamma = 6$, $\delta = 10^{-6}$, $\tau = 0.13$, $\bar{\rho} = 1.8$, $\underline{\rho} = 0.9$, and $\rho^N = 0.9$.

figure hold in general. First, assuming fiscal capacity is above a minimum value $\underline{\tau}$, only the no-run equilibrium exists when the fraction of affected banks n is small enough.

Proposition 1. *With no CBDC, there exists $\underline{\tau} < \bar{\tau}$ such that $\tau > \underline{\tau}$ implies $\alpha^N = 0$ is the unique equilibrium of the withdrawal game for all σ when n is sufficiently small.*

When there are few weak banks (and τ is not too small), the bailouts chosen by the government will be sufficiently generous to ensure a non-mover has no incentive to withdraw early regardless of what she expects other non-movers to do.

Our second result shows that, if the return earned by non-movers is above a minimum value ρ_N, a bank run necessarily occurs at all weak banks when the loss σ and fraction of weak banks n are large.

Proposition 2. *With no CBDC, there exists $\underline{\rho}^N < \bar{\rho}^N$ such that $\rho^N > \underline{\rho}^N$ implies $\alpha^N = 1$ is the unique equilibrium of the withdrawal game when σ and n are sufficiently large.*

Significant losses at a sufficiently large fraction of banks will strain the government's resources and result in a relatively small bailout payment for each weak bank. This small bailout, in turn, implies that a large part of the bank's losses will fall on its remaining depositors when the bank is placed in resolution. As long as the return ρ^N is not too small, a non-mover will then be incentivized to withdraw before the bank is placed in resolution, even if she thinks other non-movers will wait to withdraw. In this case, withdrawing early is a dominant strategy for non-movers and the only equilibrium of the withdrawal game has a run on all weak banks. In between these two cases, there is a region where both the bank run and the no-run equilibrium exist, as illustrated in Figure 1.

For the remainder of the analysis, we assume both τ and ρ^N lie in the regions identified by these propositions, which implies the banking system is fragile for some pairs (σ, n) but not others. We analyze the financial-stability effects of introducing a CBDC below by studying how it alters the sets of (σ, n) for which each type of equilibrium exists. Before addressing this question, however, we discuss some of the key assumptions in our baseline model.

2.5 Discussion

Studying how the introduction of a CBDC affects financial fragility requires starting from a framework in which banks may or may not be fragile, depending on parameter values and the incentives they create for agents in the model. Many papers follow Diamond and Dybvig (1983) in assuming that banks must pay a promised amount to depositors until they are completely out of resources. In such settings, a run will always exhaust the resources of an illiquid bank at $t = 1$, implying it is always fragile. We follow Wallace (1990), Green and

Lin (2003), Peck and Shell (2003), Ennis and Keister (2009, 2010) and others in assuming policymakers *react* once they learn the relevant features of the situation. This reaction preserves resources in the banking system and may give depositors an incentive to stay invested. This approach allows us to study how the introduction of a CBDC would change the policy reaction to a crisis and, hence, withdrawal incentives and financial fragility. In the following paragraphs, we briefly discuss some key features of our model and their roles in our analysis.

Fixed fiscal capacity. We assume the government's fiscal capacity is fixed at the time our model begins and moderate in size. If τ were very large, the government would choose *ex post* to fully compensate banks for their losses, including any losses associated with depositor runs. In that case, financial fragility would never arise. Conversely, if τ were very small, banks would very often be susceptible to self-fulfilling runs. One can think of τ as reflecting tax revenue that was raised in the past, as in Keister (2016). If the *ex ante* probability of the loss event is sufficiently small, the optimal tax rate would put the government's fiscal capacity in this moderate region. Our assumption that fiscal capacity is fixed simplifies the analysis while allowing us to focus on this relevant region.

No runs on sound banks. A sound bank could, in principle, be subject to the standard type of self-fulfilling run by its depositors. However, it is well known that this type of run can be prevented by deposit contracts that sufficiently limit early payouts by, for example, suspending payments or imposing withdrawal fees after a pre-specified threshold of early withdrawals. Following Keister and Mitkov (2019), we could assume that banks can use such contracts and these contracts are enforced whenever the bank is not in resolution. The availability of these contracts would then imply that runs never occur on sound banks in equilibrium. Our assumption of no runs on sound banks leads to this same outcome without the need for the additional notation associated with such contracts.

No looting. Given that weak banks anticipate being bailed out, they have an incentive to pay out as much as possible to withdrawing depositors before being placed in resolution. We assume regulators can prevent banks from paying out more than x_1^* to a withdrawing depositor at $t = 1$, since doing so would be inefficient for either type of bank. Similar results can be obtained in a version of the model where depositors fully "loot" a bank before it is placed in resolution, but at the cost of additional model complexity. We also assume depositors cannot loot a sound bank, which implies there will never be an incentive to bail out a sound bank or place it in resolution.

No bail-ins. When weak banks are in the fragile region, their depositors might want the bank to impose fees on early withdrawals to prevent a run. However, applying this type of voluntary "bail in" is costly because it decreases the bailout payment the bank will receive from the government once it is placed in resolution. The incentive distortion created by bailouts thus helps justify our assumption that weak banks continue to allow depositors to withdraw as if things were normal.[8] Keister and Mitkov (2021) study what they call the *bail-in game*, where each bank decides whether to impose withdrawal fees taking the actions of other banks as given. They show the outcome of this game often has no voluntary bail-ins, but not always. To simplify our analysis, we assume voluntary bail ins are not allowed, which corresponds to the case in Keister and Mitkov (2021) where voluntary bail-ins are zero in equilibrium. It may be interesting to extend our analysis to include the bail-in game and to study how introducing a CBDC can affect equilibrium bail-ins.

Keister and Mitkov (2021) also show how a policy of requiring all banks to impose withdrawal fees can raise welfare when policymakers cannot determine the size of the losses in each bank. Such a policy would be useful in the present model for some configurations of parameter values. Adding a mandatory, system-wide bail-in would complicate the notation and change payoffs in our model, but would not alter our two fundamental points. Introducing a CBDC into an environment with mandatory bail-ins would still (i) change the equilibrium banking contract and (ii) provide information that potentially allows policymakers to place weak banks into resolution (and to remove the mandatory bail-in at strong banks) more quickly. We use the simpler model with no bail-ins to illustrate these points in the sections below.

3 Introducing CBDC

We now introduce a central bank that can issue digital currency, which is an alternative way for depositors to transfer funds from $t = 1$ to $t = 2$. We ask how the introduction of CBDC changes the fragility of weak banks *holding fixed* the point θ at which they are placed in resolution. We defer to the next section the question of how the information generated by a CBDC changes the timing of the policy reaction to a bank run. We first show that – absent information effects – introducing a CBDC has two competing effects on fragility. First, the ability to store funds that have been withdrawn from a bank in the new CBDC gives non-movers in weak banks a stronger incentive to withdraw early. This effect, on its own, would make weak banks more fragile. At the same time, however, the availability of CBDC in normal times leads banks to do less maturity transformation, which on its own

[8] The withdrawals made from a weak bank before it is placed in resolution can be interpreted as partially coming from informed creditors or bank insiders. Several recent papers have documented the prevalence of withdrawals by informed creditors before regulators intervene in a failing bank; see, for example, Acharya et al. (2011), Henderson et al. (2015), Iyer et al. (2016).

would make weak banks more stable. We illustrate how parameter values determine which of these two effects dominates.

