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Use of distributed ledger technology by central banks: A review

(Uso de la tecnología de contabilidad distribuida por los bancos centrales: Una revisión)

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Abstract:
This paper reviews what stage the central banks of the world's leading economies are at in their study and adoption of distributed ledger technology (DLT) to reengineer their various systems and functions. A brief description of DLT will be given, followed by an analysis of central banks' publications and pronouncements to determine what each central bank is doing on their journey to DLT adoption. It was found that of the central banks for which information was available, all of them have expressed interest in DLT and have evaluated it to some extent. Nevertheless, no central bank has an operational DLT-based system at this point. This is because some issues remain regarding the speed, cost of processing, security, transparency and privacy, legal settlement finality, scalability and network effects of the technology. As DLT matures, the expectation is that these issues will begin to be resolved.

Keywords: dlt; blockchain; distributed ledger; fintech; digital currency.

Resumen:
Este artículo examina en qué punto se encuentran los bancos centrales de las economías más avanzadas en su estudio y adopción de la tecnología de contabilidad distribuida (TCD) para transformar sus diferentes sistemas y funciones. Se dará una descripción breve de TCD, seguida por un análisis de las publicaciones y anuncios de los bancos centrales para determinar qué está haciendo cada banco central en su ruta a la adopción de TCD. Se encontró que de los bancos centrales para los cuales había información, todos expresaron interés en TCD y la han evaluado por lo menos hasta cierto punto. Sin embargo, ningún banco central tiene un sistema basado en TCD que esté operacional en este momento. Esto es debido a que hay todavía algunos problemas relacionados con la velocidad, el costo del procesamiento, la seguridad, la transparencia y privacidad, la finalidad de la resolución legal, el escalado, y los efectos de red de la tecnología. A medida que TCD madure, la expectativa es que estos problemas se resolverán.

Palabras clave: contabilidad distribuida; cadena de bloques; fintech; dinero digital.

1. Introduction

Distributed Ledger Technology (DLT)—or blockchain, the most common DLT implementation underlying cryptocurrencies such as Bitcoin—has been said to be the most disruptive invention since the internet itself (Hiesboeck, 2016). Since its inception in 2009 (Nakamoto, 2009), interest in DLT has grown to the point that it is now being applied in fields as diverse as data management, diamond identification and transaction verification, energy production and consumption, the internet of things, media and content distribution, and, of course, the financial industry (Mesropyan, 2016). Over three-quarters of all financial institutions worldwide expect to adopt blockchain as part of a production system or process by 2020 (PwC, 2017).

Some businesses are already making use of the technology. Banco Bilbao Vizcaya Argentaria (BBVA), a multinational Spanish banking group, completed the first real-life

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implementation of an international money transfer using Ripple's DLT at the end of 2016. The transaction, running on BBVA infrastructure using real money, successfully completed transfers between Spain and Mexico in a matter of seconds (BBVA, 2017).

Almost every major bank around the globe is testing DLT. According to Business Insider UK (Meola, 2017), there are three major factors behind the push for DLT in the finance industry:

- **Cost savings and efficiency**. Banks are dealing with rising costs for maintaining or replacing their aging infrastructure and ensuring compliance with heavy regulatory burdens. Furthermore, banks must deal with increasing economic instability. To that end, DLT-based solutions could generate cost savings of up to $20 billion per year, according to Banco Santander (Belinky, Rennick, & Veitch, 2015).
- **Competing with startups**. Financial technology companies (FinTechs) are using DLT to offer services (such as remittances and international payments) at reduced costs, with greater speed, and with more user-friendly interfaces than major banks. As a result, banks have started to construct their own DLT-based solutions to better compete with these up-and-comers.
- **New business models**. Banks can use DLT-based systems to circumvent central bodies or legacy infrastructure. Banks could potentially develop these systems to create brand new business models that disrupt the current financial ecosystem.

Central banks, though also interested in the technology, have been more cautious in their embrace of DLT. Some central banks, such as the European Central Bank and the Bank of Japan, have declared DLT not mature enough at this stage of development to power the world's biggest payment systems (Koranyi & Evans, 2017). Likewise, the Bank of Canada stated in a recent report that for critical financial market infrastructures, such as wholesale payment systems, current versions of DLT may not provide an overall net benefit relative to current centralized systems (Chapman, Garratt, Hendry, McCormack, & McMahon, 2017).

