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Design and Policy Considerations

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BOXES

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Acronyms

AML/CFT ... anti-money laundering/combating the financing of terrorism
AMM ..... automated market maker
API..... application programming interface
BIC ..... bank identifier code
CBDC ..... central bank digital currency
CBN..... Central Bank of Nigeria
CCP..... central counterparty
CFM..... capital flow management measure
FMIs ..... financial market infrastructures
HTLC ..... hashed time lock contract
IBAN ..... international bank account number
IPS..... instant payment system
MTO ..... money transfer operator
NFC ..... near-field communication
PSP ..... payment service provider
PvP..... payment versus payment
QR ..... quick response
RTGS ..... real-time gross settlement

1. Introduction

Many central banks are currently exploring the possibility of issuing retail central bank digital currency (CBDC). While the primary objective varies between jurisdictions, many central banks consider improved cross-border payments as a potential benefit[1] and previous work has shown that CBDC can help overcome some of the frictions in cross-border payments.[2] CBDC is a safe and liquid asset reducing the number of financial intermediaries and the settlement risk. In addition, the introduction of CBDC offers a window—a clean slate—to build cross-border payment functionality from the start, thus more efficiently. Past experiences suggest that making legacy payment systems interoperable across borders has been difficult once systems are up and running and have initially been designed for domestic purposes (FSB 2020b). Furthermore, CBDC, as a new means for cross-border payments, is commonly meant to coexist with and complement existing options, and can thus increase payment diversity and stimulate resilience, competition, and efficiency. Effects are potentially macro-critical, as faster, cheaper, and more inclusive payments could facilitate international commerce and remittance transfers. In turn, central banks could also see greater CBDC use domestically (Tan 2023).

Designing CBDC systems for cross-border payments is not fundamentally different from tailoring other payment systems. In fact, many of the same challenges, opportunities, and implications highlighted in this paper apply generally. That said, the roles and responsibilities might be slightly different in a CBDC system, and the central bank may play a more pivotal role given CBDC's nature as public money as opposed to commercial bank money. In a CBDC setting, end users would directly hold a central bank liability, just as when they hold cash, and the central bank is likely to have a large role in establishing and operating the infrastructure and scheme.[3]

This paper draws lessons from ongoing experimentation and research to identify design and policy considerations when developing retail CBDC systems so it may be compatible for cross-border payments. The paper focuses on retail CBDC—a CBDC primarily targeting households and non-financial firms—and leaves wholesale CBDC considerations for future work, although many of the discussions are applicable to wholesale CBDC and other forms of money as well.[4] Many central banks are currently exploring retail CBDCs for domestic purposes, while many of the cross-border CBDC experiments to date have focused on wholesale transactions (see BIS, IMF, and World Bank 2021 and 2022). Project Icebreaker was, however, a first cross-border payment experiment using retail CBDCs (BISIH and others 2023c; see also Annex IV). The project used a communication hub to interlink the CBDC test systems of the central banks of Israel, Norway, and Sweden. This paper refers to lessons drawn from the Icebreaker project, as well as existing non-CBDC arrangements like Project Nexus (BISIH 2021). Nexus is a blueprint for how to connect multiple national payment systems into a cross-border network that enables international retail

[1] See Soderberg and others (2023) and Kosse and Mattei (2023) for central bank motivations for exploring CBDC.

[2] See CPMI (2020) for challenges and frictions and BIS, IMF, and World Bank (2021 and 2022) for how CBDC can provide some benefits.

[3] A CBDC system is a relationship of three components: the instrument, the infrastructure, and the scheme. The instrument refers to the liability issued by the central bank. The infrastructure is the software and hardware technology allowing the instrument to be transferred, and the scheme is the rules, standards, and practices clarifying processes and roles of ecosystem participants.

[4] A wholesale CBDC is typically intended only for banks and financial institutions.

payments in seconds. It overcomes the limitations of bilateral interlinking by standardizing how instant payment systems (IPSs) connect. Moreover, this paper also draws on lessons in publications issued under the "G20 Roadmap for Enhancing Cross-Border Payments" (see FSB 2020a).

The paper provides an analytical framework by viewing cross-border CBDC payments through the lens of five interrelated elements: access, communication, currency conversion, compliance, and settlement. For each element, the paper identifies key CBDC design choices, many of which can be tackled in the initial preparation phases.[5]

By making early decisions, central banks can diminish risks of having to redesign or adjust their domestic CBDC system at a later stage. Thus, the overarching key message is to factor in cross-border implications at an early stage, and that clear objectives on cross-border use can help make early design choices even if the CBDC is initially only used domestically. In addition, international cooperation is important: information sharing, consistent messaging standards and regulatory approaches, and common infrastructure can all facilitate CBDC interoperability. Such international cooperation can be more impactful if achieved at a global level to avoid fragmentation and walled gardens.

Other key messages from our work are as follows:

- **Assessing access policies and roles and responsibilities is paramount**: Central banks should carefully evaluate access policies for end users and intermediaries. Wide access could reduce the cost associated with foreign exchange provision but might cause macrofinancial risks such as capital flow volatility or currency substitution.
- **The adoption of international standards for payment initiation, data, and messaging helps**: Even in a CBDC environment, these standards, such as ISO 20022, will continue playing a role.[6]
- **Having instant settlement and 24/7 availability helps mitigate some risks**: By providing instant payments and 24/7 availability, settlement and liquidity risks can decrease.
- **Programmability can deliver efficiency gains**: Experiments suggest that programmability could lower settlement risks by allowing synchronous payment versus payment (PvP).
- **Compliance with international regulatory frameworks should be factored in**: These include technologies to ensure privacy and enhance regulatory compliance such as for anti-money laundering/combating the financing of terrorism (AML/CFT).
- **Flexible or modular technical designs can help**: Solutions that can "plug into" different arrangements can more easily adapt to the likely continuous evolution of the future cross-border CBDC payments landscape.

The remainder of the paper is structured as follows. Section 2 presents a basic framework and Section 3 discusses design considerations and policy implications, including boxes summarizing key design considerations. Section 4 concludes.

[5] See Tourpe and others (2023) for the product development phases of a CBDC project.

[6] ISO 20022 is an international financial messaging standard that provides a common language for communicating data between financial institutions.

2. A Framework to View CBDC Design through the Lens of Cross-Border Payments

Suppose Alice needs to send money to Bob who lives in a different country. One option for Alice is to send cash to Bob via mail. For the transfer to go through, certain requirements must be met. First, Alice needs access to banknotes. Second, Alice needs Bob's postal address. Third, there needs to be a reliable postal service to deliver the envelope. Since Alice and Bob live in different countries, several postal services might be involved unless Alice uses a multinational delivery service. Fourth, Alice and Bob must ensure they comply with all rules and regulations, which may be difficult in the case of sending cash in an envelope. Fifth, they must agree on who owns the money at what stage and when the ownership is transferred.

Most cross-border payments are not made by sending money in an envelope; instead, they are made in a digital form. Currently, there are many different types of models including correspondent banking, closed loops, and aggregators (see Box 1). In addition, more formal arrangements between payment systems exist, such as the interlinking of payment systems and common platforms (see Box 2).

The models and arrangements underlying digital payments can nevertheless be understood through the envelope analogy. In every model, the question of access arises. Who can access what money and what rules govern that access? While Alice and Bob can easily access any country's banknotes, having a bank account to hold a foreign currency is more sophisticated in the digital world. This typically gives rise to the need for a currency conversion for each payment. Addressing is also important in the digital world. In the envelope case, Alice needs the physical address where Bob lives. In the digital world, she often needs to know what bank Bob uses, the identifying number of that bank, and Bob's account number. Also digital payments typically need an intermediary, like postal services in the envelope case. For example, multiple financial intermediaries are used in the correspondent banking model, as not all banks typically operate in all countries. Sometimes, fewer financial intermediaries are needed. For example, in a closed loop, a monetary transfer operator might be active in multiple countries and offer transfer services.

To ensure compliance with regulatory requirements in the digital world, payment service providers (PSPs) must conduct various checks (discussed in more details later) to facilitate payments.[7] These will be easier to undertake with CBDC than in the simple example of sending cash in an envelope. It is also essential to determine the ownership of the funds being transferred and the way the transfer occurs in the digital realm. When it comes to cross-border payments, multiple transactions take place within the payment chain, all of which must be settled and have the change of ownership agreed upon.

As demonstrated by the Alice and Bob example, cross-border payments involve multiple distinct elements. In this paper, we therefore analyze cross-border CBDC payments in terms of five key elements: access, communication, currency conversion, compliance, and settlement. These elements, as outlined in Figure 1, form the fundamental components of a cross-border payment. Access refers to who is permitted to hold and transact a given currency and any potential restrictions on that access. Communication is the

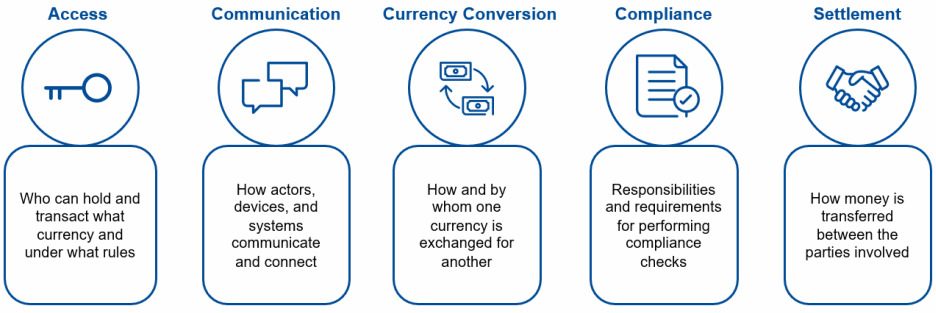
[7] A PSP is an entity that provides payment services. Payment service providers include, but are not limited to, banks and other deposit-taking institutions, as well as specialized entities such as money transfer operators and e-money issuers.

way in which the payer, payee, intermediaries, devices, and systems communicate and link up during a payment. Currency conversion refers to how and by whom one currency is exchanged for another.[8] Any cross-border transaction must adhere to applicable legal and regulatory requirements. Accordingly, responsibilities and requirements for compliance constitute an element. Compliance is very broad and could cover many aspects, and the legal considerations are many, especially as international standards and domestic legal and regulatory frameworks are still evolving. In this paper, recognizing broad scope and depth of compliance issues, we will focus on technical aspects as well as high-level policy considerations related to AML/CFT, privacy, anonymity, and capital flow management measures (CFMs), and we leave in-depth legal considerations and broader CBDC compliance issues for future work. Lastly, settlement is an element that encompasses how the transfer of funds between the parties involved is completed. By viewing cross-border CBDC payments through the lens of these five elements, the paper will identify relevant design choices that need cross-border consideration.[9]

The elements are interconnected; for instance, access policies determine the need for currency conversion and who is qualified to offer foreign exchange services. Access policies also determine the need for financial intermediaries and, ultimately, how settlement is achieved. The necessary compliance checks will depend on who is involved in the payment chain, determined by access and the model utilized for currency conversion. Central banks must recognize this interconnectedness in their CBDC exploration and design.

