Central bank digital currency (CBDC) has gained much attention among central banks, as it could potentially improve efficiency, inclusion and innovation in the financial system. The present paper contains a review of the CBDC journey of the Bank of Thailand (BOT), from the guiding principles, to test results of the CBDC prototypes and challenges going forward. It provides insights with regard to the introduction of CBDC into the economy, as well as how a public institution such as a central bank can go about exploring cutting-edge technologies for use in public policy.

Keywords: central bank digital currency (CBDC), digital financial infrastructures, payments systems, innovations, financial inclusion, financial stability

JEL classification: G21, G28, H31, H41, H53, O31, O36, O38
I. INTRODUCTION

In recent years, with advancements in technology and digitalization of the economy, a growing number of central banks have embarked on a journey towards introducing a central bank digital currency (CBDC). Compared to cash and traditional payment systems, CBDCs have the potential to help improve efficiency, encourage innovations and raise financial inclusion. The introduction of CBDCs to the economy, however, requires careful planning and design as CBDCs have vast potential implications on financial stability, monetary policy and the roles of financial institutions and the central bank.

The Bank of Thailand (BOT) is among the first emerging market central banks to explore the potential benefits and challenges in introducing CBDC to the economy (PwC, 2021). By 2021, BOT had conducted a total of five proofs of concept for wholesale and retail CBDC, and it is planning to introduce a live retail CBDC pilot in 2022. The present paper provides a review of the CBDC journey of BOT, from its initial goals and guiding principles, to the findings and lessons learned from proofs of concept and the plan to introduce a retail CBDC live pilot in 2022. It aims to provide insights into a variety of policy issues with regard to CBDC, and how an emerging market central bank can prepare itself and its stakeholders in CBDC development, which has the potential to improve the financial system and transform the economy.

II. BACKGROUND

The CBDC journey of BOT began in 2017, with the planning of Project Inthanon. The overarching motivation at the time was to understand how technology, particularly blockchain or distributed ledger technology (DLT), can address long-standing pain points in the financial system by improving efficiency, access and inclusion. Along the way, BOT and stakeholders gained more understanding of the technology and policy implications, as well as potential benefits and challenges. It is expected that the accumulated body of knowledge and experience has prepared BOT and stakeholders to roll out CBDC that will help address pain points in the financial system without bringing undue risks to the economy.

Guiding principles

Throughout the journey, BOT adhered to three guiding principles: learning by doing, involving a dedicated team of staff from different parts of the central bank in the various aspects of building and testing of CBDC prototypes, from information technology development, business process design and stakeholder engagement; ecosystem building, engaging relevant stakeholders, including banks, non-banks, technology providers, government agencies, foreign central banks, corporations and,
ultimately, retail users in multi-faceted collaborations; and taking an iterative approach, where lessons learned from one prototype helped to build the next prototype, and designs could be drawn and redrawn based on lessons learned.

III. THE JOURNEY SO FAR

By early 2022, BOT had built and tested three categories of CBDCs, namely domestic and cross-border wholesale CBDC and retail CBDC, as shown in figure 1. Starting off with domestic wholesale CBDC, the journey branched off into cross-border wholesale CBDC, including multi-currency CBDC, followed by a series of retail CBDC projects.

![Figure 1. Journey of the Bank of Thailand towards a central bank digital currency](image)

### Abbreviations:
- BIS, Bank for International Settlements
- BOT, Bank of Thailand
- CBDC, central bank digital currency
- DV, Digital Ventures
- SCG, Siam Cement Group

#### 3.1 Wholesale CBDC

Wholesale CBDC refers to CBDC that is used for payments and settlement at the financial institution level (i.e. interbank payments). In Project Inthanon phase I and II, BOT tested domestic wholesale CBDC prototypes with eight domestic commercial
banks. Then in collaboration with Hong Kong Monetary Authority (HKMA), BOT tested cross-border wholesale CBDC based on DLT along with a set of commercial banks in the two jurisdictions. The collaboration with HKMA has since expanded to include People’s Bank of China (PBC), Central Bank of United Arab Emirates (CBUAE), and the Bank for International Settlements (BIS) in a multi-currency CBDC project for cross-border payments.