3.1 The central bank

The central bank operates in all locations in the model.[9] We assume the central bank has access to a storage technology with return $\rho^C \in \left[\underline{\rho}, \bar{\rho}\right]$. The central bank accepts deposits of goods at any time in period 1 and pays the return ρ^C on these deposits at $t = 2$. We interpret these deposits as CBDC. Importantly, depositors can withdraw these funds in any location at t = 2, which implies that CBDC provides movers with an alternative to transporting goods to their new location. Note that, in a symmetric allocation, the central bank does not need to transport goods across locations, as the withdrawals of movers arriving in a location can be paid using the deposits of movers who exited that location.

Whether CBDC is attractive to an individual mover depends on whether her idiosyncratic return ρ_i is higher or lower than ρ^C. We interpret these values as capturing how well different payment methods meet an individuals' needs. A mover with a high value of ρ_i is well served by existing payment methods and will have no incentive to use CBDC, while a mover with a low value of ρ_i will find CBDC preferable to existing payment methods. We think of the return ρ^C as capturing a range of design features that will determine how attractive CBDC is to users in practice, including privacy features, ease of access, caps and other limits on its use, offline capabilities, and any fees or interest paid on balances. In Section 4.4, we discuss some tradeoffs that arise when policymakers can determine ρ^C through such design choices. For now, however, we treat ρ^C as fixed and study the implications of introducing a CBDC with given design features.

Non-movers are also able to deposit funds in the CBDC. Because relocation status is private information, the central bank is initially unable to tell if the funds being placed into CBDC are coming only from movers or from a mix of movers and non-movers. In the next section, we show how policymakers can make inferences based on the amount of funds flowing into the CBDC. For now, however, we assume that a weak bank is placed into resolution at the end of $t = 1$ or when the fraction of early withdrawals exceeds π, whichever comes first.

[9] There is no central bank in Champ et al. (1996), but they study a policy regime in which private banknotes can be traded across locations. Our interpretation here is similar to Antinolfi et al. (2001), who study lender-of-last-resort policy by assuming a central bank operates across locations.

3.2 Revised payoffs and withdrawal incentives

Revised banking contract The availability of the CBDC technology changes the constrained efficient allocation of resources within a sound bank. In particular, a fraction $F\left(\rho^C\right)$ of movers will have an idiosyncratic return on storage ρ_i lower than ρ^C and will deposit goods with the central bank after withdrawing at $t = 1$. The fact that these movers now receive a higher return changes the marginal value of resources paid out at $t = 1$. The constrained efficient allocation now maximizes expected utility in equation (2), but with the distribution function F replaced by

$$F^C\left(\rho_i; \rho^C\right) \equiv \begin{Bmatrix} 0 \\ F(\rho_i) \end{Bmatrix} \quad \text{for} \quad \rho_i \begin{Bmatrix} < \\ \geq \end{Bmatrix} \rho^C. \tag{13}$$

The resource constraint in equation (3) is unchanged. Let $\left(x_1^*(\rho^C), x_2^*(\rho^C)\right)$ denote the solution to this modified problem, which is characterized by the first-order condition

$$\rho^C u'\left(\rho^C x_1^*\right) F^C\left(\rho^C; \rho^C\right) + \int_{\rho^C}^{\bar{\rho}} \rho_i u'\left(\rho_i x_1^*\right) dF^C\left(\rho_i; \rho^C\right) = R u'\left(x_2^*\right). \tag{14}$$

Note that if $\rho^C = \underline{\rho}$, no one will use the CBDC and the constrained efficient allocation is unchanged. When ρ^C is greater than $\underline{\rho}$, some movers will use CBDC to receive higher consumption. Our next result shows how (x_1^*, x_2^*) varies with ρ^C in this case.

Proposition 3. *When CBDC is introduced, $x_1^*\left(\rho^C\right)$ is strictly decreasing and $x_2^*\left(\rho^C\right)$ is strictly increasing for $\rho^C \in \left(\underline{\rho}, \bar{\rho}\right)$.*

Recall that fragility arises in the Diamond-Dybvig framework because the efficient allocation provides liquidity insurance, that is, sets $x_1^* > 1$ as a way of sharing the benefits of long-term investment with depositors who need to withdraw early. When CBDC allows some of these depositors to earn a higher return after they withdraw, there is less need for the banking system to provide this liquidity insurance. As a result, Proposition 3 shows that the constrained efficient allocation gives a smaller payment $x_1^*(\rho^C)$ to movers and a larger payment $x_2^*(\rho^C)$ to non-movers, who thus share some of the benefits of CBDC.

We continue to assume that banks offer deposit contracts based on the constrained-efficient allocation, meaning that depositors who withdraw at $t = 1$ are each given $x_1^*(\rho^C)$ unless the bank has been placed into resolution. As a standard, $x_1^*(\rho^C)$ can be interpreted as a bank's short term liabilities per depositor. Proposition 3 thus shows that the introduction of CBDC will lead banks to issue fewer short term liabilities or, equivalently, to do less maturity transformation.

Bailouts and resolution. We assume in this section that a weak bank is still placed in resolution after a fraction π of depositors have withdrawn at t = 1. The availability of the CBDC technology changes the optimal resolution of a weak bank at this point. The government's objective function in choosing bailout payments and resolution plans is again given by equation (7), using $\theta = \pi$ and $\hat{\pi}$ from equation (9), but now with the distribution function F replaced by F^C from equation (13). Let

$$\left(\hat{x}_1^C\left(\alpha;\rho^C\right), \hat{x}_2^C\left(\alpha;\rho^C\right), \hat{b}^C\left(\alpha;\rho^C\right)\right) \tag{15}$$

denote the solution to the resolution problem in this case, where the C superscript indicates that the environment now includes a CBDC. This solution is characterized by the resource constraint in equation (8) together with the first-order conditions

$$\rho^C u'\left(\rho^C \hat{x}_1^C\right) F^C\left(\rho^C;\rho^C\right) + \int_{\rho^C}^{\bar{\rho}} \rho_i u'\left(\rho_i \hat{x}_1^C\right) dF(\rho_i;\rho^C) = Ru'\left(\hat{x}_2^C\right) = v'\left(\tau - n\hat{b}^C\right). \tag{16}$$

Following the logic of Proposition 3, it is straightforward to show that $\rho^C > \underline{\rho}$ will lead the government to decrease $\hat{x}_1^C$ and increase $\hat{x}_2^C$, all else equal. In other words, the resolution process will tend to provide smaller payments to the remaining movers, some of whom will choose to use CBDC, and larger payments to non-movers who wait to withdraw at t = 2.

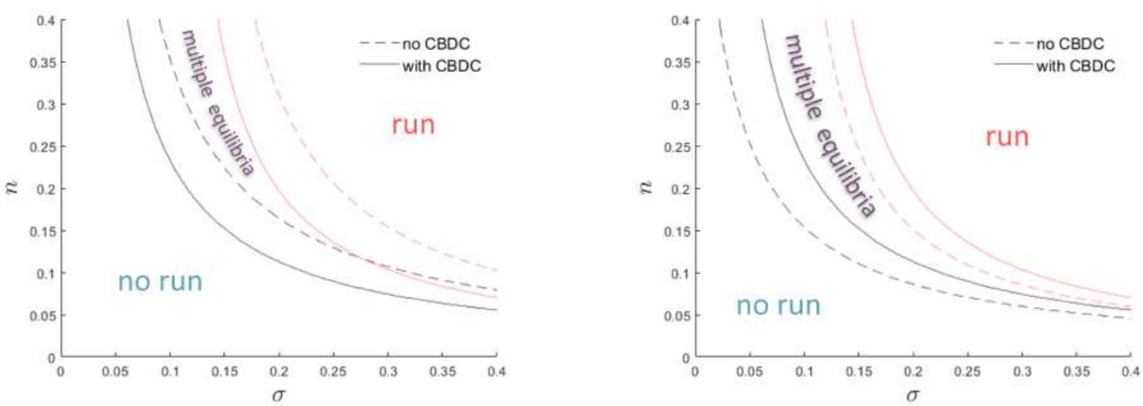
The withdrawal game. A non-mover who withdraws early will prefer depositing in CBDC over storing the funds directly if $\rho^C > \rho^N$, and they will not use CBDC if this inequality is reversed. As before, the revised banking contract and the solution to the revised resolution problem determine the payoffs of the withdrawal game. We continue to focus on symmetric equilibria, which are now characterized by a scalar $\alpha^C \in [0,1]$ satisfying

$$\alpha^C \begin{Bmatrix} = 0 \\ \in [0,1] \\ = 1 \end{Bmatrix} \quad \text{if} \quad \hat{x}_2^C\left(\alpha^C, \rho^C\right) \begin{Bmatrix} > \\ = \\ < \end{Bmatrix} \max\{\rho^C, \rho^N\}\, x_1^*\left(\rho^C\right). \tag{17}$$

