Tiered Access in RTGS systems: a DLT-based approach

Miguel Musa, Raúl Morales-Resendiz, Miguel Cárdenas,

Mario Sanclemente, Carlos Madeira, León Sanz

April 2023

Abstract

Distributed ledger technologies (DLT) are increasingly considered to enhance the operation of real time gross settlement (RTGS) systems and other prominent payment and market infrastructures. We explore DLT architecture options enabling a (new) tiered access in the RTGS system of Chile to underpin a more integrated retail and wholesale payment ecosystem, with improved accessibility for new payment service providers (PSP). We find that the decentralized apps (DApps) are a purposeful architecture for such providers to have a tiered access to the RTGS system under a safe and efficient environment. Our work also suggests that central banks exploring design alternatives for retail Central Bank Digital Currencies (CBDC) could find relevant our approach as a pivot to build a far-reaching PSP network.

JEL Classification: E41; E58; G10; G20.

Keywords: RTGS; DLT; Real Time Gross Settlement; Distributed ledger technology; Blockchain; Payment service providers; Financial market infrastructures; PSPs; FMIs; Central Bank Digital Currencies; CBDC.

Tiered Access in RTGS systems: a DLT-based approach

1. Introduction

A Real Time Gross Settlement (RTGS) system contributes to financial stability by providing the final and irrevocable settlement of (wholesale) payments. RTGS systems serve also as a transmission channel for a central bank to support intraday and overnight liquidity of its participants, both in normal and stress periods (CPMI 2003).

Access policy to the RTGS systems is largely defined by law to specific regulated financial institutions, in particular commercial banks which have well-established technical capabilities, as well as sound risk management frameworks. The growing presence in payment activity from BigTech and FinTech companies in addition to novel forms of money (e.g., e-money, crypto-assets and stablecoins) are prompting central banks to rethink the structure of the monetary and financial system. This includes how new -usually non-bank- payment service providers (PSPs) could access some to critical services provided by a RTGS system, namely settlement in central bank money (CPMI 2022).

Recent experience (e.g., India, México, United Kingdom) proves that enabling access to nonbanks supports financial stability through greater diversity of payments, risk-reducing payment technologies, and expanding the range of transactions settled in central bank money (World Bank 2020).[1] More recently, central banks considering the potential development of a Central Bank Digital Currency (CBDC) also incorporate a broader participation of non-bank PSPs (Auer et al. 2022).

Currently, only a limited number of RTGS systems provide access to non-bank PSPs (CPMI 2022a, World Bank 2020). By providing a greater access to non-bank PSPs, a more integrated retail and wholesale payments ecosystem could be fostered, which ultimately would increase the role of the central bank money in the economy[2]. To satisfy institutional, regulatory, and legal constraints of the central banks, a tiered access to the RTGS system could be a suitable solution to increase the number of participants, especially among non-bank PSPs.

A DLT system is a community consensus-based distributed ledgers where the data storage meets these principles: a) decentralisation of consensus, b) transparency, c) security, and e) immutability. In particular, DLT acts as a decentralised repository of information and can be designed to underpin transfers between parties (Schar & Berensten 2020). A DLT-based market infrastructure could improve the financial system by allowing smart contracts[3] to automate the execution of rules or agreements, without using intermediaries, so that all participants can be immediately certain of the outcome (Townsend 2019). For instance, DLT arrangements can provide real-time settlement of securities and associated funds transfers such as cross-border payments by reducing the use of collateral and record-keeping, reconciliation costs and settlement costs (Auer 2019, Bech et al. 2017)[4].

[1] Access to a payment system infrastructure by a PSP can be characterised as being either direct or indirect. A PSP which can directly execute payment orders with the centralised payment system infrastructure and is bound by the rules of the system is classified as a direct participant. In contrast, a PSP which is accessing the services provided by the centralised payment system infrastructure but is not bound by the rules of the payment infrastructure is defined as an indirect participant. Access to the payment system infrastructure can be further divided into whether a PSP has access only to the clearing service, settlement service, collateralised intraday liquidity support, permitting third-party transfers along with own-account transfers, or allowing for participation in primary market auctions of government securities (World Bank 2020).

[2] In May 2020 the IMF issued a technical assistance report on Chile for central bank services to nonbank financial institutions stated that providing access to nonbank payment service providers could support innovation and a level playing field and is expected to increase the efficiency of the system; however, access to central bank facilities could impact the central bank's ability to implement monetary policy.

[3] Smart contracts are decentralised applications that allow programming business logics that operate automatically. Smart contracts can be feasible in a DLT infrastructure despite an efficiency limit to the number of trusted nodes in the system due to computation and communication costs.

[4] A DLT-based system operates without a central validator and rather distributes the responsibility of validating and recording of such transactions among the network peers. This consensus replaces the trust provided by a

Simulations of DLT asset markets showed that the investor welfare can be increased due to the higher transparency of the holdings and trading intentions of the agents (Malinova and Park 2017).

Our work explores Distributed Ledger Technology (DLT) architecture options that could enable a (new) tiered access in the RTGS system of Chile, whereby underpinning a more integrated and accessible payments ecosystem. We present an RTGS system architecture under four different groups of functional and technical features. This representation reflects the properties of accessibility, interoperability, safety and efficiency of a payment system. We find that decentralised applications apps (DApps) are a purposeful architecture to enable access to the RTGS to new participants, while preserving safety and efficiency features.

Our article is closely related to a recent literature on technological innovation in terms of the monetary and financial infrastructure (Auer et al. 2022), particularly with respect to the RTGS developments (Bech and Hobijn 2007, D'Andrea and Limodio 2022), fast payment systems (Bech et al. 2017), the risk features of large value payment systems (Humphrey 1986, Kahn et al. 2003, Bech and Hobijn 2007), and the application of DLT architectures in finance (Chapman et al. 2017). It is also related to a literature analysing the growing presence of FinTech and BigTech firms in the payment services market (Frost et al. 2019, Boissay et al. 2021, Aramonte et al. 2022) and the positive effects of financial access and competition on financial stability (Schaeck and Cihák 2014, Sigraiova and Havranek 2016, Degryse et al. 2019). Finally, our work is related to the governance of central banks (Auer et al. 2022), the effects of communication on the financial markets (Madeira and Madeira 2019) and financial development (Levine 2021).

In our understanding, enabling tiered access for non-banks in the RTGS system using DLT is a new area of study that could represent a contribution to support a more integrated retail and wholesale payments ecosystem. In some cases, it could also help to overcome institutional constraints to provide a tiered access to non-bank PSPs. Our contribution is twofold. First, we provide an analytical framework to understand how DLT could enable a tiered access to the RTGS system for nonbank PSP. Second, we discuss how DLT architectures could be relevant for the accessibility and integration of the payments system.

An expanded access of the RTGS to non-bank PSPs could also be a relevant approach as a close alternative for a retail Central Bank Digital Currency (rCBDC), as suggested in Auer et al. 2022, BIS 2022a and BIS 2020). A permissioned DLT architecture for a selected number of institutions[5] updating a centralised ledger could increase the resilience of the financial system and become an alternative for a CBDC (Auer et al. 2022). An expanded access to the RTGS system for non-bank PSPs could gradually pave the way for a hybrid CBDC and increase the resilience of the retail payment systems (Auer & Boehme 2020). Such an architecture could balance direct claims on the central bank while enabling different types of PSPs, including non-banks, to deploy their capacity for the customer-facing side of retail payments (BIS 2022).