**Domestic wholesale CBDC: Project Inthanon phase I**

Project Inthanon phase I began in 2018 and involved BOT issuing and distributing wholesale CBDC to eight participating commercial banks (Bank of Thailand, 2019). Tests were made to see if the participants could make and settle payments among themselves and with BOT in a peer-to-peer (decentralized) manner. This contrasted with the existing real-time gross settlement system that relied on a central counterparty such as the central bank to settle the payments for the parties involved.

Technically, a prototype of a decentralized real-time gross settlement system using wholesale CBDC was created to achieve various key payment functionalities, including the following:

- Cash/bond tokenization, whereby tokenized cash (i.e. CBDC) and tokenized bonds (for use to exchange for tokenized cash) were created on a DLT platform;
- Bilateral transfers, whereby two parties could transfer CBDC/bonds between them on a DLT platform;
- Queuing mechanisms, to ensure that CBDC payments on a DLT platform could be settled according to a queue, in a decentralized manner (i.e. payments did not need to queue up at centrally at the central bank);
- Gridlock resolution, where a DLT platform could help automatically, without direct intervention from the central bank, resolve a payment gridlock;\(^1\)
- Automated liquidity provision, whereby a bank could access liquidity from the central bank in an automated manner, by selling the bond to the central bank, whenever the bank had a cash shortage.

Results from Project Inthanon phase I showed that wholesale CBDC could be issued on a DLT platform, which potentially allowed for 24/7 wholesale payment

\[^1\] A payment gridlock can occur when a payment could not be settled because the payer needed cash from another party, who directly or indirectly, needed that particular payment to be settled first, in a cyclic manner.
and settlement among the banks. Unlike the existing system, the prototype showed the potential that participating banks could settle funds among themselves without waiting for the central bank operating hours, thus improving efficiency.

**Domestic wholesale CBDC: Project Inthanon phase II**

Project Inthanon phase II began in 2019, and enhanced functionalities were implemented using smart contracts on a DLT platform (Bank of Thailand, 2020). Specifically, smart contracts were used to do the following:

- Automate fraud prevention for third party CBDC funds transfer on a DLT platform, ensuring that that CBDC would only automatically go to the intended third party, which would alleviate the pain point where the existing real-time gross settlement system was vulnerable to fraud, given the costly and error-prone manual inputting and verification processes involved at the customer touch points;

- Automate compliance for non-resident regulation, i.e. the amount of Thai baht to be held by each non-resident could be automatically checked and kept within regulatory limits on a DLT platform, which could also reduce costly and error-prone manual imputing and verification processes;

- Allow for interbank bond trading and repurchase agreements (repos) using CBDC on a DLT platform.

Results of Project Inthanon phase II showed vast potential of smart contracts, and enhanced functionalities such as automated fraud prevention, automated regulatory compliance, as well as atomic delivery-versus-payment in bond trading and repos could be implemented. This could reduce risks related to wholesale payments, resulting in lower costs and improved efficiency.

**Cross-border wholesale CBDC: Project Inthanon-LionRock phase I**

The goal of Project Inthanon-LionRock was to test DLT for more streamlined cross-border funds transfers and foreign exchange settlement between Thailand and Hong Kong, China. The existing correspondent banking model often resulted in a long wait (multiple days), high costs and low transparency in cross-border payments, as cross-border funds had to pass through many steps and the steps were difficult to

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2 A delivery-versus-payment transaction means that the delivery of an asset would be made only if the payment for that asset is also made at the same time or prior. Borrowing a computer science term, atomic delivery-versus-payment means that the transaction is settled only if both the delivery of asset and the payment between the two parties are successful, otherwise the transaction does not take place. Conditions could be written on a smart contract to ensure that if the conditions on either the asset or the payment side are not fully satisfied, the transaction will not take place.
track. With the peer-to-peer nature of DLT, cross-border payments could potentially be made in seconds, with fewer intermediaries, more transparency and lower costs.

Project Inthanon-LionRock established a Thai baht – Hong Kong dollar corridor prototype that bridged the wholesale domestic CBDC networks of the two currencies and jurisdictions. All participating banks have their own presence and could make peer-to-peer payments via CBDC to each other. Among other things, tests were done on the following:

- Cross-border funds transfer, where peer-to-peer funds transfer could be made in an instantaneous manner;
- Atomic payment-versus-payment settlement, whereby a payment made in one currency and the receipt of another currency would need to occur together, otherwise none would occur (i.e. atomic);
- Liquidity management, whereby a queuing mechanism was used for the participating banks to set their priorities and manage their outgoing queues, and a multi-currency gridlock resolution mechanism was employed;
- Regulatory compliance, where both Thai baht and Hong Kong dollar wallets were monitored on a real-time basis, and regulations on non-residents in certain areas must be complied.