3.3 Competing effects on fragility

The three places where ρ^C appears in equation (17) represent the three ways in which the introduction of CBDC can affect the fragility of weak banks. Two of these effects have already been discussed. First, $\rho^C > \underline{\rho}$ decreases x_1^* in the constrained-efficient allocation, which by itself would decrease the incentive for a non-mover to withdraw early, making the no-run equilibrium more likely and the run equilibrium less likely to exist. Second, $\rho^C > \underline{\rho}$ increases $\hat{x}_2^C$ in the resolution process, holding all else equal, which would have the same effects. However, the third effect points in the opposite direction: $\rho^C > \rho^N$ raises the return to non-movers of withdrawing at t = 1. This effect captures the concern expressed by policymakers that runs into CBDC may destabilize the financial system.

Figure 2 demonstrates that introducing a CBDC can either increase or decrease fragility, depending on parameter values. One key factor in determining which effect dominates is the difference between the returns non-movers earn on the goods they store across periods, ρ^N, and the return on CBDC, ρ^C. Suppose we normalize $\rho^C = 1$. Panel (a) presents the fragility diagram for an economy with CBDC using the same parameter values as in Figure 1. The dashed lines correspond to the boundaries of the regions in Figure 1, where there is no CBDC, and the solid lines show these boundaries when CBDC is introduced. In this case, introducing CBDC clearly increases the fragility of weak banks: the set of (σ, n) for which the run equilibrium exists expands and the set for which the no-run equilibrium exists shrinks.



(a) $\rho^N = 0.9$ (b) $\rho^N = 1$

Figure 2: CBDC may increase or decrease fragility
Source: Authors' analysis

Panel (b) of Figure 2 presents the fragility diagram for a different economy where non-movers are better able to store goods across periods on their own; that is, the return ρ^N is higher in economy (b) than in economy (a). All other parameter values are the same, which implies the constrained efficient allocation (x_1^*, x_2^*) and the banking contract are the same in both economies.[10] However, comparing the dashed curves in the two panels shows that economy (b) is more fragile than economy (a) before CBDC is introduced because the better storage technology ρ^N makes withdrawing early less costly for non-movers. When CBDC

[10] Recall that non-movers only withdraw at $t = 2$ in the efficient allocation, so the value of ρ^N plays no role in determining that allocation.

is introduced, non-movers in both economies can store goods at the same return $\rho^C = 1$, which implies all payoffs are the same in both economies and, hence, they are equally fragile. (In other words, the solid lines are the same in both panels of the figure). Comparing the dashed and solid lines in panel (b) demonstrates that introducing CBDC *reduces* fragility in this economy. That is, the set of (σ, n) for which the run equilibrium exists shrinks and the set for which the no run equilibrium exists expands.

The intuition for these patterns is easy to see. In both cases, introducing CBDC changes the banking contract and the resolution process by the same amount. The difference between the two cases is how much better non-movers find CBDC than directly storing goods. For the economy in panel (a), where $\rho^N = 0.9$, CBDC is significantly better, and the direct effect of CBDC on non-movers' withdrawal incentives dominates the indirect effects. For the economy in panel (b), $\rho^N = 1$ and CBDC is equally effective as storing goods directly for non-movers. In this case, the direct effect disappears and the indirect effects dominate.

Some observers claim that the destabilizing effects of a CBDC could be minimized through appropriate design choices. Suppose, for example, policymakers could place a cap on individuals' CBDC holdings that would not be binding in normal times but would prevent individuals from shifting significant amounts into the CBDC in periods of financial stress. A design that allows CBDC to be useful in normal times would correspond to having ρ^C significantly higher than $\underline{\rho}$ in our model, which would lead to significant changes in the banking contract and resolution process. To the extent that the design limits the usefulness of CBDC as a store of value, it would correspond to having a small difference between ρ^N and ρ^C, as for the economy in panel (b) of Figure 2. Our results in this section thus support the idea that such a design, if feasible, would not increase and may even decrease financial fragility.

However, the analysis in this section and in most of the policy discussion of CBDC leaves out an important point. If introducing a CBDC increases fragility, it is because non-movers find it attractive to withdraw from their banks and deposit in CBDC. Policymakers will observe this flow of funds into the CBDC and can use the information to improve the resolution process. We now turn to the study of this information effect.

4 The information effect

In the economy with no CBDC in Section 2, the government can either observe or infer which banks are weak after a fraction π of depositors have withdrawn. In Section 3, we introduced CBDC but assumed the government continued to place weak banks in resolution after π withdrawals. In this section, we show how observing the flow of funds into CBDC provides the government with additional information that allows it to infer more quickly when a run is underway. This quicker inference can allow the government to resolve weak banks sooner, which has two beneficial effects. First, quicker resolution implies fewer early withdrawals are made before the run stops and, therefore, the consumption levels of the remaining depositors are higher. In addition, these higher consumption levels diminish the incentive for non-movers to withdraw early, which improves financial stability.

4.1 Inferring a run through CBDC

To begin, it is useful to review why the policy reaction occurs after π withdrawals when there is no CBDC. If there is no run, only the fraction π of depositors who are movers withdraw at $t = 1$, and the government observes each bank's status at the end of the period. If depositors do run on weak banks, more withdrawals will occur before the government directly observes each bank's status. However, the government sees these withdrawals as they are being made from each bank. Once withdrawals at a bank go above π, the government will infer that a run is underway and, since runs only occur on weak banks, the bank must be weak and should be placed in resolution.

When CBDC is introduced, we assume the government observes the flow of funds into the CBDC from each bank as they occur. In this way, the government gains additional information in real time within the period. If a bank is not experiencing a run, only the π depositors who are being relocated withdraw at $t = 1$. Those movers with $\rho_i < \rho^C$ will now deposit in CBDC, which implies total conversions to CBDC from a bank that is not experiencing a run will be $\pi F\left(\rho^C\right)$.

Now suppose a fraction $\alpha > 0$ of non-movers run on the bank and attempt to withdraw at $t = 1$. If $\rho^C > \rho^N$, these non-movers will all convert to CBDC.[11] The measure of depositors who desire to withdraw and convert to CBDC is now given by

$$\pi F\left(\rho^C\right) + \alpha(1-\pi) \;>\; \pi F\left(\rho^C\right) \text{ for any } \; \alpha > 0.$$

Define θ to be the total measure of depositors who have withdrawn from a bank when the conversions to CBDC by that bank's depositors reaches $\pi F\left(\rho^C\right)$, the amount that would occur when there is no run. We then have

$$\theta\left(\alpha, \rho^C\right) = \frac{\left(\pi + \alpha(1-\pi)\right) F(\rho^C)}{\pi F(\rho^C) + \alpha(1-\pi)}\pi \quad \leq \; \pi. \tag{18}$$

[11] If $\rho^C < \rho^N$ held, non-movers who withdrew at $t = 1$ would not use CBDC. In this case, there would be no information effect and equilibrium outcomes would be identical to those in regime C above. For the remainder of the analysis, we assume $\rho^C \geq \rho^N$ holds. In addition, to simplify notation, we assume all non-movers use CBDC in the knife-edge case where these two returns are equal.