A major concern that both CBDC and a permissioned DLT architecture could help addressing, relates to consumer privacy. Given that individuals have fewer incentives to protect their privacy data to prevent price discrimination, the creation of a CBDC underpinned by DLT could help ensuring a framework for PSPs accessibility against data monopolists and hence improving consumer welfare by giving an outside option to consumers that protects privacy due to cryptographic techniques (Auer et al. 2022). To this end, DLTs are increasingly under experimentation for a wide range of payment systems' operational purposes (Auer et al. 2022).[6]

central validator and at the same time provides security, immutability, and transparency to the network. The decentralisation achieved in this system reduces the risk of having a single point of failure.

[5] Decentralised permissionless systems have a high economic cost in terms of updating the ledger and a risk of "forks" dividing the network, which makes permissionless systems inviable for a CBDC (Auer et al. 2022).

[6] Some recent retail CBDC experiments also relied on a DLT architecture, such as Jasper by Bank of Canada, Stella by Bank of Japan, Ubin by the Monetary Authority of Singapore, Khokha by the South African Reserve Bank, Inthanon by the Bank of Thailand, the CBDC Sand Dollar project by the Central Bank of the Bahamas, the DCash pilot by the Eastern Caribbean Central Bank, and a DLT project by the European Central Bank.

This paper is organised as follows. Section 2 summarises the relevance of the RTGS system for the financial system and the economy. Section 3 presents the relevant features of the RTGS systems, and it also introduces key issues for access to these systems. Section 4 elaborates on our analytical approach and findings for a DLT infrastructure to enable a tiered access to the RTGS system. Section 5 presents a comprehensive analysis of the selected DLT architecture option and its main design and performance issues. Finally, section 6 concludes with a final discussion of our findings.

2. Use and relevance of the RTGS system across the world and in Chile

a. Adoption and use of the RTGS systems

RTGS systems are an essential infrastructure of the financial system. These infrastructures are suited for low-volume, high-value transactions, eliminating credit risk in settlements and informing about the participants central bank reserve accounts in real time. Worldwide, after the first RTGS system was created in 1970 by the Federal Reserve System[7], adoption took up gradually in advanced economies during the 1980s and 1990s (Bech and Hobijn 2007). While its adoption took place across developing economies mainly during the first decade of the 2000s (Bech and Hobijn 2007) and by 2010 its use among national central banks was almost universal for all countries (Bech et al. 2017, World Bank 2020). By 2018, around 96% of the countries were using at least one RTGS system, with 87% of the economies channelling more than half of the total value of their large-value payments through the RTGS system. Currently, 18 countries channel large-value payments through other systems besides the RTGS, either partially or exclusively. In the case of Chile both the RTGS system and a Deferred Net Settlement (DNS) systems serve large value payments (World Bank 2020). According to D'Andrea and Limodio (2022), RTGS adoption produces real positive effects on firms in jurisdictions with weak pre-existing interbank markets, by introducing financial technologies to lower transaction costs on the interbank market and by generating market integration with higher access and liquidity.

Despite the importance that RTGS systems embed for the financial and monetary system, the last decade saw a decline in the value of transactions settled in these systems. Namely, the annual value of transactions reduced to multiple of 30 times the global GDP in 2018 compared to the multiples of 36.3 and 32.8 recorded in 2015 and 2012, respectively (World Bank 2020). Furthermore, there was also a decrease in the use of the RTGS systems within most countries, with the average GDP turnover of the annual transactions per country decreasing from 21.6 times in 2015 to 17.9 times in 2017 (World Bank 2020). Relative to other payments and market infrastructures, the RTGS systems offer immediate finality of the payments with funds from central bank money, which are settled individually and irrevocably on a gross basis in real time. Since payment finality is one of the main roles of money, therefore central banks typically assume the role of managing the RTGS systems in each country (Auer et al. 2022, BIS 2022).

Relative to other systems such as Deferred Net Settlement (DNS) systems, which registers transactions in real time during the day but defers the payment to a net settlement of the accounts at the end of the business day. A major drawback of netting systems, however, is the risk that a party will default on its payment obligations, which can set a cascade of settlement failures and a systemic payment crisis (Humphrey 1986). This has led central banks across jurisdictions to underpin DNS system by guaranteeing payment finality in case of default (Bech and Hobijn 2007). RTGS systems, however, are not without disadvantages, being one of them that RTGS participants are often limited by law to banks.[8] This limited access is a growing concern given that non-bank PSPs are not yet regulated

---

[7] The first RTGS system, Fedwired, was created in 1918 by the Federal Reserve System in the United States, but it only became automated in 1970 (Bech and Hobijn 2007).

[8] Commercial banks are the only type of entity that has access to the RTGS systems in all systems worldwide, with all but one case being direct access. Other types of banks and supervised NBFIs have direct access in 52 and 30 percent of the cases, respectively (World Bank 2020). Direct access of supervised NBFIs and FMIs is more common in high-income economies, especially in High-income OECD members. In contrast, unsupervised NBFIs typically do not have direct access to RTGS systems. Only four countries reported direct access of unsupervised NBFIs reported, all of them without access to central bank credit (World Bank 2020). Where applicable, direct access to the RTGS system is granted to other system operators (central counterparties (CCP), securities settlement systems

financial institutions, whereby their business models have prompted important payment innovations (Frost et al. 2019).

The lack of access to the RTGS system by non-banks may help explaining its relatively declining relevance in terms of transaction relative to the GDP (World Bank 2020), since non-bank PSPs are taking an increasingly large role in providing retail payment systems over the recent years (Frost et al. 2019) and BigTech[9] have been growing at a much faster rate than financial firms (Boissay et al. 2021). It is relevant to note that the factors causing this decline in the RTGS system transactions are still not fully studied, therefore other several factors (such as an increase in the use of physical money) may be also playing a role.

In preserving their role as the bedrock of the financial system, and with that supporting an integrated monetary system, RTGS systems may have to expand their access to non-bank PSPs. The prospect of a divided payment system between banks and non-banks is becoming clear in some emerging markets, with BigTech companies such as Ant Financial's Alipay and Tencent's WeChat Pay in China[10], Vodafone M-Pesa in Africa and Mercado Libre's in Latin America. This fragmentation can imply that separate payments infrastructures might not interoperate with each other. Besides, entities operating these new payment infrastructures usually overlay with their core products in a vertically integrated business model[11]. This type of fragmentation favours regulatory arbitrage, duplicates the long-standing bank-based payment infrastructure, and eventually jeopardises the monetary system (CPMI 2022b, Frost et al. 2019, FSB 2022)[12].

