CENTRAL BANK DIGITAL CURRENCIES FOR CROSS-BORDER PAYMENTS

A Review of Current Experiments and Ideas

NOVEMBER 2021

WORLD BANK GROUP

FINANCE, COMPETITIVENESS & INNOVATION GLOBAL PRACTICE
Payment Systems Development Group

1818 H Street NW
Washington DC 20433
Telephone: 202-473-1000
Internet: www.worldbank.org

CENTRAL BANK DIGITAL CURRENCIES FOR CROSS-BORDER PAYMENTS

A Review of Current Experiments and Ideas

WORLD BANK GROUP

ACKNOWLEDGMENTS

This note was drafted by Biagio Bossone (Senior Payments Advisor, World Bank), Oya Ardic (Senior Financial Sector Specialist, World Bank) with contributions from Ahmed Faragallah (Senior Financial Sector Specialist, World Bank), Sheirin Iravantchi (Financial Sector Specialist, World Bank), Maria Chiara Malaguti (Senior Legal Advisor, World Bank), Gynedi Srinivas (Senior Financial Sector Specialist, World Bank), and Holti Banka (Financial Sector Specialist, World Bank). Harish Natarajan (Lead, Payments and Market Infrastructure, World Bank) provided overall guidance and coordination. This note is part of a three-piece World Bank package on CBDC. The other two include: *Central Bank Digital Currency: A Payments Perspective* (flagship report); *Central Bank Digital Currency Background Technical Note*.

TABLE OF CONTENTS

ACRONYMS AND ABBREVIATIONS

AMF	Arab Monetary Fund
AML/CFT	Anti-Money Laundering and Combating the Financing of Terrorism
ATM	Automated Teller Machine
AWPS	Africa Wide Payments System
BGP	Byzantine Generals Problem
BOC	Bank of Canada
BOE	Bank of England
BOT	Bank of Thailand
CAD	Canadian Dollar
CBDC	Central Bank Digital Currency
CPMI	Committee on Payments and Market Infrastructures
CRDR	Cross-Registered DR
CS	Credit Swiss
DEA4	
DLT	Distribute Ledger Technology
DR	Depository Receipt
FATF	Financial Action Task Force
FBA	Federated Byzantine Agreement
FIGI	Financial Inclusion Global Initiative
FSB	Financial Stability Board
FX	Foreign Exchange
GCC	Gulf Coordination Council
GPI	Global Payments Innovation
HKD	Hong Kong Dollar
KHMA	Hong Kong Monetary Authority
HTLC	Hashed Time Lock Contracts
IIN	Interbank Information Network
IOI	Indication of Interest
ITU	International Telecommunication Union
KYC	Know Your Customer
LVTS	Large Value Transfer System
MAS	Monetary Authority of Singapore
MSME	Micro Small Medium Enterprise
OMS	Omnibus Accounts
OTC	Over the Counter

PoC	Proof of Concept
POS	Point of Sale
PvP	Payment versus Payment
RBC	Royal Bank of Canada
RTGS	Real-time gross settlement
RPW	Remittances Prices Worldwide
SADC	Southern Africa Development Community
SCP	Stellar Consensus Protocol
SDEX	Stellar Decentralized Exchange
SDR	Special Drawing Right
SGD	Singapore Dollar
SPV	Special Purpose Vehicle
THB	Thai Baht
TTP	Trusted Third-Party
UAE	United Arab Emirates
USC	Utility Settlement Coin
U-W-CBDC	Universal W-CBDC
WBG	World Bank Group
W-CBDC	Wholesale CBDC
XLM	Stellar Lumen cryptocurrency
XRP	Ripple cryptocurrency

I. CONTEXT AND BACKGROUND

Over the years, the demand for seamless and inexpensive cross-border payments has grown in parallel with growth in international e-commerce, remittances and tourism.[2,3] Yet, cross-border payments have not kept pace with the intensive modernization that has characterized domestic payment services worldwide. Cross-border payments continue to be largely based on the old correspondent banking model, which has not quite benefited from the same flow of innovations as domestic payments have over the recent decades.[4, 5] This is mainly because managing change in the cross-border payment and settlement space is considerably more challenging than doing so in the area of domestic payments and settlements, due to the inevitable presence and complex interactions of multiple jurisdictions that feature different policy and regulatory requirements, use dissimilar standards and operating procedures, and difficulties in the organization of the necessary collective action.

When effecting cross-border payments, some key challenges affect end-users, commercial banks and central banks. Cross-border payments require intermediaries, and existing intermediaries benefit from high barriers to entry. In many cases, barriers stem from high fixed and sunk costs required to interface with users, comply with regulation, build trust in services, and operate large back-offices. In addition, size matters for these institutions: there are scale economies in liquidity and risk management, network externalities are prevalent in messaging, and access to multiple counterparties facilitates transactions. Restrictions on operating hours and payment processing cut-off times make end-users experience uncertainty on the status of payment transactions, while lack of transparency does not give them clarity on the fees that are charged for their execution. Commercial banks, on their side, suffer from the fragmented settlement infrastructure, the inability to adopt straight-through processing procedures, the high use of liquidity and the large involvement of manual operations, which result in increased cost for end-to-end payments processing. Finally, different regulations and standards set by central banks for domestic large-value payment and settlement systems that are used for the processing of cross-border payments create barriers for all but the largest banks to join multiple systems and increase the need for, and the number, of intermediaries required to complete cross-border payments.[6] As a result, the cost of services to end-users increase.

Other significant challenges affect cross-border payments to/from emerging market economies and developing countries. Since the global financial crisis, banks have been reducing the number of their correspondent networks and, over the past decade, cross-border correspondent bank relationships have declined by about one fifth. One of the largest drivers of this phenomenon appears to be banks' reconsideration of their business strategy.[7] Another key driver relates to risk considerations. As correspondent banks conduct business globally, they must comply with the relevant laws and regulations in all jurisdictions in which they operate. These include anti-money laundering and combating the financing of terrorism (AML/CFT) regulations, tax transparency codes, and economic and trade sanctions. In recent years, stringent enforcement of AML/CFT regulations, tax transparency requirements and economic and trade sanctions has resulted in high-profile actions and penalties across the banking industry.[8] Faced with higher regulatory expectations, several banks have chosen to scale down or stop providing correspondent services, concentrating the business in larger global transaction banks,[9] the so called "de-risking".[10] De-risking may threaten progress that has been achieved on financial inclusion, and also has the potential to reverse some of the progress made in reducing remittance prices and fees, if banks close or restrict access for money transfer operators.[11] Furthermore, the loss of corresponding banking relationships may have precarious consequences on monetary transmission channels, as small banks and payment services providers that are unable to bear the increased compliance costs by correspondent banks are pushed out of the market. Finally, and almost paradoxically, de-risking can frustrate AML/CFT objectives and may not be an effective way to fight financial crime and terrorism financing. By pushing higher risk transactions out of the regulated system into more opaque, informal channels, they become harder to monitor (the so called "re-risking").

Against this background, consideration has been given recently to whether and how new technology solutions applied to finance (FinTech) could reshape the cross-border payments landscape.[12] New technologies may reduce service shortcomings and alter market structure by favoring market platforms over intermediaries, remodeling business plans and firm boundaries, and encouraging entry. In fact, the emergence of distributed ledger technologies (DLT) as well as the entry into the market of providers like TransferWise, and the global payments innovation (GPI) initiative by SWIFT are revolutionizing cross-border payments, enabling transactions to be executed within minutes (see Annex 1). In addition, the role of BigTechs and global Stablecoin arrangements as providers of cross-border payment services might become prominent, due to the large network effects their solutions could bring that would lower transaction costs, widen access, and open the possibility of complementary services offered on social networking and e-commerce platforms of global scale. Obviously, these same solutions could also raise significant issues of monetary sovereignty and financial stability, creating policy challenges that would require the utmost attention.[13]

An alternative avenue to modernize delivery of cross-border payment services is being increasingly explored in the context of central banks issuing their own digital currency. A central bank digital currency (CBDC) could well incorporate options and features specifically designed to execute cross-border payments, with a view to reducing the inefficiencies and rents discussed above by shortening the payments value chain. CBDC would have many of the same implications on cross-border payment services and market structure as a hub & spoke network, but possibly with some unique qualities: by virtue of being a central bank liability, public trust in CBDC would be greater if the central bank had a sound reputation for managing currency issuance and circulation, for implementing monetary and exchange rate policies effectively, and for being in charge of national financial stability.

This report discusses the use of CBDCs for cross-border payments.[14] The report reviews the models that have been developed for this purpose to date and discusses critical legal issues that arise in the context of cross-border use of CBDC. While no CBDC project has an explicit focus on payments beyond the jurisdiction of the issuing central bank,[15] a number of central banks are working on cross-border payment models in parallel to their CBDC efforts,[16] and international cooperation among central banks on CBDC, including for cross-border payments, is intensifying.[17] The currently ongoing cooperative efforts, some of which will be reviewed in this report, focus on wholesale types of CBDC. Their analysis, and more broadly the analysis of how CBDC can improve the safety and efficiency of cross-border payment service delivery, are within the spirit of the WBG's recent work in the area of cross-border payments (Box 1).

The report is organized as follows. Section II specifically discusses the models developed jointly by the Bank of Canada, Bank of England, and Monetary Authority of Singapore, those developed jointly by the Bank of Thailand and Hong Kong Monetary Authority, those proposed under the R3 initiative, the model developed by the Saudi Arabian Monetary Authority Central Bank of the United Arab Emirates and the joint undertaking by the European Central Bank and Bank of Japan, and draws from the experience in Africa with cross-border payment systems lessons that could be used for "regional" CBDC arrangements. Section III evaluates how cross-border CBDCs address challenges of the existing correspondent banking arrangement. Section IV discusses the legal issues involved in cross-border use of CBDCs, and Section V concludes the report with some general remarks. Annex 1 describes recent important changes and initiatives in the realm of cross-border payments and Annex 2 illustrates experimental models of cross-border digital payment systems that are not based on CBDC and discusses the outlook for cross-border payments looking forward.

A caveat is in order as regards the scope of this report. The report is intended only to show how CBDC-based solutions can facilitate cross-border payments. To this end, the report reviews and evaluates models that are being considered by the international central banking and payments

BOX 1 SUMMARY OF THE KEY WORK DONE RECENTLY BY THE WORLD BANK GROUP ON CROSS-BORDER PAYMENTS

In the context of the work done by the Financial Stability Board (FSB) and Committee on Payments and Market Infrastructure (CPMI), the WBG has highlighted the specific challenges faced by micro, small and medium enterprises (MSMEs) and individuals in emerging market and developing countries and has also provided insights from the Remittances Prices Worldwide (RPW) database:

- The RPW results are contributing to bring attention to the topic of foreign exchange fees, role of competition and innovation.
- The WBG has highlighted the need to segment the cross-border payments landscape into: (i) large corporates; (ii) smaller local corporates, MSMEs, cross-border ecommerce and freelancers; and (iii) international remittances.
- The WBG has also shared its experience as leader of the global effort on remittances price reduction, which could be useful for the global effort on improving cross-border payments.

More broadly, the World Bank has pioneered and continues to be involved in some relevant work on regional integration of payments and market infrastructures. Some examples are:

- Informing the Arab Monetary Fund efforts to establish the Arab Regional Payments System—which seeks to bring real-time cross border payments reducing the time to seconds from the current 2.2 days and the cost from $33 to around $5. WB served on the advisory committee guiding this implementation, it went live in late 2020.
- Supporting the development of the Africa Wide Payments System (AWPS)—a virtual integration of existing sub-regional systems- as part of the Digital Economy for Africa (DE4A). The AWPS is seen as critical to reduce the cost of intra-Africa transactions to less than 1% of transaction value. We had supported the establishment of one of the sub-regional systems in the SADC region back in the early 2000's and are now contributing to expanding the offering of this sub-regional system to a cross-border retail payment system.
- The WBG is also working in the Pacific Region to develop domestic infrastructure in individual island countries which will all be also interconnected in the next stage.
- The World Bank's work on Digital ID (ID4D Initiative) and contributions to FATF's new guidance on Digital ID has relevance for cross-border payments as well. AML/CFT related compliance processes are one of the key frictions in the cross-border payment processes. Increased coverage and usage of Digital ID is seen as a key solution to this issue. The World Bank's ID4D initiative is seen as a key source of knowledge and research on Digital ID and further our deep country experience in implementing ID systems would be of relevance to the work on cross-border payments.
- The International Finance Corporation made a few investments in entities working on cross-border payments—notably Earthport (divested in 2019) and Currencycloud, which provided a platform for cross-border payments by leveraging accounts that Earthport and Currencycloud opened in multiple countries. Something like a Western Union but for more larger amounts but much smaller than payments of large corporates.

community and discusses some of advantages they feature and challenges they raise. The report does not assess or rank the models discussed on the observance of given standards or resolution of given challenges, nor does it make recommendations as to which model(s) would or should be preferable.

Moreover, the report is part of a World Bank three-piece package on CBDC, supplementing a Technical Background Report on CBDC as well as the flagship report on *Central Bank Digital Currency: The Payments Perspective.*

II. CBDCs FOR CROSS-BORDER PAYMENTS

THE BOC-BOE-MAS MODELS

Central banks and the payments industry are considering ways to improve cross-border systems. The Bank of Canada (BOC), Bank of England (BOE), and Monetary Authority of Singapore (MAS), in consultation with payment industry stakeholders,[18] have joined efforts to review the existing challenges and frictions that arise when undertaking cross-border payments and issued a report that explores proposals for new and more efficient models for processing cross-border transactions—from whose contents this section draws. Specifically, the report identifies the following challenges from end-users, commercial banks and central banks prospective: i) lack of transparency regarding payment status, visibility and certainty of outcome; ii) limited availability of cross-border payment services; iii) time taken for payment processing; iv) high costs associated with the correspondent banking model; and v) challenges associated with legacy payments infrastructure across networks, central banks and commercial banks.

The above report proposes three models. The first two models (which will not be discussed here) are based on enhancing existing domestic interbank payment systems using traditional technology.[19] Without changing the underlying correspondent banking model, these two models could overcome some, but not all, of the identified challenges and frictions. The third model builds on the experience from the Bank of Canada and Monetary Authority of Singapore with research on tokenized forms of central bank liabilities for domestic use cases and considers three variations based on issuing wholesale central bank digital currencies (W-CBDCs) as tokenized, limited-access form of central bank liabilities used for wholesale interbank payment and settlement transactions. In order not to confuse readers that may want to consult the original source, in the following the numeration of the W-CBDC model and its variants will remain indicated as Model 3a, 3b e 3c, respectively.

The descriptions below of Model 3 and its variants build on the following basic structure. Two countries (Country A and Country B) are considered, each with its own central bank (Central Bank A and Central Bank B) and one or more commercial banks (A1, A2, etc. in Country A, and B1, B2, etc. in Country B). The scenario is one where Bank A1 needs to make a payment across the border to Bank B1, and that Bank B1 needs ultimately to receive currency B. Bank A1 holds a settlement account with Central Bank A and, similarly, Bank B1 holds a settlement account with Central Bank B. Both countries have their existing real-time gross settlement (RTGS) platforms in place (RTGS platform A and RTGS platform B, respectively) for interbank payments and settlements within their jurisdictions. In both countries a new platform is created for the issuance, exchange, redemption and cancellation of W-CBDCs (referred to below as "W-CBDC platforms"). Thus, the W-CBDC platforms would operate in parallel with the existing RTGS platforms. W-CBDC platforms are assumed to be based on DLT. Finally, the conversion of W-CBDCs denominated in different currencies could take place through a new W-CBDC-specific foreign exchange (FX) market.

Some general considerations apply to Model 3 and its variants. The three variants assume a common W-CBDC infrastructure as well as common solutions to address service availability, payment visibility, and harmonized and data-rich messaging standards. Also, to enable interoperability of the various systems interlinked with the common W-CBDC infrastructure, consensus will be required of the participating jurisdictions around a governance framework, common standards, oversight requirements, etc. The onus will therefore be on the founding jurisdictions to agree on common solutions. Furthermore, the model implies an enhanced role for the central banks to process the issuance, tracking and redemption of W-CBDCs, both within and beyond their jurisdictions. The governance structure for operating the common W-CBDC platform will need to be evaluated and defined appropriately. Model 3 does not address the issue of access for non-banks or smaller banks to the common W-CBDC payment platform. Access policies will remain a decision for each national central bank. Overall, the cost of implementing any of the Model 3 variants in countries with less developed financial market infrastructure may prove prohibitive. This is likely to reduce the likelihood that Model 3 will be used by these countries to alleviate the challenges and frictions identified of existing cross-border payment methods. Finally, a parallel market for the exchange of W-CBDCs within each jurisdiction might emerge in addition to the existing currency exchanges. Further analysis would be required to evaluate the implications of such critical development.