Taking as given the withdrawal strategies of non-movers, $\theta\left(\alpha, \rho^C\right)$ measures the speed with which the government is able to identify weak banks and place them in resolution. Once withdrawals at a given bank exceed $\theta\left(\alpha, \rho^C\right)$, deposits into CBDC from that bank will exceed $\pi F\left(\rho^C\right)$ and the government will know a run is underway.

Note that setting $\alpha = 0$ in equation (18) yields $\theta = \pi$; if there is no run, the government will not be able to learn which banks are weak until the end of $t = 1$, as before. For $\alpha > 0$, however, it is straightforward to show that θ is strictly decreasing in α: as more non-movers withdraw early and convert to CBDC, fewer total withdrawals occur before the central bank is able to infer a run is underway. In other words, a larger run will be detected more quickly. We show below that this feature makes withdrawing early less attractive and can switch the withdrawal decisions of depositors from stategic complements to strategic substitutes.

Discussion. Because the only uncertainty in our model is idiosyncratic, it is important in our setting that the government be able to observe the flow into CBDC originating from each bank. In practice, such tracing may not be straightforward, especially if weak banks could take actions to mask the eventual destination of funds being withdrawn (by routing transfers through third parties, for example). The effects we identify here will be present as long as the government can extract some information about the flow of funds from each bank into CBDC, even if this information is imperfect. In addition, as part of our concluding remarks in Section 5, we describe an extension of the model where there is aggregate uncertainty and the government does not know the total number of weak banks. In that case, monitoring aggregate inflows into CBDC, regardless of their origin, would generate an information effect similar in spirit to the idiosyncratic one we identify here.

4.2 How faster resolution affects withdrawal incentives

The constrained-efficient allocation $\left(x_1^*(\rho^C), x_2^*(\rho^C)\right)$ and the banking contract are the same as in the previous section. However, the change in timing of the government's intervention changes the resolution problem and non-movers' withdrawal incentives.

Bailouts and resolution. When the government intervenes after θ withdrawals, the fraction of the remaining depositors in weak banks who are movers is given by

$$\hat{\pi}\left(\alpha, \rho^C\right) = \frac{\pi}{1 - \theta\left(\alpha, \rho^c\right)} \frac{\pi + \alpha(1 - \pi) - \theta\left(\alpha, \rho^c\right)}{\pi + \alpha(1 - \pi)}. \tag{19}$$

The resolution problem is now given by equations (7) - (8) with θ from equation (18), $\hat{\pi}$ from equation (19) and the distribution function F^C from equation (13). Let

$$\left(\hat{x}_1^I\left(\alpha;\rho^C\right),\hat{x}_2^I\left(\alpha;\rho^C\right),\hat{b}^I\left(\alpha;\rho^C\right)\right) \tag{20}$$

denote the solution to the problem in this case, where the I superscript indicates that resolution now responds to the information generated by the CBDC. It bears emphasizing that the only differences in this optimization problem from the resolution problem in Section 3 are the timing of the intervention, θ, and the type-composition of the remaining depositors, $\hat{\pi}$. The solution is again characterized by the resource constraint in equation (8) and the first-order conditions in equation (16).

When there is no run ($\alpha = 0$), the government again identifies weak banks after π withdrawals and the resolution process is exactly the same as in the previous section. When $\alpha > 0$, however, equation (18) shows $\theta < \pi$ and fewer withdrawals occur before weak banks are placed into resolution. At this point, fewer resources have been paid out and weak banks have more resources per remaining depositor. This fact increases the payments made to remaining depositors and thus decreases the incentive for non-movers to run on the bank.

The withdrawal game. The revised banking contract and the solution to the revised resolution problem determine the payoffs of the game played by non-movers. A symmetric equilibrium is $\alpha^I \in [0,1]$ satisfying

$$\alpha^I \begin{Bmatrix} = 0 \\ \in [0,1] \\ = 1 \end{Bmatrix} \quad \text{if} \quad \hat{x}_2^I\left(\alpha^I,\rho^C\right) \begin{Bmatrix} > \\ = \\ < \end{Bmatrix} \rho^C\, x_1^*\left(\rho^C\right). \tag{21}$$

The only difference between equations (17) and (21) is in the payoff $\hat{x}_2$ that a non-mover will receive as part of the resolution process if she waits until $t = 2$ to withdraw.

4.3 Information reduces fragility

Our next result shows that the information effect does not change the set of parameter values for which the no-run equilibrium exists. When all non-movers wait to withdraw ($\alpha = 0$), the flow of funds into the CBDC does not reveal any information about which banks are weak. The government places weak banks into resolution only at the end of $t = 1$, after all movers have withdrawn. The payoffs of the withdrawal game are then exactly the same as in the previous section, where the information effect was assumed to be absent, as are the conditions under which the no-run equilibrium exists.

Proposition 4. *$\alpha^I = 0$ is an equilibrium if and only if $\alpha^C = 0$ is an equilibrium.*

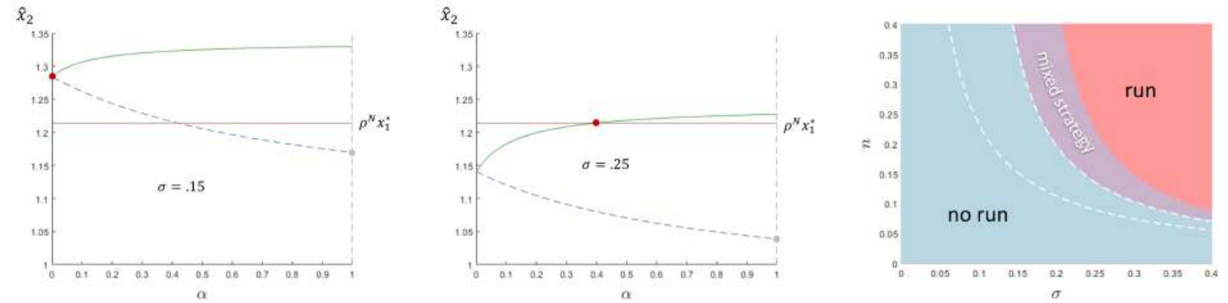
The effect of information on fragility appears when we ask whether there exists an equilibrium where non-movers run on weak banks. When there is a run ($\alpha = 1$), equation (18) shows $\theta < \pi$ holds and weak banks are placed in resolution sooner. As a result, a non-mover who deviates and waits to withdraw receives a higher payoff. This higher payoff, in turn, shrinks the set of parameter values for which the bank run equilibrium exists.

Proposition 5. *The set of (σ, n) for which $\alpha^I = 1$ is an equilibrium is strictly smaller than the set for which $\alpha^C = 1$ is an equilibrium.*

One way of understanding the intuition behind these two results is to observe that the information effect decreases the strategic complementarity in non-movers' withdrawal decisions. When the resolution timing is fixed at π withdrawals, our model exhibits the usual strategic complementarity in the Diamond-Dybvig framework. In our notation, early withdrawals by other non-movers increase α, which decreases the amount $\hat{x}_2^C(\alpha)$ received by a non-mover who waits until $t = 2$ to withdraw (as depicted in panel (a) of Figure 1), giving an individual non-mover a stronger incentive to withdraw early. When the resolution timing is given by equation (18), in contrast, a countervailing effect arises. Early withdrawals by other non-movers now also decrease θ, meaning they allow the government to more quickly infer which banks are weak and place them in resolution. This second effect raises $\hat{x}_2^I(\alpha)$ and thus strengthens the incentive for a non-mover to wait and withdraw at $t = 2$.