It is therefore increasingly relevant to create a modern RTGS infrastructure that can provide both banks and non-banks with a suitable access to relevant settlement services. By fostering such an expanded access of RTGS systems, innovative payment and financial services and increased opportunities to foster financial inclusion can be fostered. For instance, BigTech firms often start with payments, but then expand towards the provision of credit, insurance, money management, savings and investment products, often attending customers underserved by traditional financial institutions (Frost et al. 2019). In addition, recent literature shows that higher financial inclusion and competition in financial services also fosters financial stability (Schaeck and Cihák 2014, Sigraiova and Havranek 2016, Degryse et al. 2019) and economic growth (Levine 2021), primarily by boosting small firms and households' financial opportunities (Levine 2021). Finally, expanding the reach of central banks' RTGS

(SSS), automated clearing houses (ACH), payment card network operators) with securities settlement systems (SSS) being the most common participants (World Bank 2020).

9 BigTech companies are currently the largest companies in the world by market capitalisation, with the largest 6 technology companies all surpassing the largest global systemically important financial institutions (Frost et al. 2019).

10 China is by far the world's largest market for payments outside the traditional banking infrastructure, with BigTech mobile payments for consumption reaching 16% of GDP (Frost et al. 2019). Alipay (launched in 2004) and WeChat Pay (launched in 2011, although its virtual currency Q was created as early as 2002) have surpassed 500 million and 900 million monthly active users, respectively, or 36% and 65% of the overall population. Together, these two firms account for 94% of the mobile payments market in China (Frost et al. 2019).

11 These products can include mobile e-commerce, services, messaging, social media, and credit.

12 In spite of the importance of a wider access to the RTGS by new players, there are not substantial changes in RTGS access policies, according with a World Bank survey. In 2018, banks remain as the only participant type to have direct access to account-services of RTGS systems worldwide (World Bank 2020). Only 19 percent of the reported systems can be accessed directly by (nonbanks) participants other than banks. In fact, nonbanks (supervised and unsupervised) are more likely to have no access at all (38 and 53 percent, respectively), and a tiered access is only available in 20 and 9 percent of the systems, for supervised and unsupervised nonbanks. About 90 percent of all RTGS systems have explicit access criteria, mainly related to the institutional standing of participants (i.e., whether participants are banks or other types of financial or even non-financial institutions), minimum capital, and technological requirements. For instance, the e-money service providers have a tiered access in less than 20 percent of the RTGS systems worldwide and no access in other cases.

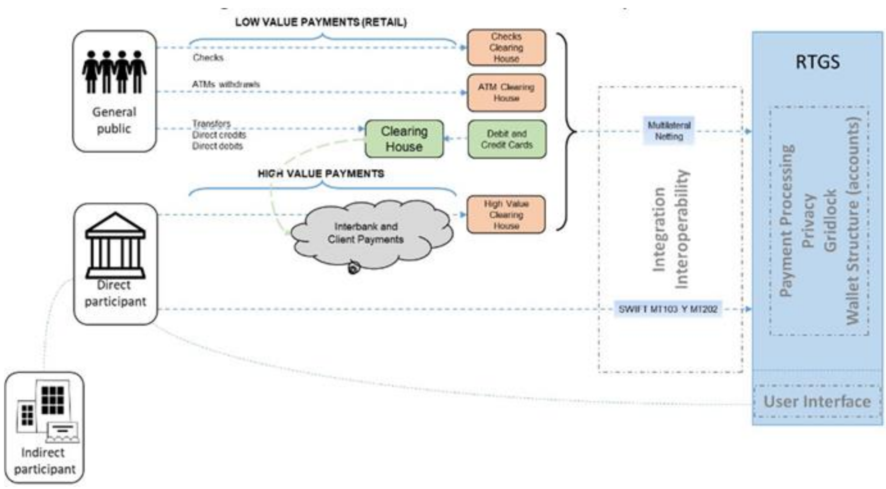
systems may enhance financial stability by enhancing the role of transparent central clearing institutions and reaffirming the role of central bank money (Aramonte et al. 2022).

b. The taxonomy of the Chilean RTGS system

The Chilean RTGS system is owned and managed by the Central Bank (Banco Central de Chile 2017). The RTGS is supported by an operational architecture made of conventional web technology, an operating system, and multiple architecture components and standards that enable the integration of such core payment infrastructure with its participants. An important feature is that all transactions are irrevocable and unconditional once they are settled, with the funds transferred from the payer's account to the payee's account. The settlement account of each participant is linked to a reserve account that is debited or credited in central bank money depending on the participants' position.

The cycle for a retail payment in Chile usually starts with customers including firms and households initiate transactions, either through a direct or indirect participant, with different payment instruments that are first cleared by customers' PSP in other (retail) payment infrastructures. After clearing, the net results are then settled in the RTGS system. Transactions that are directly ordered and settled in the system only correspond to those initiated by RTGS direct participants, while retail transactions occur first in other payment platforms. As such, interoperability, access with and to the RTGS is crucial for the well-functioning of instruments being used by businesses and households (see Figure 1).

Figure 1: RTGS operational architecture



The technological architecture of the Chilean RTGS system has a core layer relying on primary foundations payment processing, a gridlock resolution algorithm, and the user interface for participants' communication. Within this core layer, payment processing rules of queuing, settlement, accounts (i.e., wallets) and privacy features are defined. Besides the core layer, other key elements play a fundamental role in the RTGS workflow, including the messaging interface (a Virtual Private Network, a SWIFT closed-group service, and others), a central platform which runs the payment orders to be settled by the RTGS, and the access (i.e., integration) and interoperability aspects are specified.

Given that the legal framework of the Chilean RTGS sets that besides commercial banks, only authorised payment platforms such as systemically important payment systems (SIPS) can settle in central bank money through RTGS accounts, the current operational architecture hinders RTGS system suitability to support a growing digital payments market with non-bank PSPs becoming significant players. [13] While bilateral arrangements between non-bank PSPs and direct participants to the RTGS system can take place, interoperability and accessibility are considerably limited.

[13] In the case of the new tiering participants, liquidity could be reduced when having a regulated customer relationship with a direct participant. First, because payments between a tiering participant and its settlement bank (direct participant) would be settled in the book of the direct participant instead of being sent to the core processing system of the RTGS on a gross basis. Second, subject to the liquidity requisites for direct participants, the payment

3 Approach

In this section, we present our approach to suggest the DLT architecture options to enable a tiered access for new non-bank PSPs in the Chilean RTGS system. Our approach relies on a conceptual analysis of functional and technical features of the RTGS system and of the DLT networks.

Our analysis is remarkably qualitative-oriented. It distinguishes from recent experimentation by employing a complex system approach that introduces novel concepts to represent an RTGS system architecture under functional and technical features. We examine the impact different DLT architecture options have on key payment systems' properties, namely accessibility and interoperability, and safety and efficiency. These features are also analysed against a set of indicators that help determining the relevance of each RTGS system for accessibility and interoperability, mainly. In our analysis, we consider the impact of these different DLT architecture options have on enabling a tiered access to non-bank PSPs.

3.1 Accessibility, interoperability, safety and efficiency: a benchmark to measure the effects of RTGS tiering participants

We consider the following six indicators to determine how each RTGS system feature could contribute to improve the accessibility and interoperability into the payments ecosystem.

Number of participant institutions: We assume a higher number of (direct and tiering) participants in the RTGS system could improve the interoperability with other systems and it could also represent a greater accessibility in general.