The Alice and Bob example and the elements also highlight that many CBDC systems would have several actors—end users, PSPs, operators, the central bank—and the responsibilities of these actors can differ between different systems. We identify three main categories of responsibilities: first, *technical services,* such as providing the underlying infrastructure, an interface of payment device, digital wallet, or messaging; second, *customer relationships,* such as onboarding and addressing customer complaints and questions; and third, *financial functions,* such as financial intermediation and foreign exchange provision. We return to these functions and responsibilities throughout the paper.

Figure 1. The Core Elements of a Cross-Border Payment



Source: IMF staff.

[8] Many cross-border payments include a currency conversion. As such (at least) two currencies and two payments are involved. We define it to be a cross-border CBDC payment as long as at least one of the payments are made using CBDC. That is, a payment can, for example, be initiated using CBDC but be received as commercial bank money, e-money, or even cash (or reversed).

[9] Cross-border payments can be viewed through additional elements, such as resilience, governance, and legal frameworks, but we leave these out of scope as they can be seen to "sit above" our five elements.

Box 1. Prevailing Models for Cross-Border Payments

There are three prevailing models for processing cross-border payments: correspondent banking, closed loops, and aggregators. Hybrid forms are also possible, for example a closed-loop system utilizing correspondent banking relationships to maintain its liquidity and manage risks.

- **Correspondent banking** is one of the most common methods to facilitate cross-border payments. It involves two or more banks, typically located in different countries, establishing relationships to facilitate cross-border transactions. In this relationship, one bank acts as a correspondent bank and provides services to another bank, the respondent bank, sometimes with the use of intermediary banks. The respondent bank uses the correspondent bank's services to facilitate cross-border payments for its customers.
- **A closed-loop system** operates within a specific network, usually owned by a single company, such that the payer and the payee interact with the same entity—exemplified by Western Union, PayPal, Wise, and Revolut. The payment is processed within the network, allowing quick and secure transfer of funds between accounts. The closed-loop system can facilitate cross-border payments because it has a local presence in multiple countries or has agreements with banks or financial institutions in the countries where the payment is being sent or received.
- **Cross-border payments via aggregators** refer to the process of PSPs using a third party, the aggregator, to process cross-border payments—exemplified by VISA, MasterCard, and Wise Platform. These payment aggregators establish a global network and do not communicate directly with end users but with PSPs, who interact with the end users. The aggregators typically use a correspondent banking network to gain access, but can also participate directly in local financial market infrastructures (FMIs).

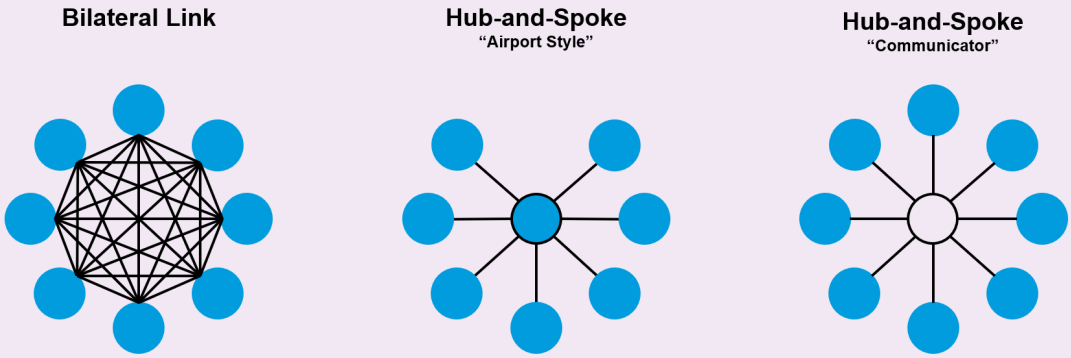
In addition to these prevailing models, other models and arrangements do exist; see CPMI (2018) for more on cross-border retail payments. See also Annex I for how the above models are viewed through the five elements. The three models described above can be used also for processing cross-border retail CBDC payments, although some refinements of the models would occur. See Annex II for an example of the process for inbound diaspora remittances using the eNaira.

Box 2. Interlinking and Common Platforms

Interlinking can be defined as a set of contractual agreements, technical links and standards, and operational components between systems. There are two interlinking models at the highest categorization: bilateral links and hub-and-spoke (see Figure 2). The key difference is that a bilateral link model rests on each payment system establishing an interlinking arrangement with each of the other payment systems, while the hub-and-spoke is characterized by having only one technical counterpart—the hub. The hub-and-spoke model can be further divided into two categories: the "airport model" and the "communicator model." The key difference is that the hub in the airport model is a separate currency payment system itself, while the hub in the communicator model is not a payment system but rather a technical infrastructure that facilitates communication between systems.[10]

Figure 2. Stylized Interlinking Models

The figure shows three stylized models for interlinking of payment systems. Each solid blue circle represents a payment system, while the non-filled circle represents a technical communicator.



Source: IMF staff.

An alternative to interlinking separate payment systems is to use a common platform. Again, we can think of two main classifications. First, we can consider having a limited-purpose common platform only for cross-border payments so that domestic payments are facilitated in domestic payment systems, while only cross-border payments are facilitated on a common platform. Second, we can consider a single common platform facilitating both domestic and cross-border payments.[11]

[10] Examples of non-CBDC bilateral links are: *Directo a Mexico*, linking the US and Mexico; *euroSIC*, linking Switzerland and the Euro area; and the link between the PayNow system in Singapore and the PromptPay system in Thailand. In addition, there are wholesale CBDC experiments such as Jasper-Ubin (Bank of Canada and Monetary Authority of Singapore 2019). For hub-and-spoke, the REPSS (COMESA) solution is an airport-style model, while Nexus (BISIH 2021), Icebreaker (BISIH and others 2023c), and Swift (2022) are all examples of communicator models. See also CPMI (2022b) and BIS, IMF, and World Bank (2021 and 2022).

[11] Wholesale CBDC experiments such as mBridge (BISIH and others 2022a; BISIH 2023b), Jura (BISIH and others 2021), and Dunbar (BISIH and others 2022b), are examples of using a limited-purpose common platform. TIPS is designed as a multicurrency platform—currently offering instant payments settlement in two currencies: the euro and the Swedish krona—would be more of an example of a single common platform (ECB 2024). The framework presented by Adrian and Mancini-Griffoli (2023) and Adrian and others (2022) could be seen as either a limited-purpose or a single platform.

3. CBDC Design Considerations and Policy Implications through the Lens of the Elements

This section discusses design and policy implications of cross-border CBDC through the lens of the elements. For each element—access, communication, currency conversion, compliance, and settlement—we look at different cross-border CBDC arrangement options to identify the main trade-offs and core design questions for cross-border consideration in domestic CBDC design.[12] At the end of each element subsection, we provide a small box covering some of the key design considerations where cross-border attention is needed. There are certain options and elements that are more policy-related, while others are more technical in nature. Although not comprehensive, the objective is to pinpoint the primary CBDC design areas where cross-border attention is required, while acknowledging that there may be additional options within these elements.

Element 1: Access

Central banks need to determine access policies for end users, financial intermediaries, and foreign exchange providers. Access policies—who has access to what currency and under what rules—impact both the domestic CBDC system and the possible models for cross-border payments. Key design options regard access by non-residents and foreign financial institutions as well as any restrictions to holdings or transactions. Access policies come with policy trade-offs that each jurisdiction needs to consider. For example, while wider access might increase risk sharing and currency diversification, risks associated with currency substitution in other jurisdictions would also increase.

End User Access

Most central banks consider a CBDC mainly accessible to residents of the issuing jurisdiction. However, central banks recognize the possibility for non-resident citizens to gain access since they often have a strong presence in the payments market of their origin—remittances being one use case.[13] In addition, some non-resident foreigners can need to access the CBDC—tourism being one use case.[14] Hence, when a non-resident foreigner visits the country, they might want to exchange their home money for the CBDC to make payments in the local currency. Some jurisdictions consider supporting non-resident access on the same basis as residents—subject to certain requirements (see, for example, Bank of England and HM Treasury 2023). Any access to a CBDC will require someone to serve the end user with onboarding, customer service, technical interface, and other functions needed. Hence, actual adoption by non-residents might be limited if PSPs do not find it profitable or satisfactory from a regulatory viewpoint to serve these market segments. In addition, jurisdictions will have to consider potential regulatory

[12] Thus, the focus is not on designing the cross-border arrangements themselves, but rather the implications for domestic design.
[13] A non-resident citizen is an individual who is a citizen of the issuing jurisdiction but residing abroad.
[14] A non-resident foreigner is an individual who is neither a resident nor a citizen of the issuing jurisdiction.

implications such as privacy laws and KYC requirements, among others, by allowing for non-resident access.

If users can directly hold and transact a foreign CBDC, the cross-border CBDC transaction would not necessarily need a currency conversion but could mimic domestic payments, apart from potential differences in compliance checks; we return to compliance issues in element 4. If users cannot access the foreign CBDC directly, there is a need for a currency conversion and a financial intermediary to facilitate the transaction. The need for a financial intermediary highlights the importance of a model that ensures everyone with access to the CBDC also gains access to cheap cross-border, cross-currency functionality; we return to this in the third element on currency conversion.

While widespread adoption of a CBDC outside of the issuing jurisdiction could ease the complexity of the actual cross-border payment by limiting the need for currency conversion, there would be various macrofinancial implications (IMF 2020). Such macrofinancial implications include currency substitution, capital flow volatility, and faster transmission of shocks. There is an international coordination problem related to the currency substitution risk as the risk would be materializing in countries other than the jurisdiction issuing the CBDC. Hence, a jurisdiction needs to consider negative spillover effects on its neighboring countries in addition to managing destabilizing effects in their own jurisdictions due to, for example, large capital inflows. Principle 7 from the Public Policy Principles for Retail CBDC by the G7 covers this issue and stresses that "CBDCs should be designed to avoid risks of harm to the international monetary and financial system, including the monetary sovereignty and financial stability of other countries" (G7 2021).[15] To combat these risks, mitigation measures such as limits on holdings and transactions could be implemented.[16] These design options will be further explored in the Restrictions on Holdings and Transactions section.

Access by Financial Intermediaries and Foreign Exchange Providers

When the end users make cross-border payments without direct access to both CBDCs, a financial intermediary and a foreign exchange provider will be needed. For example, say Alice resides in country A with access to its domestic CBDC, and she wishes to send money to Bob living in country B. Alice does not have access to CBDC-B, and Bob cannot access CBDC-A. Hence, if Alice wishes to send CBDCs to Bob, there needs to be a currency conversion (see element 3 on currency conversion for further details).[17] Therefore, there will be a need for a financial intermediary and a foreign exchange provider. To offer cross-currency financial intermediation or foreign exchange services, direct or indirect access to both currencies is needed.