The effects of these changes are illustrated in Figure 3. Panel (a) shows the payoffs of a non-mover who waits to withdraw as a function of α, as in panel (a) of Figure 1. The dashed curve is the payoff in regime C, where the information effect is absent. This curve is decreasing, reflecting the usual strategic complementarity in withdrawal decisions, and both the no-run and the run equilibrium exist. When the information effect is introduced, $\hat{x}_2^I$ takes the same value at $\alpha = 0$, but lies above $\hat{x}_2^C$ for all $\alpha > 0$. In this example, $\hat{x}_2^I$ has become an increasing function of α, meaning the withdrawal decisions of non-movers are now strategic substitutes. As a result, the run equilibrium no longer exists and the unique equilibrium of the withdrawal game has all non-movers waiting to withdraw at $t = 2$.

Panel (b) of Figure 3 depicts a situation in which $\hat{x}_2^C$ lies below $\rho^C x_1^*\left(\rho^C\right)$ for all α and, therefore, only the run equilibrium exists under regime C. When the information effect is introduced, $\hat{x}_2^I$ again becomes an increasing function of α and, as in panel (a), $\alpha = 1$ is no longer an equilibrium. In this case, the unique symmetric equilibrium is in mixed strategies, with $0 < \alpha^I < 1$. The outcome in this equilibrium is a form of partial bank run in which a fraction α^I of non-movers attempt to withdraw early and the remaining fraction $(1 - \alpha^I)$ choose to wait.



(a) Eliminating the run equilibrium

(b) Unique equilibrium in mixed strategies

(c) Fragility with information

Figure 3: The information effect
Source: Authors' analysis

Panel (c) of Figure 3 presents the fragility diagram once the information effect is taken into account, using the same parameter values as in panel (a) of Figure 2. Recall that, in this case, a CBDC increases fragility when the information effect is neglected. Panel (c) shows how the information effect can reverse this result. In line with Proposition 4, the set of (σ, n) for which the no-run equilibrium exists is the same as that shown for regime C in Figure 2. In line with Proposition 5, the set of (σ, n) for which the full-run equilibrium exists is strictly smaller. In this example, the information effect has eliminated the overlap of these two regions, so there is now a unique symmetric equilibrium for all (σ, n). In between the regions where this equilibrium has $\alpha^I = 0$ and where it has $\alpha^I = 1$, there is now a region where the equilibrium is in mixed strategies, with $0 < \alpha^I < 1$.

In summary, the information effect generated by introducing a CBDC in our model always reduces the incentive for depositors to participate in a run on their bank. This decreased incentive to run can affect equilibrium outcomes in one of three ways, depending on the current situation. If there are multiple equilibria with no CBDC, introducing a CBDC may eliminate the run equilibrium and leave 'no bank run' ($\alpha^I = 0$) as the unique equilibrium. If only the run equilibrium currently exists, introducing a CBDC may lead to a unique, mixed-strategy equilibrium ($0 < \alpha^I < 1$) with a smaller run on weak banks. Finally, even if a full bank run ($\alpha^I = 1$) occurs in equilibrium, introducing a CBDC will lead to quicker resolution of weak banks, which mitigates the effect of the run.

4.4 Policy tradeoffs

So far, we have taken the return ρ^C that depositors earn on CBDC as a fixed parameter. In practice, we think of this return as representing a variety of design features that determine how well the CBDC meets the needs of households and firms. Such features include, for example, the form in which CBDC is held and transferred, any restrictions on holdings, offline capabilities, and any fees or interest payments on CBDC. Many of these features are choices a central bank can make when designing a CBDC. In other words, the central bank will be able to influence the value of ρ^C, at least within some bounds, which raises the question of how it should be set. How attractive should the CBDC be made to potential users? In the absence of financial stability concerns, the answer in our model would be clear: ρ^C should be set has high as possible. Doing so would maximize the usage of the CBDC by movers, for whom CBDC represents a more efficient way of transferring funds across locations. However, a tradeoff emerges when financial stability concerns are taken into account.

To highlight this tradeoff, consider first an extreme case where $\rho^N < \underline{\rho}$. That is, suppose non-movers receive a lower return on funds held outside the banking system than all movers, and suppose further that policymakers were to set ρ^C strictly between ρ^N and $\underline{\rho}$. Then movers who withdraw at $t = 1$ will never convert to CBDC, while non-movers who withdraw will always use CBDC instead of their own storage technology. *Any* flow of funds into CBDC would then indicate that a run is underway and would identify the depositors' bank as weak. Formally, $\rho^C < \underline{\rho}$ implies $F\left(\rho^C\right) = 0$, which by equation (18) implies $\theta = 0$ for all α. In this extreme case, a run would be detected before any measurable fraction of depositors withdraw. The fact that weak banks would be immediately placed in resolution, in turn, implies the payment $\hat{x}_2$ received by non-movers at $t = 2$ will be relatively large. In other words, quick resolution minimizes the incentive for non-movers to run in the first place. In this way, designing a CBDC so that it is never used in normal times allows it to be an effective financial stability tool.

Now suppose policymakers increase ρ^C above $\underline{\rho}$. Doing so will give some movers a more efficient way of transferring consumption across locations. As described above, the banking contract will then adjust in a way that benefits all depositors. However, the fact that movers now use CBDC in normal times implies that it takes longer for policymakers to infer when a run is underway. Formally, equation (18) shows that, for any $\alpha > 0$, $\theta\left(\alpha, \rho^C\right)$ is strictly increasing in ρ^C on $\left(\underline{\rho}, \bar{\rho}\right)$. The more non-movers use a CBDC, the more withdrawals that occur before policymakers are able to identify weak banks. This delay in resolving weak banks implies lower payments $\hat{x}_2$ to non-movers who wait until $t = 2$ to withdraw, which increases their incentive to join the run. If ρ^C is set to $\bar{\rho}$, so that all movers choose to use CBDC, equation (18) shows $\theta\left(\alpha, \rho^c\right) = \pi$ for all α, meaning the information effect completely disappears.

Figure 4 shows how increasing the attractiveness of the CBDC affects financial stability. As ρ^C increases, the set of values of the loss σ for which the no-run equilibrium exists becomes smaller and the set for which the run equilibrium exists becomes larger. In addition, as the information effect becomes less important, the strategic complementarity in non-movers' withdrawal decisions returns. When ρ^C is small, there is a range of values for σ where the unique equilibrium is in mixed strategies and a partial run occurs, as in panel (b) of Figure 3. For larger values of ρ^C, however, multiple equilibria reappear for some values of σ.

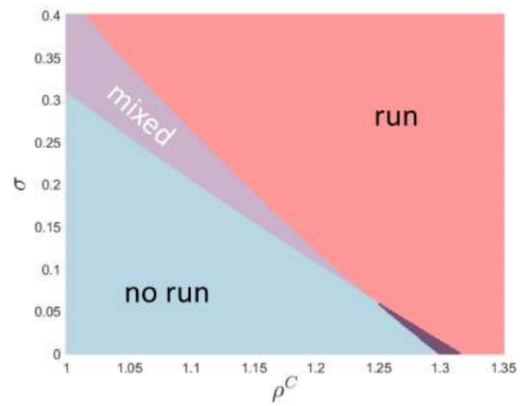


Figure 4: Fragility as ρ^C varies
Source: Authors' analysis

These results illustrate a tension between designing a CBDC to promote efficiency in normal times and designing it to promote financial stability. If digital currency is superior to existing payment technologies in some respects, then efficiency considerations would argue for a design that will be widely used. However, widespread use of the CBDC masks the flows that would identify an incipient run on some banks, slowing the policy response to a crisis. As Figure 4 shows, this muting of the information effect makes a CBDC more likely to increase financial fragility.