Concentration ratios (two indicators): (i) concentration ratio of direct participants, (ii) concentration ratio of intermediaries. We define the concentration ratio as the percentage of the total number of transactions of the 5 largest participants or intermediaries divided by the total number of transactions. We assume that lower ratios could represent an improved accessibility.

Total number of transactions: We assume that an increased number of transactions settled in the RTGS system could reflect a greater safety and efficiency given the larger amount of transactions settled in central bank money.[14]

Cost of entering the system: We assume that at lower costs of entering the RTGS system, there could be fewer barriers for new entrants.

Cost of transactions: We assume that decreasing marginal cost per transaction could encourage tiering participants and improve the overall efficiency and accessibility in the payments ecosystem.

New services: We assume that a more flexible architecture for the RTGS system, namely PSP offered with new services, also improves innovation (i.e. efficiency) and interoperability.

3.2 De-structuring the RTGS

A payments system is a set of instruments, procedures and rules among participating institutions, including the systems' manager, to handle payment transactions. Its architecture involves two different layers. A front-end that is the workflow user interface of payments and allows the interaction among end-users, the payers and the payees. The second layer is the back-end arrangements that directly supports the transaction clearing and settlements.

We propose a representation of the RTGS system under (seven) functional and technical features. The first feature is the payment processing, which involves mainly: 1) settlement of payments, preceded by checking balances in the participants' accounts to instruct the settlement or the queuing of the

flows of tiering participants may allow the settlement bank to fund more payments from receipts rather than from liquidity provided by the Central Bank. There could be alternative approaches to liquidity saving mechanisms given a tiered access, depending on each RTGS operation rules, but in general tiering participants should be expected to require less liquidity. A deeper discussion would be necessary to define if the RTGS should establish new liquidity requirements and vehicles, but this goes beyond the scope of our work.

[14] We consider all transactions settled through a clearinghouse as the gross value of each individual transaction.

transaction; 2) first-in, first-out (FIFO) and priority arrangements, to allow the system to queue transactions and settle according to the priority and funds available; 3) payment-versus-payment mechanisms for settling two linked transaction instructions between two participants, with both payments settling at the same time.

The second feature is the gridlock resolution to optimise liquidity. A gridlock takes place in the RTGS system when a group of senders/receivers (i.e. participants) with queued payment instructions are unable to settle unilaterally in a sequential manner due to insufficient funds. Liquidity requirements increase when the payments are settled individually in real time. As such, to avoid liquidity costs, direct participants may prefer to wait for incoming payments before sending their own. There are DLT alternatives to manage transitory negative balances, for instance, customised decentralised applications (DApp). A customised DApp[15] could mint and burn tokens depending on users' wallet limits, allowing different users to be safely connected to the RTGS system.

The third feature is the privacy of network participants. We define privacy as the capability to access transaction information only by the parties involved in it. In the case of the RTGS system, the central bank accesses the information of all transactions. In a DLT permissioned network, privacy can be set at the node (encrypted channels of communication) or at the transaction level. To avoid hampering the performance of the RTGS system, enabling a tiered access for nonbanks could be designed at the transaction level. This requires implementing scalable Zero Knowledge protocols[16].

The fourth feature is the access (integration) to the RTGS system. It entails rules on how new players will connect into the system. Usually, this entails infrastructure investments that could represent a major barrier for non-banks, preventing them to become a tiering participant of RTGS systems. In this vein, the DLT operational architecture must be coherent with a design that lowers costs, but also fits with the RTGS access policy, and with the security- and payments-related regulation set by central bank.

The fifth feature is interoperability. It involves the capability to share information across different payment infrastructures, which is key for new PSPs to offer different business models and services. Using APIs or a "DLT Manager" (a piece of software that translates between standards or protocols from different systems) allows the RTGS to be interoperable with other infrastructures.

The sixth feature is the wallet structure. Direct participants hold reserve balances in central bank accounts, while tiering participants interact with direct participants by means of "wallets" (special accounts for indirect participants). The design of the wallet permitting tiered access should concern features such as: holdings limits, overdraft limits or abilities, etc. Thus, the wallet design is of special importance in our analysis. The DLT operational architecture for a wallet structure could be critical to design also a retail CBDC that operates under a two-tier architecture. This type of CBDC model can be defined also as hybrid CBDC as Auer and Boehme (2019). Under a hybrid CBDC model several bank and non-bank PSP intermediates between the central bank and the end-users.

[15] Decentralised Application (DApp) is an application software deployed in different computers connected to the same decentralised network. This implies that any functionality or transaction can be triggered from any node in the network and is validated by the rest of the nodes to reach consensus. APPs and DApps are designed to perform functionalities for the end users connected to the network. Particularly, a DApp considers a backend communication (blockchain) and smart contract deployment representing the business logic. DApps implement standardised protocols to establish tokenisation characteristics that allow managing user's permissions and token's transfers. In Ethereum, blockchains standards are defined by the Ethereum Request for Comments (ERC) which define a set of rules required to implement tokens into the ecosystem (ie. ERC20, ERC721). This architecture allows connection of participants through DApps, therefore participants do not need a node for connecting. Moreover, all nodes in the network could be deployed by a central party, which simplifies the maintenance and upgrade of new functionalities in the network, consequently, improving scalability.

[16] Scalable Zero Knowledge proof encryption protocols for privacy solve the problem of having verifiable transactions, while keeping privacy in terms of participants (anonymity) and transaction details (confidentiality). In other words, validation of transactions can be made without revealing the transaction information. Therefore, there is no need for participants to have a node to keep privacy of their transactions (privacy at a node level).

The seventh feature is the user interface. This feature provides a visual interface for direct and tiering participants to check balances of their accounts (or wallets), allowing participants to display their most relevant information in the RTGS system (balances, queued instructions, etc.).

In our analysis, the features interrelate seamlessly to enable the transaction flow. If one feature fails, the system collapses or freeses. Similarly, we assume that the throughput of the RTGS system can be managed under the current operational architecture and also by selecting DLT architecture options that are responsive to peak demand.

3.3 DLT architecture options

RTGS systems are increasingly more technology intensive, with significant improvements like Straight-Through-Processing (STP) that equip systems with enough throughput to underpin millions of retail payment transactions as illustrated recently in fast payment systems operating under RTGS systems (CPMI 2017).

We discuss DLT architecture options for the RTGS system that could enable a new tiered access for non-bank PSPs and that accounts for the going improvements for RTGS system using conventional technology. We classify the RTGS system features into four groups given the functional and technical affinity of each feature given the DLT architectural elements, namely: (i) interoperability, integration and payment processing; (ii) privacy and wallet structure; (iii) user interface; and (iv) gridlock resolution.

3.3.1 Interoperability, Integration and Payment Processing

One challenge for DLT is to interact with centralised technologies of payment systems including RTGS systems. Interoperability between platforms is a milestone to improve accessibility (i.e., integration). To achieve this, DLT protocols must allow safe communication between the RTGS and the tiering participants. Relatedly, the payment processing rules should be designed to allow queuing algorithms while guaranteeing settlement finality.

