5-2023

CBDC: Context, challenges, and conditions for a successful adoption

Charlie Nhuc Hiang LAY
Singapore Management University, charlie.lay.2020@phdgm.smu.edu.sg

CBDC: CONTEXT, CHALLENGES, AND CONDITIONS FOR A SUCCESSFUL ADOPTION

CHARLIE LAY NHUC HIANG

SINGAPORE MANAGEMENT UNIVERSITY

2023

CBDC: Context, Challenges, and Conditions For a Successful Adoption

Charlie Lay Nhuc Hiang

Submitted to Lee Kong Chian School of Business
in partial fulfilment of the requirements for the
Degree of Doctor of Philosophy in Business (General Management)

Dissertation Committee

Lim Kian Guan (Supervisor / Chair)
OUB Chair Professor of Finance
Singapore Management University

Low Kee Yang
Associate Professor of Law
Singapore Management University

Mandy Tham Tze Minn
Associate Professor of Finance (Education)
Singapore Management University

Henry Chan Hing Lee
Visiting Senior Research Fellow
Cambodian Institute for Cooperation and Peace

Singapore Management University

2023

I hereby declare that this PhD dissertation is my original work,
and it has been written by me in its entirety.

I have duly acknowledged all the sources of information
which have been used in this dissertation.

This PhD dissertation has also not been submitted for any degree
in any university previously.

Charlie Lay Nhuc Hiang

1 May 2023

CBDC: Context, Challenges, and Conditions For a Successful Adoption

Charlie Lay Nhuc Hiang

Abstract

Central bank digital currencies (CBDC) are the digital version of physical notes and coins. They are the latest milestone in the evolution of money over the centuries due to technological advancements. This digitalisation of physical money primarily serves as a medium of exchange that has a central bank anchor. There are two versions of CBDC, wholesale and retail. This thesis focuses on retail CBDC, which targets the general public and small daily transactions. It discusses the issues and the plausible implementation of a retail CBDC. A CBDC will preserve monetary sovereignty, foster financial stability, and counter private network effects, i.e., prevent private payment system monopolies and safeguards the payments system. It can also promote lower fees via increased domestic payment competition. More importantly, it can facilitate interoperability among foreign CBDCs and considerably lower fees for cross-border payments. While there are arguments against CBDC, the concerns about financial disintermediation, loss of privacy, and cyber threats can be mitigated by well-considered design choices.

A successful CBDC adoption must be preceded by at least four key foundations: the maintenance of the two-tier fractional banking system, an account-based model, an intermediated architecture, and a centralised system to facilitate real-time gross settlement (RTGS). Other essential conditions include co-existence with physical cash, a cap on CBDC deposits, non-interest yielding, offline functionality, and strong cybersecurity. Importantly, it will require broad public support, which will depend on cultural and social norms. All major central banks are stepping up research into CBDC, and its introduction is a matter of when and how, not if. However, implementation will be a significant challenge, and getting the public's support will be the key. It will differ from country to country. For countries with high digital transactions and low interchange fees, the urgency to introduce CBDC may not be high, e.g., Scandinavia. For countries with high cash usage, the cost savings will be more significant, but this will also entail higher investments in the necessary infrastructures, education, and public promotion. This thesis provides an examination of these foundational and auxiliary issues surrounding a successful CBDC adoption.

Keywords: Central bank digital currencies (CBDC), crypto assets, monetary policy, monetary sovereignty, financial stability, payments system.

Table of Contents

List of tables

List of figures

Acknowledgment

A big thank you to Professor Lim Kian Guan and Professor Mandy Tham for their advice and suggestions.

My special thanks to Professor Low Kee Yang for his constant encouragement, to get the thesis off the ground, and to keep it going during challenging times.

My sincere thanks to Dr Henry Chan for his expert opinions and guidance throughout the thesis journey. It would not have materialised without his unceasing help and expertise.

My heartfelt gratitude to Professor Ho Yew Kee from the Singapore Institute of Technology. He was a great support in tough times.
God is still using OCF Australia to be a channel of His love.

My sincere thanks to Dr Ulrich Bindseil from Market Infrastructure and Payments, European Central Bank, Tansaya Kunaratskul, CBDC Expert at the IMF, Money and Capital Markets, and Dr Marc Sánchez Roger, head of credit financials strategy, investment banking industry for their helpful input and advice.

A big thank you to my friends who helped me tremendously along the journey.
Truly the journey matters as much as the destination.
You guys were all so willing to chip in to provide opinions, views, and a great sounding board. You were all so very kind.

Thank you to Manu Bhaskaran, Boon Swan Foo, Goh Mui Hong, Emily Lay, CD Lim (Richard), Reuben and Shantel Seevaratnam, Anthony Tse, Weiwen Ng, Adrian Boyd, Adrian Khew, Andrew Lee, Vishnu Varathan, Dr Carlos Eisenberg, Professor Meik Friedrich, and Professor Gunter Dufey.

Dedication

To my darling wife and precious girls, Emdse.

You girls are the delight, joy, and pride of my life.
Papa appreciates and loves you all very much.

May you continue to ginosko the Lord.

May the Lord always be the glory and lifter of your heads,
and surround you with His love.

Psalm 3:3

Chapter 1: Introduction

This thesis explores the context, challenges, and conditions for the successful adoption of central bank digital currencies (CBDC). CBDC is the digital form of notes and coins which is legal tender in a country and is a direct liability of the central bank (Coeur et al., 2020). The simplest definition is the digital version of notes and coins or M0. It is the natural evolution of money over the centuries due to technological advancements.

CBDC is an important topic because it touches on the relevance of notes and coins in the increasingly digital domestic payments system. In recent years, the advent of crypto assets and the possibility of their use as an alternate mode of payment rocked the central banking community. Innovations such as Facebook's Libra project raised several questions: if crypto assets were widely adopted, what would be the implications for monetary sovereignty and financial stability? Would they compromise the central bank's ability to conduct monetary policy? Would central banks lose control over the monetary and payments system? Would it severely impact the seigniorage income for governments? The rising risks compelled central banks to raise the ante on CBDC research. As of the end of 2022, over 110 countries representing more than 95% of global GDP are exploring CBDC (Atlantic Council, 2022; Meir, 2021),

There are two versions of CBDC, a wholesale and a retail CBDC. A wholesale CBDC applies only to a small number of players in the interbank market. The transaction sizes are large, running in the millions. On the other hand, a retail CBDC is targeted for use by the general public, i.e., there will be many more users. It will entail millions of small size transactions that occur daily. A retail CBDC is not targeted at million-dollar size transactions but millions of small one-dollar to one-hundred-dollar-size transactions. In other words, one million one-dollar transactions, as opposed to a single one-million-dollar transaction.

The deposits of commercial banks at the central bank or what is known as reserves are a form of wholesale CBDC. They are digital and direct liabilities of the central bank. The wholesale interbank market is already operating smoothly and is relatively efficient. As such, a wholesale CBDC may result only in incremental benefits or may include the dimension of strategic benefits that are outside the scope of this thesis. On the other hand, a retail CBDC will be transformational for the domestic payments system and is the primary focus of this thesis. If implemented, it will mean that for the first time in history, the general public can hold a “digital asset” that is a direct liability of the central bank.

The benefits of a retail CBDC can be significant. It can preserve monetary sovereignty, foster financial stability, safeguard the payments system, and promote lower fees via increased competition in the domestic payments space. More importantly, it can facilitate interoperability among foreign CBDCs and considerably lower fees for cross-border payments, including remittances. Given the complicated web of correspondence banking relationships, cross-border payments remain notoriously cumbersome and expensive. A retail CBDC can counter adverse private network effects. In other words, to prevent the payments system from being dominated by a few private dominate players that could crowd out viable and vibrant new entrants. It is to avoid private payment system monopolies. Private organisations may not have interoperability and cost savings for users as their top objectives.

However, there are several challenges. Topping the list are concerns over privacy, data protection, and fears over increased surveillance by the government. Could these be adequately addressed by appropriate regulations, CBDC design, and the use of technology? Other apprehensions include increased cybersecurity threats and financial disintermediation. For example, will CBDC introduction lead to significant bank outflows to CBDC deposits?

Will this lead to a higher cost of credit for borrowers? Will it increase the risks of detrimental digital bank runs, which could occur swiftly in the digital age?

For the widespread adoption of CBDCs, certain conditions must be in place. These are centred on four foundations: a two-tier banking system, an account-based model, an intermediated architecture, and a centralised system to facilitate real-time gross settlement (RTGS). RTGS is to facilitate payment efficiency and scalability. Both factors are important for a retail CBDC. Appropriate measures must also be in place to protect privacy, personal data, and fend off cybersecurity risks. These conditions are the basic building blocks for the successful adoption of a retail CBDC.

However, these conditions by themselves do not necessarily guarantee success. Other social factors must be considered, such as whether there will be demand for CBDC. There needs to be a strong value preposition for citizens to shift from the status quo and adopt a new payments system. The adoption for each country will be dictated by the cultural and social norms and the citizens' openness to change.

Governments must assure the public that sufficient protocols are in place to allay privacy concerns. Public education campaigns and incentives to encourage adoption will be needed. Central banks worldwide are pressing ahead with the technical preparations but will need broad political and public support.

CBDC poses risks but is also a golden opportunity for central banks to regain the initiative on domestic payments and firmly establish sovereign central bank money in the digital age. At first glance, it may appear to be a risky and ambitious project by central banks. However, given the speed of technological change, it should be viewed as a proactive initiative and an ongoing evolution in central bank money. There may not be an overtly strong case if it is just for the domestic payments sector. However, there is a much stronger case for it to lower cross-border payment fees by facilitating interoperability among foreign CBDCs. The G20

Leaders' Declaration in Bali in November 2022 (G20 Leaders, 2022) welcomed the continued exploration of CBDC to facilitate cross-border payments and lower fees.

Rather than the private sector, the sovereign states are the best agents to lead such an initiative. They can establish common standards, regulations, and governance for foreign CBDCs. Interoperability among foreign CBDCs will be the ultimate long-term goal.

All major central banks worldwide have stepped up the pace of CBDC research in the past year. It includes the Federal Reserve, the European Central Bank (ECB), the Bank of Japan (BOJ), and the People's Bank of China (PBOC). PBOC is the most advanced in CBDC research and rolled out pilot programs in different cities in early 2020 (Cheng, 2020). CBDC introduction is a matter of when and how rather than if. However, it will differ for each country and depend on the existing payment system setup. For countries with low cash usage, a relatively efficient and advance payments system, and low interchange fees due to regulation, the desire for CBDC adoption may be low. For countries with high cash usage, the benefits and cost savings for CBDC will be more significant, and there could be a more substantial user case.

CBDC is an extensive and challenging topic encompassing multiple disciplines, including political economics, monetary economics, the payments system, law, and technology. There is ongoing research involving the appropriate design features, the role of commercial banks, legal implications, and cross-border interoperability. The implementation and widespread adoption challenges are monumental and should not be underestimated.

The outline of the rest of the thesis is as follows. Chapter 2 looks at the context and catalysts for CBDC. Chapter 3 examines the arguments for CBDC and Chapter 4 examines the misconceptions and arguments against CBDC. Chapter 5 looks at the challenges of implementation. Chapter 6 outlines the necessary conditions for adoption. Chapter 7 looks

at the current central bank setups. Chapter 8 assesses the arguments and future research, and Chapter 9 concludes the thesis.

Chapter 2: Context and catalysts for CBDC

2.1 History of money

Money is one of the oldest and most enduring institutions in human history. It does not appear in nature; it is a human invention. Societies established the monetary system to motivate human behaviour and the exploration of resources (Robertson, 2012).

The shape and form of money have not been static over the centuries. It has constantly evolved and adapted to the available technology of the day. We are in an exciting time in history where we can witness the introduction of a new form of money, a once-in-a-century event.

The form of money has ranged from cowrie shells and copper ingots to silver and gold coins. The invention of paper in China around 105AD by Ts'ai Lun, a court official in the Han Dynasty (25-220AD), ushered in the world's first official paper money by Emperor Zhenzong (998-1022), the third emperor of the Song Dynasty (960-1279) (Kampmann, 2012). Marco Polo wrote about the use of paper money under the reign of Kublai Khan (1215-1294) under the Yuan Dynasty (1271-1368) (Redmond, 2021). In 1661, Stockholms Banco became the first central bank to issue banknotes in Europe (Redmond, 2021; Sveriges Riksbank, 2022). By the late 1800s and early 1900s, paper money became widely used across the world and was an important milestone in the evolution of money.

Today, paper money has evolved into a colourful polymer with high-tech security features, accompanied by credit cards and a digital form by way of deposits in commercial banks. In other words, a complex tango has always existed between technology and the form of money.

The enduring trait of money is not in its physical attributes but instead, the function that money plays in each epoch. Regardless of the form, money must fulfil three functions: a store of value, a medium of exchange, and a unit of account. Beyond these three primary

functions, other common features include convenience, ease of use, cost-effectiveness, efficiency, safety, and security. Undergirding the stability of money is trust. This trust is not set in stone or a given; it can quickly evaporate if the economic or political situation becomes unstable.