Although the test on the functionalities was successful, Project Inthanon-LionRock provided many important lessons learned. First, the 24/7 nature of the corridor network affected existing operations, since legacy systems did not run 24/7 and CBDC must be reserved for off-hour transactions. Second, the elimination of correspondent banks in cross-border transactions caused foreign exchange liquidity shortage such that the help of a liquidity provider or liquidity saving mechanism would be needed in this supposedly peer-to-peer environment. Third, the atomic nature of corridor network made it difficult to comply with jurisdiction-specific foreign exchange regulations, since regulations could be vastly different across borders. Fourth, DLT had scalability and performance limitations, as the CBDC networks still could not handle a large number of transactions per second.

Cross-border wholesale CBDC: Project Inthanon-LionRock phase II and Project mBridge

Project Inthanon-LionRock phase I showed the possibility of bilateral cross-border payment based on wholesale CBDC and revealed challenges ahead. In addition, it was also only natural to ask if wholesale CBDC could be used for cross-border payments in a multilateral manner.
In 2021, BOT, HKMA, PBC, CBUAE and BIS Innovation Hub Centre in Hong Kong, China embarked on Project Inthanon-LionRock phase II, which was renamed Project mBridge, to indicate a multi-currency CBDC bridge (BIS Innovation Hub and others, 2021). As of 2022, Project mBridge is still ongoing, with further experimentation with design choices and technology trade-offs. The goal is also to define a future road map from prototype to an open-source, production-ready system.

3.2 Retail CBDC

Retail CBDC is not used for interbank payments, but rather for payments among corporations, firms and individuals, although financial institutions might be distributors of retail CBDC. Since 2020, BOT has embarked on two proofs of concept for retail CBDC. In addition, a live pilot for retail CBDC will take place in the latter half of 2022.

Retail CBDC: CBDC for business payments

In 2020, BOT tested CBDC for corporate use with Siam Cement Group (SCG), one of the largest Thai conglomerates, and Digital Ventures, a fintech firm affiliated with Siam Commercial Bank (Bank of Thailand, SCG and Digital Ventures, 2021). A prototype was developed to test how smart contracts attached to CBDC could be used to improve supply chain financing, a prevalent business use case. Specifically, a prototype was developed where the central bank issued retail digital currency and distributed it to corporations and small and medium-sized enterprises (SMEs) via banks or payment service providers. By integrating the retail CBDC network with a business procurement platform, smart contracts could be employed with retail CBDC on the network, to create “programmable money”, which could lead to greater market efficiency and more competitive funding costs for SMEs that are supplier firms to corporate buyers.

In supply chain financing, SMEs often have to wait 90–180 days for payments after delivering their products and issuing invoices to corporate buyers. While waiting for payments to arrive, SMEs may need to raise additional funds to pay for the inputs needed to continue to produce their products and fulfil additional product orders. Smaller enterprises may have limited ability to raise funds in the formal credit market, even though the corporate buyers that owe them money (as specified in the invoices) may have a very good credit rating. The inability of SMEs to raise funds based on invoices is partly because lenders may doubt invoice authenticity, or they may worry that SMEs have already used the invoice to raise funds from other lenders (i.e. double financing), which could jeopardize a lender’s legal claims.

Tests were done to see if the invoices issued by SMEs could be validated and tokenized on the business procurement platform, and used as securities to raise funds from lenders in the integrated CBDC network. The fact that tokenized invoices were
validated on the business procurement platform minimized the risks of fake invoices. The tokenized invoices were also used to raise funds on a DLT-based CBDC network where transactions were recorded on a blockchain; thus minimizing the risk of double financing. Furthermore, smart contracts could be written to minimize payment risk. Smart contracts could be written on the tokenized invoices such that CBDC would move from the lenders who bought the tokenized invoices to the SMEs, and once the corporate buyers made CBDC payments on the invoices, the CBDC would move directly to the lenders according to the terms set out in smart contracts.