In the first option, interoperability could be achieved through side-chain protocols and smart contracts (e.g., Solidity, Kotlin) developed within a traditional blockchain network. Access (integration) for direct participants is made via a network node and tiered access is achieved through a sponsor direct participant's node. Private operations between direct participants would be executed through the side chains[17]. The sidechain should be designed to improve the efficiency of processing a potential growing number of transactions. Moreover, interoperability is necessary, considering that direct and tiering participants in the RTGS system may be connected to other clearing processing infrastructures. Regarding payment processing, the instructions would be executed in the bilateral channel between the sender and the receiver. A centralised authority, the central bank, must participate in all channels, both bilateral and multilateral, to audit and track all transactions. Also, the central bank would play a major role to endorse the settlement transactions once a successful gridlock resolution is found. The use of bilateral channels could allow to settle bilateral queue payment mechanisms before settling multilaterally mechanisms within the whole network using gridlock resolution for each sender-receiver pair.

In the second option, interoperability could be achieved within the same DLT platform, accessed through DApps within a main DApp using the same standards and privacy protocols. The DApps serve as the back-end arrangement for the decentralised platform of tiering participants. DApps could make it possible to use smart contracts and the tokenisation of value transferred in the RTGS system. Platform access would be made through a DApp, independently of the nature of the participant (direct or indirect). There is no need for a direct participant to own a node to provide this service, as a result of using scalable Zero Knowledge proof protocols (SK proofs). Payment instructions would be executed

[17] A side chain is a parallel blockchain that extends functionalities allowing the use of tokens from one blockchain to be used in the other blockchain.

privately between two parties (sender-receiver). Balance validation could be performed by the entire system with scalable SK proofs, supporting the payment processing rules set by the RTGS system.

It is worth underscoring that the access provided by each option may imply different legal responsibilities in terms of safety and entrance to the system. The legal analysis and its potential implications are beyond the scope of our work. In the second option, the central bank[18] provides all nodes and the whole infrastructure for the network. For the first option, the relationship and responsibility of the infrastructure for tiering participants is straightforward given nodes would be provided by each RTGS direct participant. Regarding the consensus, the suggested algorithms (RAFT, POA, BFT, and IBFT)[19] could increase speed, throughput and scalability compared to other popular algorithms such as Proof of Work (PoW) or Proof of Stake (PoS). Similarly, the use of smart contracts (e.g., Solidity and Kotlin) would be a key element to consider under this architecture.[20]

We consider that the second option based on DApps could enable a better tiered access of the RTGS system for non-bank PSPs. DApps could give more control to the central bank as both infrastructures, the existing platform and the DLT for tiering participants, will be operated by the central bank. This could contribute to the interoperability between the different participants' classes. Given that the option based on nodes involves that each direct participant has to uphold its DLT node, this could have negative effects on the throughput and accessibility as the network grows. Moreover, operational and entry costs could be higher by employing nodes.[21]

3.3.2 Privacy and Wallet Structure

Privacy involves two key requirements that should be borne by either conventional or decentralised based technologies, that is confidentiality and anonymity. Confidentiality is achieved when inputs and outputs of a transaction remain hidden, but the identity of the network participants is public. SK proofs and private node architectures allow confidential transactions. Anonymity is attained if the identity of the system participants is hidden. Stealth address protocols allow anonymity in the transactions. And full privacy is achieved when both confidentiality and anonymity are provided.

The wallet for tiering participants serves to monitor and manage balances. The wallets allow users to interact within the platform, either by making checkable information about their own transactions, balances, or by executing transactions with the use of their private keys. Scalable SK proof protocols for privacy solve the problem of having verifiable transactions while keeping privacy in terms of participants (anonymity) and transaction details (confidentiality).

---

[18] The nodes in the network could be provided by other institutions, such as other SIPS. However, we suggest that the Central Bank should provide all nodes in order to simplify the conceptual model by not introducing governance issues to the implementation, which is not within the scope of our work.

[19] RAFT is a consensus algorithm achieved through an elected leader, designed as an alternative to the Paxos family of algorithms. POA is an algorithm based on identification as stake for the validator nodes, which delivers comparatively fast transactions throughput. IBFT uses a pool of validating nodes to determine if a proposed block is suitable for addition to the chain. BFT is an algorithm designed to resist attacks and could be implemented in public, private, or hybrid platforms.

[20] Solidity is the primary programming language for developing smart contracts on the Ethereum Virtual Machine. Syntactically, it resembles Java, JavaScript, and C++. Kotlin is a programming language compiled on Java Virtual Machine (JVM) and JavaScript. Although it is not the same as Java language, it is remarkably similar and easy to learn for Java developers. Both languages are supported by the leading DLT based platforms, where most of the applications have been developed internationally (i.e. Ethereum, Quorum, Hyperledger Besu, and Corda).

[21] Entry costs are higher due to the need for direct participants to integrate through its own node. The operational costs are higher because each participant's node adds higher complexity in managing the system (e.g., the complexity of adding new features is directly related to the number of nodes).
The technical feasibility analysis of the Chilean Central Bank's Cryptobonds Project discussed business criteria such as cost of infrastructure. The results suggest that a DApp could work efficiently with seven nodes per network. Nevertheless, it required additional networks (composed by three to seven nodes) for other environments such as development, testing and quality assurance.

In a first option, privacy operates at a platform level and participants could access it through a standard wallet. The second option provides privacy at the node level and participants should access through a node. The third option provides privacy at transactional level and each participant must have a wallet and access through a DApp. Our discussion separates privacy and the definition of roles and permissions. Privacy in options 2 and 3 could be managed in a more complex way than option 1, allowing privacy business rules to be implemented using smart contracts. In option 1 privacy is defined at a platform level through writing/reading rights.

In the first option, privacy will depend on the network and platform protocols, and therefore it could not support smart contracts. If confidentiality or anonymity is compromised, all information may be at risk. Direct participants could provide wallets to nonbank PSPs and could provide custody service of the private keys of the tiering participants. Connection will fully depend on the direct participants.

In the second option, privacy could be provided at the node level through private communication channels. In this case, a breach in privacy could affect only information related to a node. Direct participants would have a wallet associated directly to a node and tiering participants a tiered access through a direct participants wallet. Again, connection of a non-bank PSP would depend on the direct participants.

Finally, in the third option privacy is at transaction level via DApps. Privacy would be provided with standardised and scalable SK proofs that focus on ensuring an efficient performance of wallets for direct and tiering participants. In this case, if a breach takes place, it affects only individual transactions. Wallet structure in this architecture would have one wallet per user, either for direct or tiering participants.

In a similar way to the first group of features, an architecture based on DApps could have significant enhancements in accessibility in comparison to the other two options. This is explained because the first option does not allow smart contracts natively, therefore it hinders the potential development of new services. The second option brings higher entry and maintenance costs, making the DApps more suitable for the privacy and affordability of wallet solutions.