As a store of value, money must be stable, predictable, and preserve its value over time. The extreme volatility and sharp collapse in crypto assets in 2022 disqualified it as a reliable store of value. Central banks strive to ensure their fiat currencies' integrity, reliability, and stability by fostering a stable macroeconomic and inflation environment. This will cement public trust in central bank money. Historically, episodes of hyperinflation have often led to a collapse in currencies – for example, from 1921 to 1923 in the Weimar Republic, which resulted in immense internal political instability, and in Zimbabwe from 2008 to 2009.

Central banks are discussing CBDC today because of the advent of the computer, internet, smartphones, and wireless communications. This was not possible 10 to 20 years ago.

By sovereign or central bank money, we refer to money issued by or on behalf of the sovereign state[1]. For the past century, central banks have had a monopoly over the issuance of money used as legal tender. It has not always been the sovereign state's sole purview, as private commercial entities have also issued commercial money used in an economy (Champ, 2007). In the context of this thesis, commercial bank money refers to money licensed commercial banks create as part of the fractional banking arrangement. Central bank notes and coins deposited in commercial banks are liabilities of commercial banks and not the central bank. However, there is an implicit one-for-one convertibility between the central bank and commercial bank money. The central bank maintains strict regulatory and supervisory oversight of commercial banks.

2.2 Taxonomy of money

Bech and Garratt (2017) compiled a taxonomy of money in a Venn diagram in terms of the "money flower" Figure 1. The early literature referred to CBDC as central bank cryptocurrencies or CBCC. There are four key properties, which include:

i) Issuer – central bank or private entities. Money issued by central banks includes physical cash and central bank reserves or deposits of commercial banks with the central bank. The liabilities of commercial banks include bank deposits, for example, sight or call deposits, savings accounts, checking accounts, and money market accounts;

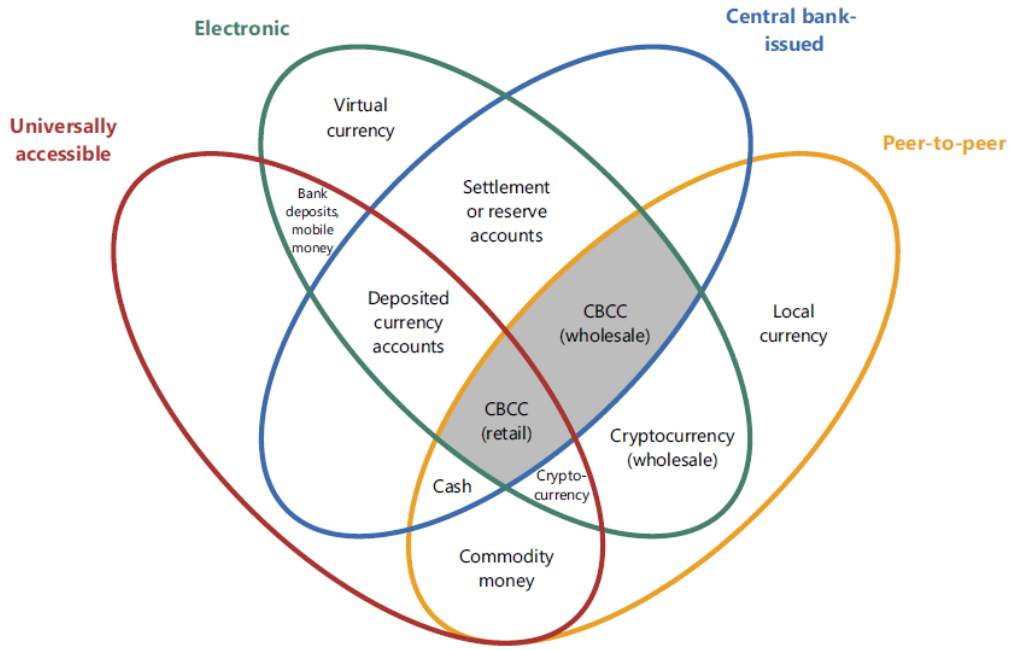
ii) Form – digital or physical. Digital or electronic money comprises i) savings deposits at commercial banks; and ii) reserve accounts that banks hold with the central bank. In the UK, 96% of the money is digital rather than physical cash (Bank of England, 2020b). This is consistent with the average for developed economies, where 92% of the money is already digital (Callaghan, 2021). There are obvious practical reasons, including convenience, durability, storage, and security.

iii) Accessibility – referring to its universality, i.e., available to the general public or limited to interbank institutions that have accounts with the central bank; and

iv) Usability in peer-to-peer transactions – whether transfers between peers can be settled directly or cleared without going through a bank-based clearing system. They include wholesale or retail CBDC and, theoretically, crypto assets.

This taxonomy also shows that CBDC can be exchanged peer-to-peer in a de-centralised manner. On the other hand, bank reserves are exchanged among financial institutions with the central bank acting as the central clearing system. These institutions have accounts with the central bank but the general public does not.

Figure 1
The money flower



Note: From (Bech & Garratt, 2017; Schweizerische Eidgenossenschaft, The Federal Council, 2019). The early literature initially referred to CBDC as central bank cryptocurrencies or CBCC.

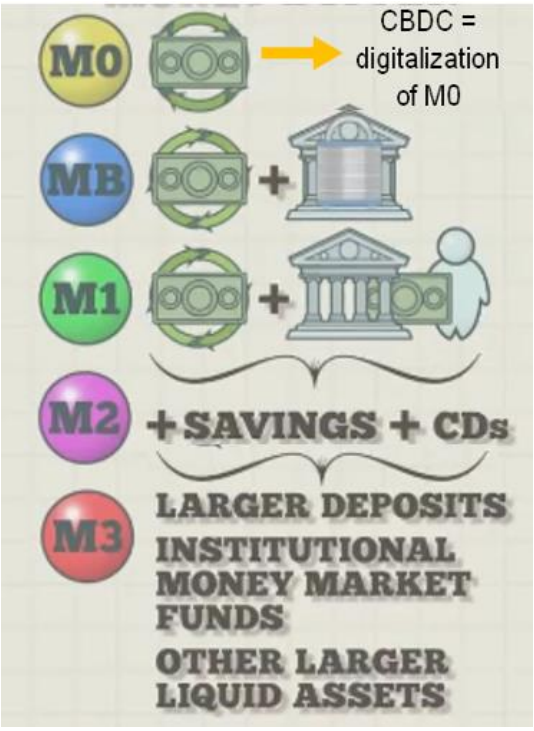
Economists classify money into different categories, as shown in Table 1 and Figure 2. M0 refers to notes and coins or currency in circulation (CiC), sometimes called reserve money. M0 forms a small percentage of the overall money supply in the economy. A retail CBDC will be the digital version of M0. M1 or narrow money is M0 plus demand deposits, also known as sight or chequing deposits. M2 is M1 plus certificate of deposits (CDs), retail money market funds (MMFs), savings deposits, and small-time or term deposits, usually below USD100,000. M3 or broad money is M2 plus large time deposits, institutional money market funds, short-term repurchase agreements (repo), and other large liquid assets.

Table 1
Money supply classification

Classification	Composition
M0	Currency in Circulation (CiC) or Reserve Money. The narrowest definition of money consists of notes and coins in public circulation.
MB	Monetary Base. M0 + notes and coins held by banks as cash reserves (also known as “vault cash” or “reserve balances”).
M1	Narrow Money. M0 + demand deposits (sight deposits or chequing deposits).
M2	Money and Close Substitutes. M1 + certificate of deposits (CDs) + retail money market funds (MMFs) + savings deposits + small time deposits* (also known as term deposits).
M3	Broad Money (BM). M2 + large time deposits, institutional money market funds, short-term repurchase agreements (repo), and other large liquid assets.

Note: * less than USD100,000. From US Federal Reserve, https://marketbusinessnews.com/financial-glossary/money-supply-2/

Figure 2
A pictorial description of money supply classification



Note: From Investopedia.com

2.3 Catalysts for CBDC

Four catalysts in recent years compelled central banks globally to step up research on CBDC. They include:

1) The digitalisation trend and the COVID-19 pandemic;
2) The proliferation of crypto assets;
3) China's advanced CBDC development, known as the electronic-CNY or e-CNY; and
4) The potential GDP and efficiency gains from reduced physical cash usage in transactions.

2.3.1 Digitalisation and COVID-19

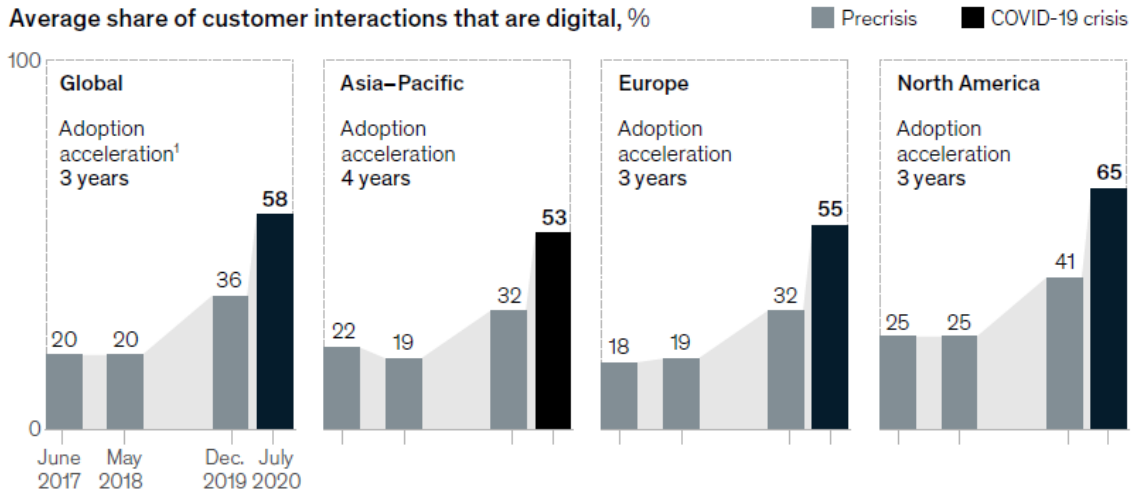
A crisis often accentuates existing trends rather than initiating one. The COVID-19 pandemic was a once-in-a-century health shock. The last major pandemic, the Spanish flu, was in 1918. The enforcement of social distancing, lockdowns, and concerns that the virus could be transmitted via physical cash gave greater impetus to digital transactions and payments.

The pandemic boosted the digitalisation drive across industries worldwide. It lifted non-physical cash payments and increased the take-up of e-payments by merchants to facilitate e-commerce and contactless exchanges. For example, a 2020 survey from McKinsey and Company found that the average share of digital customer interactions accelerated by three years globally and four years in Asia-Pacific during the pandemic. Globally, the average share rose from 36% in December 2019 to 58% in July 2020. In Asia Pacific, the percentage catapulted from 32% in December 2019 to 53% in July 2020 (McKinsey & Company, 2020), Figure 3.

Even though the pandemic facilitated digital payments, it did not result in a complete migration away from physical cash. Lingering fears over the uncertain trajectory of the pandemic prompted citizens to hold the most trusted form of money: physical cash.

Figure 3
The percentage share of digital transactions over time

The COVID-19 pandemic accelerated the digitalization of e-commerce, e-payments



Note: From (McKinsey & Company, 2020)

2.3.2 Facebook's Libra project and stablecoins

Crypto assets, sometimes called cryptocurrencies, have proliferated in the past few years, led by the popular Bitcoin and Ethereum. The extreme volatility in 2022 disqualified them as a viable medium of exchange or store of value. However, a critical development was Facebook's (renamed Meta) ambitious and audacious project to launch its own private crypto money, called the Libra (renamed Diem), in June 2019. It was to be an asset-backed digital currency, i.e., a stablecoin that could act as a means of payment for its expansive network of three billion users worldwide.

On 5 August 2019, the governing bodies in Albania, Australia, Canada, Burkina Faso, the European Union (EU), the United Kingdom (UK), and the USA issued a joint statement on the global privacy expectations of the Libra Network (European Data Protection Supervisor, 2019). They outrightly expressed concerns over Meta's handling of personal user data.

Meta's proposal shook central bankers and policymakers out of their complacency. It highlighted the speed of digitalisation and technological advancements in finance, particularly in the important payments space. It dawned upon policymakers that privately-

issued crypto assets could gain traction and rival – or partially displace – central bank and commercial bank money as a means of payment. This is reminiscent of the economic situation in the United States before the turn of the 20th century. Different versions of money circulated in the economy before the creation of the Federal Reserve Act of 1913, which centralised and monopolised legal money printing.