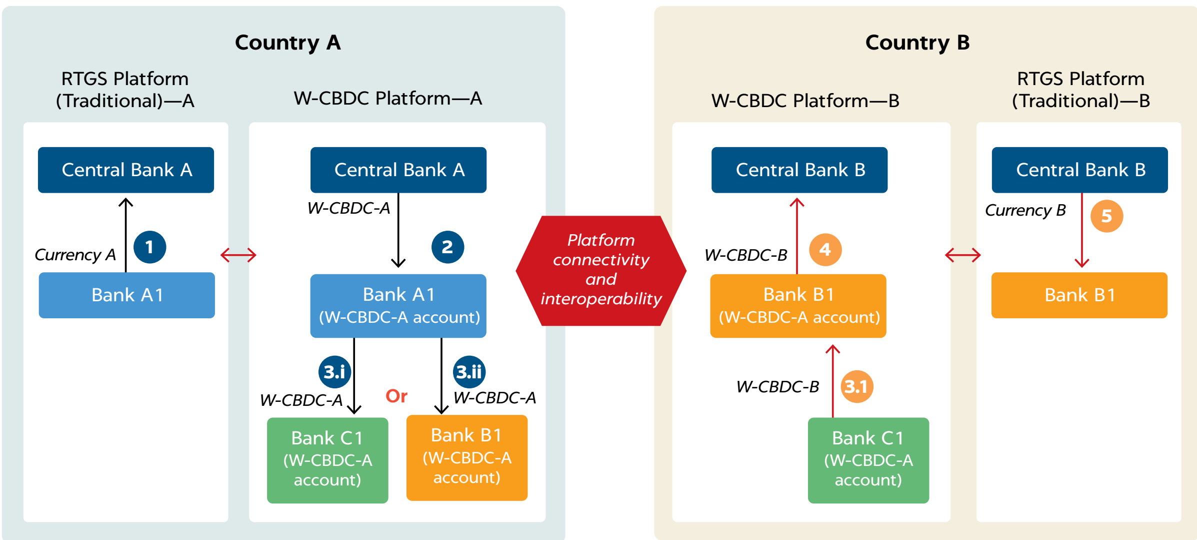
The BOC and MAS have further collaborated to explore the technical architecture for two of the proposed models (Model 3a and 3b). Under the Jasper-Ubin project, they have built a proof of concept (PoC) to understand the technical challenges in implementing these models. The project assumes that DLT-based domestic RTGS systems sit on different platforms in each country—the R3's Corda platform in Canada and JP Morgan's Quorum platform in Singapore. The project successfully implemented and demonstrated the ability to perform "atomic" transactions between a Quorum-based network in Singapore and a Corda-based network in Canada using and Hashed Time Lock Contracts (HTLC) to support the atomicity in transferring two assets across two separate ledgers.[20,21]

Model 3a

Model 3a is based on currency-specific W-CBDCs where these W-CBDCs can be transferred and exchanged only within their home jurisdictions and cannot be transferred outside their home jurisdictions. In this model, each central bank provides single-currency accounts (wallets) for W-CBDC, that's is, denominated only in their own currency. This would require commercial banks to open multiple account (wallets) with multiple central banks if they wish to hold multiple currencies.

Description of Model 3a. Each central bank issues its own W-CBDC, against its country's local currency, to the participating banks in its own jurisdiction. The two central banks enter into an agreement whereby participating banks from each jurisdiction maintain a W-CBDC account (wallet) with the central bank of the other jurisdiction denominated in the currency of that jurisdiction. These are single-currency accounts (wallets) and thus may hold only one digital currency. Alternatively, a bank operation in a third country could hold W-CBDC accounts (wallets) with the two central banks and offer correspondent services to banks in the two countries. As Chart 1 shows, Bank A1 maintains a W-CBDC-A account (wallet) in Country A and similarly Bank B1 maintains a W-CBDC-B account (wallet) in Country B. On the other hand, Bank C1 in Country C holds W-CBDC-A and

CHART 1 MODEL 3A



W-CBDC-B accounts (wallets) in Countries A and B, respectively, and offers correspondent services to A1 and B1.

Example of funds transfer. If Bank A1 wants to remit funds to Bank B1, it can transfer W-CBDC-A to Bank B1's account (wallet) at Central Bank A. Bank B1 would then have to exchange W-CBDC-A into W-CBDC-B. Alternatively, Bank A1 can effect an atomic, synchronized transfer of W-CBDC-A from itself to Bank C1 and W-CBDC-B from Bank C1 to Bank B1.

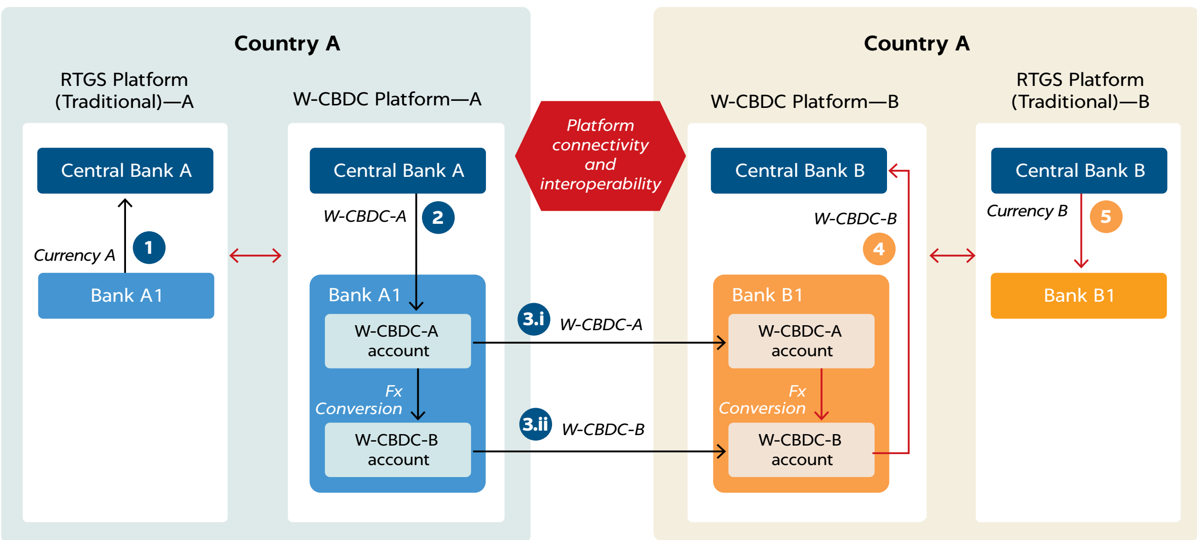
Considerations. This solution retains a dependency on intermediary (i.e., correspondent) banks for cross-border payments and settlement. In fact, it is nothing more or less than a tokenized form of the currently existing model. Importantly, for the model to substantially address the challenges of the status quo, access to settlement accounts should be broadened to enable entities to hold W-CBDC wallets in each RTGS system (which remains a decision for each participating central bank to take): without broader access, the solution would end up resembling the current correspondent banking model, where banks with liquidity in multiple digital currencies will offer services to those without. Also, as in the traditional model, in Model 3a correspondent banks would need to ensure adequate funding of W-CBDC accounts to be able to honor payment obligations. This requires the monitoring of positions and appropriate balance sheet management similar to current practices: trapped liquidity would remain a significant issue for banks with networks of nostro/vostro accounts. Furthermore, usage of W-CBDCs does not remove the credit risk arising from the use of correspondent banks. Finally, the development of a Model 3a platform for cross-border payments could deliver some relief from some challenges, in particular as regards interoperability between members, transparency for users, and 24-7 availability. However, such reliefs would be due to the new platform, not the use of W-CBDC per se.

Model 3b

Model 3b is similar to Model 3a but based on currency-specific W-CBDCs that can be transferred and exchanged beyond their home jurisdictions. In this model, commercial banks can hold multiple W-CBDC accounts (wallets) with their home central bank (e.g., a bank based in Canada can hold W-CBDC in Canadian dollars as well as pounds sterling and Singapore dollars in a wallet with the Bank of Canada). This would require each central bank to support multiple W-CBDC tokens.

Description of Model 3b. Central Banks A and B enter into an agreement whereby participating banks in both countries may hold and exchange the W-CBDCs issued by both central banks with each other. This means, for instance, that W-CBDC-A can be held by banks in Country B and W-CBDC-B can be held by banks in Country A. Each participating bank maintains multi-currency W-CBDC accounts (or wallets) with the central bank of its own jurisdiction. As Chart 2 shows, Bank A1 maintains W-CBDC-A and W-CBDC-B in one or more account (wallets) with Central Bank A, and likewise for Bank B1 with Central Bank B.

CHART 2 MODEL 3B



Example of funds transfer. If Bank A1 wants to remit funds to Bank B1, it can transfer W-CBDC-B form its account (wallet) held at Central Bank A to the W-CBDC-B account (wallet) that Bank B1 holds at Central Bank A. Alternatively, Bank A1 can transfer W-CBDC-B from its account (wallet) at Central Bank B and further transfer W-CBDC-B to the W-CBDC-B account (wallet) that Bank B1 holds at Central Bank B.

Considerations. In this model, holding a W-CBDC beyond the home jurisdiction offers the possibility of greater efficiency via peer-to-peer exchange, with reduced reliance on the correspondent banking model. However, the model requires the opening or holding of multicurrency accounts in each RTGS—a significant departure from the status quo. Also, central banks would have to consider the impact that the creation of W-CBDCs would have on money supply and monetary policy when W-CBDCs are circulated in other jurisdictions. In addition, the impact should be evaluated for participating central banks holding on their balance sheet other central banks' W-CBDC intra-daily and potentially overnight. The model would enable a settlement account holder in Country A to hold a digital account (wallet) in Country B without having to go through the on-boarding process for the RTGS system of Country B; participating central banks would thus have to agree on a defined set of eligibility criteria for this new platform. Furthermore, Bank A's holding of W-CBDC-B would have to be collateralized via reserves held at Central Bank A; an exchange rate risk would therefore emerge, which would need to be carefully managed by central banks and participants. This raises fundamental questions for central banks about control over the money supply, exposure to exchange rate risk, and the relationship between CBDCs and reserves. The scale of these policy challenges might impact the willingness of a jurisdiction to join the W-CBDC scheme, limiting the uptake of the solution and thus its overall success. In a scenario where this model were widely adopted, there might be an increase in the complexity of the system based on it because every participant would need to hold multiple W-CBDC accounts (wallets) in multiple currencies, and the technical challenges would have to be considered of synchronizing transactions across two or more W-CBDC platforms.

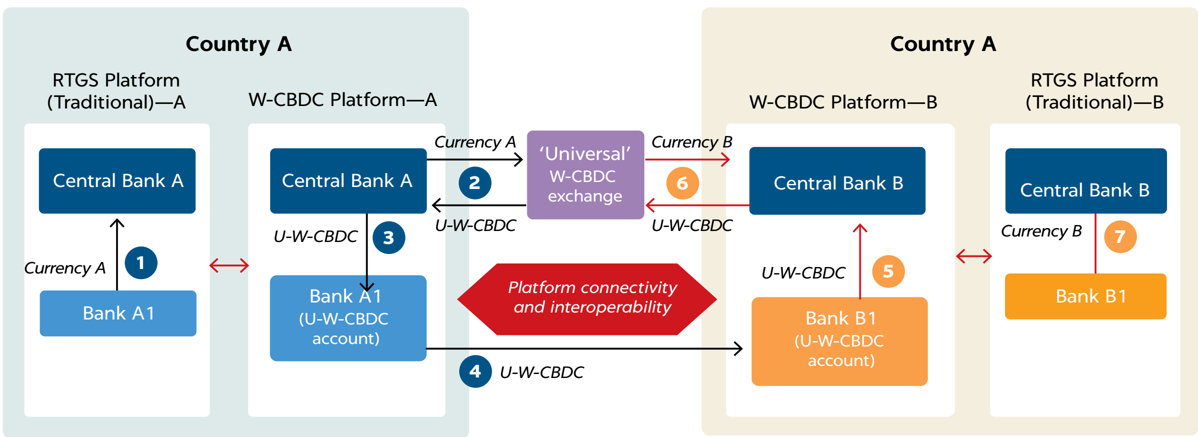
Model 3c

Model 3c is based on a universal W-CBDC that is backed by a basket of currencies and accepted by all participating jurisdictions.[22] Unlike models 3a and 3b do, model 3c does not involve the use of multiple currency-specific W-CBDCs; rather, it involves a single universal W-CBDC.

Description of Model 3c. Several participating jurisdictions, through either their respective central banks or a global multilateral institution, agree to create a "universal" wholesale CBDC (U-W-CBDC) (Chart 3). The U-W-CBDC would be backed by a basket of currencies issued by the participating central banks and would be issued via an exchange specifically created to allow for its issuance and redemption. The conversion of a jurisdiction's currency into the U-W-CBDC would create an exchange rate between that currency and the U-W-CBDC. A framework for how this would be managed should collectively be determined by the participating central banks.

Example of funds transfer. There would be nothing peculiar in the transfer modalities under this model, since transfers

CHART 3 MODEL 3C



would take place like in any real-time large-value payment and settlement system. Banks (and in general all entities permitted to participate in the system) would use the U-W-CBDC to settle peer-to-peer cross-border transactions.

Considerations. This model seems most comprehensively to address the identified challenges and frictions of the existing arrangements. By introducing a universally accepted and traded W-CBDC, it offers a solution that could be more easily implemented in many jurisdictions as it lacks many of the policy challenges outlined in Model 3a and Model 3b. Yet, the model raises important policy issues that might limit its feasibility. Under this model, central banks would need to manage and monitor the supply of funds in cash, domestic RTGS and U-W-CBDC, and there will need to be frameworks to ensure adequate collateralization of U-W-CBDC with central bank reserves in the face of a potentially volatile intraday exchange rate. The creation of a U-W-CBDC exchange introduces a single point of failure in the model that is not present in the other variants of Model 3. This exchange would facilitate the trading and use of the U-W-CBDC for purposes other than transactions and, as a result, the U-W-CBDC could take on the properties of a financial asset rather than those of a simple medium of exchange—speculation and hoarding in particular could impact the price and hence the utility of such a token as a medium of exchange. The model involves a huge change and might present significant frictions in onboarding a new currency to the basket of currencies backing the U-W-CBDC: the resulting complexity might hamper its adoption.

The BOC-BOE-MAS report offers only a starting point for further analysis of the above models. Several aspects of the models would still require further and deeper consideration, including the legal basis and risks associated with each model, and in particular the legislative changes required to recognize W-CBDCs as legal tender for interbank payments and settlements; the cross-jurisdictional governance framework required to ensure harmonized standards; the impact on monetary policy; and the eligibility criteria for financial institutions and payment system participants to become direct participants in the CBDC platforms.

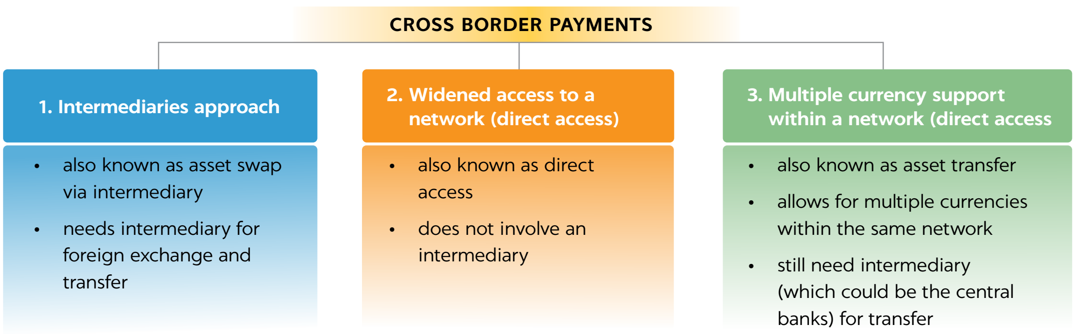
In particular, the report identifies three areas of future research for policymakers and industry. The first is to conduct further research and experimentation to better evaluate the different models, in particular the hypothesis that a holistic approach to infrastructure change can deliver more far-reaching benefits than incremental improvements to the current model. This could include the creation of a technical solution aimed at assessing the delivery of future capabilities. The second is to consider further the policy implications of some of the more radical changes outlined in the report, especially on monetary policy, broader access to central bank money, and the role of the RTGS operator in the future state. Finally, while the report focuses on change driven through revolution in the central payment infrastructures, further thinking should be done on how policymakers and industry could work together on private-sector innovation to address, in the shorter term, the challenges and frictions faced by users of existing cross-border payment services.