3.3.3 User Interface

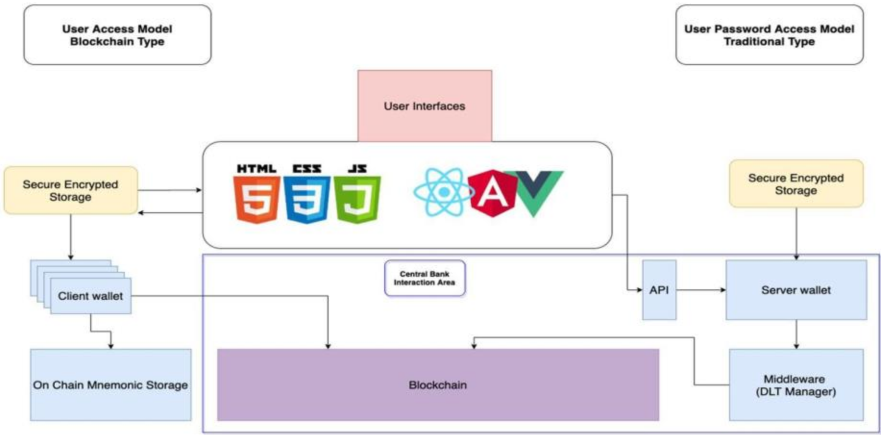
The user interface allows users to interact with the wallets in a safe way. We identify two DLT architectures for it (See figure 2).

First, a client wallet system with wallets connected to third party servers to scan a blockchain. Users would be responsible for their private keys, either on their own or through a third party (custodian). Users could handle browser plugins to make transactions via web applications. For instance, Metamask[22] generates passwords and keys on the user's device, so only the user has access to accounts and data. This browser extension allows users to run DApps without being part of the Ethereum network as a node.

Second, a server wallet system. This is a conventional model of user-password access used by current payment infrastructures. Private keys and passwords could be stored and restored only by the DLT manager. The DLT manager would verify basic transactions' information before settlement. The other function of the DLT manager would be to transform the standard message type of the server wallet to a simpler format (e.g. JSON) that could be compatible with smart contracts.

[22] Metamask is a cryptocurrency wallet that enables users to store cryptocurrencies and it can also be used to interact with decentralised applications (Dapps)

Figure 2: DLT architecture options for wallet structure



The first option comprises a connection through the Client Wallet system in which tiering participants would own their private keys and store them locally. The private keys' storage would be encrypted and participants could access them through a password. Participants' user interfaces are connected to these client wallet systems through web applications, which allow users from tiering participants to interact directly with the platform (i.e., Metamask).

The second option is a connection through a server wallet system. An off-chain server could provide an encrypted system to securely store users' private keys. This server would play a custodian role for both direct and tiering participants. The custodian could sign requests on behalf of users, verifying the authorisations to execute specific transactions. This process could operate through a middleware, which manages a traditional role's system (i.e., DLT Manager).

Central banks wishing to explore a rCBDC with individual accounts for numerous non-bank PSPs, would find a server wallet more affordable DLT architecture option to improve accessibility. Nevertheless, if the number of users significantly increases, the account management at user level would require greater infrastructure, maintenance, and support capabilities.

Our analysis suggests that there are no relevant differences across the two different options. Furthermore, it could be desirable to implement both client and server wallet systems to provide different types of participants (i.e., non-banks) with flexibility to access the RTGS system. Notably, for the first option, the DLT manager (i.e., the central bank) would be responsible for the development of the architecture, therefore it could decide how to structure the entry and transaction costs. In contrast, the server wallet interface would be developed mainly by the direct participants. This could potentially be done by large participants with interest in becoming a hub for new PSPs of a rCBDC, for instance.

We also find that the server wallet interface could enhance the development of complementary services compared to the first option. Furthermore, the second option would use a direct connection channel with the ledger of the platform, and development of new services could be decoupled from the RTGS system.

3.3.4 Gridlock Resolution

Under a DLT architecture, all queued payments should be feasible either simultaneously or by one or more RTGS direct participants. They could supply additional liquidity, avoiding deadlocks that require extra system liquidity.

In the selected options, the first one refers to a conventional off-chain solution outside the DLT platform. The second option is a DLT platform fork (a modification of protocols); in this on-chain solution, the gridlock resolution functionalities would be specific to each blockchain network. The third option is provided through DApp functions (similar to the option 2), but in this case the on-chain solution could be integrated through a DApp instead of changing the native DLT protocol.

We suggest that the first option would be a complex alternative in terms of integration (between off-chain and on-chain functionalities), but its experimentation is more remarkable[23]. Both options. 2 and 3, could require a hybrid solution that connects the DLT system with an off-chain system. Although this allows the implementation of gridlock resolution logic into smart contracts, the on-chain tests and proof of concepts carried out so far have not shown enough robustness to implement feasible gridlock resolution rules.[24]

In our view, deploying an off-chain architecture is the best fit for the RTGS system to ensure a scalable and smooth operation of the algorithm with tiering participants. We also suggest that both on-chain, forks and DApps (options 2 and 3) might not be suitable for this RTGS system feature given limited experimentation[25]; In effect, the third option has the highest probability of encountering unknown development risks[26]. An off-chain solution is thus the one with the lowest development risk. Nevertheless, the main challenge for the first option would be the integration of on and off-chain platforms.

Finally, and given that on-chain gridlock solutions have high levels of performance uncertainty, the second and third options might also entail higher development costs to achieve a robust architecture, which in turn could increase the entry costs of tiering participants[27]. As result, the off-chain architecture could have an indirect positive impact in access due to lower entry costs. Overall, we suggest that this RTGS system feature could be migrated to a DLT architecture (i.e., as an on-chain functionality) once these algorithms are more mature as an on-chain functionality.

4. Tiered access in the RTGS: Tailoring a well suited DLT-based architecture

In the previous section we discuss how different DLT architectures could make workable, scalable and reliable alternatives to underpin RTGS system access for tiering participation. This section proposes a final architecture for the seven RTGS features and analyses this architecture using the indicators described in section 2. Below, we discuss how a DLT architecture could impact the safety, efficiency, accessibility, and interoperability of an RTGS system given an expanded access to non-bank PSPs.

4.1 A DLT-based architecture for tiered access in the RTGS

We find that the decentralised apps (DApps) are a purposeful architecture for non-bank payment service providers (PSP) to have a tiered access to the RTGS system while preserving safety and efficiency features of the RTGS system. This option does not present significant trade-offs. First, the DApps could foster greater accessibility from the perspective of the first and second group of features (i.e., payment processing, integration, interoperability, wallet structure and privacy); their compatibility under a DLT architecture could be workable. Furthermore, the DLT architectures that could work for the gridlock resolution and the user interface are complementary with the DApps based architecture. In Figure 3, we depict the operational architecture for the RTGS system under the proposed DLT architecture.