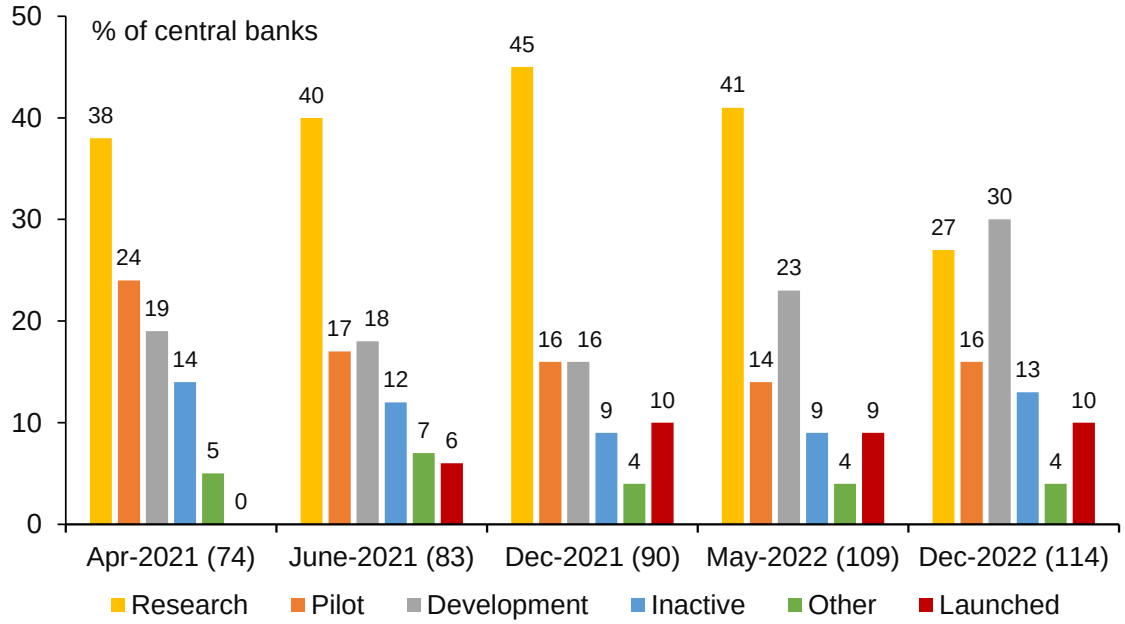
The consequences of complacency could be dire. Central banks could lose control over the payments system to a private entity, where network effects can be expansive, powerful, and damaging. Ultimately, this could undermine monetary sovereignty and threaten financial stability.

Such threats no longer seemed distant or implausible. Regulators worldwide stepped up and banned privately-issued crypto assets as legal tender. Meta eventually abandoned the Diem project in January 2022, citing regulatory hurdles. However, the genie was out of the bottle, and the project left an indelible legacy that catapulted CBDC research.

The Atlantic Council launched a Central Bank Digital Currency Tracker on 22 July 2021 (Meir, 2021). As of December 2022, all G7 economies and 18 of the G20 economies are in the advanced development stage (Atlantic Council, 2022). Figure 4 shows the increase in the percent of central banks researching CBDC in the past year. The number of central banks that stated they were researching, piloting, or in active development of CBDC increased from 60 in April 2021 to 171 in December 2022.

China is the most advanced in CBDC research among the major economies. It launched pilot runs in early-2020 in several cities, covering over 200 million people. China is pressing ahead with its CBDC project known as the e-CNY, and this same trend is observed among other major central banks, including the Federal Reserve, the European Central Bank (ECB), and the Bank of England (BOE). Over two-thirds of central banks have said they will likely issue a retail CBDC in the short to medium term (Kosse et al., 2022).

Figure 4
% of central banks that have launched CBDC or conducting CBDC research



Note: From https://www.atlanticcouncil.org/cbdctracker. Numbers in brackets ( ) are the total number of central banks conducting CBDC research, e.g., 114 in December 2022 compared to 74 in April 2021. 11 countries have launched CBDC as of December 2022.

A word on stablecoins

Stablecoins are crypto assets 100% backed by reserves or other means – e.g., by fiat currencies such as USD or physical metals like gold. The popular stablecoins are pegged one-to-one to the USD. This addresses the issues of extreme price volatility and the absence of fundamental backing for crypto assets. Stablecoins are an attempt to have the best of both worlds of crypto assets: decentralisation and an anchor from fiat currencies issued by central banks. Stablecoins can be classified by the type of collateral used. There are three main types:

1) One-to-one fiat-backed – e.g., Tether (USDT), the largest stablecoin. However, it turned out that not all of the assets were in USD. It reported in May 2022 that it had USD286 million in non-US government bonds or just under 3% of the reported assets of USD82 billion. USD Coin (USDC) is pegged to USD and managed by a consortium called Centre. Another example is Gemini USD (GUSD), which is supposed to be 100% backed by USD deposits

at banks (including Silvergate Bank, which collapsed in March 2023 due to its exposure to the crypto market), money market funds, and US Treasury bills. After the collapse of the crypto exchange FTX, concerns have risen on whether some of these stablecoins are fully backed one-to-one and solely by USD assets;

2) Crypto-collateralised – these are even more volatile and over-collateralisation is common; and

3) Non-collateralised or algorithmic – e.g., TerraUSD stablecoin (USDT). It collapsed in May 2022 as investors lost confidence. The world experienced the crypto asset equivalent of a bank run. It wiped out over USD400 billion in the crypto market capitalisation. At the end of February 2023, the market capitalisation of stablecoins stood at around USD135 billion. The top three were Tether, USD Coin, and Binance Coin, comprising over 90% of the market capitalisation (Coin Market Cap, 2023).

Stablecoins have been put forward as a viable alternative for crypto assets to gain legitimacy for digital payments. However, confidence in stablecoins has declined in the past year due to the extreme price volatility in crypto assets. There were also damaging revelations that not all were 100% backed by fiat currencies as promised (Browne, 2022). Some are backed by synthetic instruments, as revealed by Tether, which reported that it held non-USD assets even though it was supposed to be pegged directly to the USD (Sigalos & Browne, 2022). Greater transparency of the underlying assets remains a key issue for stablecoins. Until investors and users are convinced of this, scepticism will persist over its adoption as a medium of exchange.

2.3.3 China's e-CNY development

PBOC's decision to issue banking licences to Alibaba and Tencent in 2014 was a defining and transformative moment. The tech companies brought technological know-how and innovation into the payments space. In less than a decade, China went from a predominantly physical cash economy to almost cashless (Turrin, 2021). Alibaba's Alipay and Tencent's WeChat Pay were phenomenally successful and exceeded expectations. By 2020, Alipay and WeChat Pay captured 98% of the digital payments market in China (Bloomberg News, 2021; Lee, 2021).

One motivation behind PBOC's e-CNY project is to wrest control of the digital payments space from the two big tech companies. If left unchecked, the payments system will be vulnerable to oligopolistic pricing and anti-competitive activities – to the detriment of users and society. In other words, China hopes to re-establish monetary sovereignty, regain control over the domestic payments market, and reduce negative network efforts from the two private entities. The e-CNY introduction will also provide a more level playing field and lower the barrier to entry for new contenders, promoting competition and innovation.

Outside of China, there are concerns that the e-CNY could be used more widely for cross-border trade settlements, particularly with China's major trading partners. The implications are that it could diminish the role of the USD. The geopolitical tensions and rivalry between the US and China prodded the Biden Administration to step up research on CBDC. For instance, on 9 March 2022, President Biden issued Executive Order 14067, titled *"Ensuring Responsible Development of Digital Assets"* (White House, 2022a). It was a clarion call for greater urgency and research into the design and deployment options of a US CBDC or digital USD. The White House issued three reports in September 2022 outlining the objectives, technical design choices, and technical evaluation for a US CBDC (White House, 2022c, 2022d, 2022e). The Harvard Kennedy School Belfer Centre stated that China's CBDC could disrupt the international financial system which has benefitted the US and aided

its global influence (Sewall & Luo, 2022). The report highlighted that China could use the e-CNY to chip away at the USD's reserve currency status and hence, the US' global standing and influence (Sewall & Luo, 2022).

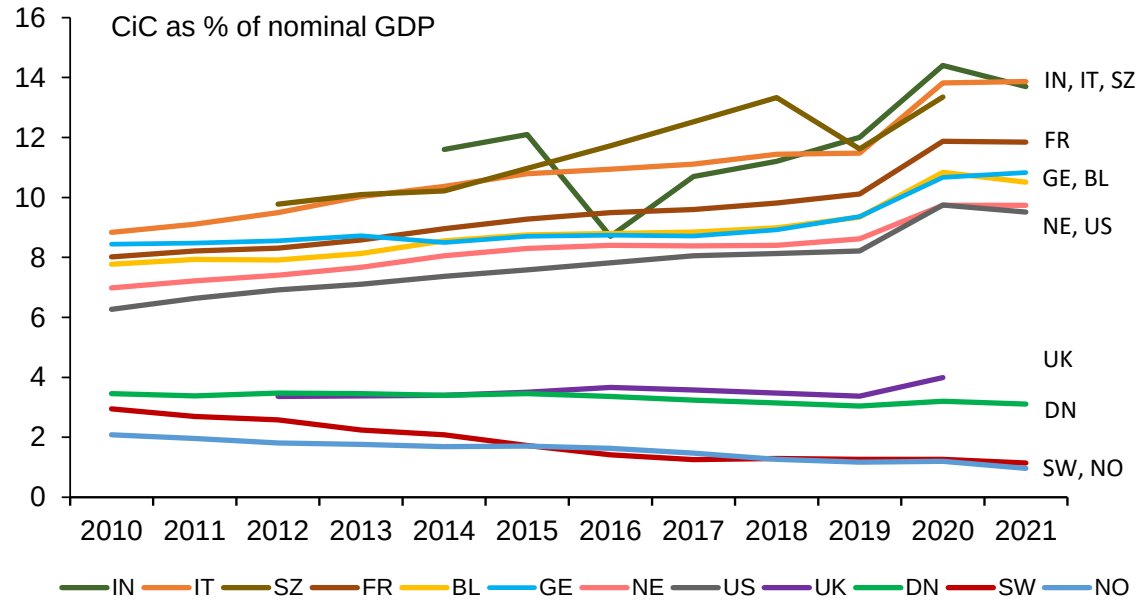
2.3.4 GDP efficiency gains

Physical cash is still the most widely used medium of exchange worldwide. The pandemic accelerated online payments and the digitalisation trend, but at the same time, there were few signs of a total abandonment of physical cash use. Demand for physical cash remains high in many countries.

Massi et al. (2019) estimate that the global physical cash in circulation (CiC) to nominal GDP ratio stood at 9.6% in 2018, even higher than 8.1% in 2011. CiC to nominal GDP in the US stood at 9.5% in 2021, even higher than 6.6% in 2011 and 5.8% in 2001 (Statista, 2023b). In Germany, the ratio also rose in the past decade to 10.8% in 2021 compared to 8.5% in 2011 (Statista, 2023a), Figure 5.

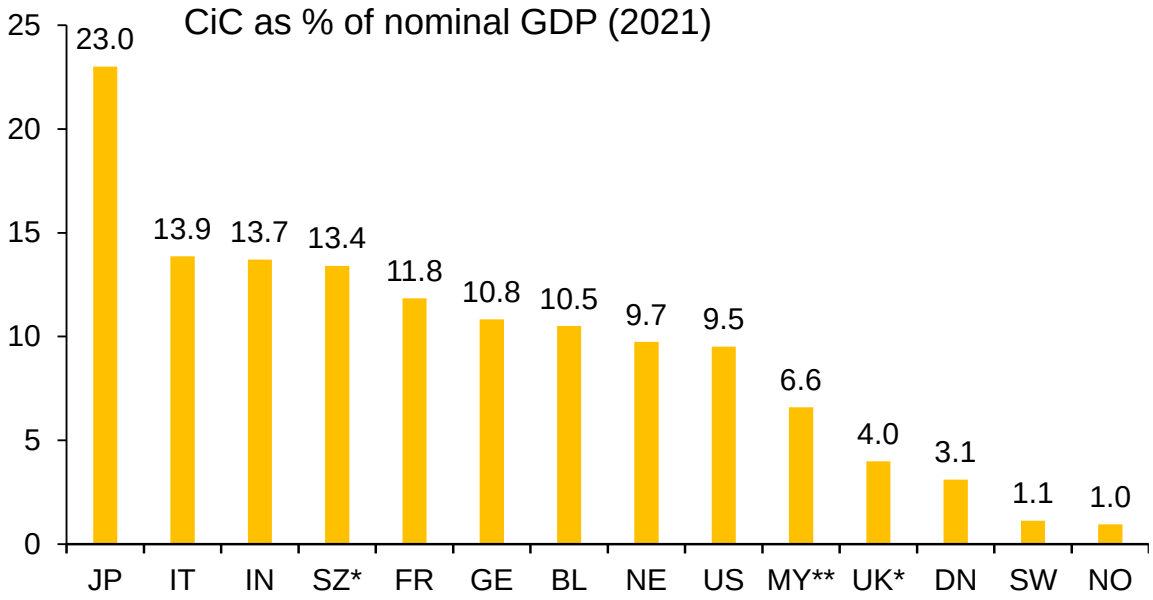
Figure 6 gives a snapshot of CiC to nominal GDP in 2021. Japan has the highest ratio, with CiC to nominal GDP above 20% since 2017 and rising to 23% in 2021. This is followed by Italy and India, which stood at 13.9% and 13.7%, respectively. Sweden and Norway are the lowest at 1.1% and 1.0%, respectively.