Finally, particular consideration should be given to the potential impact of U-W-CBDC on monetary policy and financial stability of participating jurisdictions. The critical concerns with regard to these areas, which are raised by the prospect of using domestically CBDC issued by foreign countries, would only be amplified if the prospect were that of a single CBDC becoming universally available. The risk of currency substitution, in particular as a source of problem for the domestic transmission mechanism of monetary policy and the stability of national financial institutions and systems, would become material especially in jurisdictions with unsound macroeconomic policies and poorly credible policy institutions, which reflect in weak national currencies.[23]

Further developments: The Jasper-Ubin Project

More recently, building on the 3 models just discussed, the BoC and MAS explored how their originally CBDC projects could be developed so as to offer cross-border payment solutions.[24] In 2016, the two central banks had embarked on Project Jasper and Project Ubin, respectively, to investigate the use of DLT for the clearing and settlement of payments and securities. Specifically, the two projects envisioned a tokenized form of W-CBDC issued on blockchains by the central bank for use by commercial banks. The two central banks then joined forces to understand how the Jasper and Ubin prototype networks, developed on different blockchain platforms, could interoperate, allowing for cross-border payments to be settled on central bank digital currencies. Essentially, the model allows for cross-border, cross-currency, and cross-platform atomic transactions to take place through an intermediate account and without the need for transacting parties to hold funds with a third party. In this model, the intermediate escrow account is used and operated autonomously as a smart contract with predefined rules, such that no action proceeds if any preceding action fails, thus ensuring the end-to-end consistency of each transaction. In the context of cross-border payments, where the transaction consists of two parts, one in a home country and one in

CHART 4 PROJECT JAPSER-UBIN—CROSS-BORDER TRANSACTION APPROACHES



a foreign country, the Hashed-Timelock Contracts (HTLC)[24] protocol is used to manage both parts of the transaction in a Payment Vs Payment (PvP) mode eliminating principal risk.

The BoC-MAS project proposes three broad conceptual design options for cross-border payments. (Chart 4). The first option involves using intermediaries, and the second and third involve granting transacting parties access to the central bank's liabilities. Access to the central bank's liabilities can be achieved through two different designs. The first design achieves direct access by granting transacting parties direct access to accounts or wallets on the network. i.e., allowing a financial institution to hold the currency issued by the foreign central bank; the second design allows the local currency to flow into foreign currency networks where it can be transacted directly. This latter arrangement can be viewed as a multi-currency settlement system.

THE PROJECT INTHANON-LIONROCK

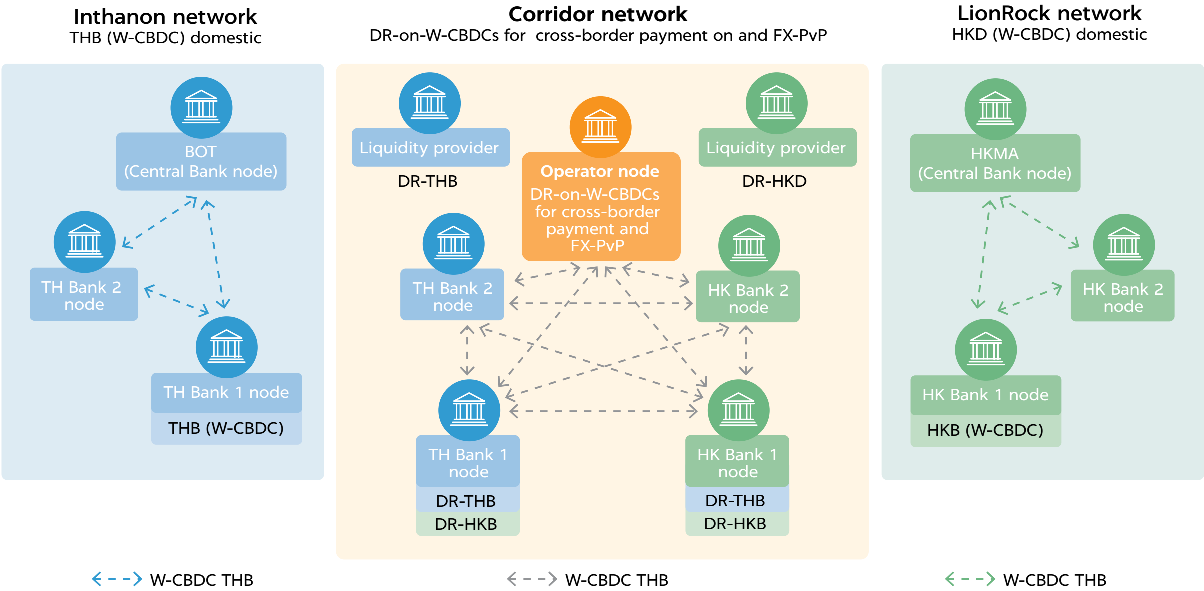
Project Inthanon-LionRock is a joint initiative by the Bank of Thailand (BOT) and Hong Kong Monetary Authority (HKMA), initiated in May 2019, to explore the application of CBDC to cross-border payments.[26] A Thai Baht (THB)–Hong Kong dollar (HKD) cross-border corridor network prototype was developed, allowing participating banks in Hong Kong and Thailand to conduct funds transfers and foreign exchange (FX) transactions on a peer-to-peer basis, which helps reduce settlement layers. Leveraging on smart contracts, the cross-border funds transfer process was enhanced to a real-time and atomic PvP modality. Project Inthanon-LionRock was completed in December 2019 and a DLT-based PoC prototype was developed successfully together with ten participating banks from both places. The key findings of the project were presented in January 2020, and the two authorities agreed to proceed with further joint research work in relevant areas, explore business cases and connections to other platforms, and encourage participation of banks and other relevant parties in cross-border funds transfer trials.[27]

The model

The THB-HKD corridor network acts as a bridge to connect the domestic W-CBDC payment networks of the two countries. All the participating banks have their own nodes on both the local payment network and corridor network, while the two central banks have their own nodes in the local payment network and a separate node in the corridor network (called the "operator node"), whose control is shared by the BOT and HKMA. In principle, a foreign currency liquidity provider node should exist in the corridor network in order to facilitate the provision of foreign currency liquidity.

Description of the model. In the proposed model, each central bank issues its own W-CBDC (Chart 5). The domestic settlement networks (i.e., Inthanon network and LionRock network) are separated from cross-border transactions. Non-resident banks are not allowed to access the domestic network and to hold foreign W-CBDC. Participants in the corridor network are the banks participating in the Inthanon and LionRock networks, respectively. The corridor network provides cross-border settlement services. These services include liquidity management processes for both local and foreign currencies, through a queueing mechanism, gridlock resolution procedures, and liquidity provision. In parallel with the corridor network, each central bank plays a role in its respective domestic settlement network to facilitate the conversion of W-CBDC into a special vehicle called Depository Receipt (DR) denominated in domestic currency and vice versa. To settle transactions in the corridor network, the DR is used for transferring value amongst all participants.[28] In the corridor network, participating banks may hold DR-THB

CHART 5 INTHANON-LIONROCK—PROPOSED MODEL



and DR-HKD for cross-border funds transfer and FX PvP transactions, which are performed on a peer-to-peer basis with finality.[29] Corridor network parties include the corridor operator node, the participating bank nodes, and the foreign currency liquidity providers. The corridor operator node is a joint BOT-HKMA body, which is responsible to issue and destroy DR-THB and DR-HKD (in response to DR conversion request by participating banks), provide gridlock resolution services, ensure regulatory compliance. Participating bank nodes in the corridor network initiate and settle cross-border payments and manage their own liquidity in both local and foreign currencies. The foreign currency liquidity providers provide foreign currency liquidity when deadlock occurs.

Example of funds transfer. Cross-border transfers of funds may involve a sending bank submitting instructions to transfer funds in either local or foreign currency to a receiving bank. A transfer of funds can thus happen in one of the following three types of transaction: transfer of local funds from a local bank to a foreign bank; transfer of foreign currency funds from a local bank to another local bank; and transfer of foreign currency funds from a local bank to a foreign bank.[30] In all cases, a sending bank submits a cross-border payment instruction and the transaction is settled simultaneously (if there are sufficient funds) or is placed in the queue (if there are insufficient funds) and settled when liquidity is sufficient. The most relevant cases are those involving FX transactions. When a bank in the corridor network wants to do an FX transaction, there are three different ways of doing in the Inthanon-LionRock model (Board Rate, Request for Quote, and Off-corridor Arrangement) and are discussed below. All settle in an atomic PvP fashion, and smart contracts are developed to track the settlement process of the trade.

Board rate

This option allows banks to seek the best FX bid-offer rate from other participants in the corridor network. A bank choosing to conduct an FX transaction via the board rate method can obtain HKD/THB rates published by market maker banks. The system takes the best board rate available into the FX transaction. The bank, as a market taker, will get the best rate amongst rates submitted by market maker banks. To publish the rates, the market maker banks input the HKD/THB quote into the system.[31] For the market taker looking for a board rate, the system will automatically match the market taker's board rate request with the best available board rate and book the FX transaction. Once matched, the market maker's available amount will reduce accordingly.

Request for quote

The request for quote provides banks with the option of selecting specific counterparties within the corridor network. The bank, as a market taker, asks for a quote directly from a market maker bank in the corridor network. To request for a quote, the market taker bank inputs the settlement details which are the required amount, currency, preferred counterparty, and option of quoting an FX rate from one or multiple market makers. Once the market makers respond, the market taker then reviews and confirms which quoted rate it wants to execute.

Off-corridor arrangement

This option provides an alternative way of FX dealing outside the corridor network between participating banks and non-participating (off-corridor) banks. Once the FX rate has been agreed upon, the transaction can be settled via a participating representative bank of the non-participating banks in the corridor network. The representative bank and the counterparty bank both input the transaction details in the system to settle the transaction. The two transactions entered by the two transacting parties must be matched using the same reference number and transaction details. The matched transaction then proceeds to settlement. If the transaction details do not match, the deal is rejected.

Considerations. The PoC has shown that, with the use of CBDC and the connection of the Inthanon, LionRock and corridor networks, cross-border payments can be completed within seconds without intermediaries or settlement layers (assuming that the sending bank has sufficient liquidity in the corridor network). The PoC has shown additional important benefits in terms of enhanced liquidity efficiency, better regulatory compliance and improved reporting ability, and scalability. These benefits, however, are the effects of the technology solutions adopted, not necessarily of CBDC use. The PoC has also indicated that the model requires supplementary analysis from a number of important angles (legal and regulatory, operational, and technical), in preparation of moving the project to next stage of developing a full production-grade system in a sandbox environment.

Further regulatory considerations

Particular attention will have to be placed on the model's legal basis in the presence of different national regulatory frameworks. An ongoing periodic revision of existing regulations will be necessary to make sure that the proposed model design is consistent with the ever-changing regulatory environment comprising Thai, Hong Kong and global regulations (any change in the regulatory environment will raise compliance issues in the proposed model) and consideration will have to be given to the possible harmonization of the different regulatory frameworks. Also, the model should integrate AML/CFT standards as well as mechanisms to deal with legal claims to central banks and data integrity and privacy concerns. Another legal dimension to consider is settlement finality: prior to rolling out the PoC into production, settlement finality should be clearly defined in the legal and operational sense.

Further operational considerations

An issue to be addressed concerns the expansion of the network to include other foreign currencies or central banks. The proposed corridor network model allows for flexible expansion. Yet, integration issues from the technical and operational perspectives will have to be explored for connecting the corridor network to other systems. There will be governance issues of how to set up the multi-currency DR issuing node's entity in terms of governing laws, data privacy, and node's location. In addition, roles and responsibilities will need to be deliberated in relation to the development of new functionalities (e.g., for liquidity provision in the system through cross-currency repo operations).

Further technical considerations

Performance, scalability, security and operational resilience are key concerns for facilitating real-time payments and onboarding new participating members. Under the PoC testing scenario, it was found that if a bank holding a certain amount of cash tokens needed to make payments to different banks at the same time, the payment transactions would occur in a sequential order whereby one transaction chain must be completed before the other(s) can be executed. Consideration will have to be given to parallel computing and optimization processes for the transfer of cash tokens without order dependency. Security is another area which needs to be addressed. DLT-related controls must be implemented to mitigate risk. For example, private keys, which are generated and stored in DLT nodes to identify nodes and sign transactions, should be integrated with the hardware security module and managed properly to avoid being compromised. Finally, high availability is related to the capability for disaster recovery, which requires the presence of a procedure to handle different degrees of system component failures. Future work may include exploration of new high-availability deployment configuration options for the nodes and higher capability to monitor running flows in the system.

THE R3 MODELS[32]

Recently, R3 conducted a study intended to stimulate ideas for new, different approaches to improve wholesale cross-border settlement using DLT.[33] Three of the proposed models assume active involvement of central banks: in the first model (Option 1) central banks issue their own CBDC; and in the second model (Options 2), the central banks coordinate to issue a dual-registered digital currency for a specific currency pair; the third model (Option 3) involves credit lines. Only the first two models are discussed below, since their further development was deemed to be particularly useful. Conversely, the third model significantly departs from the traditional role of the central bank and has the potential to dramatically expand the central bank's balance sheet and influence the money supply; thus, it will not be discussed in the following. Similarly, the other model proposed by the R3 study (based on a trusted third party) will not be considered in this report but will only be briefly referenced below. The R3 study evaluated each model based on its monetary supply implications, impact on liquidity management for commercial banks, settlement risk, credit risk, and complexity for central banks.

Underlying the two models illustrated below is the concept of "intermediate cryptocurrency," introduced by the study. An intermediate cryptocurrency is a W-CDBC adopted worldwide, which can thus flow freely across borders. The ledger where the intermediate cryptocurrency is issued provides open access such that foreign financial institutions can hold accounts on it. Cross-border transactions would therefore take the form "Currency A ⟶ Intermediate cryptocurrency ⟶ Currency B," which would allow for greater efficiency since the intermediate cryptocurrency can be transferred directly from the sender's account to the receiver's account. DLT and smart contracts support a decentralized PvP solution for settling FX transactions.

Option 1: Central Bank-Issued Intermediate Cryptocurrency[34]

This option assumes that intermediate cryptocurrencies are all issued on an interoperable, common ledger.[35] With a common ledger, the need for inter-ledger transactions is effectively eliminated. The more currencies are issued on an interoperable ledger, the less likely a given intermediate cryptocurrency needs to be converted into off-ledger assets.

Example of funds transfer. Using the example from the R3 study, assume Canada and Singapore issue, respectively a Canadian-dollar CBDC (CAD) and a Singapore-dollar CBDC (SGD). Royal Bank of Canada (RBC) needs to pay Credit Swiss (CS) in SGD (Chart 6). Both CAD and SGD are intermediate cryptocurrencies in the language of the R3 study (W-CBCDs). As RBC seeks to buy SGD in exchange for CAD, which RBC holds on its account (wallet) with BOC, exchange providers or brokers match RBC's indication of interest (IOI) and return a quote. Once RBC selects and accepts a quote, the FX transaction is executed and the transfer of SGD to CS is then effected. Transaction settlements take place through omnibus accounts (OMS) held by RBC, CS and the dealers (brokers) at BOC and MAS.[36] Equivalently, RBC could pay CS using CAD and CS would convert CAD on SGD through the dealers (broker) network.

Considerations. This option places a heavy burden on central banks as it requires their ledgers to be opened to a much broader range of financial institutions than is currently the case. The legal and policy frameworks of most jurisdictions would be incompatible with this model and would require significant adaptations.

Option 2: Cross-Registered Intermediate Cryptocurrency

This option proposes the use of a "depository receipt" that can be circulated in multiple currency jurisdictions. A depository receipt is issued by a central bank in the form of digital tokens and confers on its holder the title to receive (a claim on) an equivalent net balance of central bank-issued currency payable on redemption by the central bank. A cross-registered depository receipt (CRDR) consists of central bank-issued digital tokens that are backed by collateral held at the central banks of issue.[37,38] A CRDR that is issued

CHART 6 CENTRAL BANK-ISSUED INTERMEDIATE CRYPTOCURRENCY MODEL

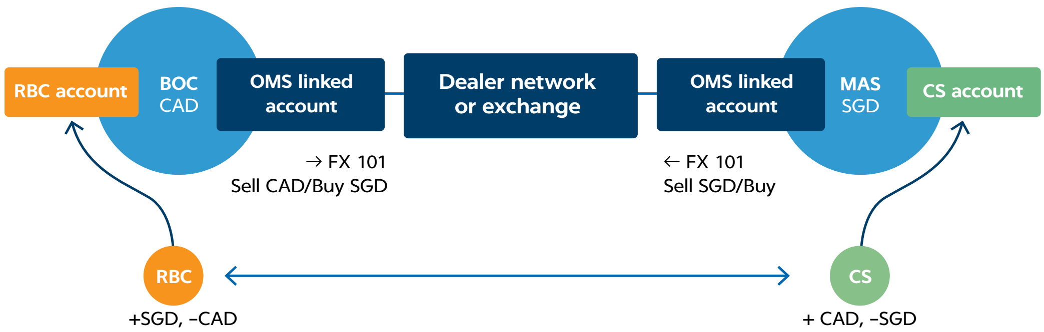
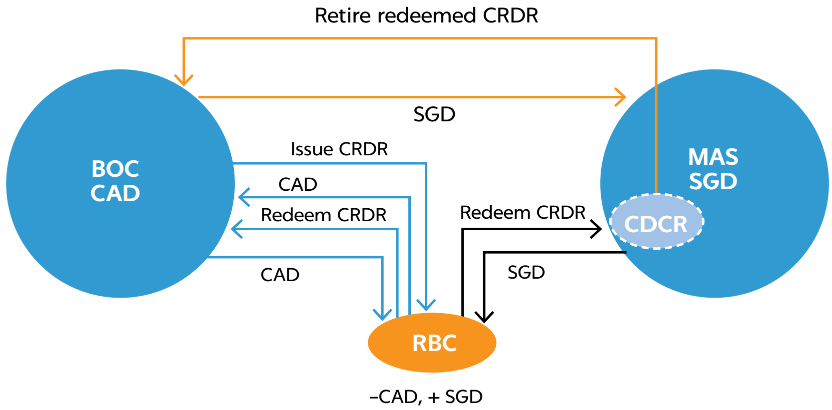


CHART 7 CROSS-REGISTERED INTERMEDIATE CRYPTOCURRENCY MODEL



to Bank A1 by Central Bank A against its own currency A can be redeemed at Central Bank B against its own currency B at a predetermined exchange rate.[39] By providing an alternative—widely accepted—settlement asset, Option 2 is useful in those cases where transactions involve currency pairs that are not heavily traded, for which the market is therefore thin and a counterparty to an FX transaction cannot be found easily. CRDRs may eliminate the need for currency exchange and hence the need for finding a counterparty to the currency exchange in a thin market.