By lowering risks associated with supply chain financing, the proof of concept demonstrated that CBDC together with smart contracts have the potential to help improve efficiency in the funding market for SMEs, allowing for greater financial inclusion. It demonstrated the vast potential of CBDC as “programmable money”, whereby business logic could be embedded into complex transactions for which CBDC underlies conditional transfer of value among relevant parties.

**Retail CBDC: Retail CBDC as digital banknotes**

In the previous proofs of concept, whether domestic wholesale CBDC, cross-border wholesale CBDC or domestic retail CBDC for business payments, CBDC was issued, distributed and used on DLT. Although the number of stakeholders participating in the CBDC network in each test was very limited, DLT platforms showed signs of strains in terms of scalability, i.e. the ability to process a large number of transactions per second. Although DLT itself is evolving so fast that scalability may not be an issue in the future, in 2021 BOT tested a new, non-DLT approach to CBDC, i.e. the issuance of CBDC as digital banknotes.

Conceptually, digital banknotes could be perceived as digital tokens representing money issued by the central bank, and digital banknotes could be distributed by banks or payment services providers to CBDC wallets of merchants or individuals. To ensure that a retail CBDC payment is valid and that there is no double spending of the same token, public key cryptography could be used. Unlike CBDC on DLT, there is no common ledger distributed to the participants to record digital banknote transactions. Similar to CBDC on DLT, and similar to physical banknotes, however, transactions using digital banknotes could be settled peer-to-peer among the participants without the need of a central counterparty.

Unlike physical banknotes, CBDC digital banknotes could be used like debit cards or e-money to make payments through electronic interfaces such as point-of-sale machines or through online channels. Unlike debit cards or e-money that have claims on the private sector (banks and e-money providers, respectively), holders of CBDC digital banknotes would have a direct claim on the central bank, similar to holders of physical banknotes.
In this proof of concept, BOT tested prototype CBDC digital banknotes to see if they could be issued, destroyed, redeemed and used for transactions securely. The prototype was also tested to see if it could handle transaction throughputs at a scale that reflected real-life usage. The success of this proof of concept in 2021 has enabled BOT to go forward with a retail CBDC pilot in 2022, with a sizeable number of stakeholders using and processing CBDC for everyday transactions.

IV. RETAIL CBDC PILOT

The aim of the retail CBDC pilot forecasted for the latter half of 2022 is to investigate how retail CBDC might be a complementary infrastructure that helps to future-proof the Thai financial system. At a strategic level, the pilot would allow BOT to investigate how, compared to existing retail payments systems, retail CBDC would raise efficiency, innovation and financial inclusion. At a more technical level, the pilot will allow BOT to investigate if retail CBDC digital banknotes could be issued, distributed and used safely for retail transactions. Innovations to solve existing pain points will also be tested. Key issues such as cybersecurity, data privacy and transaction scalability will also be investigated.

4.1 Design characteristics

Based on a survey taken among stakeholders and BOT research (Bank of Thailand, 2021a and 2021b), BOT selected the following design characteristics for the retail CBDC pilot prototype: (a) the system will have two tiers, whereby the CBDC is issued to payment services providers (banks and non-banks) that distribute CBDC to the general public; (b) the system will be non-interest bearing; (c) there will be limits on the amount of CBDC that can be held in different types of wallets; (d) the system will be open to innovations, whereby banks and non-banks can develop applications for the CBDC infrastructure; and (e) the system will ensure appropriate levels of data privacy.

The decision to design a two-tier system was based on the desire to ensure that CBDC would not unduly disrupt the underlying financial system. Intermediaries such as banks provide valuable services to the economy (i.e. efficient allocation of funds into productive use). As such BOT deemed it inappropriate to bypass the intermediaries and issue digital banknotes directly to individuals and firms. By not directly interacting with the general public, this would also help to lessen heavy operational burdens on the central bank, as otherwise it would also need to do know-your-client (KYC) operations on a large number of users and manage a large number of CBDC wallets.

The decision to design a non-interest-bearing system for retail CBDC was based on financial stability concerns. Interest payments on CBDC would make it a direct
competitor to bank accounts, disrupting the ability of the intermediaries to raise and allocate funds in the economy. Although interest payments on retail CBDC could hypothetically make monetary policy transmission much faster, since individual holders of CBDC could be directly and instantly affected by changes in interest rates paid on CBDC, this would amount to the central bank’s direct intervention into the balance sheets of households and firms.