Figure 5
Physical currency in circulation (CiC) as % of nominal GDP, 2010-2021



Note: From Statista.com IN (India), IT (Italy), SZ (Switzerland), FR (France), BL (Belgium), GE (Germany), NE (Netherlands), US (United States), UK (United Kingdom), DN (Denmark), SW (Sweden), NO (Norway).

Figure 6
Physical currency in circulation (CiC) as % of nominal GDP, in 2021



Note: From Statista.com JP (Japan), IN (India), IT (Italy), SZ* (Switzerland, for 2020), FR (France), BL (Belgium), GE (Germany), NE (Netherlands), US (United States), MY** (Malaysia, for 2019), UK* (United Kingdom, for 2020), DN (Denmark), SW (Sweden), NO (Norway)

Factors that could explain the affinity to physical cash use include emotional attachment, ease of use, accessibility, reliability, the finality of payments, lack of tech savviness among the population, and the inclusiveness of cash. Trust in physical cash is an added factor as it does not entail the involvement of a third party; settlement between two consenting parties is final. The lingering distrust of digital payments is another possibility. These include apprehension towards tech adoption, perceptions that digital alternatives could open up risks from inadequate infrastructure, complexity, cyber thefts and hacks, and system failure – e.g., loss of power or cyberattacks.

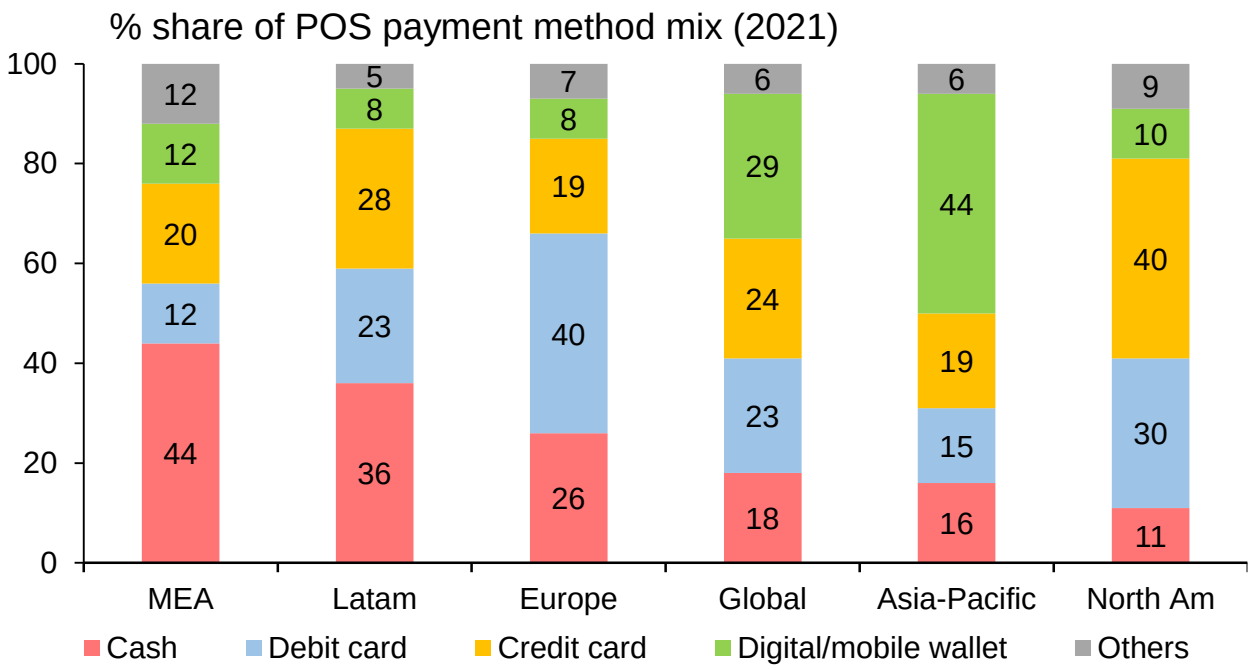
The annual Global Payments Report from FIS (2022) provides detailed breakdowns of point-of-sale (POS) transactions by the various payment methods. They include physical cash, debit cards, credit/charge cards, digital/mobile wallets, and other methods which include prepaid cards, retailer/bank financing, and Buy Now Pay Later (BNPL) arrangements. The data are available for the world and major regions, along with projections for 2025 and individual countries. They are summarised in Figures 7 and 8.

Globally, physical cash usage accounted for 18% of POS transactions in 2021 and is projected to drop to 10% by 2025. By region, physical cash usage in 2021 in the Middle East and Africa (MEA), Latin America, Europe, Asia-Pacific, and North America stood at 44%, 36%, 26%, 16%, and 11% respectively. Cash usage is projected to drop in all regions by 2025, e.g., to 31% in MEA, 24% in Latin America, 17% in Europe, 8% in Asia-Pacific, and 6% in North America.

The relatively high physical cash usage in MEA, Latin America, and to a lesser extent, Europe points to the potential net savings and welfare gains if physical cash usage is replaced with digital alternatives. In Europe, the relatively high deployment of debit and credit cards and digital/mobile wallets suggests that the essential digital infrastructure is

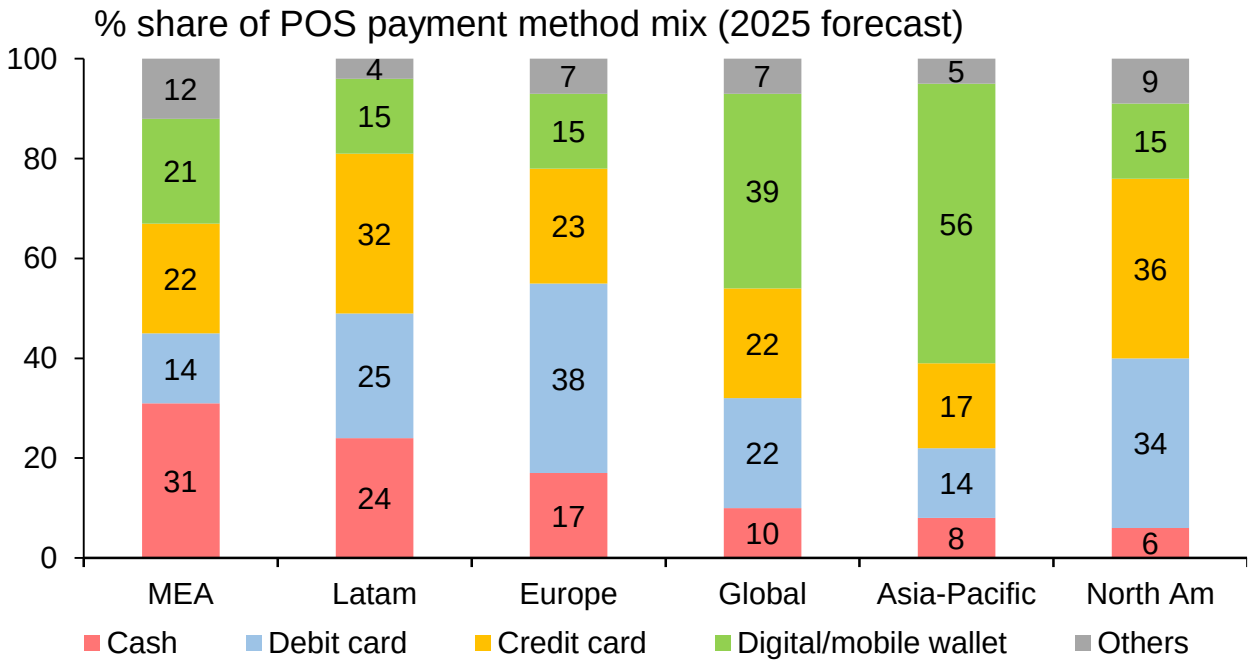
already in place. This is an advantage as it points to minimal additional investment in the necessary infrastructure for a CBDC rollout.

Figure 7
2021 - % share POS transactions with physical cash by region



Note: From The Global Payments Report, March 2022 (FIS Worldpay, 2022)

Figure 8
2025 projection - % share POS transactions with physical cash by region



Note: From The Global Payments Report, March 2022 (FIS Worldpay, 2022)

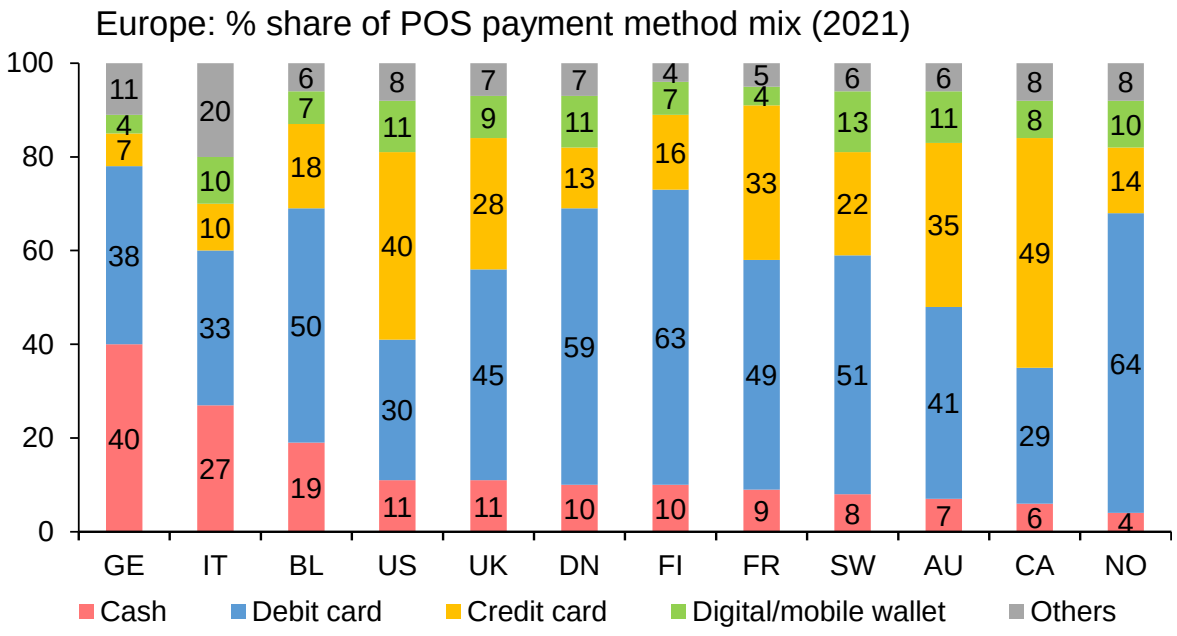
Figure 9 gives the breakdown of POS transaction methods for selected European countries and Figure 10 provides the breakdown for selected countries in Asia.

For example, physical cash usage is still relatively high in Germany at 40% in 2021, while cash usage is relatively low for the Scandinavian countries. In Asia, Japan stands out as a developed economy with a large share of physical cash as a mode of payment (50% in 2021). Thailand, Indonesia, and the Philippines were also relatively high at an average of 54% in 2021.

There are two implications:

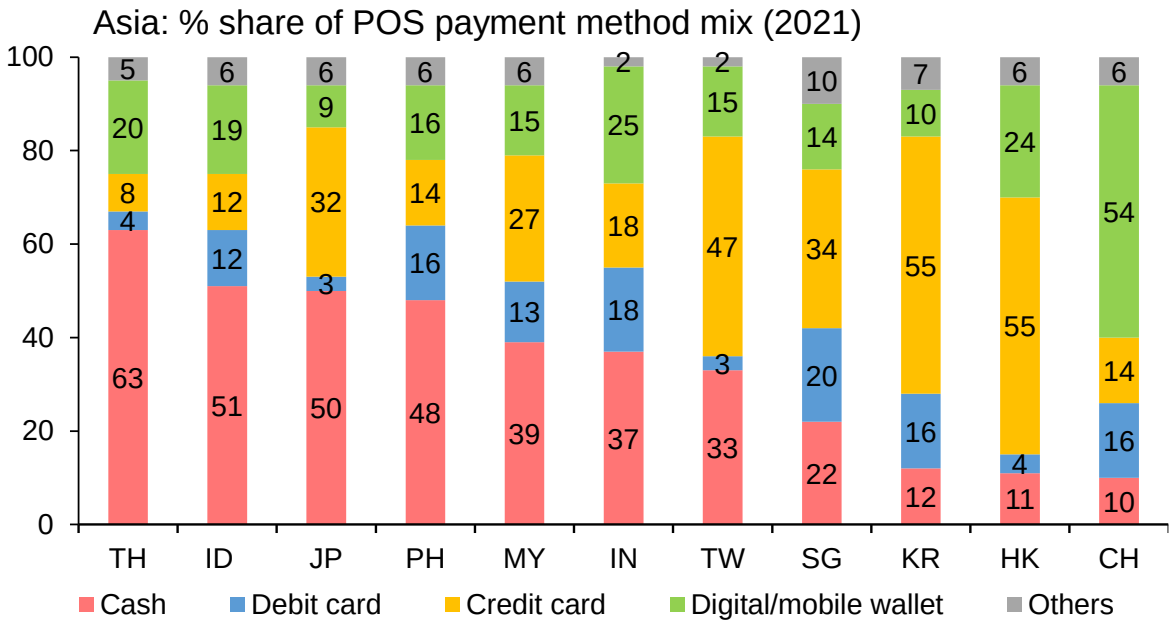
1) The high physical cash usage countries stand to gain the most in a shift towards digital payments and CBDC adoption, and
2) Given the low percentage of debit/credit/e-wallet use as a mode of payment in countries like Thailand, Indonesia, and the Philippines, higher investment in digital infrastructure may be required for a CBDC rollout.