Direct access refers to models where a domestic or foreign entity directly holds and participates in the CBDC system, while an indirect model refers to a situation where a foreign entity gains access via a domestic entity. In the case a foreign entity can have direct access, the entity would be under the

[15] The People's Bank of China has also introduced three principles for cross-border CBDC arrangements, which are "No disruption/Do no harm, Compliance, and Interoperability" (Mu 2023).

[16] In addition to policy measures, enhanced data frameworks can be important to better understand and mitigate risks. An international coordination effort is underway to establish a standard data reporting framework among central banks for digital money, as outlined in Recommendation 11 of the G-20 Data Gaps Initiative (DGI-3).

[17] Both legs of the payment do not have to be CBDC. It could for example also be that one leg uses CBDC while the other uses commercial bank money.

supervision of its home government—hence under foreign supervision from the CBDC issuer's perspective. This is uncommon today, but examples do exist. For example, the Swiss real-time gross settlement (RTGS) system allows foreign banks to participate via remote access if they meet the same level of standards regarding supervision, anti-money laundering and counter-terrorism financing, and communications infrastructure as domestic participants are subject to.

A foreign entity (typically a financial institution) without direct access to the CBDC can gain indirect access via a correspondent banking arrangement. A foreign entity can use a nostro account with a domestic entity to hold and transact the CBDC on its behalf.[18] However, this model would defeat some of the benefits of CBDC. Indirect holdings of CBDC through a correspondent bank would constitute a claim on a private entity. They would not be a direct liability of the central bank and not fall under the definition of a CBDC. Hence, such model would have credit risk.[19]

As mentioned above, a narrower access policy for end users increases the need for financial intermediaries and foreign exchange providers in a cross-border setting. This implies that domestic or foreign entities may need access to hold and transact an ample amount of CBDC unless the central bank plays an active role in acting as an intermediary, or even a foreign exchange provider if willing to take currency risk (see element 3 for more on intermediation and foreign exchange provision). While access to foreign service providers has the potential to increase competition and market depth, those benefits must be balanced with potentially increased supervisory complexity. Similar trade-offs arise regarding access to central bank RTGS systems and reserves.

It is, however, important not to replicate existing challenges observed with correspondent banking (for example, long transaction chains and lack of commercial incentives may leave certain corridors unserved or underserved). In addition, a growing concentration of cross-border flows can potentially exacerbate financial fragilities in countries significantly affected by correspondent banking relationship withdrawal, as it can have consequences such as higher costs and reduced scope of service (IMF 2022). Such flows, including remittances, are important for financial stability and support economic growth and development (IMF 2017). The use of CBDC and interlinking of systems, as well as greater diversity of intermediaries and foreign exchange providers, can reduce transaction chains (BIS, IMF, and World Bank 2022; CPMI 2022b) and dependencies on correspondent banks. In principle, anyone able to hold multiple currencies and willing to take on currency risk can act as a foreign exchange provider. Thus, a reduction in the number of intermediaries in the transaction chain is beneficial, but increasing the pool of intermediaries and foreign exchange providers to choose from is also important.

Restrictions on Holdings and Transactions

In addition to determining who has access, there are options regarding restrictions on holdings and transactions. Limits can be motivated from both domestic and cross-border objectives, and from international standards, and can thus create trade-offs. To limit CBDC use by foreign (or domestic) users, restrictions can be applied. One alternative is to limit the maximum amount allowed to hold. Another

[18] A nostro account refers to an account that a bank holds in a foreign currency at another bank.

[19] See BIS, IMF, and World Bank (2022) for more on access policies and CPMI (2022d) for best practices for self-assessments for improving access to payment systems for cross-border payments more generally. See also Project Dunbar (BISIH and others 2022) for an example of an indirect "sponsor" model.

alternative is to limit the size of any transaction to ensure low-value payments. Yet another alternative is to limit the number of transactions allowed within a certain timeframe. These alternatives are not unique to CBDC, and the policy trade-offs are largely similar for other forms of money as well.

From a domestic perspective, limits might be warranted to reduce disintermediation risk in the short term (see also Das and others 2023). Yet, limits could reduce digital financial inclusion if set too low as CBDC might be the only digital alternative for those financially excluded (see Lannquist and Tan 2023, for more on CBDC and financial inclusion). Too low limits could also affect the usability of a CBDC and hinder uptake and adoption.

From a cross-border perspective, limiting the amount of CBDC individuals or institutions can hold could reduce risks in the international monetary and financial system. If residents and non-residents can use CBDC for cross-border payments, capital flow volatility could increase. Additionally, if non-residents can use a foreign CBDC for domestic payments, it could lead to currency substitution in the country where the non-residents reside. Limiting holdings and transactions could mitigate these risks. However, the jurisdiction responsible for implementing such limits does not gain from it as the currency substitution is a risk in the foreign jurisdiction. That said, jurisdictions should mitigate negative spillovers and avoid risks of harm to the international monetary and financial system, including the monetary sovereignty and financial stability of other countries.

One possible approach to mitigate these negative consequences would be to set different limits for residents and non-residents. It would lift some of the negative consequences, such as financial inclusion and privacy concerns due to low limits on holdings and transactions by residents, while addressing the concerns regarding capital flow volatility and currency substitution. On the other hand, different limits for residents and non-residents can be viewed as discriminatory treatment. In addition, non-resident's access could be subject to (bilateral) agreements between central banks, further mitigating and balancing these risks. Limits for non-residents can also be conditional on their whereabouts. That is, limits can be different depending on if they are in CBDC issuing jurisdiction or abroad; such that tourists experience less stringent restrictions while visiting but more stringent restrictions when returning home. Risks with currency substitution arise when non-residents can use the CBDC outside of the issuing country, rather than from when given access temporarily when visiting the issuing country. Moreover, even if a CBDC can be used outside of the issuing country, the actual usage would still depend on the local demand. Thus, jurisdiction-specific assessment needs to be made.

Limits can, however, create complexity. Setting and enforcing limits would require the development of rules, regulations, and monitoring systems. This could create additional costs and administrative burdens for central banks and financial institutions, and potentially reduce the efficiency of the system. In addition, technical complexities would arise in ensuring that payments are still processed even when limits are hit.

One alternative to solve problems with limits is to use "waterfall models." Suppose an incoming payment will bring the wallet balance over the limit. One possible way to address this problem would be for any payment taking CBDC holdings above a certain limit to be accepted but trigger an automatic transfer of the excess funds from the CBDC wallet to another asset. This asset could be an account with a commercial bank. Hence, each wallet holder would have to designate a "waterfall" account. See Annex III for more details on restrictions, and element 3 for more on foreign exchange liquidity management.

Key Design Considerations: Access

Wide access to non-residents is not needed to facilitate cross-border payments as long as intermediaries exist with access to both currencies. While wide access can remove some frictions, there are macrofinancial risks, such as currency substitution in other countries. Thus, non-residents' access should be carefully analyzed and negative spillover effects should be avoided. That said, with mainly domestic access, currency conversion will be needed, and a key design question regards who should be the foreign exchange provider and how the foreign exchange provider gains access to the currencies. Some central banks might be willing and able to act as foreign exchange providers, but this would entail taking currency risk. Hence, many central banks might want to leave this role to the private sector, at least for well-served payment corridors with sufficient competition, and for some central banks, the mandate could prevent them from taking such role. Any limits and restrictions must be designed to allow for cross-border CBDC transactions by intermediation, and financial intermediaries and foreign exchange providers need to be able to transact large volumes of CBDC, although their holdings can be limited via waterfall accounts. Key design considerations where cross-border attention is needed include the following:

- Non-resident access
- Domestic and foreign financial intermediary and foreign exchange provider access
- Holding and transaction restrictions
- Waterfall accounts

Element 2: Communication

When access is established, the payer, payee, and potential intermediaries need to communicate. The section focuses on two main parts of communication: payment initiation and messaging, and infrastructure and connectivity. Payment messages are essential for payments, but they also pose several challenges in a cross-border setting that must be addressed to ensure secure, efficient, and compliant transactions. Challenges in a cross-border setting include lack of standardization, incomplete or incorrect information, limited transparency, lack of security, and regulatory differences. In addition to messaging, key design options regard responsibility for technical intermediation, payment initiation standards, and what infrastructure to use for communication, as this could impact competition.

Payment Initiation and Messaging

The first instance of technical communication occurs when the payment is initiated. For example, when the payer in country A wishes to send money to a payee in country B, they need to communicate with each other. The payer needs to know the “address” of the payee. Today, for standard credit transfers, the payer typically addresses the payee via IBAN and BIC codes.

Many central banks are investigating the use of proxies, sometimes called aliases, such as phone numbers, nicknames, and email addresses, for addressing CBDC payments domestically. Cross-border addressing would be significantly more straightforward if the same proxies used domestically could be

used also for cross-border payments, since they are more familiar to the users. Indeed, this is addressed in the Nexus project when connecting fast payment systems, such that Nexus allows the payer to use the proxy format used in the system of the payee.[20] In the Nexus blueprint, each system shares the service-level description—describing, among other things, the account number format and proxy format—so the payer PSP can retrieve this information.

The address book with proxies would likely need to be made available to foreign PSPs to validate the address and perform compliance checks. Initiating a cross-border CBDC payment with only a phone number would probably not meet most countries' regulatory requirements. Hence, central banks should consider using proxies for simplified addressing for the end user and options for making the full address book available to foreign PSPs for compliance checks (such as those required for AML/CFT purposes). Furthermore, the authentication of users via digital ID systems is envisioned for many CBDC systems. Having standardized digital ID frameworks across jurisdictions would certainly be beneficial in facilitating more efficient communication and messaging across borders and systems.[21]

In the case of person-to-business payments, there are additional complexities. For example, suppose a consumer is buying something online or in-store from a merchant abroad using her phone's CBDC application, and that the local payment initiation method uses Near-Field Communication (NFC) or QR codes.[22] To offer a seamless experience, the consumer’s phone must be able to read and understand the message being transmitted via NFC or QR codes from the foreign merchant. Following international standards would not only facilitate cross-border interoperability but can also facilitate interoperability with domestic non-CBDC systems. If different standards are used, it increases the burden on PSPs to facilitate technical intermediation, which could hinder competition and market entry by smaller service providers. Coordination on international standards is, however, challenging but beneficial to limit the technical burden on intermediaries. Thus, international cooperation is needed.

When communicating across borders, a common “language” is achieved by standardizing data and messages. Currently, lack of standardization in payment messages creates friction since countries and financial institutions may use different formats, codes, and languages. Limited transparency can make it difficult for senders and recipients to understand the true cost and timing of the transaction, while a lack of security can compromise the confidentiality and integrity of the payment message, leading to unauthorized access, alteration, or theft of funds.