Limitations on the amount that may be held in different types of CBDC wallets reduces the possibility of bank runs. If there were no limits on the amount of CBDC to be held in the CBDC wallets, unfounded rumors could easily cause bank runs, as people could use their mobile phones any time to transfer large balances out of their bank accounts and into risk-free CBDC wallets. To allow for reasonable use of CBDC wallets, the limits could depend on the types of holders of CBDC wallets (e.g. individuals versus merchants), or different KYC levels on the wallets.

The emphasis of the pilot on openness to innovation is reflected in the architecture of the CBDC network. In contrast to wholesale CBDC that can be accessed only by banks, participating banks and non-banks would distribute digital banknotes to the general public and act as custodians of CBDC wallets. Banks and non-banks can thus develop applications for CBDC wallets customized to particular use cases. Smart contracts could be built for CBDC wallets to allow for complex, conditional payments.

On data privacy issues, BOT differentiates between identifiable personal data and transactions data. As banks and non-banks deal with KYC, BOT will not have direct access to identifiable personal data. This is similar to the existing systems in the banking industry, where BOT does not have a direct access to identifiable personal data on the bank accounts of individuals. Banks, including BOT and non-banks acting as payment service providers all need to comply with regulations on data privacy.

Another aim of the pilot is to test the security and reliability of the system, thus a limited number of users (merchants and individuals) and payment services providers (banks and non-banks) would be invited at the start. Once the results of the pilot have met pre-defined criteria, there may be an extension in terms of participants, scope and timing.

4.2 Differences between retail CBDC and existing e-payment systems

A question that often arises when discussing retail CBDC is how it would be different from the existing payment systems, including PromptPay, the existing faster payment system. PromptPay is already very popular in Thailand, as it allows a user to make payment from a mobile banking application to a bank account that is linked with the recipients' mobile phone number or linked with a QR code, free of charge.
By the end of 2021, there were more than 66.9 million registered PromptPay bank accounts (Thairath Online, 2021). Furthermore, in April 2021 BOT and the Monetary Authority of Singapore launched the world’s first linkage of real-time payment systems, PromptPay-PayNow, enabling the transfer of funds between the two countries using only a mobile phone number (Bank of Thailand and Monetary Authority of Singapore, 2021).

At first glance, there may seem to be few differences between making payments using retail CBDC or PromptPay, as both use a mobile phone application. The key differences, however, are the underlying payment and settlement system architecture and how the transactions are processed. Such differences could have vast implications on innovations that build on the payment infrastructure.

The existing faster payment systems, including PromptPay, are centralized, and payments between banks are settled at a central switch. These payments require interactions with the core information technology infrastructure of the payer and payee banks. Typically, a fund would be debited from the payer’s account at one bank and credited into the payee’s account at another bank. As a bank’s core information technology infrastructure typically houses millions of accounts, it cannot be readily modified to accommodate customized debiting or crediting for individual accounts. Specifically, it would not be easy, or even possible, to write smart contracts on legacy bank accounts to allow for complex, customized and automated payments among them.

In contrast, payments using retail CBDC would be settled on a peer-to-peer basis. The transfer of value between two CBDC wallets would occur as soon as the payer instructs her CBDC wallet to make a transfer to the payee’s wallet. There would be no need for a centralized switch, nor for integration with the core information technology infrastructure for banking (except where an individual wants to move funds between her retail CBDC wallet and her own bank account). As such, smart contracts could be written to allow for complex, customized and automated payments among the retail CBDC wallets. The decentralized nature of retail CBDC allows for the possibility of programmable money to be ready for implementation. As retail CBDC payment and settlement occur on a peer-to-peer basis, new financial services providers have the potential to propose innovative payment solutions through smart contracts written on retail CBDC wallets, uninhibited by legacy information technology systems or barriers-to-entry that might be imposed upon by the company that owns a centralized payment switch.

4.3 Possible pilot use cases

To encourage innovation, BOT invited private sector participants to propose use cases. Participating banks and non-banks may identify pain points of their customers,
whether individuals or merchants, and provide solutions using retail CBDC. As of early 2022 there has yet to be a decision on the retail CBDC pilot use case, but an oft-cited possibility is the targeted government welfare payment, as it could explore actual use of smart contracts.