Figure 9
Europe - 2021 % share POS transactions with physical cash



Note: From The Global Payments Report, March 2022 (FIS Worldpay, 2022). GE (Germany), IT (Italy), BL (Belgium), US (United States), UK (United Kingdom, DN (Denmark), FI (Finland), FR (France), SW (Sweden), AU (Australia), CA (Canada), NO (Norway).

Figure 10
Asia - 2021 % share POS transactions with physical cash



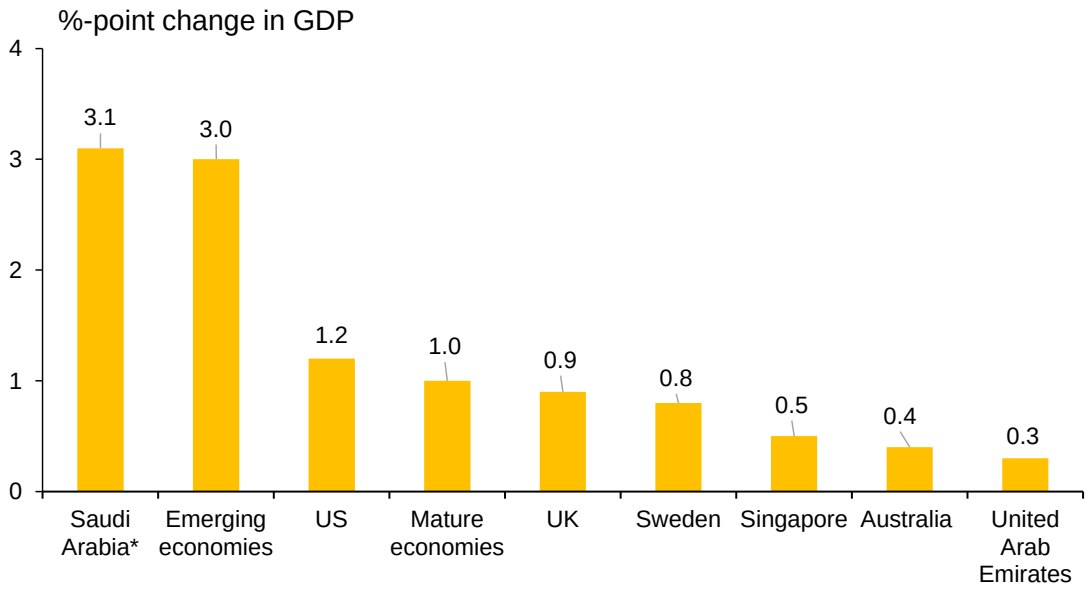
Note: From The Global Payments Report, March 2022 (FIS Worldpay, 2022). TH (Thailand), ID (Indonesia), JP (Japan), PH (Philippines), MY (Malaysia), IN (India), TW (Taiwan), SG (Singapore), KR (South Korea), HK (Hong Kong), CH (China).

Physical cash use entails costs and inefficiencies in an economy. This is due to costs related to printing, replacement, and maintenance. It requires proper handling, safe transportation, security, and machines or people to count the money. Continued investment in security-enhancing features is also necessary to guard against counterfeiting, which translates to costs.

Reduced reliance on cash as a mode of payment could lead to efficiency gains via reduced leakage and make it easier to send and receive money. This could then lead to increased money velocity and economic activity. Furthermore, digital transactions aid in greater transparency on the financial positions of both consumers and firms. This could assist in obtaining financing for consumption or investment. For policymakers, greater digital transaction data could also help to set more timely and appropriate policies, thus enhancing the efficacy of both fiscal and monetary policies.

The Boston Consulting Group (BCG) estimates the potential gain to GDP growth for certain economies if they move to a physical cashless society, Figure 11. For example, the US could post an extra 1.2%-point to annual GDP, and the UK could gain by 0.8%-point (Massi et al., 2019). For mature economies, BCG estimates a move to a cashless system could add 1%-point to GDP and even more for emerging economies by more than 3%-points.

Figure 11
Potential GDP benefits of a move to cashless for selected countries



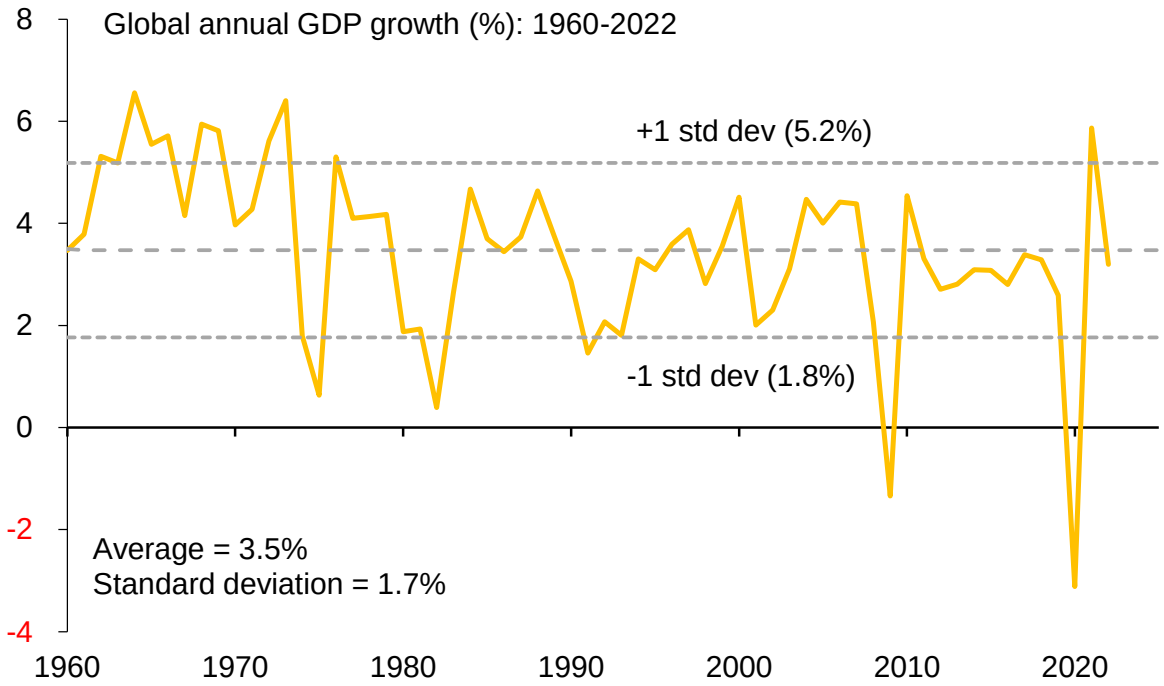
Note: From (Massi et al., 2019), Boston Consulting Group, World Bank, GlobalData, Cashless Cities: Realizing the Benefits of Digital payments, Visa and Roubini ThoughtLab, 2017, BCG estimates, (Richey, 2017). *Based on non-oil GDP.

A Mastercard White Paper estimates that the cost of excessive physical cash usage in transactions amounts to 3.2% to 4.5% of global GDP (Aad et al., 2020). In other words, this is the cost or leakage from the payments system measured as a percentage of GDP.

In the past 60 years between 1960-2021, data from the World Bank showed global real GDP growth ranged between -3.1% to 6.6% and averaged 3.5% (World Bank, 2023), Figure 12. As such, a 1%-point reduction in the cost of leakage due to digitalisation will be significant,

accounting for almost a 30% boost in global GDP growth. The bottom line is that cash handling and usage in an economy entails costs. CBDC, as an alternative medium of exchange, can lower costs and deliver efficiency gains, translating to higher GDP growth.

Figure 12
Annual world real GDP growth (% change)



Note: From World Bank (2023)

Chapter 3: The pros

This chapter outlines the pros of CBDC in the literature and assesses its merits and weaknesses. Academics and reformists put forward at least seven major arguments favouring CBDC. The rationale centres on preserving the integrity and relevance of central bank money in the payments space. The aim is also to foster efficiency and cost savings in transactions, particularly cross-border payments.

3.1 Monetary sovereignty and financial stability

As crypto assets gained popularity and their possible adoption as a means of payment caught the attention of regulators and policymakers. If privately-issued crypto assets take root in the payments system, they will encroach on the central bank's sovereignty over the monetary system (Carstens, 2021). Meta's proposed Diem project starkly highlighted this. If there is an alternative to "legal tender" in an economy, central banks will no longer be the main issuer of the currency in circulation in the economy. It will lose close surveillance and oversight of payment flows. It cannot maintain accurate records and will lose control over the money supply. This will compromise the central bank's ability to conduct monetary policy. It will lose an important tool to influence aggregate demand, control inflation and inflation expectations, and safeguard financial and macroeconomic stability. In other words, the efficacy of both monetary and fiscal policy will decline.

The bottom line is that if a country adopts a foreign digital currency, a privately-issued crypto asset, or a global stablecoin as a major medium of exchange in the domestic payments space, it will impair the central bank's ability to carry out important functions.

This may not be an immediate threat, but central banks have a fiduciary duty to look ahead and adapt to safeguard financial stability. It will require them to act pre-emptively via appropriate regulation and innovation. IMF (2023b) advocated nine action points in response to the increasing popularity of crypto assets. It stated explicitly that crypto assets should not

be granted “official currency or legal tender status” (IMF, 2023b). It also highlighterd that central banks should intentionally “safeguard monetary sovereignty and stability by strengthening monetary policy frameworks” (IMF, 2023b).

The continued provision of central bank money, whether in physical or digital form, will help to prevent adverse network effects from private payment providers (Bindseil, 2022). It will avert market dominance from both domestic and foreign actors. For foreign actors, there is even less leeway to police and regulate them as they operate outside a country’s jurisdiction and regulatory oversight. This is not ideal from a national security viewpoint.

Another consequence, if crypto assets become a dominant medium of exchange, it undermines the central bank’s monopolistic privilege to print legal tender. This is known as its “seigniorage privilege”. Seigniorage is the revenue raised for the government from central bank money printing, times the prevailing interest rate minus the cost of production. The higher the value of the money printed and interest rates, the greater the seigniorage income.

Governments can spend this revenue on public goods and infrastructure for economic development and social welfare, e.g., public works, healthcare, and education. In contrast, if this privilege is afforded to a small group of private enterprises, the net gains to society will most likely drop. This is because the objectives of private firms are likely to differ from governments. If usage of the government’s legal tender wanes, it will severely impact seigniorage income for the government. Central banks can still print money, but the importance and value will decline if there is no demand for it.

Another important function of the central bank is to act as a “lender of last resort” (LLR). This is a crucial automatic stabiliser in the economy. It is part of the central bank’s mandate to ensure financial stability. It is often under-appreciated in regular times but imperative in times of financial stress, such as the Global Financial Crisis (GFC) of 2008 or bank failures, e.g., the collapse of Silicon Valley Bank and Signature Bank in March 2023. It helps to prevent

systemic bank runs and stabilises the financial system. Central banks will forego the ability to play this role if monetary sovereignty is compromised.

Hence, the argument for central bank innovation on CBDC to preserve monetary sovereignty and to ensure financial stability is strong and compelling.

3.2 Safeguard and promote efficiency in the payments system

Former Federal Reserve Chairman Alan Greenspan wrote in *The Age of Turbulence*, "*We had always thought that if you wanted to cripple the U.S. economy, you would take out the payment systems. Banks would be forced to fall back on inefficient physical transfer of money. Businesses would resort to barter and IOUs; the level of economic activity across the country would drop like a rock"* (Greenspan, 2008). This underscores the importance and centricity of the payments system in our modern economies. Central banks, policymakers, and regulators need to do whatever they can to safeguard and protect the payments system from being hijacked by a few dominant actors or by innovation in crypto assets.

The nature of the payments system is that it gravitates toward a natural monopoly. This is due to the extremely high start-up costs, minimal marginal costs after that to run the system, and the lack of interoperability between different providers. The result is that powerful network effects could take root, become entrenched, and be hard to dislodge. This is because of user familiarity, incentives from platform providers to retain users on their networks, and the inconvenience and resistance to change from users. If a few private companies dominate the payments system, they could stifle innovation, exercise monopolistic pricing, result in market power abuse, and expose the system to moral hazard issues. In other words, they become systemically important and “too big to fail”. As such, any corporate default could have seismic repercussions.

Another consequence is that silos could develop. The platform providers have few incentives to make their systems interoperable with one another. Instead, they would strive to exclusively keep as many users as possible in their networks to maximise profits. This is the equivalent of keeping users in “walled gardens” (BIS Annual Economic Report 2021, 2021). Society will be the net loser in this scenario if payment silos develop.