Figure 3: DLT architecture for a tiered access to an RTGS system

---

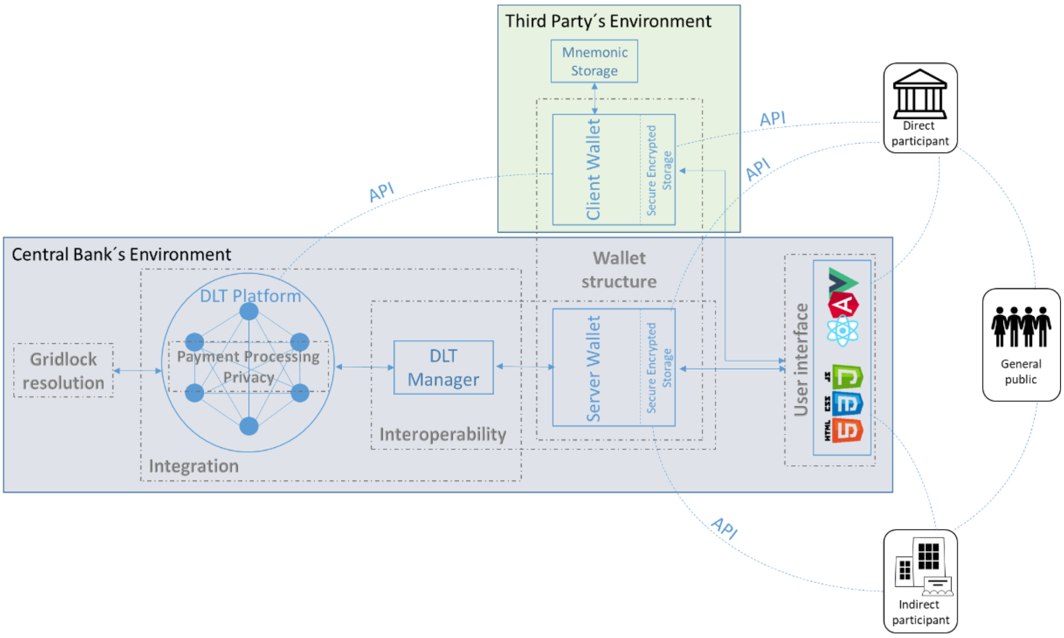
[23] Currently, the most widely used queue engines based on traditional technology (i.e. IBM, RedHat) offer limited options (such as libraries or tools) to facilitate the interconnection with the DLT platform. There is no certainty of the volume that could be transacted.

[24] Ubin DLT experiment by the Monetary Authority of Singapore comprise a relevant example.

[25] Project Ubin tested different gridlock resolution mechanisms with option 2, and identified several scenarios in which queued payment instructions were not settled, arguing that further testing and development was needed.

[26] Typically, in development projects, these can arise from new integrations or new components.

[27] We assume that development costs are transferred totally, or at least partially, to the participants.



We propose that all nodes in the system can be controlled by the central bank as a DLT manager. All functionalities (i.e., use cases for tiering participants) developed at the smart contracts layer would need to be deployed in the platform (and its nodes). This involves that having a single entity in control of all nodes simplifies the maintenance and upgrade of new functionalities. Connection and access of tiering participants would be done by DApps removing the need for multiple individual nodes and making this architecture simple and scalable. Given that the tiered access environment would be a permissioned network interoperating with the RTGS system, it would not require the implementation of algorithms providing trust among participants.

DApps architecture also allows greater interoperability by means of enabling smart contracts to execute transactions safely on the validator nodes using consensus protocols, even if there are no responding nodes. A private or a hybrid (public permissioned) network would fit the requirements for the proposed tiered access to the RTGS system. In both cases, the infrastructure to be developed should support and process a minimum number of transactions. A private network could help to control and upgrade the required infrastructure. Other best practices would be taken into account to ensure full efficiency and safety of the tiered access (e.g., Linux as operational system).

The use of application programming interfaces (API) to connect participants could facilitate integration within the payments ecosystem by introducing the tiered access; it could also support interoperability of the RTGS system with other payment systems. The tiering participants could only connect through the client/server wallets ensuring that direct participants' environment remains functional under current technology. This would not preclude direct participants to connect through these user interfaces. By doing so, both direct and tiering participants could submit their transactions without affecting STP conditions in the RTGS system. Correspondingly, the gridlock resolution would work off-chain while the user interface could be managed by server and client wallets, the central bank would manage a server wallet system, and this will be supplemented by other user interfaces developed by third-parties. Finally, we note that the payment processing and the privacy features could perform seamlessly under a DLT platform.

4.2 Accessibility and interoperability: measuring the effects of RTGS tiering participants under a DLT architecture

This subsection discusses the implications for the accessibility and interoperability of the proposed DLT operational architecture that could enable a tiered RTGS system access for non-bank PSPs.

4.2.1 Number of institutions

In terms of interoperability, access, and processing, we suggest that the DApps has lower entry costs. The need of node access in other architecture options could be an entry barrier for new players, hindering accessibility. Interoperability with other payment platforms could be more complex with this architecture. For instance, to ensure interoperability with new services, the same platform, standards, and protocols should be used.

In terms of privacy and wallet structure, a DApp architecture could provide lower entry barriers than other options (lower costs) and the potential to support a higher variety of financial services (e.g., programmable money). A multichannel or bilateral architecture could also have the potential of allowing a higher number of tiering participants.

4.2.2 Concentration ratio

The higher entry costs of architectures requiring connection through a node imply that a DApp architecture could bring greater opportunities to improve the concentration ratio, especially for tiering participants. This could help to level the playing field for nonbanks. A DApp architecture can be also used as a tool to implement portability for tiering participants between direct participants. Interoperability could also perform better for accessibility. No effects could be anticipated in terms of privacy, as accessibility would be closely related to the wallet design in the DApp. Thus, this architecture could result in less concentration, higher access and increased activity for tiering participants.

4.2.3 Total volume of transactions

The DApp architecture could perform better due to its scalability regarding a greater number of transactions to be settled at the RTGS system. A multilateral channel platform could result in lower scalability due to the higher complexity of the network (higher number of nodes and the coordination and replication between all bilateral or multilateral channels).

4.2.4 System entry costs

Our analysis indicates that the costs of entering the system could be lower with a DApp architecture for both interoperability and accessibility. In terms of wallet structure, the architecture based on privacy at a platform level could also lower entry costs. A node-level architecture may play against access, due to development, maintenance, and complexity costs.

4.2.5 Cost of transactions

Marginal costs for transactions rely heavily on the consensus algorithm. The DApp option could also provide lower operational costs due to a higher operational complexity of the other options, while the DApp currently presents lower network maintenance costs. The DApp architecture could also improve the interoperability and processing of transactions settled at and in connection with the RTGS system. Regarding the wallet structure, the cost per transaction will depend on the consensus algorithm, but overall, the DApp should favour lower marginal transactional costs.

4.2.6 New services

We find that a DApp architecture could enable new functionalities or services within the same application (for all tiered participants). This ease of innovation may differ for a node-level platform, given that new services entail business logistics that need to be replicated in each node (of all direct participants). By that, it could lead to more complex operations to ensure interoperability of potential new services. Relative to the wallet structure and the privacy at the RTGS system, a DApp architecture could have higher potential of new services due to the possibility of using smart contracts.

5. Conclusions

Providing a wide access to the RTGS system for non-bank PSPs is paramount at the face of their growing presence in the retail payments market. However, non-bank PSPs lack access to the settlement services of the RTGS system, markedly under regulatory restrictions. In this context, a tiered access based on decentralised technologies could provide the payments ecosystem with greater interoperability and accessibility.

Employing a DLT architecture to support the operation of an RTGS system needs to be accompanied by a series of institutional foundations like a suitable regulatory framework and appropriate business rules. Technology should be reliable, adaptable and scalable to respond to potential growing needs of its participants.

We explore DLT architecture options that could enable a tiered access for non-banks in the Chilean RTGS system.