Example of funds transfer. Taking the same example of Option 1, RBC needs to pay CS (Chart 7). RBC can make the payment using CRDR issued by BOC, which CS can redeem at MAS against SGD; in turn, MAS redeems CRDR at BOC in exchange for SGD. As an alternative, RBC can redeem CRDR holdings against SGD at MAS and pay CS in SGD.

Considerations. A major advantage of the CRDR as settlement asset for bilateral trading is that the instrument can flow freely across the borders of the two currency jurisdictions involved in the exchange. In the best case, only one ledger would be involved for a single trade if the CRDR is used as settlement asset. One challenge arising from using CRDR is that money supply in the issuing and receiving jurisdictions might be subject to erratic fluctuations due to the cash-in-and-out preferences of traders, since issuing CRDRs denominated in a currency shrinks the supply of the currency while the opposite happens when CRDR holders redeem their holdings. In other words, the imbalances of cross-border transactions are reflected as instability of the money supply. There are other risk implications as well. First, the holder of CRDR is exempted from the foreign exchange risk because the exchange rate is predetermined; however, the FX risk is transferred to central banks. The hedging cost on the central banks might in turn be priced in as a premium on the CRDR or as haircut on the collateral paid against CRDR issues. Second, the model might be difficult to scale up as it requires each pair of central banks to commit to honoring two CRDRs. Third, the model would introduce arbitrage opportunities for CRDR holders as the foreign exchange market dynamics might cause actual exchange rates to diverge from the predetermined rates applied on CRDRs. Fourth, as exchange activities using CRDR are conducted in a decentralized way, they might be anonymous.

The R3 study proposes also a model that is based on a trusted third-party (TTP) issuer central bank. Since the TTP model (in its various variants) does not envisage the adoption of CBCD solutions, it will not be discussed here and interested readers are referred to the R3 study for illustration of the model.[40]

PROJECT ABER

In early 2019, the Saudi Arabian Monetary Authority and the Central Bank of the United Arab Emirates announced in a joint statement the launch of their pilot Project Aber (after the Arabic name that stands for "one who crosses boundaries"). The vision of the project is to create a CBDC instrument that can be used for settlement of cross-border payment obligations between commercial banks in the two countries as well as domestically. The initiative aims to implement a proof of concept for, studying, understanding, and evaluating the feasibility of issuing wholesale CBDC, with a view to reducing transfer times and costs between banks, in addition to experiment the direct use and actual application of technologies such as the distributed ledgers. Initially, the joint venture for digital currency will be restricted to banking institutions and will not be open for public usage. A few selected commercial banks (three Saudi and three UAE) were selected to participate in the development of the currency. In November 2020, the two central banks issued a report on the status of the project, which documents the solutions, results, and main lessons learned through the pilot stage.[41]

The model

The Abel model is based on a DLT called Hyperledger Fabric (HLF).[42] HLF is a permissioned blockchain technology, with a pluggable architecture that allows "plug and play" of important components such as consensus and membership service. This technology allows for two types of peers: endorsers and committers. Execution of smart contract or chain code is limited to endorsing nodes, while committers only maintain the ledger.

The HLF technology allows for the system to be as decentralized as possible. The purpose is to enable commercial banks to settle with each other even in cases where the central bank is unavailable or disconnected from the network. The rationale behind this is for the system to offer a higher level of architectural resilience than traditional centralized systems, which depend on the availability of centralized services, and thus to avoid a single point of failure. Given that the two national currencies (i.e., the Saudi Arabia Riyal and the UAE Dirhams) are pegged to the USD, the digital currency will be pegged as well and the exchange rate or conversion rate for fiat currency to CBDC will be fixed. Thus, the same currency will be used for both domestic and cross-border transactions and will be transferrable and redeemable both domestically and cross-border. Moreover, each central bank's issuance can be used/redeemed in the other jurisdiction; thus, each central bank will be able to see the total amount generated and issued by the other central bank and, therefore, it will have full visibility to all CBDC issued in the network. Since CBDC will remain a liability of the issuing bank, regardless of the jurisdiction of redemption, the system will support settlement between central banks when redeeming cross-border issued CBDC.

While all CBDC issued goes through this cycle, step 4 can be repeated as many times as needed as CBDC is exchanged between participants. In step 6, issued CBDC is destroyed by the central bank, as part of a redemption request in which converted back to cash and deposited back with the commercial bank. Aber uses three types of channels for transferring funds:

CHART 8 PROJECT ABEL—THE MODEL

- ***Primary channel:*** All the banks (commercial as well as central) participate in this channel (ledger). The endorsement policy on this channel requires at least 5 (out of the total 8) participants to endorse transactions (with at least 2 of them from each jurisdiction). CBDC is issued by central banks through a special "issue" transaction on the primary channel.
- ***Bilateral channels:*** these are the peer-to-peer channels (ledgers) between each pair of commercial banks. The central bank of each peer also participates in the channel. The endorsement policy on this channel requires only the two commercial banks to endorse a transaction. This allows a payment to be confirmed even when one or both central banks are unavailable.
- ***Private channel:*** A private channel (ledger) between a commercial bank and its central bank. This is used for making private requests such as CBDC issue and redeem requests. The endorsement policy on this channel requires both the bank and the central bank to endorse a transaction.

Description of the model. The Aber model involves a life-cycle process of CBDC, from issuance to destruction, which involves the following steps (Chart 8):

- A commercial bank pledges cash collateral in an account held by the central bank in its jurisdiction

- The central bank converts cash collateral to generate CBDC
- The central bank funds the newly created currency in the commercial bank's account on the ledger
- The commercial bank transfers the new currency to an account belonging to the counterparty on the ledger
- The counterparty redeems the currency for cash collateral via the central bank in its jurisdiction
- The central bank that has facilitated redemption returns the redeemed CBDC to the issuing central bank
- The issuing central bank destroys the created CBDC.

Example of CBDC issue. As bank A makes an issuance request, the process can be described as follows (Chart 9):

- Using the bilateral channel (ledger), bank A and bank B generate a pseudonym each, against which CBDC will be issued. Bank B also issues a consent agreeing to full ownership by bank A
- Using the private channel (ledger), bank A requests the central bank to issue shares (slices) of CBDC on its bilateral channel with bank B
- The central bank issues the shares (slices) of CBDC in the primary channel (ledger)
- Bank A requests allocation of the CBDC shares to its bilateral channel (ledger) with bank B.

CHART 9 ABER PROTOCOL—ISSUE WORKFLOW

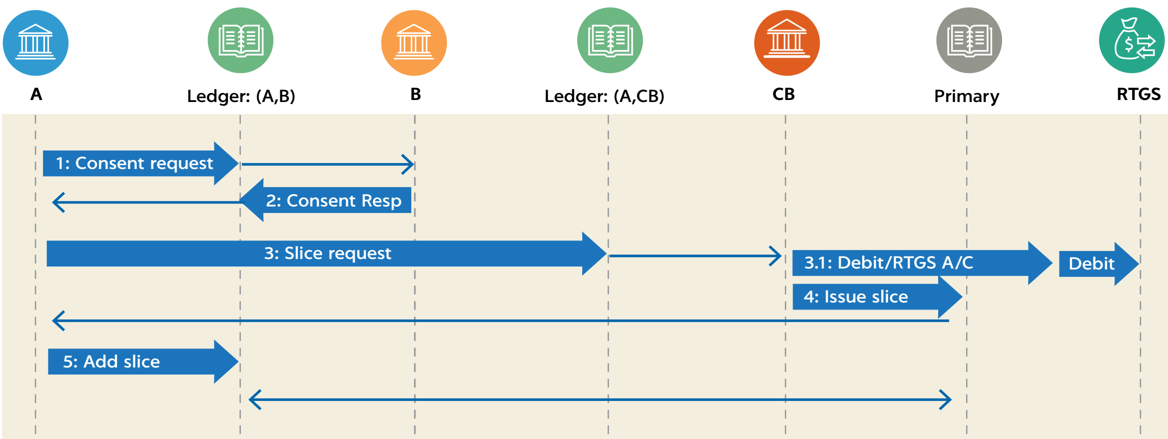
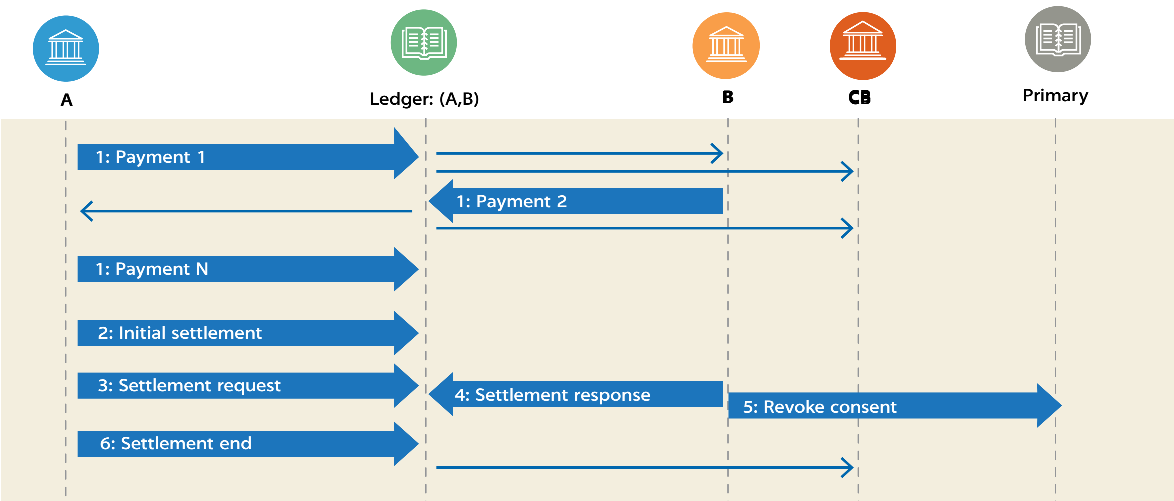


CHART 10 ABER PROTOCOL—TRANSFER WORKFLOW



Example of funds transfer. Aber uses a distinctive transaction flow that goes through the steps of endorsement, ordering and validation. When bank A wants to make a payment to bank B, the process works as follows (Chart 10):

- Banks A invokes the chain code (smart contract in the HLF language) on the bilateral channel (ledger) between bank A and bank B to activate a transfer of CBDC to B. In case of insufficient balance, payments get processed in an on-chain queue. Bilateral netting is implemented; thus, before adding a payment to a queue, netting opportunities with payments queued on the other side are explored
- The settlement cycle gets triggered. This could be after every transaction, and would be based on time, number of payments or movement in positions/balances, following the last settlement
- Bank A issues consent with B based on the new shares (slices) of CBDC to be transferred
- Consents previously issued by bank A on those slices of CBDC need to be invalidated by bank B. This operation is performed on the primary channel (ledger).

Considerations. A single digital currency moving across a single network for settlement of cross-border payments would be especially useful in a region like the GCC [Gulf Coordination Council] states, where there is substantial intra-regional trade and movement of citizens and residents. Also, in the Aber system, the movement of funds would occur in real time, with no need for commercial banks to hold correspondent bank Nostro account in each country. This would address the inefficiencies in the existing correspondent banking-based payment systems, which often results in delays and require commercial banks to maintain substantial Nostro account balances with correspondent banks. This issue, characterized as "trapped liquidity,"[43] currently causes significant opportunity and compliance costs for commercial banks. Also, by requiring that only counterparties to the payment transactions need to be online for payments to be settled,[44] the Aber system offers a higher level of operational resilience than traditional centralized systems, which depend on the availability of the central bank and to avoid single point of failure. Finally, in point of visibility, cross-border payments will be auditable by both central banks. On the other hand, the project still needs to address some critical issue. One concerns the impact that in a context of a dual-issued digital currency could derive from differences in monetary policy between the two jurisdictions, in particular differences in interest rates. As CBDC would be backed by pledged commercial bank funds held with the respective central banks, there could be a differential opportunity cost imposed for banks holding CBDC where a higher interest is paid. Another issue concerns finality, since both parties involved in a transaction are legally accountable for the transaction, the two central banks should give unambiguous direction to determine when finality would occur in the system. Yet another issue is about CBDC redemption, in light of the dual-issued nature of the currency: since the funding of redemptions will take place at the Nostro account that each central bank holds with the other, a bilateral agreement should be required between the two central banks on how overdrafts would be handled and on how each central bank would be expected to replenish funds when acquiring the other currency.

PROJECT STELLA

Project Stella was born as a joint research undertaking by the European Central Bank (ECB) and the Bank of Japan (BOJ). Launched in December 2016, the project aimed to contribute to the ongoing debate with experimental work and conceptual studies exploring DLT's opportunities and challenges for financial market infrastructures. In 2018, the two central banks built on the insights gained from the earlier stages of the project to explore innovative solutions for cross-border payments, i.e., payments between currency areas.[45] Stella Phase 3, thus, studied whether cross-border payments could be improved, especially in terms of safety, by using new technologies. In particular, it studied a ledger-agnostic protocol that synchronizes payments across different types of ledgers and assessed the safety and efficiency implications of a variety of payment methods that could be used in the cross-ledger payment. These models show distinctive characteristics, which can be summarized as follows: i) whether individual payments are settled on-ledger or recorded off-ledger, ii) whether funds are locked or escrowed, iii) whether payments are enforced when the predefined condition for the payment is fulfilled, and (iv) whether specific ledger functionalities are required to conduct transfers, such as the functionalities to enforce conditional transfers and process signed claims.

Description of the models. The different payment methods are the following:

- ***Trustline:*** This model involves an arrangement between the payer and the payee outside the ledger where the payer promises to make a payment if the payee fulfils a predefined condition. At the same time, the total of payments which has not been settled must not exceed the predetermined maximum amount that the payer can pay without settlement on the ledger.

- ***On-ledger holds/escrow:*** This model uses the HTLC technology (referred to earlier), which allows for conditional transfers that are recorded on the ledger and enforced by the ledger if the payee fulfils a predefined condition.
- ***Third party escrow:*** This model is conceptually similar to the on-ledger escrow but relies on a third party which is trusted by the payer and the payee rather than on the ledger to enforce the conditional transfers.
- ***Simple payment channel:*** This model involves an arrangement between the payer and payee using escrowed funds in a shared temporary account on the ledger. Both parties promise to exchange signed claims off-ledger, which represents their entitlement to a specific portion of escrowed funds, if the payee fulfils a predefined condition. Only the final net position of multiple bilateral payments is actually settled on the ledger.
- ***Conditional payment channel:*** This model uses HTLC and is similar to the simple payment channel in the sense that both parties exchange signed claims off-ledger, but in addition has an enforcement mechanism by the ledger for the transfers based on whether the payee fulfils a predefined condition.

Example of a funds transfer. Here only a general illustration is reported of how the Interledger Protocol—a ledger-agnostic protocol—allows the sender to make payments across different types of ledgers, The building blocks of the protocol are Participants, Ledgers and Payment Methods, whereby Participants are entities that have accounts on one or more ledgers and participate in the cross-ledger payment, ledgers indicate any system used to track transfers of value between, and balances on, accounts, and payment methods (as above) are bilateral agreements between participants on specific methods to make payments and settle obligations on the ledger. The choice of payment method depends on participants' preferences and ledger functionalities. Participants can assume three roles within the Interledger Protocol: Sender, Receiver, or Connector. Connectors are entities with accounts on two or more ledgers, which act as liquidity providers that relay payments across ledgers and play a critical role for the successful execution of cross-ledger payments. A liquidity provider enables a cross-ledger payment by exchanging an incoming payment from its account on one ledger for an outgoing payment to its account on another ledger. When Connectors relay a payment across ledgers denominated in different currencies, they conduct currency conversion. Where a single Connector cannot link the payment between the Sender and the Receiver, or cannot do so in an efficient way, multiple Connectors can be composed into a payment chain (Chart 11).