This tension might be eased if the CBDC could be designed to have differential appeal to movers and non-movers, or if the central bank could issue two distinct types of CBDC. Suppose, for example, the central bank could introduce one type of CBDC that is redeemable only in a different location from where the deposit was made, and a second type of CBDC that is redeemable only in the same location. If non-movers are unable to travel to another location, then use of each type of CBDC would be restricted to a single type of depositor. In practice, this type of separation between transactions and store-of-value users might be achieved by placing balance limits on the first type of CBDC and perhaps fees on balances not spent in a certain timeframe. The second type of CBDC might have unlimited balances but high transaction fees or perhaps not offer payment services. However the separation is achieved, the optimal policy would be to make the transactions CBDC as attractive as possible, maximizing the value it creates, and to intervene immediately whenever any funds are placed in the store-of-value CBDC, which serves only as a financial stability tool.

It may be difficult, however, to cleanly separate depositors by motive in this way. In our model, if non-movers can choose to move to another location, they would be able to use the first type of CBDC and the policy tradeoff re-emerges. In practice, individuals and firms wishing to hold large CBDC balances may be able to open multiple accounts and automatically move funds across accounts to circumvent balance limits or inactivity fees. More generally, it may be difficult to design a CBDC that is effective as a payments instrument without also being an attractive store of value.[12] To the extent that these two roles cannot be cleanly separated, our analysis highlights an important tradeoff between efficiency and financial stability that policymakers will face in designing a CBDC.

5 Concluding Remarks

The possibility of central banks issuing digital currency has raised fundamental questions about the role of money and its relation to the banking and financial system. Research is beginning to provide insights into some of these questions, but much remains to be learned. One concern that has been raised repeatedly in policy discussions is that the option to hold CBDC may be particularly attractive during times of financial turmoil and, as a result, could increase the likelihood of runs on banks and other financial intermediaries. Some commentators have suggested that this risk can be mitigated by imposing caps, graduated fees, or other restrictions on CBDC holdings during periods of financial stress. Others have even suggested that holding CBDC should be made risky to discourage excessive use.[13] Whether such policies would be credible in times of financial stress remains to be seen. Even if they are credible, however, policies that limit the use or attractiveness of CBDC risk losing many of its potential benefits as well.

Our analysis suggests that other factors may mitigate the financial stability concerns associated with CBDC, without the need to restrict its use. Our model is designed to capture the commonly-expressed concern: all else equal, the ability to hold CBDC increases the incentive for depositors in a weak bank to withdraw. However, the introduction of CBDC creates two other key changes. First, it reduces depositors' need for liquidity insurance and, therefore, leads banks to do less maturity transformation. Second, inflows into the CBDC give policymakers real-time information that can be used to improve the policy response to a crisis. Both of these changes decrease depositors' incentive to withdraw from weak banks.

[12] Keister and Sanches (2022) discuss the possibility of issuing two types of CBDC in different context, where digital currency may compete with physical currency, bank deposits, or both. They also discuss the difficulty of designing a type of CBDC that can only be used for a single purpose.

[13] Birch, D.G.W. "Lost your electronic cash? Tough luck." *Forbes*, March 14, 2022.

In some cases, the net effect of introducing a CBDC in our model is to improve rather than undermine financial stability.

While our results are derived in the context of a particular model, the main lessons seem likely to apply much more broadly. For example, our model assumes the government knows the aggregate state of the economy, including what fraction of banks have experienced losses, from the start. In reality, policymakers have much less detailed information at the onset of a crisis, which increases the scope for them to learn by observing usage of the CBDC. Consider an alternative environment with two aggregate states, one in which the fraction of banks that have experienced a loss is close to zero and another in which this fraction is much larger. In such a setting, learning the aggregate state would help the government take appropriate actions even before learning which individual banks are weak. In this case, observing the *aggregate* flow of funds into the CBDC would help policymakers learn the aggregate state more quickly, even if they cannot observe the flows originating from each bank as we assume here. If policymakers can use this information to impose withdrawal fees or otherwise "bail in" depositors at all banks (as in Keister and Mitkov, 2021), the information gleaned from CBDC usage would decrease financial fragility in much the same way as we have shown here.

More generally, the information effect of CBDC is likely to be relevant in many settings where policymakers' reaction to a run on the financial system is endogenous. Even relatively coarse information about inflows into CBDC can affect policymakers' beliefs about the state of the financial system and about the motivations behind depositors' actions. If changes in these beliefs lead policymakers to act sooner, they will also alter depositors' withdrawal incentives and, therefore, the likelihood of a run on one or more banks. We believe this mechanism will prove important in settings beyond the one we study here and hope our analysis provides a starting point for future work that studies the stability and information effects of CBDC.

Appendix: Proofs

Proposition 1. *With no CBDC, there exists $\underline{\tau} < \bar{\tau}$ such that $\tau > \underline{\tau}$ implies $\alpha^N = 0$ is the unique equilibrium of the withdrawal game for all σ when n is sufficiently small.*

Proof. As a first step, we show that the payoff for the remaining non-movers in a weak bank that has been placed in resolution, $\hat{x}_2^N$, is strictly decreasing in the size of the run, α. Using the utility function in equation (1), the first-order conditions in equation (11) can be written as

$$\mathbb{E}\left[\rho_i^{1-\gamma}\right]\left(\hat{x}_1^N\right)^{-\gamma} = R\left(\hat{x}_2^N\right)^{-\gamma} = \delta\left(\tau - n\hat{b}^N\right)^{-\gamma},$$

where

$$\mathbb{E}\left[\rho_i^{1-\gamma}\right] \equiv \int_{\underline{\rho}}^{\bar{\rho}} \rho_i^{1-\gamma} dF(\rho_i).$$

Combining these conditions with the resource constraint in equation (8) and solving for $\hat{x}_2^N$ yields

$$\hat{x}_2^N = \left(\frac{R}{A}\right)^{\frac{1}{\gamma}}\left(1 - \sigma - \theta x_1^* + \frac{\tau}{n}\right), \tag{22}$$

where

$$A \equiv \left((1-\theta)\left(\hat{\pi}\mathbb{E}\left[\rho_i^{1-\gamma}\right]^{\frac{1}{\gamma}} + (1-\hat{\pi})R^{\frac{1-\gamma}{\gamma}}\right) + \frac{1}{n}\delta^{\frac{1}{\gamma}}\right)^{\gamma}. \tag{23}$$

Note that A depends on the size of the run α through the fraction of remaining depositors who are movers, $\hat{\pi}$. Equation (9) shows that $\hat{\pi}$ is strictly increasing in α. Because $\rho_i \leq R$ for all i, with strict inequality for some i, and $\gamma > 1$, A is strictly increasing in $\hat{\pi}$ and, therefore, in α. It then follows from equation (22) that $\hat{x}_2^N$ is strictly decreasing in α.