The solution is to encourage many participants, which promotes competition and innovation while minimising concentration risks. By introducing CBDC, central banks can help provide a level playing field and lower entry costs for aspiring, innovative, and promising companies in the digital payments arena. It will promote an “open square” concept (BIS Annual Economic Report 2021, 2021). The need to prevent network effects is an important motivation for central banks to pursue CBDC. It provides a viable and safe alternative vehicle for digital transactions.

Social stability hinges on the fact that the payments system must function 24/7/365 or 24/7/366. The state is the only entity that can 100% guarantee the safety of commercial bank money and legal tender in an economy. Episodes of spikes in risk aversion, digital bank runs, and bank failures provide a strong case for the payments system to be anchored by sovereign central bank money. This will also help to shore up financial stability. In the digital age, CBDC can play that role. The payments system is central to all economic activities. It is the core of public trust in the financial system. The government should protect this diligently and not permit any potential erosion of public trust in the system.

CBDC introduction can also help lower digital transaction costs by encouraging competition in the payments space. The fees merchants pay to credit card companies are shared with the issuing banks. Ultimately, these fees are passed onto the end user via higher prices. Reduced payments system leakage and improved efficiency will eventually benefit the end user.

3.3 Interoperability

Interoperability among different payment providers is a significant challenge for any regulator that strives for maximum efficiency. BIS defines interoperability as *"the technical or legal compatibility that enables a system or mechanism to be used in conjunction with other systems or mechanisms. Interoperability allows participants in different systems to conduct clear and settle payments or financial transactions across systems without participating in multiple systems."*(BIS, 2016).

Private operators will not want their systems to be interoperable with others. It will eat into their monopolistic profit and pricing power if users are given choices or alternatives, diminishing the network effect. For regulators, the objective is the opposite. They desire to create a system that facilitates and encourages interoperability among many payment providers. This promotes competition, leading to best practices and competitive pricing. Unlike private operators, central banks are not motivated by profits. They aim to provide a conducive and safe digital payments vehicle that all can utilise. The adoption of CBDC is one such vehicle in the digital payments space.

3.3.1 Reduce cross-border fees

Cross-border payments remain notoriously slow, costly, and inefficient. This is despite improvements in the domestic payments space which have led to lower transaction fees. Innovation in international payments has lagged behind the rapid increase in trade, commerce, and financial flows since the end of World War II. This is due to the intricate and complicated network of international correspondence banking.

For example, a corporate in country A that wants to send funds to another corporate in country B has to ensure his sending bank has a corresponding relationship with the recipient's bank. Commercial banks have foreign currency accounts with one another. The

exchange of funds goes through multiple correspondent banks. This takes time for confirmations and incurs costs such as fees, FX conversions, staffing costs to conduct checks etc.

On the other hand, a common multi-currency platform for settlements could do away with the intermediaries, i.e., the correspondent banks, allowing companies to deal directly with each other. The G20 Leaders' Declaration in Bali in November 2022 highlighted the urgency to improve efficiency in cross-border payments (G20 Leaders, 2022). It stated that countries should explore utilising CBDC to facilitate and improve cross-border payments. Global cross-border payment flows are expected to hit USD156 trillion in 2022 (Seeh, 2021), implying scope for substantial cost savings. The bottom line is that interoperable CBDCs for different countries can help lower cross-border payment costs.

There does not exist a single international platform for cross-border payments and settlements. The Society for Worldwide Interbank Financial Telecommunications (SWIFT) is integral to the global financial infrastructure. It provides a reliable and secure messaging service worldwide between parties, but it is only for communication. It does not hold assets or get involved in transferring funds across borders.

3.3.2 Reduce remittance fees

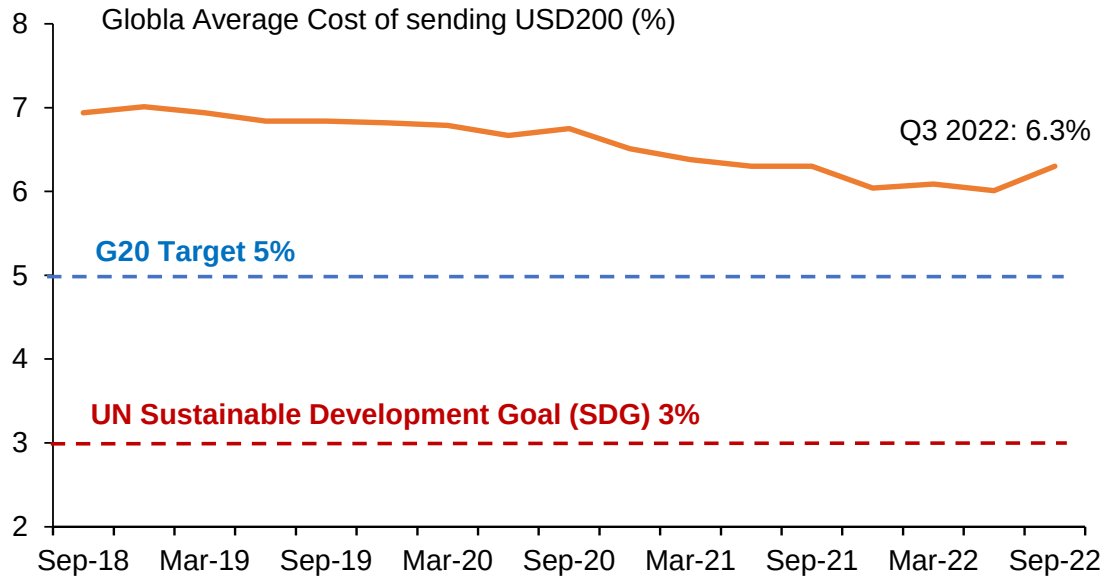
Another example of high cross-border transaction fees is in remittances. This is where interoperable CBDCs can make a big difference. Remittances are important sources of foreign income for low and middle-income countries. A failure to act hurts low-income countries more than high-income countries – the poor more than the rich.

In 2022, global remittances rose to an estimated USD794 billion, of which just under 80% or USD626 billion went to low and middle-income countries (World Bank & KNOMAD, 2022). In 2015, total remittances were USD602 billion, and 74% or USD447 billion went to low and middle-income countries.

In Q3 2022, the Global Average Cost for sending a small amount of USD200 across borders stood at 6.3% vs. 6% in Q2 2022 (International Monetary Institute, 2022; World Bank, 2022). Reducing the cost of cross-border flows and remittances will improve efficiency, lower business costs, and reduce the implicit tax for low-income countries. In the late-2000s, the G8 and, subsequently, the G20 adopted a goal to lower the cost of remittances to 5%. Building on this, the UN Sustainable Development Goals (SDGs) set an even more ambitious target of 3% by 2030. However, as of Q3 2022, it stood at 6.3% - more than double the target (World Bank, 2022), Figure 13. It underscores the need to speed up innovation in this area.

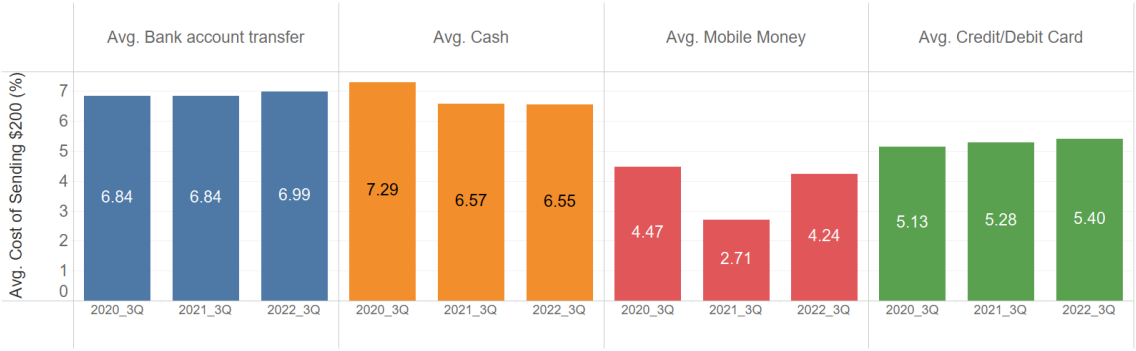
The World Bank (2022) reported that the costs of sending and receiving funds were the highest when physical cash was used. As of Q3 2022, the cost of sending USD200 abroad, initiated with physical cash, stood at 6.55%, while the cost of receiving the proceeds in physical cash stood at 5.97%, Figures 14 and 15. Moving towards a digital form of sending and disbursing funds will help lower the costs of remittances for both legs.

Figure 13
Global Average Cost of sending USD200 (%)



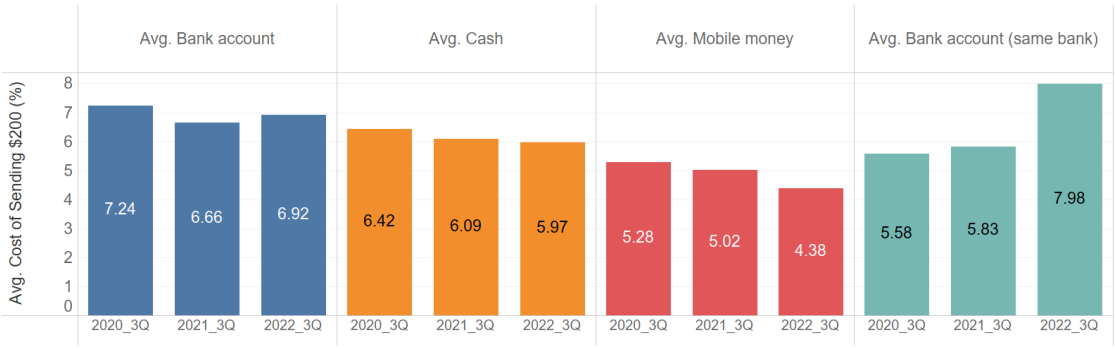
Note: From World Bank, Remittance Prices Worldwide (World Bank, 2022)

Figure 14
Average cost by the instrument used to fund the remittance



Note: From World Bank, Remittance Prices Worldwide (World Bank, 2022)

Figure 15
Average cost by means of disbursing the remittance funds



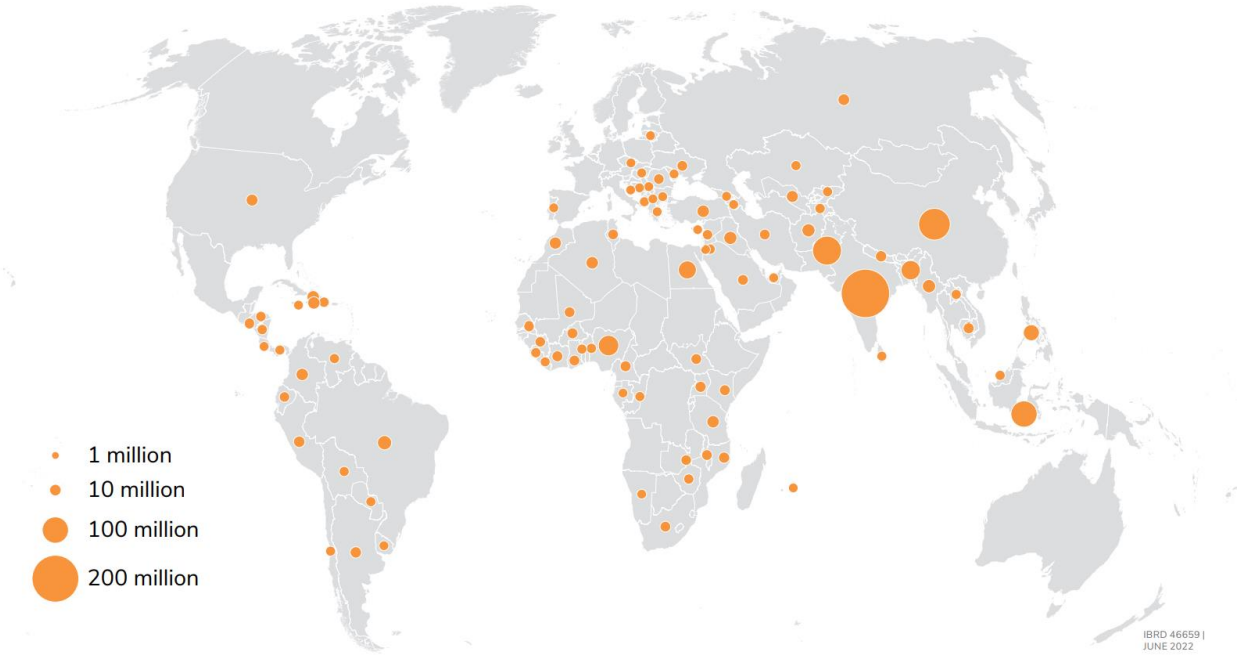
Note: From World Bank, Remittance Prices Worldwide (World Bank, 2022)

3.4 Financial inclusion

CBDC can aid the unbanked (those without bank accounts) in gaining access to financial services (H.M. Queen Maxima of the Netherlands & Carstens, 2022). The World Bank's Global Findex Database 2021 estimates that 1.4bn people were unbanked globally in 2021, down from 1.7bn in 2017 and 2.5bn in 2011 (Demirgüç-Kunt et al., 2022).