All individual payments along the payment chain depend on the fulfilment of the following condition by the payee (Receiver or Connector(s)): presentation of the preimage for a cryptographic hash value before a predetermined time (timeout). The hash value is used to define the payment condition (in the context of a smart contract), while the corresponding hash preimage marks the fulfilment of that condition. Before a cross-ledger payment is initiated, the preimage and its cryptographic hash value are produced by the Receiver. The hash value must then be shared with the Sender together with other terms of the payment, which may include payment amount, payment currency, payment timeout and Receiver information, using external means of communication (e.g., email). After the initial bilateral Sender-Receiver communication, each individual payment of the cross-ledger payment chain goes through two main phases:

- First, the payer (the Sender or Connector(s)) prepares the payment to the payee (the Receiver or Connector(s)) according to the specific payment method used.
- Second, there are three possible scenarios. If the hash preimage is presented by the payee (the Receiver or the Connector(s)) before the timeout and is verified as correct, the condition for the payment is fulfilled and the payment to the payee is executed (fulfilment scenario). Alternatively, if the timeout expires without the correct preimage being presented, the payment is aborted (timeout scenario), or if the payee does not accept the payment, the payment could be aborted even before the expiration of the timeout (reject scenario).

Payment processes based on the protocol require information exchanges between participants as well as with other relevant entities. These include the initial information exchanged between the Sender and the Receiver which does not vary along the payment chain and does not depend on the ledger and the payment method used, as well as other information which varies among each payment in the payment chain (e.g., fees and timeouts for individual payment conditions).

Considerations. The Stella report concluded that, from a technical perspective, the safety of today's cross-border payments could potentially be improved by using payment methods that synchronize payments and lock funds along the payment chain, noting in addition that further reflections would be needed on legal and compliance issues and the maturity of the technology. Specifically, in relation to safety, the on-ledger escrows, third- party escrows, and conditional payment channels (all of which have enforcement mechanisms) can ensure that each transacting party who completely satisfies

CHART 11 PROJECT STELLA—CROSS-BORDER FUNDS TRANSFERS

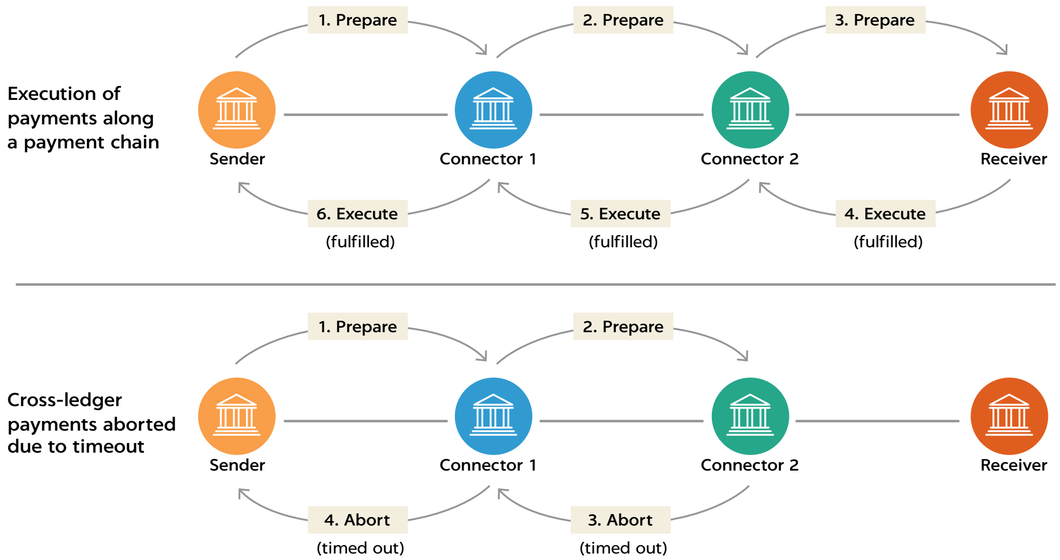


Chart 11 shows both a successful payment scenario and a rejection scenario. Both scenario feature two Connectors and illustrate the order of payment preparations and executions. In the successful payment scenario, the Sender and Connectors 1 and 2 prepare the payment to Connector 1, to Connector 2, and then to the Receiver, respectively, in this order. Then, the Receiver and both Connectors fulfil the payment conditions by presenting the hash preimage before the timeout. Depending on the arrangement between the Sender and Receiver, possession of the preimage by the Sender could be regarded as evidence of the receipt of payment by the Receiver. In the rejection scenario, the payment is first prepared but then aborted due to timeout. The Sender and Connector 1 prepare the payment to Connector 1 and Connector 2, respectively, in this order. Then, if Connector 2 remains unresponsive and does not present the hash preimage to Connector 1 before timeout, payments to Connector 2 and Connector 1 are aborted, in this order.

its responsibilities in the transaction process is not exposed to the risk of incurring a loss on the principal amount being transferred. On the other hand, with regard to liquidity efficiency, the trustline method appears to be superior to the others since it is the only post-funded payment method.

Interestingly, the study identified the so called "free option problem," a risk aspect that could materialize even when all of the preconditions used in the assessment are met. This is the exchange rate risk that participants are exposed to when relaying a cross-ledger, cross-currency payment. In the preparation of such a payment, participants enter into a commitment to deliver a fixed amount denominated in one currency in exchange for a fixed amount denominated in another currency. This could potentially be exploited by malicious actors, without the safety of payments being undermined.[46] This "free option problem" currently remains open and is being actively discussed within the Interledger community. However, it should also be noted that it does not pose direct risk to the safety of the payments. Moreover, this may not be a significant issue if the participants value reputational risk above the potential gains from exploiting the Connector's binding commitment.

THE ARCHITECTURE OF CBDCs FOR CROSS-BORDER PAYMENTS: DRAWING LESSONS FROM AFRICA

The design of the architecture of CBDCs for cross-border payments use can draw lessons from existing regional payment systems in Africa.[47] These systems comprise those in the Southern Africa Development Community, West African Economic and Monetary Union, West African Monetary Zone, Economic and Monetary Community of Central Africa, East African Community, Common Market for Eastern and Southern Africa, and BUNA (formerly known as the Arab Regional Payment System, led by the Arab Monetary Fund (AMF) and launched in December 2020 for the Middle eastern and northern African countries that are members of the AMF). As it is to be expected, each model has advantages and disadvantages, and model variants typically aim at adapting the model to the realities of the countries involved, while at the same time trying to preserve the advantages and minimize the disadvantages. Yet, some general elements and their basic features could be considered when designing CBDC models for cross-border payments.

The deepest form of payment system integration across borders is a fully centralized architecture. This would involve a common technical-operational facility to process payment transactions to which central banks, bank and non-bank PSPs connect directly. This model is mostly identified with regional integration projects that have evolved into a monetary union.[48] There is little distinction between domestic and intra-region cross-border payments (in the region's currency), and both types of payments can be processed in the same payment system seamlessly.

An alternative general architecture for the integration of payment systems across borders is the "hub-spoke" arrangement. The "hub" is a central platform for payment exchange and processing, the "nodes" are the points of delivery and the "spokes" are the communication routes between the nodes and the hub. In practice, this means that bank and non-bank PSPs do not connect directly to the central platform but rather do so through their central bank or domestic payments system, and all cross-border traffic go through the hub and then out again.

A third general architecture would consist of a fully decentralized architecture. There would be no central platform to which participants would connect to, either directly or indirectly. Typically, such a model would rest on bilateral or multilateral interlinking platforms that would link domestic systems together, with harmonized solutions for messaging and communication and for scheme management, respectively, and with settlement taking place on a bilateral basis, for each country pair. As an alternative to bilateral links, a decentralized architecture could also make use of DLT. Use of DLT has been piloted for some retail payment uses cases, like cross-border remittances. To date, experience with the application of DLT for cross-border large-value and corporate payments is limited.

Evidence shows that in Africa most cross-border payment systems are highly centralized. On one hand, this reflects the greater efficiency and reduced costs and risks of centralizing the payment clearing and settlement functions and with a rulebook that promotes robust risk management. On the other, greater usage also reflects the fact that the countries that participate in these regional systems are more highly integrated in terms of their intra-regional trade of goods and services and their financial system. Centralized solutions have also required very high commitment of stakeholders to materialize, particularly of central banks. In turn, more limited usage of regional payment systems that have a partly or fully decentralized architecture may be reflecting limited benefits of these systems, although it may also be an indication of low intra-regional trade and overall economic integration. It should as well be noted that bilateral agreements require less upfront investments relative to a central platform, and thus may be more affordable, although they may not be as scalable as multilateral network to include multiple payment corridors and currencies.

Finally, as the experience from Africa suggests, a key aspect that would need to be explored in great detail is the choice of currency. Any CBDC model for cross-border use would need to choose the CBDC(s) that would be used for settlement. This would bear implications for the underlying liquidity and FX risk management. In Africa, where participants in cross-border payment arrangements do not share a single currency, a global reserve currency like the US dollar or the Euro is normally chosen as the settlement currency, mainly because at least one of these two currencies is widely available. The latter is a very important aspect for liquidity risk management in a cross-border payment system in which the central bank acting as settlement agent is not the issuer of neither of these two currencies. Because of this reason, this central bank is unable and/or unwilling to act as a source of liquidity in the system. However, the fact that the two currencies are widely available could mean that some large commercial banks operating may be willing to act as liquidity providers. This option, however, would not be available in the absence of CBDCs functioning as global reserve currencies.[49]

Regarding FX risk and currency conversion costs (e.g., fees), these are typically borne by the originating and beneficiary end-users in a transaction rather than by the bank or non-bank PSPs that participate in the cross-border system. Two of the CBDC models discussed above, in fact, transfers the FX risk on the participating central banks.[50] In the other models described, each bank or non-bank PSP could set its own exchange rates and related rules for its clientele. Alternatively, a rulebook could be conceived of, which would include specific rules covering this aspect (e.g., a maximum spread over the prevailing exchange rates quoted by the central banks).[51]

Another element should be kept in mind when reflecting on currency choices for cross-border CBDC arrangements. In many corridors, countries mainly exchange USD or other dominant and widely accepted currencies. This is because each trading country uses such currencies both to build reserves and for trading internationally. Upon using domestic currencies for cross-border transfers (the same would hold for domestic CBDCs), there will always be the possibility of such currencies accumulating depending on the balance of trade and remittances, and hence the risk of currency fluctuations and of piling up a stock of currencies that have no value outside their counties of issue. This would be avoided by cross-border arrangements where CBDC were backed by a basket of reserve currencies. However, the pegging to a currency basket would constrain the supply of CBDC, much as any fixed exchange rate regime would do, and change its nature into something analogues to a stablecoin. Moreover, the practical complexities of such arrangements should not be neglected, such as fixing the right weights of the basket, mitigating the fluctuations in CBDC valuation (ad hence the risk to users) due to the exchange rate volatility of the basket currencies, or managing the reserves investment portfolio fund optimally—all elements that would complicate the CBDC peg.

Finally, FX controls applied in some countries are an issue that could potentially deter participation of those countries in regional arrangements that use multiple CBDCs. This aspect would need to be analyzed on a case-by-case basis, depending on the specific type of controls that are applied, to determine whether it is technically possible and financially viable for the cross-border CBDC arrangement to develop functionalities that would allow participation of bank and non-bank PSPs of countries where FX controls apply. For countries adopting a "hub-and-spoke" architecture, the respective central bank through which bank and non-bank PSPs send CBDC payments could ensure adherence to transaction limits in FX currencies.

III. HOW DO CROSS-BORDER CBDCs ADDRESS EXISTING CHALLENGES?

A general perception is that cross-border payments lag behind domestic ones. A recent assessment by the Financial Stability Board (FSB) of the existing payment arrangements has identified four types of important challenges, namely: cost, speed, access and transparency.[52] These challenges affect a number of different stakeholders on the supply side (bank and non-bank PSPs, payment system operators and technical service providers) and the demand side (end users composed of individuals, businesses and government agencies), and affect each of them in different ways.

TABLE 1 How Cross-Border CBDCs Address Existing Challenges

CORRESPONDENT BANKING	CROSS-BORDER CBDC[53]
CHALLENGE 1: High Cost	
Supply Side	
• High operational cost	• Lower cost due to scale and network economies (ceteris paribus)
• High barrier to entry and unwillingness to do business with less profitable customers • Smaller banks and non-bank PSPs may need to rely on other banks in foreign jurisdictions, with accompanying liquidity and credit risk. Others may not be able to find correspondents or bank partners • Multinational PSPs offering services in various countries and currencies need liquidity access in several currencies and face related FX risk	• Direct participation available to all applicants compliant with access requirements • Direct participation avoids the need for individual participants to rely on others (although this depends on the scalability of the model used) • Individual PSPs manage their own liquidity needs (in the relevant countries and currencies) and the associated FX risk
Demand Side	
• Individuals and MSMEs are impacted by high transaction fees in relation to smaller value payments • High costs for maintaining an account or for individual transfers may discourage use of the regulated financial system for cross-border transfers, exacerbating financial exclusion and driving some payment flows underground. In other cases, individual users may be discouraged from making cross-border payments at all	• PSPs' lower access cost to a cross-border CBDC infrastructure, and transparency of PSP's access cost structure, should discourage PSPs from adopting unfair pricing practices with service users[54] • Lower costs should encourage PSPs to (at least partly) pass them on to individual and MSME customers
CHALLENGE 2: Low Speed	
Supply Side	
• Speed is impacted by the dependence on several correspondents/ providers, cut-off times, asynchronous opening times or regulatory checks. • When processing speed is low, the cost for liquidity as well as FX settlement risk increases and liquidity management becomes more complex • Lack of system interoperability slows transactions • Non-harmonized messaging and processing standards furthermore reduce speed	• A single infrastructure would eliminate speed limitations

TABLE 1 *continued*

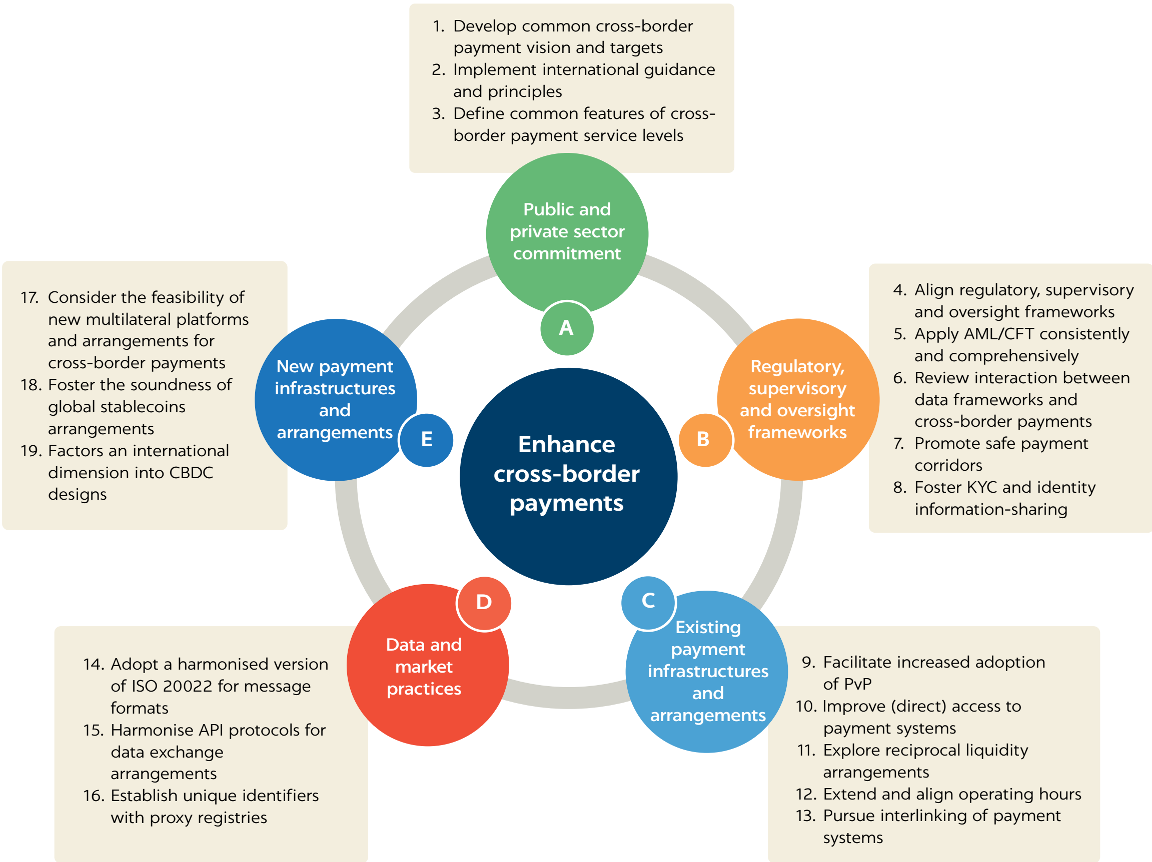
Demand Side	
• Low speed of cross-border payments brings delays and thus increases uncertainty, liquidity and credit risk, impacting all customers. Moreover, it can negatively impact business and investments, in particular where payments are time-critical	• Higher speed would enhance certainty and facilitate business and investment
CHALLENGE 3: Limited Access	
Supply Side	
• Challenges to access to payment systems and wholesale services can occur on the supply side owing to technical and financial entry barriers, regulatory requirements, or liquidity access limitations. PSPs may not be able to access directly local and foreign payment systems and possible funding in foreign currencies. This may make them dependent on other providers impacting their cross-border payments offerings	• Open, transparent and risk-based access criteria governing participation in a cross-border CBDC infrastructure, and their consistent application, would facilitate direct or indirect participation from PSPs, thereby removing all such challenges [55]
Demand Side	
• Access limitations may exist for MSMEs and individuals possibly limiting financial inclusion and pushing customers toward inefficient or costly third-party services. When unregulated payments channels are used instead, this can exacerbate financial integrity risks	• Higher speed would enhance certainty and facilitate business and investment
CORRESPONDENT BANKING	**CROSS-BORDER CBDC[53]**
CHALLENGE 4: Limited Transparency	
Supply Side	
• Limited transparency can lead to uncertainty and missed service levels to customers • Dependency on third parties can lead to difficulty in controlling the payments process and tracking the status of payments and resolving disputes • Information gaps can create a lack of transparency for AML/CFT and other purposes	• As a central bank's standard-compliant infrastructure, a cross-border CBDC would mitigate, if not eliminate, such risks
Demand Side	
• Limited transparency concerns all stakeholders on the demand side due to the uncertainty it causes. For corporates, lack of information about the speed, fees and FX rates of payments in process leads to uncertainties over the timing and amount of payments and can impact business service levels, and may lead to hedging and insurance costs to address the risks • Limitations may exist for MSMEs and individuals possibly limiting financial inclusion and pushing customers toward inefficient or costly third-party services	• As above

Based on the above description, the models discussed suggest that cross-border CBDC can be designed in ways that address effectively the above challenges. Table 1 considers the specific supply and demand side challenges that fall under each of the four types and points to how the cross-border CBDC could addresses them. The analysis reported in the table excludes references to BOC-BOE-MAS Model 3a (discussed above) since, as noted, the model closely resembles the existing correspondent banking arrangement and features many of its same challenges. Also, the analysis (realistically) assumes that central banks would run a CBDC facility as a financial market infrastructure or payment scheme and apply for it all relevant international standards. Also, the analysis (realistically) assumes that central banks running a CBDC facility would adopt cost-recovery rules and pricing criteria that would take into account the volumes and values of the transactions ordered by participants but would apply no surcharges aimed to extract extra-profits from its operation.