In a somewhat more upbeat tone, the United States' Federal Reserve System has stated that it will continue to work to understand the implications of new payment technologies and models, including DLT and digital currencies, that can facilitate a safe and efficient U.S. payment system (Federal Reserve System, 2017). Other central banks such as the Royal Bank of Scotland (Creer et al., 2016) and the Monetary Authority of Singapore (MAS, 2017) have built successful DLT-based proof-of-concept prototypes and are now ready to take the next step in their implementation of DLT. All told, two-thirds of central banks worldwide are directly experimenting with DLT protocols (Hileman & Rauchs, 2017).

This paper will do the following:

- Describe the research methodology used.
- Provide an overview of DLT, with emphasis in those aspects and capabilities of the technology that are relevant to the financial industry in general, and to central banks in particular.
- Survey what central banks are currently doing to harness DLT's potential by reviewing (a) official pronouncements and reports from the central banks themselves, and (b) the academic literature on the matter.
- Describe the current limitations of the technology.

2. Methodology

Research question

The research question for this article was determined using the PICO (Population, Intervention, Comparison, Outcomes) criteria adapted by Kitchenham & Charters (2007) from the medical field for use in the framing of research questions in software engineering. The application of the PICO criteria for this paper is shown in *Table 1*.

Table 1. PICO criteria for research question

Criterion	Question element
Population	Central banks for countries in the Organization for Economic Cooperation and Development (OECD) and the Group-of-Twenty (G20) countries
Intervention	The use of Distributed Ledger Technologies
Comparison	Benefits derived from the use of DLT vs. traditional processes and technologies
Outcomes	How successful have been the DLT initiatives pursued by central banks

Combining the ideas arising from each one of the four criteria, then, the research question pursued by this paper is: what are central banks doing toward their adoption of DLT and what benefits are they deriving from their initiatives?

Literature search strategy

The core list of peer-reviewed articles and conference proceedings to be examined by this study was obtained by searching the Web of Science, Scopus, Google Scholar and other academic and research databases for all English-language documents dated 2016 or later. The search string that was used was: "central bank" blockchain "distributed ledger technology." This yielded one peer-reviewed academic article that specifically dealt with the use of DLT by central banks, and a number of DLT-related reports and web pages by and about the central banks within the scope of this paper. They are all referenced in the "4. Literature review" section.

The search emphasized reports from the central banks themselves and announcements and speeches by their officials. This is because official statements from the central banks were required to ascertain their plans and actions in connection with DLT. The reason documents older than 2016 were not considered is that bitcoin and DLT were only released as open software in 2009 (Bitcoin.org, 2017), and interest by central banks in the technology is even more recent. DLT and central banks' attitudes have evolved very rapidly in the last couple of years, and the assessment was made that any papers or reports from 2015 or before describing DLT and central banks would be too out of date to be useful.

3. A brief introduction to DLT

A distributed ledger is a consensus of replicated, shared, and synchronized digital data geographically spread across multiple entities, sites, countries, or institutions. A blockchain is a type of distributed ledger comprised of unchangeable, digitally recorded data in packages called blocks. These digitally recorded blocks of data are stored in a linear chain. Each block in the chain contains data (e.g., a Bitcoin transaction), which are cryptographically hashed. The blocks of hashed data draw upon the previous block in the chain, ensuring that the data in the overall blockchain have not been tampered with and remain unchanged (Blockchain Technologies, 2016).

This paper considers DLT to be some combination of components, including peer-to-peer networking, distributed data storage, and cryptography that, among other things, can potentially change the way in which the storage, recordkeeping, and transfer of a digital asset is done. The composition of these combinations is dictated by the particular friction or inefficiency a particular implementation of DLT is designed to solve (Mills et al., 2016).