In 2021, 56% of the unbanked globally, or 780 million, lived in just eight countries. The two largest are India (230 million) and China (130 million). This is followed by Pakistan (114 million), Indonesia (98 million), Nigeria (64 million), Bangladesh (57 million), Egypt (49 million), and the Philippines (37 million), Figure 16.

Figure 16
1.4bn are unbanked globally in 2021 (adults with no bank account)



Note: World Bank Global Findex Database 2021 (Demirgüç-Kunt et al., 2022)

Under servicing the unbanked population is pertinent in developing economies where the financial sectors are not well developed. Even in developed economies, rural or remote areas are the most vulnerable. The traditional financial institutions may not adequately service them because of the enormous investments of time, infrastructure, and staffing needed to service these areas.

Disruptive technological advancements, such as CBDC introduction, can help countries to leapfrog in their financial inclusion goals. For example, the World Bank stated that the COVID-19 pandemic aided financial inclusion. The biggest gain was seen in digital payments due to the COVID lockdowns and aversion to handling physical notes (Demirgüç-Kunt et al., 2022).

That being said, we should remember that physical cash is still the most inclusive mode of payment. This is because of its convenience and ease of use. It is also cyber-resilient and completely anonymous (Bindseil, 2022). All major central banks exploring CBDC have

stated that they will continue to provide physical cash. They intend CBDC to complement and not replace physical cash. CBDC and physical cash will co-exist. It will not be a case of one or the other anytime soon.

3.5 Promote innovation

The digitalisation of central bank money paves the way for financial innovation. This includes the programmability of payments using CBDC by deploying smart contracts and reducing transaction friction. This can lead to efficiency gains and cost savings, which can be passed on to end users. One example is the possibility of conditional or programmable payments highlighted by the ECB (ECB, 2023). Citizens can voluntarily set pre-defined conditions for automatic payments and deductions. For example, when certain conditions are met, funds can be deducted from CBDC deposits to pay for rent, utility bills, etc.

ECB distinguishes between programmable money and programmable payments (ECB, 2022). Programmable money implies conditions can be set on the digital Euro. For example, it could entail expiry dates on stimulus funds, spending restrictions to certain localities or regions, and expenditure only on certain items, e.g., food or groceries, or prohibitions on other items, e.g., liquor and cigarettes. On the other hand, programmable payments refer to the ability to initiate payments automatically when predefined conditions are met (ECB, 2022). In essence, CBDC is a digital currency in e-wallets used for settlements. Programmable payments refer to what one can do with the CBDC in e-wallets.

ECB has outrightly ruled out programmable money but favours programmable payments (ECB, 2023). Programmable payments can improve users' experience and enhance payment efficiency. This is carried out at the commercial bank and payment service providers (PSP) level rather than at the central bank level. It requires user consent rather than something that is enforced upon them.

The Bank of England (BOE) has also stated that it will not implement central bank-initiated programmable functions. Instead, it will provide the necessary infrastructure to enable the private sector to carry out user programmability features (Bank of England, 2023b, 2023a). Once again, this will require user consent.

One pushback from sceptics is that programmable central bank money could lead to greater control by the central bank. This could reduce freedom on how and where citizens can spend their money. Another fear is that central bank money could be programmed with an expiry date. This could pertain to fiscal stimulus funds, where the government may want to encourage spending within a certain time to provide a timely boost aggregate demand. An expiration date on central money could be viewed as an oxymoron and cause the general public to lose confidence in central bank money.

However, these fears are unfounded and lead to incorrect understanding and assumptions. No major central bank intends to pursue programmable central bank money. Instead, it favours the programmability of payments. This point was emphasised by Fabio Panetta, Member of the Executive Board of the ECB, in a speech in March 2023 when he said citizens will have complete freedom to choose when, where, and how the digital Euro can be spent, just like the physical Euro now (ECB, 2023).

3.6 Improve the efficacy of fiscal policies

CBDC can improve the efficacy and potency of monetary and fiscal policies by acting as an efficient distribution channel for stimulus funds. Such funds can be deposited directly into CBDC deposits or e-wallets. The faster the recipients receive and spend the funds, the earlier the fiscal or Keynesian multiplier effect kicks in. It will also be cheaper without the need for cheques to be mailed out. Furthermore, it will reduce fraud risks and leakage as CBDC e-wallets will be linked to individual bank accounts and tracked easily.

The leakages and inefficiencies in the current setup can be significant. This was highlighted by the USD2.2 trillion Coronavirus Aid, Relief, and Economic Security (CARES) Act stimulus in 2020 in the US. An audit report from the Inland Revenue Services' (IRS) Economic Impact Payments (EIP) revealed that 157 million payments were made as of 21 May 2020. More than 4.5 million cheque payments were sent erroneously to deceased people, non-residents, or duplicates. This amounted to USD5.5 billion, Table 2. About 2.2 million payments (49% of erroneous payments) amounting to USD3.5 billion (64% of the total) were made to deceased people. (Treasury Inspector General for Tax Administration, 2021, p. 5). As of 1 October 2020, banks rejected 668,277 payments totalling USD872 million or returned them to IRS as undeliverable (Treasury Inspector General for Tax Administration, 2021, p. 10). A CBDC account will help to reduce these shortcomings.

Table 2
Erroneous EIPs (Economic Impact Payments) issued as of 16 July 2020

	Payments	Dollars
Deceased	2,174,616	$3.5 billion
Dependents	1,844,846	$1.4 billion
Nonresidents	324,864	$444 million
Duplicate U.S. Territory Payments	61,119	$92 million
Duplicate Payments for Filing Status Changes	46,763	$69 million
Total	**4,452,208**	**$5.5 billion**

Note: A breakdown of the erroneous Economic Impact Payments. Data from the Treasury Inspector General for Tax Administration (TIGTA) analysis of payments issued as of July 16, 2020.

Two other arguments are put forward on how CBDC can improve policy effectiveness. However, the jury is still out on their efficacy or relevance in practice. They are not strong arguments. The first is that CBDC can facilitate the implementation of "helicopter drops" of money (Alfonso et al., 2022; Kiff et al., 2020). Helicopter money is the injection of money directly to citizens to spend to boost economic activity. This could fight deflationary forces in economic downturns to shore up aggregate demand. However, the merits and effectiveness

of helicopter money are still debated. This was not deployed even during the 2008 Global Financial Crisis (GFC) and the COVID-19 pandemic. As such, this is not a convincing argument.

The second is that if CBDC is introduced, it can remove the zero percent lower bound (ZLB) restriction for policy rates, i.e., central banks can cut rates deep into negative territory (Goodfriend, 2016; Haldane, 2015). The rationale is that charging negative interest rates on policy rates and CBDC deposits will spur consumption rather than saving.

However, one essential requirement for this to be effective is the complete removal of physical cash. Otherwise, citizens can withdraw funds from CBDC and commercial bank deposits and hold physical cash. Further, if CBDC is promoted as a new policy lever that could facilitate a negative interest rate policy (NIRP), it is unlikely to be received favourably by the general public. This is given the public's averseness to negative interest rates as they are perceived to punish savers.

We should remember that CBDC adoption is not intended as an additional policy lever for policymakers to influence aggregate demand in the economy. This will only complicate CBDC adoption. The primary motivation for CBDC adoption is to be used as a medium of exchange, not as an additional policy lever.

3.7 Reduced costs of printing

The cost of creating CBDC will be much lower than printing physical cash, translating to increased seigniorage for the government. In 2022, the US Federal Reserve's budget for printing new notes and minting new coins was USD1.1 billion (Federal Reserve, 2021, 2022). This constitutes around 0.0045% of nominal GDP or 0.45 basis points. This includes the cost of maintaining and replacing physical notes and coins. In the US, the average lifespan of notes is between 5 years (for USD5 notes) to 23 years (for USD100 notes) as of

December 2018 (Federal Reserve, 2020), Table 3. The environmental costs of creating CBDC are also expected to be lower than physical note printing (McCook, 2014), Table 4.

Table 3
US cost of printing notes and estimated lifespan of notes

Denomination	Printing Costs (cents per note)	Estimated Lifespan* (years)
$1 & $2	7.5	6.6^
$5	12.7	4.7
$10	12.4	5.3
$20	13.8	7.8
$50	13.3	12.2
$100	17.0	22.9

Note: The cost of printing different denominations of notes and the average lifespan in the US. From the US Federal Reserve (Federal Reserve, 2020, 2022). *Estimated as of December 2018. ^Only for $1 because the $2 does not circulate widely.

Table 4
Environmental costs of paper currency in circulation

Category	Low estimate of global production cost (2014)
Energy used	18.4 million Gigajoule (GJ)
Annual water used	10 billion litres
CO2 emission (calculated)	3.2 million tonnes

Note: Estimates of the cost of printing paper currency worldwide regarding energy use, water use, and CO2 emission. From (McCook, 2014).

Chapter 4: The cons

The arguments against CBDC can be classified into two major categories: fearful and dismissive views (Bindseil, 2022). The fearful views argue CBDC introduction carries enormous risks to financial stability. These concerns can be addressed and mitigated by appropriate designs and regulations. The dismissive views portray CBDC as neither needed nor necessary. They argue that lower-hanging fruits can be attained via regulation minus the risks. For example, if the objective is to lower costs in the existing payment rails, regulations could be put in place to cap fees. They highlight risks to confidence in the central bank and government if things do not turn out well. US Fed Governor Christopher Waller exemplified this argument by labelling CBDC as a "solution in search of a problem" (Waller, 2021). The arguments against CBDC are outlined, and their merits and weaknesses are assessed.

4.1 Privacy and data protection

Unlike physical transactions with notes and coins, digital transactions leave digital footprints which are traceable and indelible. A distinctive feature of physical cash is that transactions are entirely anonymous: there is no history of transaction records. In society today, citizens in many countries have no qualms about providing personal information to social media platforms such as Meta or TikTok. Citizens are comfortable with commercial banks, PSPs, and other private payment providers accessing their transaction records, e.g., Visa, Mastercard, and PayPal. The fact is that such private enterprises already have an enormous amount of information on citizens and their spending patterns. The use of navigation apps such as Google Maps and Waze also implies that location data are captured and stored.

However, regarding CBDC, privacy and data protection concerns are seemingly magnified and accentuated. Private citizens are apprehensive about the state having access to sensitive and personal information about transactions compared to the private sector. One

explanation is that the repercussions from private enterprises could be limited or innocuous. That is, it may result in another advertisement on their devices. However, with the state, the consequences could be more severe. For example, if shared with law enforcement agencies, it could unveil tax evasion and lead to prosecution. The apprehension could also reflect an inherit distrust over governments having a large amount of data on citizens, i.e., government surveillance and the “Big Brother is watching you” maxim.

Sceptics highlight risks that greater state surveillance will encroach on individual liberties and undermine data privacy, inconsistent with liberal democratic values. A survey from the Edelman Global Report showed a greater distrust in government in the US compared to China, Figure 17 (Edelman Global Report, 2023, p. 43).

Such concerns are unfounded, however. No central bank undertaking CBDC research has indicated any intention to collect and store detailed, granular data on citizens. They do not intend to share information with other government agencies for surveillance (Bank of England, 2023b, 2023a; ECB, 2023). Instead, central banks have said the data collected will be on an aggregate level to get a better assessment and timely picture of the state of the economy. Private payment providers will have access to a swathe of data on individuals but will be limited to users on their platforms. As such, they will only know in part and not the complete picture.

Nevertheless, to assuage fears over government surveillance, the authorities would have to step up public education efforts. They must assure the public that appropriate regulations and checks and balances are in place. This will help to gain greater public acceptance of CBDC.