[20] The Nexus project is led by BISIH Singapore Centre, and in 2022, they built a working prototype to connect the test systems of three established instant payment systems (IPSs): The Eurozone's TARGET Instant Payment Settlement (TIPS) system, operated by Bank of Italy on behalf of the Eurosystem, Malaysia's Real-time Retail Payments Platform (RPP), operated by Payments Network Malaysia (PayNet), and Singapore's Fast and Secure Transfers (FAST) payment system, operated by Banking Computer Services (BCS). The BISIH Singapore Centre is now collaborating with the central banks of Indonesia, Malaysia, the Philippines, Singapore, and Thailand as they work towards connecting their domestic payment systems. For more details about Nexus, see: https://www.bis.org/about/bisih/topics/fmis/nexus.htm

[21] Related to information and identity sharing is the exploration of privacy-enhancing technologies by several central banks (see, for example, Project Aurora and Project Aurum 2.0, from the BIS Innovation Hub) demonstrating that the combination of identifiers and privacy-enhancing technologies can enable both efficient identification of all parties and ensure high levels of privacy.

[22] NFC and QR codes are both technologies used for communication and information exchange. While NFC enables short-range wireless communication between devices in close proximity, QR codes are visual representations of information that can be scanned and interpreted by a camera-equipped device. NFC requires physical proximity and is often used for secure transactions and data exchange, while QR codes are versatile and widely used for a variety of purposes. NFC and QR codes can be used for both person-to-business and person-to-person payments.

To address these problems, the G20 Roadmap has been actively promoting the adoption of ISO 20022, which is a priority theme on the updated G20 Roadmap (see Action 8 in FSB 2023). However, harmonizing ISO 20022 implementation for cross-border payments can be challenging and requires a coordinated effort among financial institutions, regulators, and standard-setting organizations to overcome the challenges associated with varying market practices, diverse payment systems, legacy systems, integration, cost, and security. Central banks are advised to follow the ongoing work within the CPMI for guidance on harmonizing the implementation of ISO 20022 (see CPMI 2023). These recommendations also apply to CBDC system design, and central banks should use ISO 20022.

Communication Infrastructure and Connectivity

When the payer has the information needed to make the payment, there must be communication between the two CBDC systems to execute the payment. This communication can be done in several ways. It can be left to the PSPs to establish the necessary messaging infrastructure (for example, via the SWIFT network) and execute the payment. An alternative is for the systems to interlink and, for example, use Application Programming Interfaces (APIs) to facilitate communication (CPMI 2022b). In the case of interlinking via APIs, the central bank would need to ensure that such functionality is possible in the CBDC infrastructure. In addition, there can be a mix of the two approaches.

Linking systems can be done in several architectural ways (as described in Box 2), and some provide better scalability than others. Bilateral links have potential scalability problems due to many different links and communication channels need to be established. However, by adopting standardized data, messaging, and APIs, the scalability problem is mitigated. The hub-and-spoke model can make it easier to communicate and connect since there is only one technical counterpart—the hub.[23] For example, Project Nexus uses standardized gateways, while Project Icebreaker uses a central routing hub (see Annex IV for more information on Project Icebreaker).[24] These models are highly scalable—from a technical point of view—as they standardize the connection and communication in a hub-and-spoke fashion so that each system only has one technical counterpart. Lastly, a common platform can facilitate all communication within the platform, and thus be very efficient. While common platforms and hub-and-spoke interlinking can be scalable and efficient from a technical point of view, they can face other challenges such as governance (BIS, IMF, and World Bank 2022).

By providing communication standards and channels within the arrangement, competition can be enhanced. If each PSP is responsible for establishing communication between systems, it might put smaller entities at a disadvantage and thus limit competition. Efforts to improve competition and expand the set of actors offering payment services should lower costs and provide more choices for end users.

[23] In a bilateral link model, connecting three countries needs three links, connecting four needs six, and a network of five requires ten links. The number of links can be calculated using the formula n(n-1)/2, where n is the number of systems to connect. In the hub-and-spoke model, the number of links is simply equal to n. See Figure 2 for an illustration.

[24] Project Icebreaker use a hub-and-spoke communicator-like model connecting the CBDC test systems of the central banks of Israel, Norway and Sweden, via a central API hub. The API hub acts as a router, so that each system communicates with the hub, and the hub routes the messages to the intended system. The hub has additional functionalities, such as a foreign exchange marketplace (see element 3 and Annex IV). Instead of a central routing hub, Nexus uses standardized gateways. The Nexus Gateway is software that manages communication between IPS to support proxy resolution, foreign exchange quote generation and payment processing between two countries. Each Gateway connects to its local (domestic) IPS infrastructure on one side and to Nexus Gateways in other countries on the other side (BISIH 2021).

While choices of interlinking model arrangements and common platforms come at a later stage, central banks should consider if communication should be an integrated part of the core infrastructure or if that communication should be left to PSPs to establish. Central banks could, from the outset, consider options for a future national gateway for communication and follow international work on, for example, APIs.

In addition to the infrastructure, there is also a connectivity aspect. Cross-border CBDC arrangements can build on synchronous communication and processing, requiring both the payer and payee wallets to be online at the same time. Synchronous communication and processing mean that when a message or request is sent, there is an immediate response. Hence, the choice of having centralized versus decentralized architectures becomes important. For example, Project Icebreaker uses smart contracts, Hashed Time Lock Contract (HTLC), to facilitate PvP settlement in two separate currencies and decentralized systems (see element 5 and Annex IV for how Icebreaker implemented the HTLC protocol).

HTLC is one approach often used in distributed ledger technology-based systems to achieve coordinated payments in separate ledgers—where the completion of all transfers comprising the transaction either succeed together or fail together—without the use of a third-party coordinator. The basic idea of the HTLC protocol is to place the money in technical escrow until all necessary conditions are met. In traditional systems, such coordination between different ledgers is often achieved through a "two-phase commit" protocol involving a coordinator.[25] For optimal and fast execution of the HTLC protocol, and many similar protocols, synchronous communication and processing is used and all wallets involved in the payment must be online and actively participating or be represented by an online agent. This is not a problem for the payer's wallet, as the payer typically must actively initiate and approve the payment.

However, the payee or intermediary might not be online, especially if their wallets are autonomous (unhosted).[26] Hence, in CBDC systems with autonomous wallets, it may be that the protocol must be asynchronous, leading to potentially significantly slower execution. Alternatively, the payee must sign up for a service that can act on his behalf in receiving cross-border payments synchronously. In a fully centralized system, this is not an issue as "wallets" cannot be autonomous. These trade-offs and alternative approaches should be taken into consideration in the CBDC design, especially since many central banks are considering enabling domestic offline payments (BIS, IMF, and World Bank 2022).

Key Design Considerations: Communication

Payment initiation is critical, and international coordination regarding standards is important to offer a seamless cross-border experience. Likewise, adopting and harmonizing the implementation of ISO 20022 emerges as a must to ease cross-border payments. Many of these standards already exist since they are not CBDC specific. By adopting standards such as ISO 20022, central banks will not only ease cross-border payments but can also ease domestic interoperability between payment systems. Standardized digital ID frameworks should also be considered. The choices of centralized versus decentralized architectures and hosted versus non-hosted wallets in decentralized systems will

[25] In these types of protocols, a coordinator sends a signal to all participants to commit to the transaction by updating its records, or to abort and roll back in the case of failure. See Bank of Canada and Monetary Authority of Singapore (2019) for more details on HTLC and similar protocols.

[26] An autonomous, unhosted, wallet refer to when the end-user holds its credentials directly instead of having a PSP as a host.

impact whether the payee's wallet is required to be online and need to be carefully analyzed. While not necessarily impacting the domestic CBDC design initially, central banks should consider if cross-border communication should be an integrated part of the core infrastructure, such as facilitating APIs, or if that communication should be left to PSPs to establish. Centralizing functions could be important to ensure better competition so to reduce the cost for end users, and it would remove the need to rely on PSPs to provide the infrastructure. Key design considerations where cross-border attention is needed include the following:

- Payment initiation (proxies, QR code, NFC)
- Data and messaging standards
- Digital ID frameworks
- Centralized or private communication solutions
- Centralized versus decentralized architectures
- Hosted versus unhosted wallets in decentralized architectures

Element 3: Currency Conversion

There are different models for how one currency is exchanged for another. The key options regard whom to offer foreign exchange services, how the end user is matched with the foreign exchange provider, and how foreign exchange providers manage liquidity. As highlighted in the framework, design elements cannot be viewed in isolation from other elements since they are interconnected. The choice of currency conversion model is closely linked to the access policies and settlement model. Thus, currency conversion options must be viewed in tandem with the other elements. For example, the need for currency conversion is determined by access policies, and access policies determine the potential entity that can provide any foreign exchange service and thus increase competition for lower fees.

Foreign Exchange Provision

Conceptually, we can think of three basic models for currency conversion in a retail cross-border payment: (1) using a foreign exchange provider, (2) using a separate foreign exchange provider and a financial intermediary, and (3) using the same PSP as a foreign exchange provider and financial intermediary (see Figure 3).[27] While the figure shows all payment legs to be CBDC, all of them do not have to be. For example, in model 2, the foreign exchange trade between the intermediary and the foreign exchange provider could be done using commercial bank money, and in model 3, it could be that the payer sends CBDC to the intermediary and the foreign exchange provider, but the payee receives a non-CBDC asset. That said, we focus on cases where all legs are using CBDC to fully understand the implications.

The first model implies that the payer exchanges CBDC-A with the foreign exchange provider for CBDC-B before sending CBDC-B to the payee. Note that this rests on the payer having access and the possibility to hold and transact both CBDC-A and CBDC-B. We assume the payee cannot hold CBDC-A.

[27] These three models are intended to show a minimum set of combination to illustrate separate functions of intermediaries and foreign exchange providers. We could think of adding more intermediaries.