The models discussed, also, mark a significant progress along the G20 roadmap to enhance cross-border payments.[56] The models address two of the five focus areas identified to address the key challenges faced by cross-border payments, by contributing to five of the nineteen building blocks of the roadmap (Chart 12).[57] In particular, by experimenting with their respective models, the stakeholder communities around the central banks undertaking the pilots are building on the shared understanding of the targeted improvements in users' experience with cross-border payments and acting as a commitment mechanism to drive change, and they are creating the potential for new payment infrastructures and arrangements for cross-border payments, which could offer solutions to existing challenges.

CHART 12 G20 ROADMAP TO ENHANCE CROSS-BORDER PAYMENTS

Focus Areas and Associated Building Blocks



IV. USE OF CROSS-BORDER CBDCs: LEGAL ISSUES

CBDC for cross-border payments is inherently exposed to a plurality of legal systems. Anything that crosses borders implies that it is potentially subject to (at least) two different legal systems. These systems do not necessarily have similar rules to govern same events or contingencies. And even when similarities exist, such as, for instance, when international standards apply to both systems, the actual application of the same standards in each country might vary and might even conflict with each other. Conflicting standards and, even worse, conflict of laws engender the risk that the expected effects of a transaction do not materialize or that unexpected consequences occur.

CBDC that is legally issued in a country should be fully recognized by the other countries. If, in the issuing country, the central bank is acknowledged to possess the authority to issue CBDC, any other country should accept this CBDC as the currency of the issuing country in the same way as it accepts foreign currencies under any other form. This means that the legal issues associated to CBDC transfers should be the same as those associated to any other cross-border transfers. A situation where a country would accept a foreign currency under a specific form (say, cash) while it would refuse another currency under another form (hypothetically, CBDC) would be inconceivable in legal terms especially if the latter is understood to be a means of payment and not a commodity (precisely the case of CBDC). However, in light of the fact that the central bank permits non-residents, at least in principle, to freely purchase their domestic CBDC, thus placing both currencies (as means of payment) in competition with each, the circumstance cannot be ruled out whereby the receiving country would impose limitations on foreign CBDC use within its jurisdiction in order to safeguard its own currency.

A different consideration would hold for cross-border CBDC that is backed by a basket of currencies as one of the models described above (and under the limitations therein noted). In this case, what is transferred is not the currency of a country but an asset similar to the IMF's SDR. As noted earlier, the SDR is essentially an artificial currency instrument, built from a basket of a number of national currencies, which the IMF uses for accounting purposes.[58] The SDR is not regarded as a currency or a claim against the IMF assets. Instead, it is a prospective claim against the freely usable currencies that are issued by select IMF member states. Although the legal definition of CBDC would change in this case from that a fiat digital currency, once all participating jurisdictions recognized its use and value by way of agreement, its validity might not be challenged in any of the relevant jurisdictions.

LEGAL OBSTACLES TO CBDC FOR CROSS-BORDER PAYMENTS

In the first place, CBDC models designed for cross-border payments might pose different legal issues according to their individual specificities. An analysis would thus be required for each model, based on the legal order involved in each case, which is not within the scope of this report.

However, one common issue is that of "applicable law." When an established infrastructure is entirely situated within a jurisdiction under a specific legal order, that legal order shall apply to its operation as well as to its participants, including when these are foreign entities. The interlinking of different infrastructures situated in different countries would require of the authorities involved to adopt common standards that would mitigate risk transfers from one infrastructure to the other. Yet, this would not change the fact that each infrastructure is subject to its own jurisdiction and its respective legal system. The situation is different when the infrastructure is cross-border. In this case, the issue of relevant applicable law does arise.

Usually, this issue is resolved by way of an express choice taken by the parties involved at the time of setting up the legal basis of the infrastructure. The agreement would seek to address most of the foreseeable issues and contingencies, leaving to the application of general principles the resolution of eventual gaps arising from issues or contingencies that are not covered under the legal basis. In this regard, where parties have not elected a specific law, the principle that currently applies to conflict-of-laws cases is the applicable law. In the case of a payments system whose operations are integrated and carried out for the purpose of executing payments, the applicable law is usually the law of the jurisdiction where the processing, clearing and settlement of payments take place.[59] This, at least, as long as the activities are centralized. Different considerations would hold for decentralized infrastructures such as those based on DLT (see below).

Payment systems or platforms are typically regulated by agreements. To that extent, it is inconceivable that an infrastructure operates without a detailed and articulated agreement having been established since the very outset, covering most of the relevant issues and identifying the applicable law. The oversight authorities usually require for these agreements to be submitted for their approval or authorization before being adopted. When multiple central banks are involved, they are expected to cooperate with each other and try to solve any emerging conflict.

Even in the presence of an agreement governing an infrastructure, however, each legal system has mandatory rules that cannot be superseded by way of agreement or contract. Possible conflict between the legal systems involved cannot be fully resolved by an agreement or the selection of the applicable law. Rules that are considered of a mandatory nature, irrespective of the applicable law, need to be applied. Thus, an effort would be required of the participating jurisdictions to adopt some key common rules and standards to the extent possible. In particular, in the case of cross-border CBDC, each participating country should recognize digital transfers as enforceable for CBDC to be accepted within its own jurisdiction and to be protected from legal risk. In the same vein, participating countries should share the same standards for verification and enforceability of the final execution of transfers under all circumstances, and similarly for cybersecurity and foreign exchange risks.

Inter-jurisdictional differences in data collection and data protection rules may affect CBDC use for cross-border payments. Such rules require specific consideration, since digital payments involve transfer of data. Consequently, relevant differences between national legislations might impair the execution of cross-border payments.

The use of DLT raises legal issues. In addition to the fact that digital transfers must be fully recognized in all relevant jurisdictions, transfer of data needs to be adequately regulated and data need to be protected. This is both to ensure effective transfers and to prevent any form of abuse of data. Moreover, the decentralization of transfers through the progressive record into nodes challenges the relevance of the applicable law. Indeed, in a horizontal and decentralized mechanism, each leg of a transfer may in principle be considered as a separate transaction. In fact, this approach is not new to law theory and also to the legal practice in the realm of payments. For instance, international wire transfers have been often considered as a chain of separate transactions from the standpoint of potential conflict-of-laws issues. However, this fragmentation can affect the legal soundness of cross-border payments, since, as noted, different legal systems may govern the same events differently.

When public entities (such as central banks) are involved in cross-border arrangements, they can stipulate agreements subject to international law. This might be the case for domestic CBDCs, and it would be even more appropriate for cross-border CBDCs. If an infrastructure is planned for the operation of a cross-border CBDC, it can be established by way of international agreement and made subject to international law. An infrastructure that would be subject to international law would be governed independently of the national laws of the participating countries. However, this solution might have its own drawbacks, since central banks offering services under international law, which compete with services supplied by the private sector under national law, would risk distorting competition. Moreover, in the event that international law applies, it is still common practice to respect high standards, and especially when domestic rules derive from the application of international standards, central banks that would be found not to be fully compliant with such standards would face reputational risk.

Finally, differences across jurisdictions may weaken the legal basis of cross-border CBDC. Regulatory inconsistencies might emerge if, for instance, different criteria exist for the authorization of financial institutions as participants, or if different conditions apply for access of participants to central bank systems and facilities or to open accounts at central banks, or still if laws differ on data privacy, storing, sharing and management (which are of special relevance in the digital space). These differences may not only affect the legal soundness of the infrastructure but may also weaken its efficiency and even prejudice the achievement of achievement of common regulatory standards for the use of the same CBDC across the jurisdictions involved and ultimately alter the homogeneous quality of CBDC services to the public across the whole arrangement.

V. CONCLUSION: "IT TAKES TWO TO TANGO"

This report has illustrated the CBDC-based models currently under consideration. The report was intended only to show how CBDC-based solutions can facilitate cross-border payments. It has not ranked the models discussed, and it has not made recommendations as to which model(s) should be preferable.

The report suggests that CBDC-based solutions could lower costs and reduce significantly the number of intermediaries involved in cross-border payments. Payments into a country using a CBDC would go from the payer's account (or wallet) to the central bank of the receiving country and then directly to the payee or directly to payees' account (or wallet) if it were peer-to-peer, without having to go through a network of commercial banks. If both countries were to issue an interoperable CBDC (or interoperable CBDCs), payments would only need an exchange market to function across borders.

However, as the heading of this section suggests, any cross-border arrangement necessarily involves two (or more) partners and requires them all to agree on the rules and procedures needed to make the underlying exchange process possible. As the model description has shown, and the legal analysis suggests, CBDCs could not possibly be used for cross-border payments without the central banks of the jurisdictions concerned being intimately involved in the process of setting up and operating the interlinking or common infrastructure, and making its various (legal, technical, operational, financial, risk management) components mutually consistent or commonly shared: the cross-border use of CBDCs is essentially a collective, cooperative undertaking.[60]

There are several preconditions and steep obstacles along the way to achieving system interoperability and to improving the flow of money across borders using CBDCs. These fall into three broad categories: legal and regulatory barriers, technological incongruities, and monetary risks.

- First, a divergence in regulatory strategies in different jurisdictions may impede CBDC's ability to improve cross-border payments. For instance, the transfer of a CBDC between two countries would require the currency to comply with the legal requirements (such as money laundering, terrorist financing, and others) of both, which may vary dramatically. Achieving smoother cross-border transfers would require significant harmonization across various legal and regulatory domains.
- Second, technical variables—such as different blockchain / DLT standards and applications—may reduce the efficiency of CBDCs across borders. Underlying blockchain / DLT systems would have to be interoperable, which may not be the case without harmonization in design and implementation, and considering this is a new technology, it may take some time for standards to emerge. Similarly, the presence of legacy systems and infrastructures in various countries contributes to the technological divergences at play.
- Third, the use of CBDCs for cross-border payments may raise risks. It would not eliminate the exchange rate risk, and costly processes would remain in place for currency exchange. In other words, even if systems became interoperable, currency conversion and cross-currency rates would still pose obstacles. Moreover, the cross-border use of CBDCs may put monetary sovereignty at risk. The cross-border use of a CBDC denominated in a certain (major) currency may have far-reaching implications for monetary and financial policy independence. This may reduce and obstruct the functionality of CBDCs denominated in other currencies as means of payment and store of value. Also, since CBDCs must be fully fungible and

convertible into and from fiat currency, the most effective solution to ensure that CBDC improves cross-border payment processes would be for issuing countries to cooperate and jointly devise harmonized, interoperable solutions. Finally, while principal risk would be obviated by using PvP modalities, the systems would still fundamentally rely on the sender having adequate liquidity, which (as is evident from experience of financial markets) is not a given. Thus, adequate liquidity support mechanisms would be needed, which would introduce credit risk and thereby necessitate developing linkages with collateral management systems that might still be based on traditional technology models. For such solutions to be truly scalable, putting in place additional market support mechanisms would likely be necessary.

In fact, central banks are in general skeptical about the ability of rules to apply across boundaries and are concerned about the potential incongruities that might arise between various CBDCs.[61] The stringency and properties of AML/CFT requirements vary across countries, making it difficult for CBDCs to cross borders. This also applies to data protection standards, which differ between jurisdictions and may pose concerns around the anonymity and privacy of CBDC transactions. Another major concern is about digital identity management and how this might work in cross-border transactions. Ideally, a single verifying mechanism should be in place not only to confirm the identity at each end of the transaction and in general to support all processes that require verification. This would be especially necessary to fulfil KYC rules in multiple country contexts.[62]

This applies not only to questions around legal and regulatory harmonization, but also to cross-country differences in technical and operational standards, which might be the main obstacles to the cross-border interoperability of CBDC systems. These standards might diverge across economies, preventing CBDCs from producing powerful efficiency gains in cross-border payments. This raises significant questions about liquidity management across borders. For instance, some CBDC systems might be transferring funds via Swift messages, while others may be using DLT-backed infrastructure reliant on tokens or stablecoins.

It is clear that some kind of unified corridor or harmonization is required to achieve maximum efficiency gains. This warrants further research, as many of

the benefits of CBDCs for cross-border use hinge on addressing this challenge effectively. In any case, it will be important that the private sector be closely involved in the dissemination and management of any prospective CBDCs and that risks be mitigated as much as possible that usage of CBDCs might destabilize the financial sector.

In conclusion. Further work is still needed in this area before workable solutions for wholesale cross-border CBDCs can be arrived at, and the issues to be addressed are still many and relevant. Once this is done, taking the next step, that is, making CBDCs available to retailers for cross-border payments would require developing interfaces for users to interact with their banks and PSPs.[63] Further, a range of other market intermediaries (like payment gateways) will need to emerge in order to integrate acceptance of CBDCs for ecommerce and other payment needs.[64] This, however, would also call for the development of some form of scheme rules and brands. In the meantime, national authorities and industry stakeholders must remain committed to continue strengthening domestic systems, adopting international standards, and enabling access to cross-border payment service providers, and improving to the extent possible the efficiency and transparency of the existing cross-border payment arrangements.

ANNEX 1
CHANGES AND INITIATIVES IN CROSS-BORDER PAYMENTS

DISTRIBUTED LEDGER TECHNOLOGIES

DLT is a tool for recording ownership. A distributed ledger is a database of transactions that is spread across a network of many computers, rather than stored in a central location. It is consensually shared and synchronized across multiple sites, institutions or geographies. The participant at each node of the network can access the recordings shared across that network and can own an identical copy of it. Any changes or additions made to the ledger are reflected and copied to all participants in a matter of seconds or minutes. Applied to cross-border payments through a so-called "hub & spokes" model, users can exchange fiat money into DLT-based tokens held in digital wallets, through ATM machines, POS terminals, online interfaces, or other means (i.e., the spokes). These tokens are then transferred across borders over a virtual currency's secure network (i.e., the hub) to the payee's digital wallet. Finally, tokens are exchanged into foreign fiat money, as desired, through the same means as above (again, the spokes). The attributes of payment services offered by hub & spoke networks may look attractive to the public, except for three important caveats: first, the potentially erratic valuation of virtual currencies introduces risks and could limit their adoption, at least for large value payments; second, the lack of trust in hub & spoke networks could erode their value; and third, the lack of interoperability among networks could keep prices of hub & spoke payments high.

TransferWise

TransferWise is a British online money transfer service founded in January 2011 by Estonians Kristo Käärmann and Taavet Hinrikus and is based in London. The company supports more than 750 currency routes across the world and provides multi-currency accounts expressed in UK sterling pound, US and Canadian dollars, and euro. TransferWise routes most payments not by transferring the sender's money directly to the recipient as it is in the case of correspondent banking, but by matching the amounts with other TransferWise's users sending the other way around. TransferWise then uses these pools of funds to pay out transfers via local bank transfer. This process avoids currency conversion and transfers crossing borders. A small commission is charged per transaction and the inter-bank mid exchange rate is used, unlike traditional currency transfers where there are buy and sell rates and the broker takes the difference between the two.