Some of the key components and features in DLT are the following (Mills et al., 2016):

- **Peer-to-peer node connections**. The nodes in a DLT arrangement, which are the devices running the DLT software that individually maintain the shared database records, are connected to each other in order to share and validate information. This structure enables any entity, such as end-users, financial institutions, or financial market intermediaries (FMIs), with a node to share database management responsibilities directly with each other on a peer-to-peer basis.
- **Distributed histories and ownership**. In a DLT arrangement, information regarding records of ownership and transaction histories can be distributed across the nodes in the network. This distribution is the foundation of the technology, with the ledger of transaction histories and ownership positions shared as one common ledger that participants agree is correct.
- **Use of cryptography**. DLT arrangements use cryptography for several purposes, such as identity verification and data encryption. For example, during asset transfers, a form of cryptography known as public key cryptography usually forms the foundation of the transaction validation process. To transfer an asset, a participant may create a digital signature with its non-shared cryptographic credential called a private key. To confirm that the asset in question belongs to the participant initiating the transaction, other participants of the DLT arrangement with the required permissions to act as validators of transactions can verify authenticity of the ledger entry by decrypting it with a mathematical algorithm and the asset owner's publicly available public key.
- **Ownership of an asset**. Ownership information with respect to an asset can be stored on a ledger within the DLT arrangement, which maintains the ownership positions of all participants in the system.
- **The DLT protocol defines the asset transfer process**. A DLT protocol is a syntax and set of procedures that define how members of the DLT arrangement interact. For a payment transfer, for example, a DLT protocol may lay out validation checks (for example, verify ownership) and conditionality checks (for example, access to sufficient funds or credit). For a securities, commodities, or derivatives transfer, a DLT protocol could provide the conditions around confirmation, clearing, and settlement.
- **The settlement process**. Settlement in a DLT arrangement involves the updating of the common ledger with the new ownership positions of the relevant counterparties. For a distributed ledger, proposed transactions and subsequent positions are broadcast to nodes that maintain a copy of the ledger and ultimately become accepted as the new version of the ledger. The process of having nodes accept a new version of the ledger is commonly referred to as consensus. Two ways to achieve consensus when validating a new transaction are:
    - *Proof of work*. Here individuals with suitable computing processing power called miners compete to win the right to validate blocks of transactions by solving a difficult mathematical puzzle. The first miner who completes a new puzzle broadcasts the block and solution to all the other miners and in return "mines" new bitcoins created with that block. Although the problem miners work on is difficult to solve, it is easy to verify. Once the other nodes have seen and verified a new solution, the new block is added to the chain, the transactions in the block are considered settled and miners begin mining a new set of transactions. The way nodes come to agreement about the new block is the consensus mechanism, and the solved puzzle is the proof of work (PoW). This is the approach used by Bitcoin (Nakamoto, 2009).
    - *Notary node*. An alternative way to reach agreement is to have a 'notary' node that is trusted by everyone and replaces the PoW function. This is the

approach used by the Corda environment, a distributed ledger platform developed by the R3 software company (Hearn, 2016).

- **Application programming interfaces**. Application programming interfaces (APIs) are a set of routines, protocols, and tools for building software applications. An API specifies how software components should interact, and within a DLT arrangement APIs can enable the addition of new features or enhancements not native to the distributed ledger protocol itself. For example, they could communicate directly with the underlying protocol of a distributed ledger to effect transfers and gather information. APIs can also provide user-friendly interfaces that make using the technology easier for a broader set of potential users.
- **Participants may have different roles or functions**. Regardless of whether a DLT arrangement is open or closed, participants may be differentiated by the roles they are permitted to play or functions they are permitted to perform. DLT arrangements in which the participants are allowed to perform all activities are often called open or permissionless. Those that restrict participants' activities are often referred to as closed or permissioned. Cryptocurrency DLT arrangements such as Bitcoin are examples of permissionless systems. The financial industry, however, is focused mainly on developing permissioned systems.
- **Smart contracts**. Smart contracts are coded programs that are used to automate pre-specified transactional events based on agreed upon contractual terms. Like with traditional contracts, a smart contract depends on participants' consent to its terms. These agreed-upon smart contracts can be used in conjunction with a distributed ledger to self-execute based on information received in the distributed ledger or from other sources. For example, several companies developing DLT products are exploring the use of smart contracts to model corporate debt issuances. In these simulations, a debt-issuing company specifies the parameters of the contract, such as its par value, tenor, and coupon payment structure. Once assigned to an owner, the smart contract would automatically make the required coupon payments until the bond reaches maturity.

4. Literature review

Analysis of central banks' DLT-related plans and actions

The subset of countries selected for this analysis are those belonging to the OECD and to the G20 organizations. As they generally represent the world's largest economies, these would be the countries more likely to lead in the adoption of new technologies such as DLT. European Union countries not in the OECD were excluded. The Bank for International Settlements (BIS)—the central banks' central bank—and the European Central Bank are also included. *Table 2* below summarizes the results of this analysis.