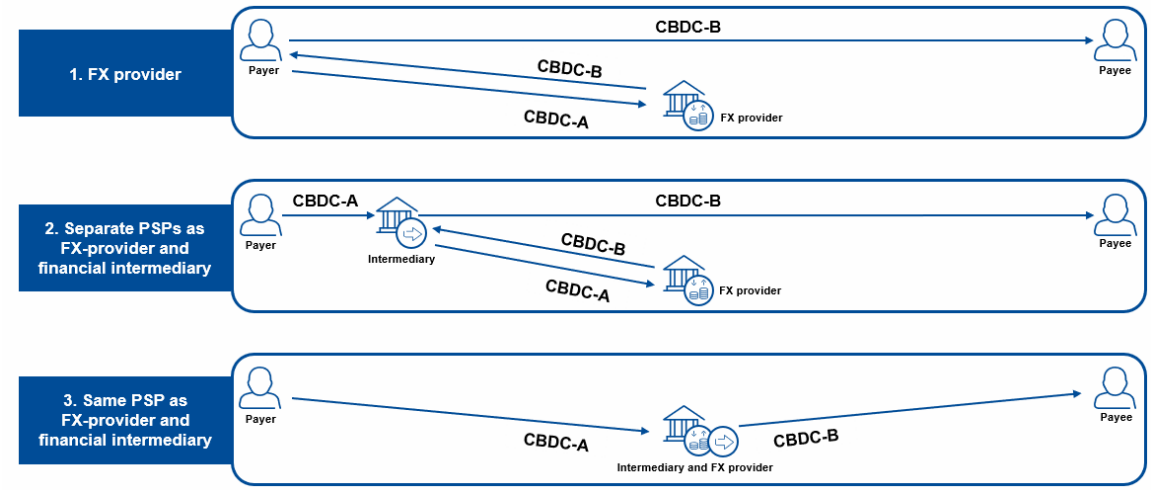
If the payer cannot hold and transact CBDC-B, a financial intermediary is needed. Model 2 is an example of this. In this model, the payer transfers CBDC-A to a financial intermediary that uses a third-party foreign exchange provider to exchange the CBDC-A for CBDC-B before sending it to the payee. This model assumes that the financial intermediary can hold and transact both CBDC-A and CBDC-B.

As the third model, we can think of one PSP taking the role of both financial intermediary and foreign exchange provider. The payer pays CBDC-A to the foreign exchange provider, who pays CBDC-B to the payee. All models rest on the foreign exchange provider being able to hold and transact both CBDC-A and CBDC-B.

All three models include a foreign exchange provision role, and two of the models include an intermediary role. With this comes counterparty risk unless there is some form of conditionality to the payment making it so that all legs happen, or none do. The more actors involved in a transfer, the greater the risk. We return to this issue in the PvP section in the settlement element.

Figure 3. Stylized Currency Conversion Models

The figure shows three stylized models for how an end user can use financial intermediaries and foreign exchange providers to exchange one currency for another.



Note: CBDC = central bank digital currency; FX = foreign exchange; PSP = payment service provider.
Source: IMF staff.

An entity only serving the role of financial intermediary does not need to hold any liquidity and can avoid currency risk, contrary to foreign exchange providers.[28] A foreign exchange provider carries currency risk and needs to manage liquidity in two currencies. Hence, financial intermediaries need to be able to transact large volumes of CBDC on their accounts, and foreign exchange providers might need to be able to hold large volumes on their accounts. Thus, access policies and holding/transaction limits for entities serving as foreign exchange providers and financial intermediaries will be important factors to consider.

[28] The intermediary can avoid currency risk if, for example, all legs of the payments are processed and settled instantly or on a payment vs. payment basis. See element 5 for more on instant settlement and payment vs payment. The intermediary may be expose to currency risk in the event of being in possession of the funds for an extended period of time.

For any of these arrangements to work, the market for foreign exchange must be sufficiently liquid. Market liquidity can be improved by concentrating order flows or improving price transparency (see, for example, Foucault and others 2013). Liquidity can also benefit from centralized foreign exchange services offered by a hub-and-spoke model or common platforms. See, for example, Adrian and others (2022) for how the centralization of information and foreign exchange trading, as well as greater competition and on-platform services like multi-currency auctions, can contribute to improving market liquidity. Similarly, the Icebreaker project demonstrated how a central hub in a communicator model could serve as a foreign exchange marketplace connecting end users with foreign exchange providers, decoupling the foreign exchange provision and financial intermediation from wallet provision. At the foreign exchange marketplace, users can choose the best foreign exchange provider and financial intermediary, leading to competition which is difficult to achieve with traditional banking relationships.

While such models can lower barriers for market entry and increase competition in foreign exchange provision, a question remains on how to incentivize a wider range of PSPs to join the market, which could be less profitable for incumbents (see BISIH and others 2023c, for more on the trade-offs associated with the foreign exchange model tested in Project Icebreaker). Lack of participation by foreign exchange providers leads to less liquidity in the market, which would not attract sufficient demand from the users. Hence, a well-functioning two-sided market might not be fully established. On this point, central banks could play an important role in providing foreign exchange in underserved corridors, although this might not fall within the mandate of all central banks. Another potential issue with separate foreign exchange markets incorporated in cross-border arrangements is the risk of emergence of multiple exchange rates if the market is segmented and trades in CBDC are constrained. In addition, if multiple non-compatible platforms, or at least platforms with limited interoperability, emerge, there is a risk of segmentation of liquidity. Such segmentation can lead to less efficient price discovery. Moreover, managing liquidity across multiple platforms or dealing with varying regulatory environments adds complexity and operational risk.

Foreign Exchange Liquidity Management

In addition to who provides foreign exchange, there is a question of how the foreign exchange providers manage their liquidity. In fact, some central banks are considering limits on transaction or holding, and such restrictions can impact foreign exchange providers' liquidity. Most of these restrictions are considered to apply only to individuals, but restrictions could also be imposed on other participants in the CBDC ecosystem. As highlighted in the access element, any restrictions must be designed to not hinder financial intermediation and foreign exchange provision. If cross-border CBDC payments are to be instant, foreign exchange providers need to either hold large amounts of CBDC or be able to fund their accounts instantly. Funding CBDC accounts can be done automatically from a "reverse waterfall" account—where CBDC payments made are instantly funded from another form of money.[29] This other form of money can be a reserve account with the central bank or a commercial bank account. In the former case, where foreign exchange providers have reserve accounts, the pool of potential foreign exchange providers could shrink significantly if access to the central bank balance sheet is restrictive.

[29] See Annex III for further details on waterfall accounts and alternative models.

Suppose instead reverse waterfall accounts can be commercial bank accounts; in that case, commercial banks will serve as liquidity providers and need to be able to hold CBDC liquidity or be able to fund their accounts instantly. However, holding liquidity in CBDC should be superior to ensure speedy transactions and leverage safety benefits. Thus, expanding access to CBDC or central bank reserves can be beneficial to reduce risks.

In either case, any holding limits imposed on intermediaries and foreign exchange providers (or liquidity providers) need careful consideration, and the ability to fund CBDC accounts instantly 24/7 becomes an important design feature. Since many central bank RTGS systems are not operating 24/7, the ability to convert central bank reserves to CBDC outside of operating hours could be limited. Thus, allowing foreign exchange providers, or other liquidity providers in the ecosystem, to hold sufficient CBDC liquidity becomes important.

In addition, the cross-border arrangements themselves can provide facilities to help with liquidity. These facilities could, for example, be in the form of liquidity bridges managed by the central banks (CPMI 2022c) or Automated Market Makers (AMMs) (BISIH and others 2023a).

Central bank liquidity bridges refer to a mechanism through which central banks can provide liquidity to financial institutions, such as banks. These bridges are essentially arrangements, liquidity pools, which allow financial institutions to borrow from the central banks and are made available on a short-term basis. The funds in the liquidity pool can be used by these institutions to meet their immediate funding needs, such as to cover unexpected cross-border flows by depositors. For example, liquidity pledged at one central bank can be used as collateral in another central bank (CPMI 2022c). In liquidity bridges, foreign exchange providers can use a local CBDC as collateral to the local central bank and borrow a foreign CBDC from the counterparty central banks. This approach could reduce the cost of foreign exchange liquidity management and the risks of currency, credit, and settlement. The collateral can potentially be other financial assets, such as government bonds and commercial papers, depending on the terms set by the central banks. Thus, central banks need to consider how such liquidity and collateral arrangement could impact CBDC system design.

Another approach is to deploy AMMs. AMMs, typically decentralized, utilize algorithms and smart contracts to provide liquidity and determine asset prices. While primarily used for crypto assets, ongoing projects, like Project Mariana (BISIH and others 2023a), explore the application of AMMs in non-crypto settings. The basic idea behind AMMs is that when a user wants to make a trade, they simply deposit one asset into the pool and receive the other in exchange. AMMs offer advantages such as liquidity provision for illiquid assets by pooling assets from various providers and 24/7 operation due to their automated decentralized exchange protocol. However, challenges arise regarding user costs, particularly when the fund supply is limited. Central banks can potentially address these challenges by providing liquidity when it is scarce. Another challenge involves determining the price between different assets. AMMs employ mathematical formulas to set prices, but discrepancies with external prices may prevent traders from executing trades at fair market prices, leading to suboptimal outcomes. One solution is integrating real-time oracles, a third-party service, that provides accurate external price information, enabling the AMM to adjust its calculations accordingly. However, determining the relevant external price and update frequency is a non-trivial task. Other challenges and risks with AMMs include potential increase in operational complexity and cybersecurity risks, as well and scalability and network congestion.

Liquidity bridges and AMMs are decisions likely taken at a later stage when formal cross-border arrangements are to be determined. However, such arrangements might impact the optimal CBDC design. For example, since AMMs typically rest on smart contracts to provide a technical escrow, such functionality, or similar, would be important to consider in the CBDC design.

Key Design Considerations: Currency Conversion

Currency conversion is primarily about access. Most cross-border payments will likely involve a foreign exchange provider and intermediary. To this end, the access policies, restrictions, and limits for potential foreign exchange providers and intermediaries are critical. Central banks should consider efforts to expand the pool of potential PSPs taking such roles, and any competition-enhancing efforts available should be considered. Decoupling of PSP services might be a tool to enhance competition but can also discourage market entry in some cases. Establishing liquidity arrangements might be important to serve corridors with lower trade and remittance volumes. To this end, central banks should also consider their own role in providing liquidity or currency conversion, as well as escrow functionality. 24/7 CBDC funding ability is also important to facilitate more flexible liquidity management. Key design considerations where cross-border attention is needed include the following:

- PSP access and limits (see Access)
- PSP competition aspects
- Foreign exchange liquidity management
- Escrow functionality
- 24/7 CBDC funding ability

Element 4: Compliance

Any cross-border arrangement must comply with relevant legal and regulatory requirements. To this end, roles of and responsibilities for various actors in a CBDC ecosystem with respect to regulatory compliance become key design considerations. Compared to the current landscape, the roles and responsibilities of entities involved in compliance might not be straightforward in a CBDC setting, and especially international standards and domestic legal and regulatory frameworks are still evolving. In addition, design options such as those intended to enhance privacy may require even more thought. These design options will bear an impact in both the domestic setting and the cross-border setting, and policy trade-offs may arise.

Financial Integrity

CBDC arrangements, whether domestic or cross-border, must adhere to AML/CFT standards and laws. The Financial Action Task Force (FATF) standards apply to CBDCs as it does to any other form of fiat currency. Jurisdictions issuing CBDCs need to assess and understand the risk associated with the CBDC being used for money laundering and terrorism financing and take measures to manage and mitigate these risks, including the application of AML/CFT preventive measures. Toward this end, thus,

intermediaries in a CBDC ecosystem that are covered by the FATF standards[30] would need to be regulated and supervised for AML/CFT purposes. Compliance challenges that arise in a CBDC setting will be similar if not identical to those present in the current financial system, but it is important to analyze and understand if there may be novel and unprecedented risks emerging. Compliance implications are also likely to vary depending on the specific design choices adopted. When considering the impact of design choices on compliance, it is important to note that the CBDC ecosystem would be more complex in a retail than in a wholesale setting and, similarly, more complex in a cross-border versus domestic arrangement, particularly regarding financial integrity concerns. However, this does not necessarily imply that a CBDC system would be more complex than current systems as it will depend on design.