In Thailand, during the COVID-19 pandemic, the Government implemented several COVID-19 relief schemes for citizens and merchants using “Pao Tang”, a smartphone application. For example, the Government introduced a scheme in 2020, whereby Pao Tang users could deposit funds and use the application to pay for goods and services from registered merchants, including street vendors, at half price. The Government paid the other half to the merchants (Bangprapa and Theparat, 2022). In a scheme to stimulate domestic tourism, the Government introduced “Thai-Teaw-Thai” to subsize bookings at registered hotels and hostels for Pao Tang users (Worrachaddejchai, 2021). The schemes were very popular, and by the end of 2020, there were approximately 40 million accounts on Pao Tang (Banchongduang, 2020).

The success of Pao Tang suggested that citizens may be willing to embrace digital welfare payment schemes. The pilot use case for retail CBDC could be the implementation of more refined, complex government welfare schemes based on smart contracts. Smart contracts could be written on CBDC wallets to implement more granular welfare schemes with eligibility criteria for participants, goods and services, and timing.

V. CONCLUSION: LESSONS AND CHALLENGES AHEAD

Central banks around the world are exploring CBDC, whether domestic wholesale, cross-border wholesale, or retail CBDC. The experience of BOT can offer important lessons for other central banks in the Asia-Pacific region, especially in emerging markets.

The journey of BOT so far has shown that CBDC has the potential to raise efficiency, inclusion and innovation for the financial system. Given that CBDC could also deeply affect financial stability, monetary policy and the roles of financial institutions and central banks, BOT is proceeding in a measured and gradual manner. Through learning-by-doing, ecosystem building and an iterative approach, BOT has built its capability along with the capacity of stakeholders to reap the benefits of CBDC while mitigating risks that might arise. The retail CBDC pilot in 2022 is expected to add to the body of knowledge and experience and help to build a road map for a possible future CBDC roll-out.

A key challenge after the retail CBDC pilot in 2022 will be to integrate all the knowledge and experience gained from each proof of concept and the pilot, to make
an informed decision whereby domestic wholesale CBDC, cross-border CBDC and retail CBDC could be integrated, and complement and coexist with existing payment systems. This will be an ongoing journey, as technology and the financial landscape continue to evolve.

Going forward, for actual deployment in the economy, wholesale and retail CBDC might not need to be introduced together in one-go. However, a well thought-out sequential introduction might be warranted. Again, the three guiding principles, i.e. learning by doing, ecosystem building and an iterative approach, should help BOT to introduce CBDC in an orderly and secure manner without jeopardizing the financial sector stability.

Lessons learned from the CBDC journey can also be applied to other public institutions in their efforts to introduce digital technologies. Moreover, CBDC could be seen as digital infrastructure that can help improve efficiency, inclusion and innovation of the financial sector. Similar to physical infrastructure, digital infrastructure is a public good that often requires public sector initiative.

Unlike physical infrastructures such as bridges, tollways or airports that can be built and run by a particular entity (public, private or public-private), digital infrastructure, including CBDC, often require a network of participants to build and run their own parts of the infrastructure based on common standards and protocols. For example, to make an automated peer-to-peer transaction on a CBDC network, participating banks will need the ability to develop and run CBDC wallets and write smart contracts that share common standard and protocols. Furthermore, as digital infrastructure can evolve much faster than physical infrastructure, all the relevant stakeholders will need to regularly come together in order to make timely infrastructure adjustments. The CBDC journey of BOT has reflected the importance of learning by doing, ecosystem building and taking an iterative approach for public institutions in the development of digital infrastructure.

ACKNOWLEDGEMENTS

The author would like to thank those involved in the CBDC journey of BOT. Such a journey has so far involved not only the BOT team, but also the participating commercial banks, information technology vendors, Thai public agencies, foreign central banks, as well as non-banks and the public, who responded to BOT surveys and public consultations. In particular, the author wishes to thank Veerathai Santiprabhob, Sethaput Suthiwartnarueput, Mathee Supapongse, Vachira Arromdee, Chantavarn Sucharitakul, Amporn Sangmanee, Titanun Mallikamas and Chayawadee Chai-anant, for their guidance from the beginning of the BOT’s CBDC journey, and the rest of
BOT Digital Currency Team for their tireless effort to introduce CBDC to improve efficiency, inclusion and innovation in the Thai financial sector. Any errors found in this paper are the author’s alone.

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