To establish that $\alpha^N = 0$ is the unique equilibrium of the withdrawal game, therefore, it is sufficient to show that a non-mover will strictly prefer to wait to withdraw even when all other non-movers attempt to withdraw early, that is,

$$\hat{x}_2^N(\alpha = 1) > \rho^N x_1^*.$$

Using equations (22) and (23) together with the fact that $\hat{\pi}(1) = \pi$, we can write this condition as

$$\frac{R^{\frac{1}{\gamma}}}{(1-\pi)\left(\pi\mathbb{E}\left[\rho_i^{1-\gamma}\right]^{\frac{1}{\gamma}} + (1-\pi)R^{\frac{1-\gamma}{\gamma}}\right) + \frac{1}{n}\delta^{\frac{1}{\gamma}}}\left(1 - \sigma - \pi x_1^* + \frac{\tau}{n}\right) > \rho^N x_1^*.$$

The left-hand side of this inequality is strictly decreasing in σ, so it suffices for the inequality to hold at the maximum loss, $\sigma = 1 - \pi x_1^*$. We can write the resulting inequality as

$$R^{\frac{1}{\gamma}}\left(\frac{\tau}{n}\right) > \left((1-\pi)\left(\pi\mathbb{E}\left[\rho_i^{1-\gamma}\right]^{\frac{1}{\gamma}} + (1-\pi)R^{\frac{1-\gamma}{\gamma}}\right) + \frac{1}{n}\delta^{\frac{1}{\gamma}}\right)\rho^N x_1^*$$

or

$$R^{\frac{1}{\gamma}}\tau > \left(n(1-\pi)\left(\pi\mathbb{E}\left[\rho_i^{1-\gamma}\right]^{\frac{1}{\gamma}} + (1-\pi)R^{\frac{1-\gamma}{\gamma}}\right) + \delta^{\frac{1}{\gamma}}\right)\rho^N x_1^*$$

This inequality will hold for some $n > 0$ if and only if

$$\tau > \left(\frac{\delta}{R}\right)^{\frac{1}{\gamma}}\rho^N x_1^* \quad \equiv \underline{\tau}. \tag{24}$$

To show that this $\underline{\tau}$ lies below the upper bound $\bar{\tau}$, note that using the first-order conditions in equation (4) and the utility function in equation (1), we can write the incentive compatibility condition in equation (5) as

$$\rho^N < \bar{\rho}^N \equiv \frac{x_2^*}{x_1^*} = \left(\frac{R}{E\left[\rho_1^{1-\gamma}\right]}\right)^{\frac{1}{\gamma}}.$$

Combining this inequality with the definition of $\underline{\tau}$ in equation (24) yields

$$\begin{aligned}\underline{\tau} &< \left(\frac{\delta}{R}\right)^{\frac{1}{\gamma}}\left(\frac{R}{\mathbb{E}\left[\rho_i^{1-\gamma}\right]}\right)^{\frac{1}{\gamma}} x_1^* \\ &= \left(\frac{\delta}{\mathbb{E}\left[\rho_i^{1-\gamma}\right]}\right)^{\frac{1}{\gamma}} x_1^* = \bar{\tau},\end{aligned} \tag{25}$$

where the last equality uses the definition of the the upper bound on fiscal capacity in equation (6) together with the utility function in equation (1). □

Proposition 2. *With no CBDC, there exists $\underline{\rho}^N < \bar{\rho}^N$ such that $\rho^N > \underline{\rho}^N$ implies $\alpha^N = 1$ is the unique equilibrium of the withdrawal game when σ and n are sufficiently large.*

Proof. The proof of Proposition 1 establishes $\hat{x}_2^N$ is strictly decreasing in α. To show $\alpha^N = 1$ is the unique equilibrium of the withdrawal game, therefore, it suffices to show that a non-mover will prefer to withdraw early even if no other non-movers run, that is,

$$\hat{x}_2^N(\alpha = 0) < \rho^N x_1^*.$$

Using equations (22) and (23), together with $\hat{\pi}(0) = 0$ from equation (9), we can write this inequality as

$$\frac{R^{\frac{1}{\gamma}}}{(1-\pi)R^{\frac{1-\gamma}{\gamma}}+\frac{1}{n}\delta^{\frac{1}{\gamma}}}\left(1-\sigma-\pi x_1^*+\frac{\tau}{n}\right)<\rho^N x_1^*.$$

If (n,σ) are sufficiently close to their maximal values of $n=1$ and $\sigma=1-\pi x_1^*$, this inequality is satisfied whenever

$$R^{\frac{1}{\gamma}}\tau<\left((1-\pi)R^{\frac{1-\gamma}{\gamma}}+\delta^{\frac{1}{\gamma}}\right)\rho^N x_1^*.$$

Using the upper bound on fiscal capacity $\bar{\tau}$ in equation (25), the previous inequality is satisfied if

$$R^{\frac{1}{\gamma}}\left(\frac{\delta}{\mathbb{E}\left[\rho_i^{1-\gamma}\right]}\right)^{\frac{1}{\gamma}}x_1^*<\left((1-\pi)R^{\frac{1-\gamma}{\gamma}}+\delta^{\frac{1}{\gamma}}\right)\rho^N x_1^*$$

or

$$\rho^N>\underbrace{\left(\frac{R}{\mathbb{E}\left[\rho_i^{1-\gamma}\right]}\right)^{\frac{1}{\gamma}}}_{=\bar{\rho}^N}\underbrace{\frac{\delta^{\frac{1}{\gamma}}}{(1-\pi)R^{\frac{1-\gamma}{\gamma}}+\delta^{\frac{1}{\gamma}}}}_{<1}\equiv\underline{\rho}^N. \tag{26}$$

Equation (5) shows the first term in the middle expression is equal to $\bar{\rho}^N$, while the second term is clearly smaller than 1. It follows immediately that $\underline{\rho}^N<\bar{\rho}^N$, which establishes the result. □

Proposition 3. *When CBDC is introduced, $x_1^*\left(\rho^C\right)$ is strictly decreasing and $x_2^*\left(\rho^C\right)$ is strictly increasing for $\rho^C\in\left(\underline{\rho},\bar{\rho}\right)$.*

Proof. Using the utility function in equation (1), the first-order condition in equation (14) can be written as

$$\hat{\mathbb{E}}\left[\rho_i^{1-\gamma}\mid\rho^C\right]x_1^{-\gamma}=Rx_2^{-\gamma}$$

where

$$\hat{\mathbb{E}}\left[\rho_i^{1-\gamma}\mid\rho^C\right]\equiv\left(\rho^C\right)^{1-\gamma}F^C\left(\rho^C;\rho^C\right)+\int_{\rho^C}^{\bar{\rho}}\rho_i^{1-\gamma}dF(\rho_i;\rho^C)\text{ for }\underline{\rho}\leq\rho\leq\bar{\rho}. \tag{27}$$

It is straightforward to show that this expression is strictly increasing in ρ^C on $\left(\underline{\rho},\bar{\rho}\right)$. Combining this condition with the resource constraint in equation (3) and solving yields

$$x_1^*=\left(\frac{\hat{\mathbb{E}}\left[\rho_i^{1-\gamma}\mid\rho^C\right]}{B}\right)^{\frac{1}{\gamma}}\quad\text{and}\quad x_2^*=\left(\frac{R}{B}\right)^{\frac{1}{\gamma}}, \tag{28}$$

where

$$B\equiv\left(\pi\hat{\mathbb{E}}\left[\rho_i^{1-\gamma}\mid\rho^C\right]^{\frac{1}{\gamma}}+(1-\pi)R^{\frac{1-\gamma}{\gamma}}\right)^{\gamma}. \tag{29}$$

The fact that $\gamma > 1$ implies $\hat{\mathbb{E}}\left[\rho_i^{1-\gamma} \mid \rho^C\right]$ is strictly decreasing in ρ^C. It is then straightforward to show from equations (28) and (29) that x_1^* is strictly decreasing and x_2^* is strictly increasing in ρ^C over this range, as desired. □