Additional compliance considerations are also likely to be raised by the introduction of new intermediaries or changes in the services and/or products provided by existing service providers (particularly those that historically have not been subject to AML/CFT rules and regulations).[31] Since a CBDC is issued by the central bank, the nature of customer accounts and the relationship between end users and PSPs may be different in a CBDC system compared to the current retail banking model. In addition, solutions such as many-to-one mapping of CBDC service providers to end users as presented in Project Sela (BISIH and others 2023b) can present new complexities as well and will require further research.

CBDC will face the same challenges as the current system when it comes to challenges with different regulatory frameworks and uneven application of AML/CFT rules and regulations across jurisdictions. CBDC alone would not solve the issue. Counterparties may still refuse to service countries with weak implementation of AML/CFT rules even if CBDCs were available. In the case the introduction of CBDC leads to a reduction in the number of intermediaries involved in cross-border payments, some risks and challenges associated to compliance checks could decrease. Long transaction chains often span multiple countries, each with its own regulatory framework and compliance standards, and they can lead to increased opacity and time delays.

The level of anonymity that would be permissible under the relevant standard is still unclear. Some central banks are considering allowing anonymous low-value transactions in a limited manner with their CBDCs domestically. Like cash, such models are vulnerable to misuse for illicit activities, such as money laundering and terrorism financing. The decision on whether and how to integrate features to allow for a degree of anonymity in transacting ultimately depends on the policy demands and priorities of the jurisdiction; however, regardless of a jurisdiction's decision in this regard, the FATF standards still apply. The cross-border dimension poses additional challenges, as jurisdictions may have different approaches to anonymous or pseudonymous payments. The same challenge applies to privacy—an individual's right to control the access and use of their information. Countries have different privacy policies and regulations, and difficulties will likely arise where countries wish to preserve the same privacy levels for cross-border payments as for domestic payments. To this end, the work in Project Aurora (BISIH 2023a) and Project Aurum 2.0 from the BIS Innovation Hub on privacy-enhancing technologies can play an important role.

[30] Namely any intermediary that qualifies as a financial institution, designated non-financial business or professional, or a virtual asset service provider, as defined in the FATF Glossary.

[31] In-depth analysis of the financial integrity implications and corruption risks of retail CBDCs will be addressed in a future IMF publication as a part of the CBDC Handbook.

Capital Flow Management Measures

Some countries rely on CFMs to limit risks arising from sudden and volatile capital flows. The IMF's Institutional View (IV) holds that CFMs can be potentially warranted in certain circumstances, but only if they do not substitute warranted macroeconomic adjustments (IMF 2022).

CFMs come in various forms, including authorization requirements, taxes, fees, or quantity limits on capital inflows or outflows. Traditionally, CFMs are applied by commercial banks and other financial service providers. These intermediaries collect information on capital flows, such as ultimate beneficiary and transaction purposes. They then use this information to apply CFMs as required by law. A CBDC system used for cross-border payments must be designed such that these checkpoints exist, and technology might play a role in this. CFMs can be described as well-defined rules or instructions. These instructions can be coded as an algorithm in the design of CBDC, which would make the CFMs automatic. This paper follows He and others (2023) and refers to this type of CFMs as "smart CFMs." The application of smart CFMs might require some streamlining of CFMs, if these are not particularly suitable for an algorithmic representation. In particular, a switch from discretionary CFMs to rule-based CFMs as much as is feasible might be necessary to reap the full benefits of digital application and automation.[32]

As described by He and others (2023), smart CFMs can be implemented broadly on three levels of the CBDC system. The first level is the one where end users interact to make payments—the technical interface. The second level is the core CBDC system operated by the central bank, while the third level would be for the central bank to coordinate with other central banks the implementation of CFMs on a cross-border platform that connects the CBDC rails, or payment systems, of different countries.

Using CFMs on the user interface can be effective for CFMs that only require basic information and do not need to be updated quickly. Private interface providers may not have the resources to implement or update CFMs quickly. Certain types of user interfaces, such as smart cards, may present difficulties in implementing CFMs that require more information as they need to be online to obtain stock information.

When the central bank implements CFMs directly within the CBDC architecture, it takes on the responsibility of both designing and enforcing the CFMs. This leads to a higher overall effectiveness for any type of CFMs, particularly for those that require a large amount of information and quick implementation. Additionally, the central bank is likely to have the majority of the required information. For example, if there is a database containing cross-border stock information, it will likely be housed within the central bank.

The ability of central banks to implement CFMs in multilateral platforms, such as the common platforms presented in Box 2, depends on the platforms' governance. The application of CFMs on the platform might not be allowed, and both the national legislation of the participating countries and the platform itself must have established roles, procedures, and responsibilities for their potential application. In addition, if the platform is operated by the private sector or a collection of central banks, changes and application are likely to be slow. However, flexible technical designs can be used to accommodate different CFMs across jurisdictions. For example, project mBridge has introduced the Lego-Bricks Approach that modularizes various rules and functions such as payment, foreign exchange, capital

[32] Other restrictions, such as for current payments (for example, payment for trade and services) could conceptually also be applied through "smart" integration via code in a similar way as for CFMs. However, Articles of Agreement of the IMF, Article VIII, Section 2(a), states that a member may not impose restrictions on the making of payments and transfers for current international transactions without the (prior) approval of the IMF.

management, and AML/CFT. The participating central banks and monetary authorities of different jurisdictions can make flexible combinations of the modules according to their needs, such as to implement CFMs.[33]

Key Design Considerations: Compliance

It is important to carefully analyze cross-border implications for compliance issues, and it is necessary to balance objectives, roles, and responsibilities. Compliance responsibility must be established, and efforts to harmonize and simplify compliance checks are also important for CBDC. Central banks should consider the potential implications of having different privacy and anonymity levels for domestic and cross-border payments since domestic choices might not be feasible in all cross-border arrangements. Utilizing new technologies to ensure privacy while enhancing compliance checks and CFMs is important consideration. Any central bank needs to ensure that the legal and policy frameworks are as robust and transparent as possible so to minimize legal risks. Key design considerations where cross-border attention is needed include the following:

- Roles and responsibilities in the ecosystem
- Anonymity and privacy measures
- Smart CFMs

Element 5: Settlement

As described in element 3, in the case of a cross-currency payment, there are two payments: one in currency A and the other in currency B. These two payments need to be settled. Settlement finality refers to the irrevocable and unconditional transfer of ownership of financial assets between parties in a financial transaction. In simpler terms, once a settlement is deemed final, the transaction is considered complete, and the parties involved can no longer reverse or cancel it. A core problem in a cross-currency payment is the settlement risk that arises due to the presence of two payments.

In addition to strong legal and regulatory frameworks, including the legal aspect of settlement finality,[34] two design choices play a crucial role in reducing settlement risk in cross-currency trades. First, 24/7 availability and instant settlement remove any settlement risk caused by timing and a mismatch of operating hours. Second, PvP settlement functions can reduce settlement risk by reducing the counterparty risk, often referred to as principal risk or Herstatt risk. Other measures, such as emergency liquidity assistance, can reduce counterparty default risk but go beyond the scope of this paper. The foreign exchange models presented earlier in Figure 3 can be used to exemplify the settlement risks. In

[33] Lessons from Project Mandala—a proof-of-concept run by BISIH Singapore Centre, the Reserve Bank of Australia, the Bank of Korea, the Central Bank of Malaysia, and the Monetary Authority of Singapore exploring the feasibility of encoding jurisdiction-specific policy and regulatory requirements into a common protocol for cross-border transactions—will also be important as the project advances.

[34] As the legal certainty in the protection of settlement finality could differ across jurisdictions, there could be potential risk for retail cross-border payments if legal uncertainty remained. This also pertains to probabilistic finality in cases where distributed ledger technologies are used (CPMI-IOSCO 2022).

models 1 and 2, the foreign exchange provider would only deliver CBDC-B if certain that the CBDC-A will be delivered. Likewise, the payer would only send CBDC-A to the foreign exchange provider or the intermediary if certain to receive the CBDC-B or certain that the intermediary will pay the money to the payee. In addition, CBDC has a unique benefit in removing the issuer default risk since the asset is a liability of a central bank rather than a private entity.

Instant Settlement

Instant payments are processed and settled individually and continuously. This means that participants must maintain adequate balances to settle transactions at any time. In a CBDC setting, this is not a problem for the payer since they already hold the funds, and for the payee, instant settlement is a big benefit since they receive the funds directly without any delay.

In most foreign exchange transactions, trade execution and settlement are decoupled. This decoupling has the advantage that multilateral clearing and netting can be performed. The disadvantage is that there are long delays between trade execution and settlement. Instant settlement would imply that trade execution and settlement are one and the same. Hence, offering foreign exchange from currency A to currency B implies that the foreign exchange provider needs to hold liquidity in currency B at the trade moment. Hence, if foreign exchange providers are to offer CBDC foreign exchange services, they would need to forecast the CBDC liquidity need. Alternatively, the foreign exchange provider needs to be able to instantly secure the CBDC liquidity needed by, for example, utilizing an intraday credit offered by the central bank, or instant issuance of new CBDC. Most central banks consider a CBDC design with 24/7 availability and therefore need to consider any potential side effects related to liquidity management for foreign exchange providers and financial intermediaries in a cross-border setting.

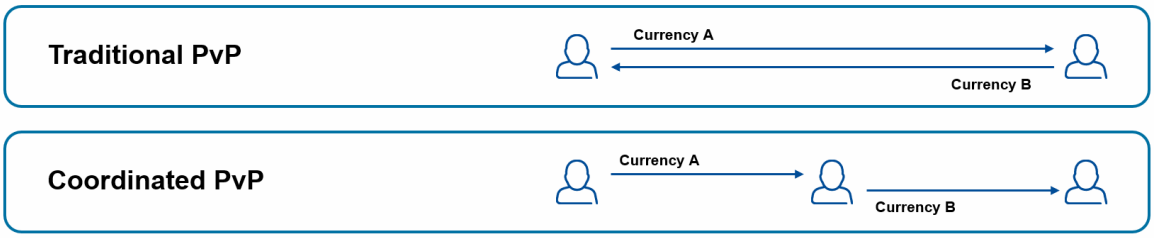
Instant settlement and 24/7 availability come with challenges such as managing liquidity in real time and ensuring operational and cybersecurity in a 24/7 environment. Another issue that arises with instant settlement is how to prevent fraud. In many payment scenarios, the person making the payment can recall the payment in case of an error before it is settled. However, in the case of instant settlement, the payment is completed within seconds, and once completed, it cannot be canceled. Moreover, the recipient can withdraw the funds immediately. This creates a challenge in detecting and stopping fraudulent payments, particularly when the recipient is the bad actor. This issue is relevant for domestic payments, and it becomes even more complicated for cross-border payments. These trade-offs must be considered and studied during the design phase of a CBDC project.