SWIFT GPI

SWIFT GPI is a new facility that makes for quicker payments with full transparency on accompanying costs, while providing on-the-spot information on the status of transactions. With GPI, a payment is effective on the same day the payment process is initiated and a breakdown of all of the costs involved in the payment, including exchange-rate costs, are provided to the party initiating the payment. The status of the payment situation with respect to correspondent banks is available at all times. This traceability is possible due to a unique reference associated with each payment that is kept and shared by the different banks involved in the operation. The process finalizes with confirmation that the payment has been deposited in the beneficiary's account. Information regarding the payment remains unchanged and homogeneous during the process, and details provided by the issuer are the same as those received by the recipient as a result of the commitment established between the banks taking part in SWIFT GPI. These technologies facilitate end-to-end tracking of payments (just like tracking a courier) and offer transparency and allow companies to optimize liquidity.

ANNEX 2

NON-CBDC CROSS-BORDER PAYMENT MODELS[65]

This annex summarizes the main current cross-border payment models—alternative to corresponding banking—that are not based on CBDCs. The annex concludes with some considerations on the future outlook of cross-border payments.

PRIVATE LABEL CRYPTOCURRENCIES

In this model, consortiums of commercial banks or non-bank entities issue digital tokens on an agreed upon digital currency standard to execute cross-border settlement and other exchanges of value in a closed system. The digital token is typically backed by central bank issued fiat currency in the form of collateralized liquidity or other asset or liability deposits at or guaranteed by the central bank or some other trusted entity. The two examples of these are the Utility Settlement Coin (USC),[66] and the JP Morgan Coin (JPM Coin).[67] Cross-border settlement using either USC or JPM coin leverages the blockchain to ensure faster and more secure cross-border payments by straight-through processing and improvements to transparency.

USC is an experimental digital cash instrument built on DLT and originated by the Swiss global financial services company UBS in partnership with Clearmatics Technologies in a consortium of fourteen banks. s of 2019, the consortium raised $63 million in funding from the 14 shareholder banks.20In the USC model, large private banks and FinTech firms create digital tokens (i.e., USCs) representing money from multiple countries that can be exchanged on a distributed ledger platform. The digital token is fully collateralized by the cash balances of participating banks which are held on the books of the central bank. Unlike Bitcoin, USC is created through liability securitization. The decentralized nature of USC enables its members to settle inter-bank positions more efficiently. Moreover, USC may also be issued by transferring non-operating cash balances into a special purpose vehicle (SPV) that manages cash without a profit-making objective. This has the benefit of reducing the regulatory collateral requirements of the participating financial institutions by moving non-profitable high liquidity flight risk deposits off their balance sheets while being able to use the liquidity for transaction settlement purposes.

Similar to USC, JPM Coin is also an experimental digital coin built on the DLT, originated by J.P. Morgan Chase. JPM coin is a digital token, redeemable in a 1:1 ratio to the US dollar. The purpose of JPM Coin is transferring value in cross-border settlement. JPM Coin is permissioned, its users are exclusively institutional customers, and it employs the Quorum ledger. Additionally, in 2017, J.P. Morgan launched the Quorum-based Interbank Information Network (IIN), as a pilot program. The IIN allows member banks to exchange payment information to overcome the challenge of sharing such information in cross-border settlement. As of April 2019, there were 220 member banks across the world participating in the IIN.[68] Both the IIN and JPM Coin aim to address the shortcomings of correspondent banking in terms of information sharing and settlement. However, they may also be disruptive to central clearing services offered by organizations such as Payments Canada and sideline the traditional wholesale payments space.

Looking at potential disruption to wholesale payment systems is crucial. A business case for USC would be to provide a vehicle for settlement within derivatives markets. An example would be the market for cross-currency and interest rate swaps. To this end, it is important to note that the gross notional value of outstanding contracts in the over-the-counter (OTC) derivatives markets at the end of Q2 2018 was US$595 trillion while the gross market value of OTC derivatives in the same period was US$10 trillion. In the context of disruption to existing wholesale payments clearing and settlement infrastructures such as Canada's Large Value Transfer System (LVTS), payments made as part of the trade life cycle events in broader securities and derivatives markets may no longer require such infrastructure. Indeed, the instantaneous cross-border transfer of digital tokens exchangeable for cash assets eliminates the need for cumbersome processes of intraday collateral management required by existing wholesale settlement systems. Moreover, as such tokens are not tied to the operating hours of the wholesale payments systems across jurisdictions, transactions are free to flow frictionlessly hours a day and seven days a week.

STABLECOINS FOR CROSS-BORDER PAYMENT

Stablecoin refers to a class of digital currencies that are relatively stable in terms of their price. Stablecoins offer instantaneous processing and security of payments as many cryptocurrencies do. They also offer stability with respect to their parity against fiat currencies. Two digital currencies that fall into this category are RippleNet's native digital currency Ripple (XRP),[69] and Stellar network's native cryptocurrency, the Stellar Lumen (XLM).[70] Both Ripple and Stellar enable faster and more efficient cross-border payments relative to correspondent banking. However, they differ in that the former aims at improving cross-border settlement between international banks, whereas the latter aims at providing low-cost cross-border payment financial services to end-users and the unbanked population.

Ripple is a real-time gross settlement system, currency exchange and remittance network created by Ripple Labs Inc., a US-based technology company. Ripple enables multinational corporations to settle cross-border payments by transferring XRP through the Ripple network, resulting in on-demand liquidity. The three parts of the Ripple ecosystems are i) servers that maintain the ledger, ii) clients, and iii) intermediaries. Unlike Bitcoin or Ethereum, Ripple does not run proof of work nor does it run a proof of stake consensus mechanism. Instead, Ripple transactions rely on a Byzantine Generals Problem (BGP) consensus protocol, known as Ripple gateways, to validate account balances and transactions of the system.[71] The Ripple settlement process involves the creation of a transaction that is signed by the account owner and submitted to the network. Badly formed transactions will be rejected immediately, otherwise, they are provisionally included on the ledger. The Ripple network has many validating nodes which are used to validate and verify transactions. For a successful transaction to take place, the validators must come to a consensus on the transaction. While Ripple claims to be decentralized, the fact is that the 55 validator nodes all belong to Ripple. This is expected to change as third-party validator nodes join the network. As this happens, each of the Ripple validator nodes will be removed for every two third-party nodes that join. Under this setup, Ripple will become de facto decentralized with time.

Any accepted type of currency or asset can be used to transact on the Ripple Network. Cross-border payments using Ripple transact using XRP, a digital currency works as a liquidity source whenever it is necessary besides acting as a bridge between two currencies. XRP, which is an open source blockchain operates on the interface of peer-to-peer servers. It is supposedly capable of settling a payment within 4 seconds and handling 1,500 transactions every second. Each transaction costs $0.00001 and requires a small fraction of XRP to be destroyed in the process (0.00001 XRP), meaning the total supply of XRP decreases over time and, in theory, maintains its value.

By contrast, Stellar enables individuals (end-users) to trade money directly with each other across jurisdictions, using entrusted intermediaries to handle FX and funds transfers. Stellar is an open source, decentralized protocol for digital currency to fiat money transfers, which allows cross-border transactions between any pair of currencies. The Stellar protocol is supported by the Stellar Development Foundation, a non-for-profit organization.

Transaction confirmation time using Stellar has been observed to range from 1,000 transactions per second to approximately 10,000 transactions per seconds in a 2016 Barclays Africa and Deloitte pilot. Stellar's transaction fees remained a fixed rate at 0.000001 XLM per transaction, thereby making XLM cost effective for retail cross-border transactions.

For a transaction to be processed in a few seconds, the Stellar network needs to reach consensus fast while ensuring accuracy.[72] The Stellar Consensus Protocol (SCP) works by utilizing groups of trusted nodes that communicate among themselves to verify transactions. Consensus is achieved, on average, every two to five seconds between the trusted nodes. Unlike Ripple where decentralization is controlled by Ripple, decentralization in Stellar is expanded by trusted nodes deciding to extend trust to other nodes according to a Federated Byzantine Agreement (FBA).[73] The Stellar Lumen can be traded to different currencies, which means that performing a cross-border transaction using XLM is essentially using XLM as the bridge currency between two jurisdictions. This currency bridge function is facilitated through the Stellar Decentralized Exchange (SDEX), an exchange allowing trading between domestic fiat currencies and XLM. As a decentralized exchange (DEX), SDEX is borderless and therefore is not subject to jurisdictional controls or frictions and currency exchange is done by way of atomic swaps.[74] Similar to Ripple, the price of XLM depends on active trading against other currencies including fiat and the widespread adoption of the digital currency itself.

More recently, Facebook announced Libra (which has now become Diem, see fn. 63), its own permissioned blockchain digital currency. Note that Libra is merely one of many social media digital currency platforms with some like LBRY and Steem being operational for a number of years now.[75] Like Steem before it, Libra's primary use would be in the area of person-to-person, person-to-business, and to pay for goods and services online. While Libra is still a relatively new digital currency, given the vast global network of approximately 2.6 billion (or one third of the global population) users in the Facebook ecosystem, Libra has a substantial advantage over many other stablecoins and digital currencies. As a digital currency not bound by borders, Libra has the potential to disrupt existing correspondent banking models of retail cross-border settlement.

THE OUTLOOK OF CROSS-BORDER PAYMENTS

Currently, cross-border payments are dominated by correspondent banking, characterized by slow, costly and nontransparent execution. In the digital age, consumers (corporates and individuals) more and more expect cross-border transactions to be fast, frictionless, and affordable, at least as much as domestic payments are becoming everywhere. But while there have been many attempts to improve the cross-border payment systems, some of the core challenges in correspondent banking remain unresolved. To address these frictions, solutions have emerged across different sectors. Large corporates and FinTechs operating on a global scale entering the payments space are able to address a number of these frictions through their reach in various jurisdictions. These firms are able to timely and transparently facilitate cross-border payments by simply engaging in transfer pricing activities between their operations across jurisdictions. In doing so, they also potentially also benefit from tax arbitrage. SWIFT has launched and is actively expanding the core functionality of its SWFT GPI platform, discussed earlier, to facilitate the instant and always on transmission of payments across borders. In addition to these initiatives, there has been an expansion of DLT-based payment protocols that appear to be yielding promising results.

As these protocols gain ground, a proliferation of digital currency might take place in the mid- to long-term. Whether it is going to be CBDC such as that envisioned under Project Jasper-Ubin, or a private label cryptocurrency like Ripple or Stella, or perhaps a consortium of commercial banks that emerge with their digital currency (USC or JPM Coin), this emerging trend suggests that blockchain is here to stay.

Although DLT-based payment protocols and the internet layer for payment services remains nascent and unlikely to replace correspondent banking infrastructure on a large scale in the short term, its low cost, transparency, and real-time processing speed provide encouraging signs to the sector in their role in the future of cross-border payments. For sure, competition is on the rise and will continue to strengthen putting pressure on the incumbents. The emerging DLT-based payment protocols are competing in the wholesale and retail payments space and have the potential to erode established clearing and settlement services provided by central banks and institutions.

ENDNOTES

1 Drafted by Biagio Bossone with contributions by Oya Ardic, Ahmed Faragallah, Sheirin Iravantchi, Maria Chiara Malaguti and Gynedi Srinivas, and under the oversight and coordination of Harish Natarajan.

2 The "cross-border payments" referred to in this report fall within the realm of retail payment services and include those payments or fund transfers and remittances that are sent by an individual, business, financial institution or government agency in one jurisdiction to a recipient in another jurisdiction. Cross-border payments may or may not involve a currency conversion.

3 For un update on the recent growth of cross-border payment until the period prior to the start of the Covid-19 pandemic, see Enhancing Cross-border Payments—Stage 1 report to the G20: Technical background report, by the Financial Stability Board, 9 April 2020.

4 Defined by Financial Action Task Force (FATF), "correspondent banking" is the provision of banking services by one bank (the "correspondent bank") to another bank (the "respondent bank"). Large international banks typically act as correspondent banks for thousands of other banks around the world. Respondent banks may be provided with a wide range of services, including cash management (e.g., interest-bearing accounts in a variety of currencies), international wire transfers, cheque clearing, payable-through accounts and foreign exchange services. Domestic banks often rely on correspondent banks to handle transactions conducted involving foreign counterparts. This allows domestic banks to gain access to a wider scope of financial markets and to extend their services abroad without the hassle of opening overseas branches.

5 Alternative arrangements for cross-border payments, which are less relevant than correspondent banking, today include the single platform or in-house/intragroup transfer model, the interlinking between the national payment infrastructures of different countries, and the peer-to-peer model, with the first of the three play a relatively large role. For a description of these arrangements, see Enhancing Cross-border Payments—Stage 1 report to the G20: Technical background report, cit.

6 For a comprehensive analysis of the costs associated with cross-border payment and settlement systems, see Cross-Border Interbank Payment and Settlements: Emerging Opportunities for Digital Transformation, a report by the Bank of Canada, Bank of England and the Monetary Authority of Singapore, November 2018. On the retreat of correspondent banking relationships for the past decade, see Rice, T., P. von Goetz, and C. Boar, On the global retreat of correspondent banks, in "International banking and financial market developments," BIS Quarterly Review, March 2020, 33-52.

7 About a third of banks reported that they exited relationships which were no longer profitable or cost-effective because of the required due diligence or other economic reasons See Correspondent banking data report, Financial Stability Board, 4 July 2017.

8 See Recent trends in correspondent banking relationships—further considerations, Policy Papers. International Monetary Fund, 21 April 2017.

9 See Correspondent banking data report, cit.

10 Relevant sources on this topic include:

- *De-risking in the Financial Sector*, Brief, The World Bank, 7 October 2016, available at https://www.worldbank.org/en/topic/financialsector/brief/de-risking-in-the-financial-sector
- *The Report on the G20 survey in de-risking activities in the remittance market*, available at https://documents.worldbank.org/en/publication/documents-reports/documentdetail/679881467993185572/report-on-the-g20-survey-in-de-risking-activities-in-the-remittance-market
- *The decline in access to correspondent banking services in emerging markets : trends, impacts, and solutions - lessons learned from eight country case studies*, The World Bank, 2018, available at https://documents.worldbank.org/en/publication/documents-reports/documentdetail/552411525105603327/the-decline-in-access-to-correspondent-banking-services-in-emerging-markets-trends-impacts-and-solutions-lessons-learned-from-eight-country-case-studies
- *The decline in access to correspondent banking services in emerging markets : trends, impacts, and solutions - lessons learned from eight country case studies*, The World Bank, 2018; the *FSB reports on correspondent banking and remittances*, 16 March 2018, available at https://www.fsb.org/2018/03/fsb-reports-on-correspondent-banking-and-remittances/
- Erbenová, M., L. Yan, N. Kyriakos-Saad, A. López-Mejía, G. Gasha, E. Mathias, M. Norat, F. Fernando, and Y. Almeida (2016), "The Withdrawal of Correspondent Banking Relationships: A Case for Policy Action,", IMF Staff Discussion Note, SDN/16/06, June; and De-risking, Council of Europe, available at https://www.coe.int/en/web/moneyval/implementation/de-risking.

11 This is particularly important as remittances have overtaken private capital flows, FDIs, and aid in terms of total cross-border capital inflows and, in several countries, they represent a substantial portion of GDP.

12 One of the first contributions in this area is Fintech and Financial Services: Initial Considerations, IMF Staff Discussion Note, SDN/17/05, June 2017.

13 See Digital Money Across Borders: Macro-Financial Implications, International Monetary Fund, October 2020.

14 For all the aspects that relate to the concept of CBDC and use of CBDC within jurisdictions (for domestic payments), the report refers to Central bank digital currencies, joint report by the Committee on Payments and Market Infrastructures and Markets Committee, Bank for International Settlements, March 2018.

15 To date only the Bahamas Central Bank has officially launched retail CBDC in its jurisdiction, and a recent BIS survey of central banks indicates that about 80 percent are engaging in work related to CBDCs, and 40 percent have progressed to experiments or proof of concept. Se Boar, C., H. Holden, and A. Wadsworth (2020),. "Impending Arrival—A Sequel to the Survey on Central Bank Digital

Currency." BIS Papers 107, Bank for International Settlements, Basel.

16 For a technical discussion of the architecture options for three types of CBDCs (wholesale, retail, and cross-border), based on stylized examples, see Reference Architecture and Use Cases Report, ITU-T Focus Group Digital Currency including Digital Fiat Currency, Focus Group Technical Report, International Telecommunication Union, July 2019.

17 In January 2020, six central banks with significant expertise in exploring digital currencies created a working group to share CBDC experiences and assess use cases, which will assess CBDC use cases, including cross-borders. See Central bank group to assess potential cases for central bank digital currencies, Press Release, Swiss National Bank, Press release, Zurich, 21 January 2020.

18. Stakeholders included a group of commercial banks led by HSBC. Other commercial banks in the group were Oversea-Chinese Banking Corporation, Toronto-Dominion Bank and United Overseas Bank. KPMG Services Pte. Ltd helped facilitate a workshop between these participants to discuss views on this topic, and compiled views from them to assist in the development of the report. See *Cross-Border Interbank Payment and Settlements: Emerging Opportunities for Digital Transformation,* cit.