Proposition 4. *$\alpha^I = 0$ is an equilibrium if and only if $\alpha^C = 0$ is an equilibrium.*

Proof. Using equation (17) and focusing on $\rho^C \geq \rho^N$, we have that $\alpha^C = 0$ is an equilibrium if and only if

$$\hat{x}_2^C\left(0, \rho^C\right) \geq \rho^C x_1^*\left(\rho^C\right).$$

From equation (21), $\alpha^I = 0$ is an equilibrium if and only if

$$\hat{x}_2^I\left(0, \rho^C\right) \geq \rho^C x_1^*\left(\rho^C\right).$$

Because the constrained-efficient allocation $x_1^*\left(\rho^C\right)$ is the same under both policy regimes, establishing the result is equivalent to establishing

$$\hat{x}_2^C\left(0, \rho^C\right) = \hat{x}_2^I\left(0, \rho^C\right).$$

The first-order conditions in equation (16), which apply under both regimes C and I, can be written as

$$\hat{\mathbb{E}}\left[\rho_i^{1-\gamma} \mid \rho^C\right]\left(\hat{x}_1\right)^{-\gamma} = R\left(\hat{x}_2\right)^{-\gamma} = \delta\left(\tau - n\hat{b}\right)^{-\gamma},$$

where $\hat{\mathbb{E}}\left[\cdot\right]$ is as defined in equation (27). Combining these conditions with the resource constraint in equation (8) yields an expression for $\hat{x}_2$ that applies in both regimes,

$$\hat{x}_2 = \left(\frac{R}{A(\theta, \hat{\pi})}\right)^{\frac{1}{\gamma}}\left(1 - \sigma - \theta x_1^*\left(\rho^c\right) + \frac{\tau}{n}\right), \tag{30}$$

where

$$A(\theta, \hat{\pi}) \equiv \left((1-\theta)\left(\hat{\pi}\hat{\mathbb{E}}\left[\rho_i^{1-\gamma} \mid \rho^C\right]^{\frac{1}{\gamma}} + (1-\hat{\pi})\, R^{\frac{1-\gamma}{\gamma}}\right) + \frac{1}{n}\delta^{\frac{1}{\gamma}}\right)^{\gamma} \tag{31}$$

and where θ is equal to π in regime C and determined by equation (18) in regime I. In addition, $\hat{\pi}$ is given by equation (9) in regime C and by equation (19) in regime I.

When $\alpha = 0$, equation (18) shows that $\theta = \pi$ holds under both regimes. Equations (9) and (19) then show that $\hat{\pi} = 0$ holds in both regimes, which implies that the constant A defined in equation (31) takes the same value in both regimes. Given that both A and θ take the same value under both regimes, equation (30) shows that $\hat{x}_2$ takes the same value under both regimes as well, which establishes the result. □

Proposition 5. *The set of* (σ, n) *for which* $\alpha^I = 1$ *is an equilibrium is strictly smaller than the set for which* $\alpha^C = 1$ *is an equilibrium.*

Proof. Using equation (17) with $\rho^C \geq \rho^N$, we have that $\alpha^C = 1$ is an equilibrium if and only if

$$\hat{x}_2^C\left(1, \rho^C\right) \leq \rho^C x_1^*\left(\rho^C\right), \tag{32}$$

while, from equation (21), $\alpha^I = 1$ is an equilibrium if and only if

$$\hat{x}_2^I\left(1, \rho^C\right) \leq \rho^C x_1^*\left(\rho^C\right). \tag{33}$$

To establish the result, it suffices to show that

$$\hat{x}_2^C\left(1, \rho^C\right) < \hat{x}_2^I\left(1, \rho^C\right). \tag{34}$$

This inequality is sufficient to establish the proposition because it implies (i) if (σ, n) is such that equation (33) is satisfied, equation (32) is also satisfied, and (ii) there exist (σ, n) such that equation (32) is satisfied but equation (33) is not.

When $\alpha = 1$, equations (9) and (19) show that $\hat{\pi} = \pi$ holds under both policy regimes. Using equations (30) - (31), we can then write $\hat{x}_2$ in both regimes as

$$\hat{x}_2 = R^{\frac{1}{\gamma}} \frac{1 - \sigma - \theta x_1^*\left(\rho^c\right) + \tau/n}{(1-\theta)B^{\frac{1}{\gamma}} + \delta^{\frac{1}{\gamma}}/n}, \tag{35}$$

where B is given by equation (29). The difference between the two regimes comes from the value of θ, which is equal to π under regime C but is strictly less than π under regime I when $\alpha = 1$, as shown by equation (18). We can, therefore, establish the result by showing that the expression for $\hat{x}_2$ in equation (35) is strictly decreasing in θ on $(0, \pi)$.

Differentiating equation (35) with respect to θ yields

$$\frac{d\hat{x}_2}{d\theta} = R^{\frac{1}{\gamma}} \frac{B^{\frac{1}{\gamma}}\left(1 - \sigma - x_1^*\left(\rho^C\right)\right) + \left(\frac{1}{n}\right)\left(B^{\frac{1}{\gamma}}\tau - \delta^{\frac{1}{\gamma}} x_1^*\left(\rho^C\right)\right)}{\left((1-\theta)B^{\frac{1}{\gamma}} + \delta^{\frac{1}{\gamma}}/n\right)^2}.$$

We will show that this derivative is strictly negative. Because $x_1^*\left(\rho^C\right) > 1$ holds for all $\rho^C \in \left[\underline{\rho}, \bar{\rho}\right]$, the first term in the numerator is clearly negative. Therefore, it suffices to show that the second terms in the numerator is also negative, or

$$B^{\frac{1}{\gamma}}\tau < \delta^{\frac{1}{\gamma}} x_1^*\left(\rho^C\right). \tag{36}$$

Using equation (6) and the utility function in equation (1), the upper bound on the government's fiscal capacity, $\tau \leq \bar{\tau}$, can be written as

$$\delta\tau^{-\gamma} \geq \hat{\mathbb{E}}\left[\rho_i^{1-\gamma} \mid \rho^C\right]\left(x_1^*\left(\rho^c\right)\right)^{-\gamma},$$

where $\hat{\mathbb{E}}\left[\cdot\right]$ given by equation (27), or as

$$\tau \leq \left(\frac{\delta}{\hat{\mathbb{E}}\left[\rho_i^{1-\gamma} \mid \rho^C\right]}\right)^{\frac{1}{\gamma}} x_1^*\left(\rho^c\right).$$

A sufficient condition for inequality (36) to hold, therefore, is

$$B^{\frac{1}{\gamma}} < \hat{\mathbb{E}}\left[\rho_i^{1-\gamma} \mid \rho^C\right]^{\frac{1}{\gamma}}$$

or, using the definition of B in equation (29),

$$\pi\hat{\mathbb{E}}\left[\rho_i^{1-\gamma} \mid \rho^C\right]^{\frac{1}{\gamma}} + (1-\pi)R^{\frac{1-\gamma}{\gamma}} < \hat{\mathbb{E}}\left[\rho_i^{1-\gamma} \mid \rho^C\right]^{\frac{1}{\gamma}}$$

or

$$R^{1-\gamma} < \hat{\mathbb{E}}\left[\rho_i^{1-\gamma} \mid \rho^C\right] \tag{37}$$

The fact that $\rho^C \leq R$ and that $\rho_i \leq \bar{\rho} \leq R$, with strict inequality for some i, together with $\gamma > 1$, implies that inequality (37) holds, as desired. □

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