Payment versus Payment

Currently, most cross-border retail payments rely on trusted relationships. Payers typically have a long-standing relationship with their PSP and trust that the PSP will carry out the actions needed for the payee to receive the money. In the foreign exchange market between banks, trust is not always the only factor. Arrangements for PvP are available for the major currencies via the use of a common platform, such as CLS (see CPMI 2022a). Based on the models presented in Figure 3, we classify two forms of PvP: traditional PvP, where two actors exchange currencies, and coordinated (or one-directional) PvP, where there is an intermediary (see Figure 4).

Figure 4. Stylized Models for Payment versus Payment (PvP)

In the traditional model, two individuals, or entities, exchange currencies with each other. In the coordinated model, it is a one-way PvP, such that there is an intermediary in between the two individuals.



Note: PvP = payment versus payment.
Source: IMF staff.

In a retail CBDC setting, an intermediary is likely needed. Hence, a cross-border retail CBDC arrangement using PvP will probably have a "coordinated" setting, such as case 3 in Figure 3. Note that case 1 in Figure 3 would have a traditional PvP function, while case 2 would have both a traditional and a coordinated part.

The choice of communication infrastructure will play a role in implementing PvP, regardless of it being traditional or coordinated PvP. In the case of a common platform, PvP is simple to facilitate, while PvP across systems is more complicated and often comes with some additional risk of failure. However, standardized communication and formal interlinking of systems reduce the risk. There are two main approaches for achieving PvP: third-party-based and peer-to-peer.

PvP can be implemented via the use of a trusted third party to facilitate the exchange of assets between two parties. The third party can take different forms, but the basic premise is that it acts as an intermediary that verifies the receipt of both assets and releases them to the respective parties. The third party can be an entity that acts as a central counterparty (CCP) so that the funds are paid to the entity, who in turn pays the final beneficiaries. The main role of such a CCP is to mitigate counterparty risk between market participants. In a typical transaction between two parties, each party is exposed to the credit and default risk of the other party. By using a CCP, both parties can reduce their counterparty risk, as the CCP becomes the counterparty to each trade.

An alternative to using a third party is to use peer-to-peer transactions which can be achieved in different ways. It is typically achieved via the use of "technical escrow" (or "smart contracts").[35] Technical escrow uses technical locks, rather than third-party accounts, with some conditionality to unlock the money. This allows for peer-to-peer transactions. This exchange can be orchestrated by a technical "oracle" taking a role where the trusted oracle countersigns the transactions without actually holding any funds.[36] Instead of an oracle, atomic swaps can be used. A common alternative for atomic swaps is to

[35] Technical escrow refers here to a risk management tool in transactions that involves computer software to ensure that the funds can be released to the beneficiary if certain predefined conditions materialize. Such functionality is often called smart contracts, which are extensively mentioned in the blockchain discussion. However, it is worth noting that the concept of smart contracts has been introduced much earlier than the emergence of blockchain, and blockchain is not the only technology on which smart contracts can be deployed and executed.

[36] Depending on the design of the oracle, it can be considered a third-party. The oracle can however be purely technical and an integrated part of the system without manual intervention.

use HTLC. HTLC can take different forms, but a traditional PvP can be seen in two stages: first, the payer locks a payment with hash of a secret, and the payee reciprocates with a mirrored payment. In the second stage, the payer reveals the secret to unlock the payee's payment, initiating a chain reaction that allows both parties to access their respective funds.[37]

The key difference between PvP by third party or peer-to-peer is the trust required between the parties. A third-party-based arrangement relies on a third-party entity to ensure that both parties receive their respective assets, which requires trust in the third-party entity. By contrast, peer-to-peer transactions do not require a third party to facilitate the exchange of assets but require trust in the technology implementation of the protocol.

For the CBDC design, ledger technology becomes an important factor to consider. While technology with innate smart contract functionality can facilitate certain protocols using trust in technology, the same protocol can be achieved with less advanced technology and even analog methods, implying that a trusted third party is needed.

Key Design Considerations: Settlement

Instant settlement and 24/7 availability, together with PvP functionalities, emerge as important to enhance cross-border payments since they reduce the settlement risk. Recent CBDC experiment and, more generally, cross-border experiments are all heavily focused on speed and utilizing smart contracts to facilitate PvP settlement. Hence, future cross-border arrangements might require programmability or alternative methods to follow such protocols, and this becomes an important design feature to consider. Key design considerations where cross-border attention is needed include the following:

- Instant settlement
- 24/7 availability
- Programmability

[37] See Annex IV for how Project Icebreaker implemented a coordinated PvP case using HTLC. It is also useful to note that the HTLC protocols can present the risk of non-atomicity due to operational events.

4. Conclusions

When designing retail CBDC systems, it is beneficial to factor in cross-border implications from the start. Even if cross-border payments are not considered to be available at the initial launch, avoiding unintended barriers for potential later stages is important. This importance was recognized in the G20 Roadmap, where Building block 19 consider "Factoring an international dimension into CBDC design" (BIS, IMF, World Bank 2021 and 2022). This paper further assists central bank in their efforts to factoring in an international dimension in their CBDC exploration.

While this paper has focused on retail CBDC, many of the lessons apply also to wholesale CBDC and other forms of money. A retail CBDC is intended to be available for household, providing them with direct access to central bank money. Instead, a wholesale CBDC is typically intended to only be available to banks and financial institutions. With a retail CBDC, households within a country transact directly and thus need fewer financial intermediaries. These are, however, likely to be needed in a cross-border payment, to convert currencies and expand access to foreign market. That said, using a retail CBDC for cross-border payments can reduce the total number of intermediaries needed, and can lower credit and settlement risks for users. If a retail CBDC is not available for cross-border payments, retail users could still benefit from cross-border wholesale CBDC arrangements. These can deliver more efficient interbank cross-border payments, which would ideally trickle down to faster and cheaper payments for end users.

Given that the future cross-border payments landscape is still unfolding and potentially fragmented, central banks should ensure their retail CBDC systems to be able to "plug in" to different forms of arrangements. Such flexible or modular design refers to an approach where systems are built using components that can be easily modified, replaced, or extended without requiring significant changes to the overall architecture.

A strong focus on international collaboration with other central banks is also important for central banks to consider. Establishing agreements, collaborations, and mechanisms to facilitate information sharing and policy coordination is paramount to the viability of these arrangements and their ability to facilitate and enhance cross-border payments. International organizations such as the International Monetary Fund, the World Bank, and the Bank for International Settlements play a significant role in fostering cooperation and providing capacity development and guidance. Such international cooperation can be more impactful if achieved at a global level to avoid fragmentation and walled gardens. Additionally, the priority actions agreed under the G20 Roadmap in the coming years will be important.

To factor in cross-border implications right from the start is not a trivial task. Central banks can establish a cross-border workstream in their CBDC exploration in an effort to consider cross-border implications. This paper has viewed cross-border payments through the lens of five elements, allowing us to identify and present some core design and policy options that central banks need to view from a cross-border perspective. However, this analysis is not comprehensive, and any technical and policy design considerations during the CBDC exploration should be viewed through the lens of cross-border payments. The questions listed in Box 3 provide additional guidance.

Box 3. Guiding Baseline Questions When Factoring in Cross-Border Implications in the CBDC Design

General

1. What are the cross-border-related objectives?
2. What role should the central bank play in facilitating cross-border payments?

Access

3. Do non-residents have access to the CBDC, and what are the rules and criteria for that access?
4. What are the rules and access criteria for financial intermediaries and foreign exchange providers?

Communication

5. What data and messaging standard(s) do the system support?
6. Are we following the guidance from CPMI on ISO 20022 implementation?
7. What standards are used for payment initiation (for example, proxies, QR code, NFC)?
8. What digital ID framework is necessary to ensure smooth and efficient cross-border transactions?
9. Is the system or the wallet providers responsible for identifying that it is a cross-border payment?
10. Should there be a national gateway for any formal interlinking with other systems?

Currency conversion

11. Who is providing foreign exchange and how are end users matched with the foreign exchange provider?
12. What is the role of the central bank in facilitating foreign exchange transactions and liquidity?

Compliance

13. How will international AML/CFT standards be incorporated into the system's compliance framework?
14. Who is responsible for AML/CFT compliance checks (including KYC)?
15. Who is responsible for CFM compliance checks?
16. Should AML/CFT compliance checks (including KYC) be automated and/or centralized?
17. Should “smart CFMs” be implemented, and at what level?

Settlement

18. Should the system offer programmability options, for example, smart contracts, to facilitate PvP?
19. Should a centralized trusted oracle/CCP be part of the baseline CBDC ecosystem?

Annex I. Traditional Arrangements through the Lens of the Five Elements

	Correspondent	Closed loop	Aggregator
Access	Bilateral setup between banks to ensure indirect access to different assets and systems	Payer and payee interact directly with the same Money Transfer Operator (MTO) that holds a global network of bank accounts utilizing direct access or indirect via correspondent banks	Payer and payee PSPs interact with the aggregator that holds a global network of bank accounts utilizing direct access or indirect via correspondent banks
Communication	Communication takes place between the correspondent bank and the respondent bank through a secure network (for example, SWIFT)	Communication can be done internally within the MTO and via, for example, the SWIFT network or communication with the correspondent banks	Aggregator can provide APIs to connected PSPs and can also communicate via, for example, the SWIFT network
Currency conversion	Each PSP determines what currency conversion rate to offer to its end users. The currency conversion process is typically handled by the correspondent bank, and currency exchange rates can be negotiated between the banks	The foreign exchange is typically provided by the MTO using its held liquidity in different currencies and takes place by debiting a MTO account in the sending currency and crediting an MTO account in the receiving currency	Typically provided by the aggregator to PSPs utilizing the foreign exchange services of the aggregator, which both comes from its centrally negotiated foreign exchange rates with larger banks and its held liquidity in different currencies. In turn, each PSP determines what currency conversion rate to offer to its end users
Compliance	The PSPs and each correspondent bank in the chain are responsible for compliance checks	The MTO or local correspondent bank providing account to the MTO is responsible for compliance checks	The end user PSPs and the aggregator and/or local correspondent bank providing account to the aggregator are responsible for compliance checks
Settlement	Settlement between bank accounts held at correspondent banks can be done bilaterally using the SWIFT network or utilizing a local FMIs, if both correspondent banks are members	The financial settlement of the transaction takes place by debiting an MTO account in sending currency and crediting an MTO account in receiving currency. The internal bookkeeping updates in real time	The aggregator provides instant settlement messages to the member PSPs and sends settlement instructions to its network of correspondent banks or local FMIs

Annex II. eNaira as a Payment Option for Inbound Remittances

The Central Bank of Nigeria (CBN) has introduced the eNaira as a payment option for inbound remittances. Hence, while the payment in the foreign currency might occur using other means than CBDC, the international money transfer operator (IMTO) can make the payment to the recipient using eNaira. As per the "Operational framework for eNaira payment option to recipients of diaspora remittances," the following guidelines are provided:[38]

1. IMTOs are to apply for a one-time "No Objection" to pay out in eNaira from the CBN.
2. The CBN shall provide account details where foreign currency from the IMTOs shall be received.
3. IMTOs are required to open Merchant Wallets through the CBN.
4. IMTOs are to prefund the CBN account mentioned in (2) above with foreign currency.
5. The CBN will subsequently fund the IMTO Merchant Wallet with eNaira equivalent of the foreign currency earlier prefunded by the IMTO.
6. Payment procedure shall be as follows:
    a. Sender initiates diaspora transfer with IMTO of choice overseas providing details of beneficiary's wallet,
    b. IMTO logs into the eNaira web wallet portal, debits its eNaira Merchant wallet, and credits beneficiary with eNaira equivalent of foreign currency sent at origin using I&E window rate[39], or
    c. Alternatively, IMTO integrates with the eNaira portal from its platform via API provided by CBN and initiates transfer of eNaira equivalent of foreign currency sent at origin at the I&E window rate.