This paper will only include uses of DLT by functions performed by the central banks themselves. Activities such as creating a regulatory environment favorable to DLT, and encouraging private financial institutions to adopt DLT will not be considered, as they do not represent DLT endeavors for the direct use and benefit of central banks.

The meaning of the column headings in *Table 2* is as follows:

- **Functions to use DLT**. These are the central bank functions being considered by the central banks as candidates for DLT enablement. They are: Payment, clearing and settlement (PCS), risk management (RM), identity management (IM), issuance of digital fiat currency (DFC), and trade reporting (TR).
- **DLT adoption status**. This specifies how far along a central bank is in the DLT evaluation or implementation process. The values are: Not interested, open, studying it, experimenting, pilot, operational.

- **Communications**. This lists the vehicles through which the central bank has communicated its intentions or actions. The possible values are: Reports, speeches, announcements, interviews.
- **Leaning**. It indicates whether the central bank currently has a positive, negative or neutral attitude regarding its adoption of DLT for functions *performed by the central bank.*

Table 2. Central banks and DLT

#	Country	Region	Central bank	Functions to use DLT	DLT adoption status	Communications	Leaning
1	Argentina	South America	Banco Central de la República Argentina	PCS	Studying it	Interview (Marty, 2016)	Positive
2	Australia	Oceania	Reserve Bank of Australia	PCS	Studying it	Report (Reserve Bank of Australia, 2017)	Positive
3	Austria	Europe	Oesterreichische Nationalbank	No info	Open to it	Interview (Das, 2017)	Neutral
4	Belgium	Europe	National Bank of Belgium	No info	Studying it	Report (National Bank of Belgium, 2017)	Positive
5	Brazil	South America	Banco Central do Brasil	PCS IM	Experimenting	Report (Burgos, Filho, Suares, & de Almeida, 2017)	Positive
6	Canada	North America	Bank of Canada	PCS	Experimenting	Announcement (Wilkins & Gaetz, 2017), announcement (TMX, 2017)	Positive for clearing & settlement, negative for payments
7	Chile	South America	Banco Central de Chile	PCS RM	Studying it	Report (Furche, Madeira, Marcel, & Medel, 2017)	Positive
8	China	Asia	People's Bank of China	DFC	Experimenting	Anouncements (Casey, 2017)	Positive
9	Czech Republic	Europe	Czech National Bank	No info	Open to it	Interview (Czech National Bank, 2017)	Neutral
10	Denmark	Europe	Danmarks Nationalbank	DFC PCS	Studying it	Speech (Levring, 2016), report (Danmarks Nationalbank, 2017)	Positive for PCS, negative for DFC
11	Estonia	Europe	Bank of Estonia	DFC	Studying it	Announcement (Daniell, 2017)	Positive
12	Finland	Europe	Bank of Finland	PCS	Studying it	Announcement (Bank of Finland, 2016)	Positive
13	France	Europe	Banque de France	PCS	Experimenting	Speech (François Villeroy de Galhau, 2017)	Positive
14	Germany	Europe	Deutsche Bundesbank	PCS DFC	Experimenting	Report (Deutsche Bundesbank, 2017)	Positive for PCS, negative for DFC
15	Greece	Europe	Bank of Greece	No info	No info	No info	No info
16	Hungary	Europe	Hungarian National Bank	No info	No info	No info	No info
17	Iceland	Europe	Central Bank of Iceland	DFC	Open to it	Interview (Central bank of Iceland, 2017)	Positive
18	India	Asia	Reserve Bank of India	DFC	Studying it	Report (IDRBT, 2017)	Positive
19	Indonesia	Asia	Bank of Indonesia	No info	No info	No info	No info
20	Ireland	Europe	Central Bank and Financial Services Authority of Ireland	TR	Experimenting	Speech (Lane, 2017)	Neutral