Our main finding is that in theory, DApps are a supportive DLT architecture option to enable access to payment systems' new participants while preserving safety and efficiency features of the RTGS system[28]. For instance, as the RTGS system would be a permissioned network, trust among participants will not require algorithms used in permissionless platforms, such as PoW or PoS. This is a key aspect for a central bank to warrant trust among untrusted participants but at the cost of hindering scalability.

Accessibility and interoperability in the payments' ecosystem could be achieved, yet privacy and scalability require real experimentation to be attested. We also find that experimentation would serve to better understand other performance aspects that are relevant for the sound operation of the RTGS system. Namely, deploying a DApp architecture requires an initial trusted setup to make validations (proofs) efficiently, which could result in initial higher costs to have both types of wallet structure being functional at the platform and under the same protocol of privacy. This is critical for operational risk reasons that a central bank and the (direct and tiering) participants would require to look at. Similarly, when more than one user interface is available, the central bank may need to set protocols and standards for third parties to mitigate potential operational risks.

Our analysis applies to the state-of-the-art DLT architecture options by 2019, and therefore new developments would require further analysis as well as real experimentation. Advancements should be closely monitored to update the RTGS system, their participants and other payment infrastructures needs to fulfil their role in the economy.

Finally, central banks exploring design alternatives for rCBDCs may find relevant our approach to inform their discussion on how to define a roadmap for an inclusive CBDC ecosystem based on DLT.

References

Aramonte, S., A. Schrimpf and H. Shin (2022), "Non-bank Financial Intermediaries and Financial Stability," CEPR Discussion Papers 16962.

Arculus, R. (2012), "The Impact of Payment System Design on Tiering Incentives," Reserve Bank of Australia, RDP 2012-06.

Auer, R, and R Böhme (2020), " The technology of retail central bank digital currency", BIS Quarterly Review, March, pp 85-100.

Auer, R., J. Frost, L. Gambacorta, C. Monnet, T. Rice and H. Shin (2022), "Central Bank Digital Currencies: Motives, Economic Implications, and the Research Frontier," *Annual Review of Economics*, 14(1), pp 697-721.

Banco Central de Chile (2017), "Gestión del Sistema de Pagos de Alto Valor del Banco Central de Chile: 2017," Chile.

Bank for International Settlements (2020), "Central bank digital currencies: foundational principles and core features" BIS, Basle.

Bech, M. and B. Hobijn (2007), "Technology Diffusion within Central Banking: The Case of Real-Time Gross Settlement," *International Journal of Central Banking*, 3(3), 147-181.

[28] We suggest complementing our theoretical work with experimentation (e.g., PoCs and/or pilots) in order to attest some properties, such as privacy and scalability.

Bech, M., Y. Shimisu and P. Wong (2017), "The quest for speed in payments," *BIS Quarterly Review*,

Boissay, F., T. Ehlers, L. Gambacorta and H. Shin, 2021. "Big Techs in Finance: On the New Nexus Between Data Privacy and Competition," in: R. Rau, R. Wardrop and L. Singales (ed.), *The Palgrave Handbook of Technological Finance*, 855-875, Springer Books.

Committee on Payments and Market Infrastructures (2003), “The role of central bank money in payment systems”

Committee on Payment and Settlement Systems (1997), "Real-Time Gross Settlement Systems," CPMI papers.

D'Andrea, A. and N. Limodio (2022), "High-Speed Internet, Financial Technology and Banking", *Management Science*, forthcoming.

Degryse, H., P. Morales-Acevedo and S. Ongena (2019), "Competition in The Banking Sector," *Oxford Handbook of Banking*, chapter 24.

Frost, J., L. Gambacorta, Y, Huang, H. Shin and P. Sbinden (2019), "BigTech and the changing structure of financial intermediation," *Economic Policy*, 34(100), 761-799.

Humphrey, D. (1986), "Payments finality and risk of settlement failure", in A. Saunders and L. Whyte (eds), *Technology and the regulation of financial markets: securities, futures, and banking*, Lexington, MA: DC Heath and Company.

Kahn, C., J. McAndrews and W. Roberds (2003), "Settlement Risk under Gross and Net Settlement," *Journal of Money, Credit, and Banking*, 35(4), 591--608.

Levine, R. (2021), "Finance, Growth, and Inequality," IMF Working Paper No. 2021/164.

Madeira, C. and J. Madeira (2019), "The effect of FOMC votes on financial markets", *Review of Economics and Statistics*, 101(5), 921-932.

Malinova, K. and A. Park (2017), "Market Design with Blockchain Technology," University of Toronto, mimeo, http://dx.doi.org/10.2139/ssrn.2785626.

Schaeck, K. and M. Cihák (2014), "Competition, Efficiency, and Stability in Banking," *Financial Managemen*t, 43(1), 215-241.

Townsend, R. (2019), “Distributed Ledgers: Innovation and Regulation in Financial Infrastructure and Payment Systems”, University of Chicago, mimeo.

World Bank (2020), "Payment Systems Worldwide - A Snapshot: Summary Outcomes of the Fifth Global Payment Systems Survey," Financial Infrastructure Series, World Bank, Washington, DC.

Sigraiova, D. and T. Havranek (2016), "Bank Competition And Financial Stability: Much Ado About Nothing?," *Journal of Economic Surveys*, 30(5), 944-981.

Annex 1. DLT architecture options for RTGS system features

Table 1: DLT architecture options for RTGS Interoperability, Integration and Payment Processing

	Option 1 Bilateral and multilateral channels	Option 2 Decentralised application (DAPP)
Privacy protocols	Multichannels node privacy	Scalable Zero Knowledge
Consensus	RAFT-POA-BFT-IBFT-POET	RAFT-POA-BFT-IBFT
Interoperability protocols	Contract interoperability	DAPP interoperability

Table 2: DLT architecture options for RTGS Privacy and Wallet Structure

	Option 1 Privacy at platform level 1 wallet per user	Option 2 Privacy at node level 1 wallet 1 node	Option 3 Privacy at transaction level (DAPP) 1 wallet per user & third party wallet
Privacy protocols	Traditional privacy at network and platform level	Multichannels node privacy	Scalable Zero Knowledge
Consensus	POW-POS-POA	RAFT-POA-BFT-IBFT-POET	RAFT-POA-BFT-IBFT
Interoperability protocols	Blockchain interoperability	Contract interoperability	DAPP interoperability

Table 3: DLT architecture options for RTGS Gridlock Resolution

	Option 1 Off-chain solution	Option 2 Blockchain Platform's Forks	Option 3 Decentralised Application (DAPP) Functions
Privacy Protocols	N/A	Multichannels node privacy	Scalable Zero Knowledge
Consensus	N/A	RAFT-POA-BFT-POET	RAFT-POA-BFT-POET
Interoperability protocols	N/A	Contract Interoperability	DAPP Interoperability

Table 4: A DLT architecture for non-bank PSP tiered access to the RTGS system

Features	Layer components
Smart Contracts	Solidity-Kotlin
Privacy Protocols	Scalable Zero Knowledge Proofs
Consensus	RAFT POA BFT IBFT
Interoperability protocols	DAPP Interoperability
Network	Permissioned
Operation System	Linux