In other words, the payment process could be as follows. A payer residing in, for example, the USA sends US dollars to an IMTO. The IMTO deposits the dollar with the CBN in exchange for eNaira. The IMTO then transfers eNaira to the wallet of the recipient of the remittances. This process requires a CBDC design that allows for IMTOs to open CBDC wallets. In its most simple form, the process can be viewed as model 3 in Figure 3 but can also be viewed as model 2 if the IMTO purely acts as intermediary and do not take the currency risk itself.

[38] See https://www.cbn.gov.ng/Out/2023/TED/TEDFEMPUBFPC001003.pdf.

[39] Investors and Exporters (I&E) window rates are the exchange rates at which investors and exporters can buy and sell foreign currencies at market-determined rates.

Annex III. Foreign Exchange Provider Restrictions

Some central banks are considering transaction or holding limits. Most of these restrictions are considered to apply to individuals but could also be imposed on other participants in the CBDC ecosystem. Some central banks might wish to restrict the amount of retail CBDC that entities can hold, and some central banks might want to limit holdings by financial institutions and other PSPs. While it is likely that foreign exchange providers will be commercial banks, efforts to allow for a more diverse group of foreign exchange providers might be beneficial from a competition standpoint. Hence, it is unclear who would take the role of foreign exchange provider, and potential limits can impact foreign exchange providers and the currency conversion mechanism in a cross-border arrangement.

One alternative to solve problems with limits is to use a "waterfall model." Suppose the payer is sending CBDC-A to a foreign exchange provider wallet, but the wallet with the additional funds will be over the limit. To ensure seamless experience for end users, the foreign exchange wallet must be able to receive the funds. One possible way to address this problem would be for any payment taking CBDC holdings above a certain limit to be accepted but trigger an automatic transfer of the excess funds from the CBDC wallet to another asset. This asset could be a designated reserve account, a wholesale CBDC wallet, or an account with a commercial bank. Hence, each foreign exchange provider would have to designate a "waterfall" account. This model can also be used for handling limits for regular CBDC wallets held by individuals.

For the sending foreign exchange wallet, it is potentially more complicated. Since the foreign exchange provider is receiving CBDC-A in country A, the foreign exchange provider's wallet in country B would need to send CBDC-B. Hence, the wallet would need to hold or source the funds. One alternative is for the wallet to instantly fund the wallet with the required amount of CBDC on a payment-by-payment basis. This model might, however, slow down the process since there would be an additional step in the payment chain. In addition, if set too low, the limits might cause a payment queue where one payment must wait for other payments to finalize.

An alternative model would be for the central bank to participate in each cross-border payment actively. Hence, instead of the payer sending CBDC to the foreign exchange provider and the foreign exchange provider sending CBDC to the payee, the instruction could be to redeem and issue CBDCs. That is, the payer could redeem its CBDC to the central bank who in turn issues reserves or a wholesale CBDC to the foreign exchange provider or the foreign exchange provider's bank. Likewise, the foreign exchange provider could redeem a wholesale CBDC, or reserves, and request the central bank to issue CBDC directly to the payee. This model would be more complicated and likely significantly slower. In addition, if the foreign exchange provider is not eligible to hold reserves or a wholesale CBDC, the benefit of CBDC and central bank money would be lost from the perspective of the foreign exchange provider.

Yet another alternative is to do an overnight sweeping of accounts. This model would allow the foreign exchange provider to hold an unlimited amount of CBDC during the day but force the foreign exchange provider to convert the CBDC to reserves or a wholesale CBDC during monetary operations.

This would not only remove potential problems for monetary policy implementation but would also create friction in the retail CBDC foreign exchange market during these operations.

Finally, foreign exchange wallets can have special rules, and any CBDC holdings in these wallets can be given the same status as a wholesale CBDC or even reserves. Such a model would, however, limit the pool of entities taking the role of foreign exchange provider to the current institutes participating in RTGS systems.

Annex IV. Design Implications of the Icebreaker Protocol

The Icebreaker project is to date the only retail-focused, cross-border CBDC project, and we use this project as a case study to identify some important design options and considerations. Based on BIS and others (2023b),[40] the payment process in Icebreaker can be described in eight phases:

Phase 1: Payer enters currency and amount, and the payer wallet sends a quote request to the hub.

Phase 2: The hub retrieves the best available quote from its foreign exchange database and responds with the best quote and the identity of the associated foreign exchange provider.

Phase 3: If the payer accepts the quote, she proceeds by entering the payee's payment address/alias and the payer wallet sends a payment request to the payee wallet.

Phase 4: The payee wallet validates its wallet address and generates a secret and sends the verification results and returns a hash value of the secret to the payer wallet.[41]

Phase 5: The payer wallet creates a locked payment to the foreign exchange provider's payer-currency wallet.

Phase 6: The foreign exchange provider's payer-currency wallet sends the payment information and the hash value to the foreign exchange provider's payee-currency wallet where it creates a locked payment in the payee currency to the payee wallet.

Phase 7: The payee wallet recognizes there is a locked incoming payment and presents the secret (generated in phase 4) to the smart contract locking the incoming payment, and the funds are released to the payee wallet only if the calculated hash value of the presented secret matches the hash value used to lock the payment.

Phase 8: The secret is now revealed to the foreign exchange provider's payee-currency wallet and the secret is sent to the foreign exchange provider's payer-currency wallet where it presents the secret to the smart contract to unlock the incoming payer currency payment.

The steps, especially in phases 1–3, might be slightly different from a user's perspective depending on the use case. If the payer, for example, scans a QR code to initiate the payment, all the payment details such as amount, currency, and address would be entered at the same time. Regardless, using the above protocol, we can identify important design considerations for domestic CBDC systems.

The first step is payment initiation. Any domestic CBDC system needs to consider how cross-border payments would be initiated. This applies to both incoming and outgoing payments. For incoming payments, one relevant design feature is whether QR codes, NFC messages, and aliases are available to and compatible with foreign systems. For outgoing payments, the reverse question applies—are foreign systems "readable" by the domestic system directly, or is it up to the wallet provider to understand foreign systems and identify that a cross-border payment is to be initiated?

In an interlinking arrangement like Icebreaker, there is a question of whether each wallet or PSP communicates directly with the other systems (the hub in the Icebreaker case) or if the connection is

[40] See also https://www.bis.org/about/bisih/topics/cbdc/icebreaker.htm for more information about Project Icebreaker.

[41] The secret can be any set of information, for example a number or a phrase, while the hash value of a secret is an encryption of the secret that is easy to compute but it is impossible to compute the secret from the hash value.

centralized through a national gateway. The three systems connected in the Icebreaker project appear to have adopted different approaches, with Israel having a gateway, Sweden connecting via PSP nodes, and Norway directly to each non-hosted wallet.

While the project demonstrates that there is autonomy for central banks in how they design their systems, it also demonstrates that the design each system chooses will impact how those systems need to adopt to facilitate cross-border payments. A fundamental part of the Icebreaker model is the use of HTLC to facilitate coordinated PvP. BISIH and others (2023c) state that "[each CBDC] system must be able to implement HTLC-based conditional settlement." It is important to clarify that for the protocol to operate correctly, it is sufficient for the foreign exchange provider to know and trust the status of the different HTLC states locally within each system and inform their foreign counterpart wallet of the status. At no point does the foreign wallet depend on the implementation details of how that status was reached. As a result, the HTLC functionality can be implemented in very different ways in different CBDC systems, depending on the underlying technology.

If a jurisdiction envisions that there might be scope for cross-border arrangements that utilize HTLC-like functions to facilitate PvP, they ought to consider technological implications. A system using distributed ledger technologies can leverage native capabilities, such as smart contracts, to provide the desired HTLC protocol. We can think of smart contracts as "technical escrow" where neither party can access the money while under the control of the smart contract.

A system without smart contract capabilities might instead use an escrow agent. This agent will have the same duties as the smart contract: release the money to the recipient if the conditions are satisfied, and release it back to the sender in case of a time-out. The agent must be a trusted third party. Hence, a jurisdiction does not need to adopt a technology that allows for smart contracts, but they may then need to establish a trusted escrow agent to achieve a payment protocol as in Icebreaker. The trade-off between having a trusted third party and utilizing technology to establish trust must be assessed.

Icebreaker assumes, for simplicity, that foreign exchange providers have the liquidity needed. A production version might have functionalities to "reserve" liquidity between phase 1 (payer asking for a quote) and phase 6 (locking of the payee currency payment). Such reservation of funds and other ill will intents might prompt illicit behavior of spamming the hub for quotes. This can easily be avoided by banning wallets that misbehave or by putting restrictions on how many requests can be sent. The design implication is whether any such restrictions are handled at the hub-connection level or on the wallet level.

Another potential spamming problem relates to the secret-generating phase. There are three main potential places for the payer to approve and commit to the payment. It could be done in phase 1 before sending the quote request. But the payer would then initiate a payment with no information regarding the foreign exchange rate. It could instead be done in phase 3, just before the payer sends the payment request to the payee. But this would still imply that the payee does not have all information. The payer does not have verification that the receiver of the money is correct or the hash value. The payer approval and commitment to the payment could instead be before phase 5 when the locked payment is created.

The problem with approving and committing late in the process is that the payer can spam other systems and wallets with payment requests, forcing them to generate address validation and hash value responses. Careful balancing of the approval process and rules regarding misbehavior will be needed to ensure that only genuine payments are initiated. It is also unclear if these decisions will be fully up to each CBDC systems, or if the cross-border arrangement will dictate the approval process.

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