21	Israel	Middle East (Asia)	Bank of Israel	No info	No info	No info	No info
22	Italy	Europe	Banca d'Italia	No info	No info	No info	No info
23	Japan	Asia	Bank of Japan	PCS	Experimenting	Announcement (ECB & BOJ, 2017)	Negative
24	South Korea	Asia	Bank of Korea	No info	Experimenting	Announcement (EconoTimes, 2017)	Positive
25	Latvia	Europe	Bank of Latvia	No info	No info	No info	No info
26	Luxembourg	Europe	Banque Centrale du Luxembourg	No info	No info	No info	No info
27	Mexico	North America	Banco de México	No info	No info	No info	No info
28	Netherlands	Europe	De Nederlandsche Bank	PCS	Studying it	Interview (del Castillo, 2016a)	Positive
29	New Zealand	Oceania	Reserve Bank of New Zealand	No info	Open to it	Speech (Fiennes, 2017)	Neutral
30	Norway	Europe	Norges Bank	DFC	Studying it	Speech (Nicolaisen, 2017)	Positive
31	Poland	Europe	National Bank of Poland	No info	Open to it	Announcement (Zhao, 2017)	Negative
32	Portugal	Europe	Banco de Portugal	No info	No info	No info	No info
33	Russia	Asia	Bank of Russia	PCS	Experimenting	Report (Khrennikov & Rudnitsky, 2017)	Positive
34	Saudi Arabia	Middle East (Asia)	Saudi Arabian Monetary Authority	No info	No info	No info	No info
35	Slovakia	Europe	National Bank of Slovakia	No info	No info	No info	No info
36	Slovenia	Europe	Bank of Slovenia	No info	Studying it	Web page	Positive
37	South Africa	Africa	South African Reserve Bank	DFC	Open to it	Announcement (Higgins, 2017), report (del Castillo, 2017)	Positive
38	South Korea	Asia	Bank of Korea	DFC	Experimenting	Announcement (EconoTimes, 2017)	Positive
39	Spain	Europe	Banco de España	PCS	Open to it	Report (González-Páramo, 2017)	Negative
40	Sweden	Europe	Sveriges Riksbank	DFC	Studying it	Report (Sveriges Riksbank, 2017)	Positive
41	Switzerland	Europe	Swiss National Bank	PCS DFC	Open to it	Announcement (del Castillo, 2016b)	Neutral
42	Turkey	Europe	Central Bank of the Republic of Turkey	No info	No info	No info	No info
43	United Kingdom	Europe	Bank of England	PCS DFC	Experimenting	Speech (Carney, 2017a), speech (Carney, 2017b), report (Cleland, 2017)	Neutral
44	United States	North America	Federal Reserve System	PCS DFC	Experimenting	Speech (Powell, 2017), report (Federal Reserve System, 2017)	Neutral
45	European Union	Europe	European Central Bank	PCS	Experimenting	Announcement (ECB & BOJ, 2017)	Negative
46		World	Bank for International Settlements	PCS	Studying it	Report (BIS, 2017), report (Bech & Garratt, 2017)	Neutral

Table 3 below summarizes where the central banks reviewed in this study are in their adoption of DLT:

Table 3. Central bank and DLT adoption summary

Adoption status	Number	Percentage	Percentage excluding central banks with no info
No information	12	26 %	-
Not interested	0	0 %	0 %
Open to it	8	18 %	24 %
Studying it	13	28 %	38 %
Experimenting	13	28 %	38 %
Pilot	0	0 %	0 %
Operational	0	0 %	0 %
TOTAL	**46**	**100 %**	**100 %**

Table 4 below summarizes how the central banks reviewed in this study are leaning in their attitude toward DLT. Central banks that lean positive for some DLT applications and negative for others have been counted as neutral:

Table 4. Central bank and DLT attitude summary

Leaning	Number	Percentage	Percentage excluding central banks with no info
No information	12	26 %	-
Negative	4	9 %	12 %
Neutral	11	24 %	32 %
Positive	19	41 %	56 %
TOTAL	**46**	**100 %**	**100 %**

Another result that leaps out is that the central bank functions that have elicited the greatest interest as potential beneficiaries of DLT are PCS and DFC (by all but one of the central banks that have identified an area of interest). A sign of the caution central banks are proceeding with in their adoption of DLT is that none of the central banks have implemented DLT as part their operations, either as a pilot project or a full operational deployment.

The single peer-reviewed academic article (Bott & Milkau, 2017) identified in the literature search did an in-depth study of the possibilities, challenges and risks central banks would face as they consider implementing PCS and DFC using DLT due to the technology's current limitations. The following section describes these limitations.