19. Just for brief reference, **Model 1** is the collection of current and planned industry initiatives, aimed at enhancing in-country RTGS systems (to expand operating hours, enhance payment status notification, improve standards, and reduce frictions) along with other improvements such as the adoption of common messaging standards, payments tracking and status visibility, improved KYC features, initiatives to link domestic payments infrastructures, and initiative to facilitate the establishment of common rules and standards for cross-currency/ cross-border payments. **Model 2** is based on an expanded role for in-country RTGS operators that act as "super-correspondents" for settling cross-border payments instead of relying on intermediary banks as correspondent banks. Central banks allow RTGS operators of different jurisdictions to open accounts in their (central bank's) books in the currency of the given RTGS operator. The central bank money for each currency resides in home jurisdictions only while, domestically, RTGS operators have a mirror account reflecting their balances with other central banks. This enables RTGS operators to effectively hold multicurrency clearing accounts for their member banks without the need for the latter to open nostro/vostro accounts globally. When banks need to fund their nostro accounts, the process is similar to the process today (i.e., the commercial banks still take the risk and source the funds); the only difference here is that the nostro accounts are now with the RTGS operator and not with a correspondent bank. The various RTGS operators are linked, potentially via a common shared platform.

20. Drawing from the field of computer science, the term "atomic" refers to an operation that requires a set of distinct changes to take effect altogether for the operation to be completed; otherwise, the operation has no effect and is reversed. Applied to financial transactions, an atomic transfer is complete if a number of events take place altogether; if it this does not happen, the transfer is not executed. As an example, consider a 100-dollar funds transfer from account X to account Y: first, the balance of account X must be checked, and 100 dollars are removed from the account and, second, 100 dollars are added to account Y, and the balance of account Y is checked as the end. If the entire operation is not completed as one whole "atomic commit," then several problems could occur. If the system fails in the middle of the operation, after removing the money from X and before adding into Y, the 100 dollars have just disappeared. Another issue is that if the balance of Y is checked before the 100 dollars is added, the wrong balance for Y will be reported. With an atomic transfer neither of these circumstances would materialize. In the former case, the transfer would be rolled back, and the money would be returned to X. In the latter case, the check of the balance of account Y would not occur until the transfer were completed.

21. See *Enabling Cross-Border High Value Transfer Using Distributed Ledger Technologies*, Jasper-Ubin Design Paper, report by the Bank of Canada and Monetary Authority of Singapore, powered by Accenture and JP Morgan, 2019.

22. The qualification of "universal" refers to a single CBDC being used by all participating jurisdictions. Such a solution might raise an analogy with the use of the IMF's Special Drawing Right (SDR) as CBDC that the central banks of member governments would make available to their commercial banks (and possibly other financial institutions) for cross-border payments activity. Yet, the SDR would not quite be associable to CBDC. The SDR is an international reserve asset, created by the IMF in 1969 to supplement its member countries' official reserves, and it serves as the unit of account of the IMF and some other international organizations, including the World Bank. Its value is based on a basket of five currencies (the US dollar, the euro, the Japanese yen, the British pound sterling and, from 2016, the Chinese renminbi). However, the SDR is neither a currency, nor a claim on the IMF; it cannot be used directly in market transactions. It can only be exchanged for these five major currencies and can therefore play a role in providing liquidity and supplementing member countries' official reserves. SDRs are generally allocated across member states according to the IMF's quota formula and principally used by developing states in need of hard currency. Members can also buy and sell SDRs in a voluntary market. The SDR mechanism is self-financing and levies charges on allocations which are then used to pay interest on SDR holdings. For further information on the SDR, see *Special Drawing Right (SDR)*, International Monetary Fund, March 24, 2020

23. This issue is discussed in the IMF's *Digital Money Across Borders: Macro-Financial Implications*, cit.

24. See *Jasper—Ubin Design Paper: Enabling Cross-Border High Value Transfer Using Distributed Ledger Technologies*, Accenture and JP Morgan, 2019.

25. https://interledger.org/rfcs/0022-hashed-timelock-agreements/

26. Prior to Project Inthanon-LionRock, the two central banks had embarked on their separate journeys to investigate the prospect of W-CBDC in the local context. The HKMA led some local financial institutions in 2017 to commence Project LionRock to study the benefits and risks of W-CBDC. The project included a PoC study on token-based CBDC and debt securities issued into a single DLT system. In 2018, the BOT initiated Project Inthanon with local participating banks to explore the feasibility of DLT to enhance Thailand's financial infrastructure, as well as to encourage collaborative learning amongst the involved parties. Upon completion of their respective domestic projects, the next step brought together the BOT and the HKMA to explore how W-CBDC could improve efficiency in cross-border payments.

27. See *Inthanon-LionRock: Leveraging Distributed Ledger Technology to Increase Efficiency in Cross-Border Payments*, report by the Bank of Thailand and the Hong Kong Monetary Authority, powered by C.RDA.

28. This is how links between CSDs are established currently allowing securities listed in a exchange in one jurisdiction to be traded in another jurisdiction—for example American Depository Receipts of Glaxo Smithkline listed in the London Stock Exchange or ADR of HDFC Bank listed in Bombay Stock Exchange (India).

29. While the BOT-HKMA report does not define the DR, the concept draws on the financial literature which defines it as a negotiable financial instrument issued by a bank to represent a foreign company's publicly traded securities. The DR typically trades on local stock exchanges and its purpose is to facilitate buying shares in foreign companies, so that shares do not have to leave the home country. A more precise definition of the DR in the context of foreign exchange markets and cross-border payment services is offered by the R3 study discussed below in sub-Section II.C.

30. The type of transaction that has been excluded is the sending of local funds from a local bank to another local bank, since this would be executed in the domestic settlement network.

31. The system requires three details to be filled out: (1) type of board rate, whether bid or ask, (2) available amount, and (3) the quoted rate. Inputted quotes can be updated at any time.

32. The denomination of these models derives from the company—R3 LLC—that has developed them. It must be noted that they differ from R3 Corda model underpinning the Jasper and Ubin projects. R3 LLC is an enterprise blockchain technology company, headquar-

tered in New York City. It leads an ecosystem of more than 300 firms working together to build distributed applications on top of Corda (known as CorDapps) for usage across industries such as financial services, insurance, healthcare, trade finance, and digital assets. It was founded in 2014 by David E Rutter. R3's blockchain platform Corda records, manages and synchronizes financial agreements and standardizes data and business processes. R3 made Corda open source in November 2016, allowing the global developer community to contribute to it, build on top of it, and to drive its design and adoption.

33. See *Cross-Border Settlement Systems: Blockchain Models Involving Central Bank Money*, R3 study by Zhao, X., H. Zhang, K. Rutter, C. Thompson, and C. Wan, 22 January 2018.
34. Notice that the term "cryptocurrency," which is part of the original name of the model chosen by its authors (and for this reason retained in this subsection), might be misleading as it is usually meant to indicate privately mined coins with no central issues. Here, in fact, the model developed by the author refers to an "intermediate cryptocurrency" as a liability jointly issued on a single ledger by the central banks participating in the arrangement. Project Aber, to be discussed below, is a good example of such a model.
35. Conceptually, this would be similar to the Universal W-CBDC discussed earlier.
36. The report does not further describe the underlying payments infrastructure.
37. Existing platforms such as Stellar could provide part of the infrastructure for this type of solution.
38. In a CBDC context, a settlement cycle would typically start with participants' pledging cash collateral into a special pooled account held by the central bank against the issuance of an equal amount of a central bank-issued digital cash that can circulate through the distributed ledger. Two banks can then send digital-cash payments to each other in real time to meet payment obligations they have agreed to settle on DLT. Alternatively, a bank may also cash out its digital-cash holdings by converting them back into cash at the central bank.
39. At CRDR expiration, Central Bank B redeems it in its own currency B at Central Bank A at the same exchange rate. The foreign exchange risk is thus born by Central Bank A.
40. The TTP model is presented under four variants, differentiated according to the type of entity that issues the depository receipt, its role in the clearing and settlement processes, and the risks involved and who bears them. Thus, the report evaluates a private sector-issued intermediate cryptocurrency, a pre-funded escrow account model, a Continuous Linked Settlement (CLS)-like model, and a deficit-fund ed account model.
41. See *Project Aber*, *Saudi Central Bank and Central Bank of the U.A.E. Joint Digital Currency and Distributed Ledger Project*, available at https://www.centralbank.ae/sites/default/files/2020-12/Aber%20Report%202020%20-%20EN.pdf
42. See Hyperledger Fabric documentation, available at https://hyperledger-fabric.readthedocs.io.
43. See McKinsey, *Global Payments 2016: Strong fundamentals despite uncertain times*, available at https://www.mckinsey.com/~/media/McKinsey/Industries/Financial%20Services/Our%20Insights/A%20mixed%202015%20for%20the%20global%20payments%20industry/Global-Payments-2016.ashx.
44. That is, commercial banks can agree on payments bilaterally without involving a trusted third party. This ensures that a commercial bank can move its funds freely between the channels in which it participates without having to depend on the central banks or any other central party.
45. See *Project Stella: Synchronised cross-border payments*, joint research project of the European Central Bank and the Bank of Japan, June 2019.
46. An example would be one where the Sender and the Receiver collude after initiating a transaction and thereby effectively locking the Connector's liquidity. In this instance, the Receiver has the option to either execute the payment (fulfil), or alternatively abort the payment by rejecting it within the timeout or by letting the timeout expire. Thus, the colluding parties can take advantage of the Connector's binding commitment depending on the movement of the exchange rate. That is, they only execute the payment if the exchange rate moves in a favorable direction for them, otherwise the payment is aborted.
47. This section builds on the extensive analysis reported in a World Bank's still-in-progress study on *Africa-Wide Payments Platform: Framework Document*.
48. A fully centralized model for settlements denominated in multiple currencies is nevertheless also possible, the prime example being CLS Bank International.
49. This would of course require that issuers of global reserve currencies (US, Eurozone) would be issuing their own CBDC and accept to make their CBDC available as settlement currency of regional CBDC arrangements.
50. See Project Inthanon-Lionrock, and R3 Option 2.
51. Inter-ledger protocols could be used for this purpose. These protocols are used for payments across different networks. A protocol connects ledgers from two different entities, such as banks.
52. See *Enhancing Cross-border Payments—Stage 1 report to the G20: Technical background report,* cit.
53. All that follows in this table as regards cross-border CDBCs excludes references to BOC-BOE-MAS Model 3a (discussed above), since, as noted, the model closely resembles the existing correspondent banking arrangement and features many of the latter's same challenges.
54. This (realistically) assumes that central banks would run a CBDC facility as public utility, possibly under cost-recovery rules and pricing criteria that would take into account transactions volumes and value by participants, but with no surcharges aimed to extract extra-profits from its operation.
55. It is (realistically) assumed that central banks would run a CBDC facility as a financial market infrastructure or payment scheme and apply for it all relevant international standards.
56. See *Overview of Saudi Arabia's 2020 G20 Presidency—Realizing Opportunities of the 21st Century for All*, Riyadh, 1 December 2019, and *Enhancing Cross-border Payments Stage 3 roadmap*, report by the Financial Stability Board, 13 October 2020.
57. The models address to Committing to a joint public and private sector vision to enhance cross-border payments (Focus A) and Exploring the potential role of new payment infrastructures and arrangements (Focus E), by contributing to Developing a common cross-border payments vision and targets (Building block 1), Developing a common cross-border payments vision and targets (Building block 3), Considering the feasibility of new multilateral platforms and arrangements for cross-border payments (Building Block 17), and Factoring an international dimension into CBDC design (Building block 19).
58. The World Bank Group and international agencies like the Bank of International Settlements, the African Development Bank, the Arab Monetary Fund, the Nordic Investment Bank, and others, may acquire and use SDR in transactions by agreement with the IMF.
59. This is not always the case, however; see, for instance, the case of the EBA Clearing's payment systems.
60. One type of CBDC cross-border payments would be an exception to this conclusion. It includes the payments and transfers of funds denominated in the currency of the issuing central bank jurisdictions and effected in favor of residents of other jurisdictions (individuals, businesses, financial institutions, government agencies). These transactions would be made possible by the issuing central bank granting CBDC access to non-residents, with the only requirement that non-residents be allowed by their jurisdiction of residence to hold accounts or wallets denominated in foreign currencies. Of course, such type of cross-border payments would permit only payments denominated in the currency of the issuing central bank jurisdiction.
61. See *Retail CBDCs: The next payments frontier*, report by OMFIF and IBM, 2019. The report findings were informed by 23 central

banks, which participated in an OMFIF survey conducted between July-September 2019.

62. Digital identity verification is essential to the operation of CBDCs, particularly in cross-border transactions. Tradeable digital assets must be tied to a digital identity system, which in turn should be tied to an automatic KYC and AML/CFT verification system. This is a foundational step to the potential use of CBDCs, and emerging developments in regulatory and compliance technology may benefit central banks' experiments in the digital currency space.
63. An example is what Novi (an app of Facebook) proposes to do for Diem (erstwhile Libra) stablecoin. See *Facebook-backed digital coin Libra renamed Diem in quest for approval,* by Anna Irrera and Tom Wilson, Reuters, 1 December 2020, available at https://www.reuters.com/article/facebook-cryptocurrency-int/facebook-backed-digital-coin-libra-renamed-diem-in-quest-for-approval-idUSKBN28B574.
64. See *Central Bank Digital Currency and the future: Visa publishes new research,* by Cuy Sheffield, Head of Crypto, Visa, 17 December 2020, available at https://usa.visa.com/visa-everywhere/blog/bdp/2020/12/17/central-bank-digital-1608165518834.html. The report explores the offline exchange of digital cash and how it could benefit consumers and economies worldwide.
65. This annex draws on Li, Z., and S. Bewaji, *How cross-border payments are evolving*, Payments Canada, 26 November, 2019.
66. See *What is 'Utility Settlement Coin' really?*, available from: https://ftalphaville.ft.com/2017/09/18/2193542/what-is-utility-settlement-coin-really/.
67. See *J.P. Morgan creates digital coin for payments,* available from: https://www.jpmorgan.com/global/news/digital-coin-payments.
68. These included four of the Canadian designated systemically important banks.
69. See *Ripple*, available on https://www.ripple.com/.
70. See *Stellar*, available on https://www.stellar.org/lumens/.
71. First proposed in 1982 by Marshall Pease, Robert Shostak and Leslie Lamport, the BGP conceptually imagines that several divisions of the Byzantine army are camped outside an enemy city, each division commanded by its own general. The generals can communicate with one another only by messenger. After observing the enemy, they must decide upon a common plan of action. However, some of the generals may be traitors, trying to prevent the loyal generals from reaching agreement. The generals must therefore devise an algorithm to guarantee that i) all loyal generals decide upon the same plan of action and ii) a small number of traitors cannot cause the loyal generals to adopt a bad plan. For further details refer to Marshall Pease, Robert Shostak and Leslie Lamport (1982) "The Byzantine Generals Problem", ACM Transactions on Programming Languages and Systems, Volume 4 Issue 3, July 1982, 382-401. See https://www.academia.edu/27660079/The_Byzantine_Generals_Problem.pdf?source=swp_share.
72. Consensus means that the entire network reaches an agreement on the transacting value. It is a vital component of decentralized network.
73. FBA comes to agreement on state updates using a unique slot where update dependencies between nodes are inferred. Nodes must agree on the slot update in each round of consensus. However, since the system is open to nodes joining and leaving the network at will, a majority-based quorum consensus mechanism will not work. Instead, the FBA in the SCP employs quorum slices that are subsets of quorums that are capable of convincing particular nodes of an agreement. See the SCP White Paper (https://www.stellar.org/papers/stellar-consensus-protocol.pdf) and Blockonomi (https://blockonomi.com/stellar-consensus-protocol/) for more details.
74. Atomic swaps, or atomic cross-chain trading, is the exchange of one cryptocurrency for another cryptocurrency (or rarely, fiat currency), without the need to trust a third-party. A relatively new piece of technology, atomic cross-chain trading looks to revolutionize the way in which users transact with each other. For example, if Alice owned 5 Bitcoins but instead wanted 100 Litecoins, she would have to go through an exchange, i.e. a third-party. However, with atomic swaps, if Bob owned 100 Litecoins but instead wanted 5 Bitcoins, then Bob and Alice could make a trade. In order to prevent, for example, Alice accepting Bob's 100 Litecoins but then failing to send over her 5 Bitcoins, atomic swaps utilizes what is known as hash time-locked contracts (HTLCs). For more on atomic swaps see https://www.cryptocompare.com/coins/guides/what-are-atomic-swaps/.
75. Steem is the Steemit ecosystem issued stablecoin with a construction similar to a self-contained macroeconomy having what is akin to government securities with short to longer term note maturity/term structures. For an overview of the economics of Steem, refer to https://steemit.com/steem/@spectrumecons/steem-explained-by-an-economist.

WORLD BANK GROUP