5. Current limitations of DLT

As central Banks continue to study and experiment with DLT, the technology's limitations have come to light. These will need to be addressed before the central banks can proceed to implement their operational systems using DLT. The limitations fall into the following broad areas:

- **Speed**. Although the speed of end-to-end processing may be adequate, the speed of transaction settlement within the infrastructure itself may be slower than existing centralized systems. For example, DLT arrangements may take longer to achieve settlement when compared with real-time gross settlement systems because the process for validating a transaction and reaching consensus in DLT is potentially more complex than with a central entity (BIS, 2017).
- **Cost of processing**. DLT arrangements can lead to changes in the way costs are allocated among participants. For example, a distributed arrangement in which

participants contribute to maintaining and updating a shared ledger allows for the sharing of maintenance across participants. In this sharing of responsibilities, participants operating certain nodes in an arrangement could see increased direct costs for contributing to the operation of the arrangement (BIS, 2017).

- **Security**. Cryptographic tools, such as public key cryptography, play a central role in ensuring the security of existing systems and are of critical importance in DLT arrangements. While current cryptographic tools are considered effective and are widely used today, future technological advancements could render existing cryptographic tools less secure and effective. This issue is of particular concern for an arrangement with a weak governance structure, which may not be able to react quickly enough to emerging security issues and threats. Integration of DLT in existing infrastructures or transition from current systems to DLT-based ones could also generate security breaches that are not inherent in the new technology but could have a strong operational impact (BIS, 2017).
- **Transparency and privacy**. A fundamental requirement for a wholesale payment system is the need for participants to keep their transactions private from parties not involved in the transaction. Proof-of-work systems are ill-suited for these types of large-value systems because they operate under the assumption that all transactions in the system are, at a certain level, publicly observable. In contrast, notary-based DLT systems permit increased privacy because a trusted third party helps validate all transactions. But the lack of transparency in the notary-based system implies that no node in the system, with the possible exception of the notary, has all the information. Therefore, if the information at one or more nodes is corrupted, it may not be possible to reconstruct the entire network since even the notary does not have a full copy of the ledger. This creates the need for backups of individual nodes and a loss of the economies of scale associated with centralized systems. Further, it raises the question of whether the proposed operational-resilience benefits of DLT are possible under the constraint that transactions remain private (Chapman et al., 2017).
- **Legal settlement finality**. Settlement finality is the legally defined moment at which the transfer of an asset or financial instrument, or the discharge of an obligation, is irrevocable and unconditional and not susceptible to being unwound following the bankruptcy or insolvency of a participant. In traditional systems, settlement finality is a clear and well-defined point in time, backed by a strong legal basis. For DLT arrangements, settlement finality may not be as clear. In arrangements that rely on a consensus algorithm to effect settlement finality, there may not necessarily be a single point of settlement finality. Further, the applicable legal framework may not expressly support finality in such cases (Bech & Garratt, 2017).
- **Scalability**. PCS systems may process hundreds of millions of transactions daily. Consensus algorithms and cryptographic verification introduce latency and limit the number of transfers that some DLT arrangements can process concurrently. Additionally, ledgers that add transactional histories on top of one another, such as blockchains, may challenge storage capacity over time (Mills et al., 2016).
- **Network effects**. If broad adoption of DLT is to take place, the industry will need a critical mass of participants for any application of the technology to be successful. Network effects are derived from the fact that each additional user of a network increases the benefit of the network for existing users. This effect can often lead to a problem for early adoption because the net benefits for early adopters may be negative without sufficient participation, leading to a possible lack of adoption (Mills et al., 2016).

6. Conclusions

Echoing the tremendous interest in DLT by the financial industry in general, central banks are starting to research the possibility of adopting some form of DLT, as they revamp their PCS systems and consider the implications of issuing some form of digital currency.

DLT offers a fundamentally different way to conduct and track financial transactions. It is an innovation that challenges the centralized nature of the existing financial systems in central banks. DLT is still in its infancy, however, and central banks are taking a variety of approaches toward its application. Given the technology's early stage, a number of challenges to development and adoption remain, including issues around speed, cost of processing, security, transparency and privacy, legal settlement finality, scalability and network effects of the technology.

An area of further research is the full range of applications and use cases by central banks beyond payment clearance and settlement, and the introduction of a complementary or parallel centralized digital currency. Another area deserving further research is the structural changes within the functioning of central banks and the financial industry in general that DLT's decentralized nature may drive.

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