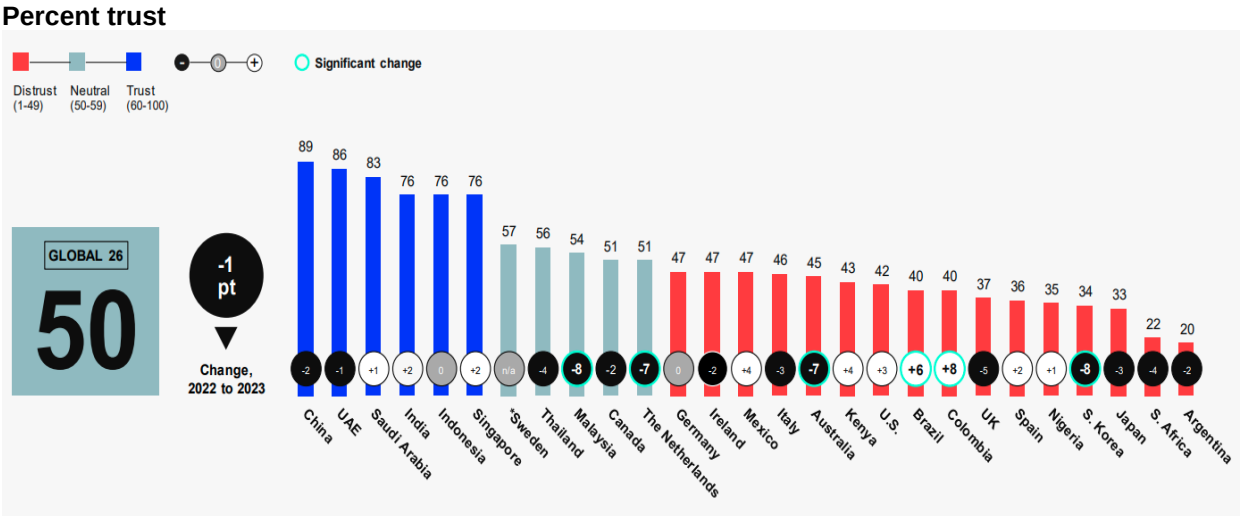
A counterargument from the proponents of CBDC is that citizens may have better privacy and data protection compared to the current situation. This is on the assumption that appropriate regulations are put in place. This is because private firms could exploit the vast

data accumulated for cross-selling. For example, in early 2018, Facebook and Cambridge Analytica were implicated in a major data privacy breach (Wong, 2019). In an increasingly digitalised world, it comes down to who has access to the data and the transaction history, whether the private sector or the government/central bank. Regulation and data protection laws will need to continue to evolve and adapt.

It boils down to the degree of anonymity and transparency that the regulators and consumers deem acceptable. This will differ for each society and jurisdiction. Each will have to reach an acceptable compromise. It will be a spectrum rather than a binary choice of complete transparency or anonymity (Gnan & Masciandaro, 2018).

Figure 17

Trust in government declines in 14, gains in 10 of 26 countries



Note: From (Edelman Global Report, 2023)

The government must assure the public and dismiss any suspicion that CBDC will be used as a surveillance vehicle or as a "digital panopticon". This will help to settle the public's doubts over CBDC. The fact is that the technology available today can protect user privacy and data. For example, MIT Media Lab (CBDC Project Overview, 2023) has noted that this can be achieved using an early cryptography technique known as non-interactive zero-knowledge proof (ZKP). In other words, cryptographic techniques can satisfy privacy and

compliance demands. More work will be needed in this field and ZKP technology is still nascent, albeit developing rapidly (Ali & Narula, 2019). The challenge will be for it to expand to a stage where it can be deployed on a scale suitable for CBDC use.

4.2 Cyber threats

PBOC's CBDC project is the most advanced in the world. It has persistently highlighted cybersecurity risk as one key factor holding back a full rollout of the e-CNY across the country (Soderberg et al., 2022, p. 30). This is a pertinent reminder to all central banks not to underestimate the enormous challenges to ensure a secure cyber system. Furthermore, cyber hacking and thefts will only grow and become more ominous over time (Quarles, 2021).

The blockchain analytics firm, Chainalysis, reported in the 2022 Crypto Crime Report that cryptocurrency theft amounted to USD3.2 billion in 2021. This was a 516% jump vs. 2020. The increase was attributed to the DeFi (decentralised finance) activity and hacking of cryptocurrency businesses (Chainalysis, 2021, 2022; Sigalos, 2022).

The BOE emphasized that the "security of the CBDC payment system must be of the highest standard" (Bank of England, 2020a). This is because the nature of CBDC payments makes it a lucrative hunting ground for hackers.

BOE singled out two key security aspects, the first being the underlying payment infrastructure. This pertains to the core ledger, the payment interface providers, the services provided, and the network that connects them. The design needs to be flexible to permit constant upgrades and development. At the same time, it needs to minimise vulnerabilities, e.g., single points of failure and key target points which could paralyse the whole system. The second is user security. This addresses the question of how users will be identified and authenticated. For instance, it must be robust enough to detect identity fraud. There will be a trade-off between complexity to enhance security and simplicity for it to be user-friendly (Bank of England, 2020a).

The Bank of Canada (BOC) has constantly emphasised the importance of security. It stated that security is at the core of the CBDC system and must be factored in from the outset of the design (Minwalla, 2020). Khan and Malaika (2021) also advocate that cybersecurity-related risks must be foundational in any system setup. It supports establishing a Security Operation Centre (SOC) to monitor and respond 24/7/365 days to cyberattacks and any other security concerns. The fact is that a retail CBDC will have broader access points to the current system and hence, increased surface area for potential attackers (Khan & Malaika, 2021).

Cyber threats are valid and top concerns and will need to be given the highest priority. For CBDC to take off, all stakeholders must ensure adequate cybersecurity safeguards are in place. This will involve the central bank, government agencies, commercial banks, PSPs, and merchants. The government and central bank alone will not be able to meet these high demands. They must collaborate with industry experts and elicit external advice to ensure the system is robust, resilient, and agile. This will inevitably involve private-public partnerships. As with any computing system, and as much as the central banks will try to tick all the boxes in terms of cyber security, the fact is that they can never be 100% foolproof. This is evident by the constant patches and system upgrades for computer systems, mobile devices etc. The important aspect will be for the system to be agile and adaptable.

4.3 Financial disintermediation

This is a significant risk and a valid one. The rationale is that it will diminish commercial banks' important intermediary role in the economy. Commercial banks facilitate efficient capital allocation from savers to borrowers and aid credit creation (Cecchetti & Schoenholtz, 2021; Quarles, 2021; Waller, 2021).

There are three channels through which disintermediation could occur. First, we could see large outflows from commercial bank deposits to CBDC accounts because of their risk-free

nature, i.e., they are backed by the full faith and credit of the state. This is particularly pertinent in times of financial stress and bank panic. In today's digital age, digital bank runs could take place swiftly and be more devastating, e.g., the recent collapse of Silicon Valley Bank was an example of an abrupt digital bank run (FDIC, 2023).

Second, significant outflows from bank deposits will mean the loss of a major source of cheap, stable, and predictable funding for commercial banks. Apart from possible bank runs and collapses, bank profitability can be severely affected, resulting in lower credit growth, more stringent credit criteria, and higher cost of funds. In turn, this leads to a higher cost of credit for borrowers (investors and consumers). Consequently, higher interest rates and lower investments in an economy could lower potential GDP growth in the long run.

Third, inflows into CBDC deposit implies increased liabilities for central banks on their balance sheet. This may not be ideal in terms of efficiency in credit allocation. Central banks will be put in an awkward position to decide how best to reallocate and redistribute these funds to the real economy. It raises the issue of greater centralisation of credit allocation. This is a decision that central banks may not wish to participate in as this is not part of their mandate. They lack the resources and expertise of commercial banks to undertake the necessary credit assessment, risk analysis, and subsequent monitoring. They may allocate funds inefficiently to the economy (Cecchetti & Schoenholtz, 2021; Quarles, 2021; Waller, 2021).

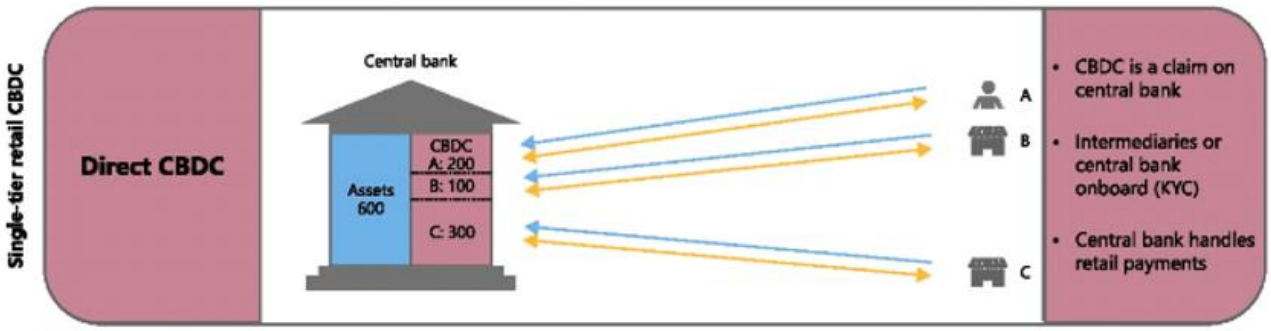
However, there are two major flaws to these arguments. It assumes there will be no caps on CBDC deposits, and more importantly, central banks will abandon the current two-tier fractional banking system and adopt a one-tier system (Auer et al., 2020).

4.3.1 One-tier system

What does a one-tier or direct CBDC architecture look like? There will only be one enormous financial intermediary in the economy, the central bank, which will interact directly with the general public (Auer et al., 2020). It will operate the payments system and will maintain and handle all payments in real-time. It will keep a ledger of all transactions and undertake all the activities currently carried out by the numerous and varied commercial banks.

This will be a monumental task for a single organisation. It will mean the centralisation of all financial activity. This will include retail and corporate account management, deposit taking, loan allocations, investment banking, and capital markets activities. For example, it implies a concentration of risk assessment, risk management, and credit allocation. At the same time, it would need to ensure adequate protection against cyber threats etc. There will no longer be a role for financial intermediaries or other PSPs. This is illustrated in Figure 18.

Figure 18
One-tier or direct CBDC system



Note: From (Auer & Böhme, 2021, p. 10)

There are numerous drawbacks to this architecture. They include:

1) Extreme disruption to the financial system as it means a complete overhaul. It means a complete dismantling of the intermediary role played by commercial banks currently;
2) It thwarts CBDC's objectives of financial inclusion, efficiency, and improved services for consumers. It is costly and cumbersome for central banks to replicate the role

currently carried out by commercial banks. Commercial banks are incentivised to maximise profits and strive to deliver the best services to the public. Furthermore, the burden of KYC (Know Your Client), AML (Anti-Money Laundering) and CFT (Counter Financing of Terrorism) checks will fall on the central bank, which can be onerous and costly;

3) A lack of competition to service the public may stifle innovation and deteriorate service quality. As such, society, in general, may be worse off; and
4) The central bank will be a monopsony, i.e., the sole employer in the financial sector. The financial behemoth will be challenging to operate and manage.

All major central banks researching CBDC have stated that the current two-tier system is the preferred architecture under a new CBDC system. Examples include the Sveriges Riksbank (2017), the Bank of England (2020a), the Bank of Canada (Shah et al., 2020), and the People's Bank of China (PBOC, 2021).

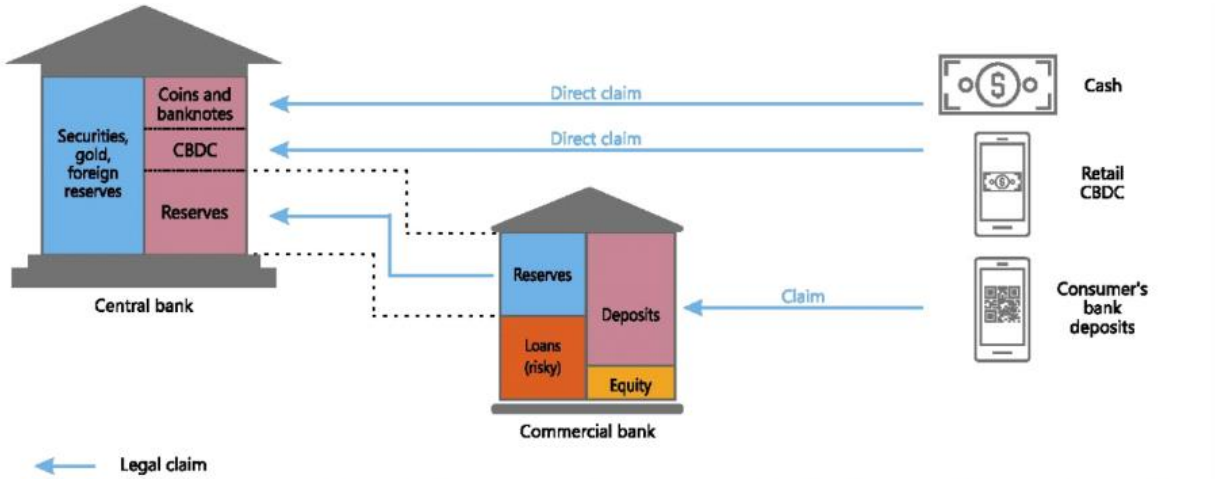
Under a one-tier system, there will only be exclusively central bank money. Throughout history, economies that rely exclusively on privately-issued commercial bank monies have underperformed relative to a system with a combination of both central bank and commercial bank money (Bindseil, 2022). They are inferior in terms of stability and resilience to shocks. A combination of central bank and commercial bank money, or a two-tier system, has shown to be the most stable, durable, and resilient (Bindseil, 2022).

There is a clear division of labour. Central bank money provides an anchor for the monetary system. It is tasked with maintaining the integrity of the money through sound economic management, i.e., stable inflation and a stable economic backdrop. At the same time, commercial banks play an important role. They facilitate credit creation to the economy via the fractional banking system.

Figure 19 illustrates the connection between consumers, commercial banks, and the central bank under a new CBDC system. CBDC will be a direct claim on the central bank. However, the central bank will not interface with the public. Instead, CBDC deposits will sit with commercial banks but not form part of their equity or capital structure. Commercial banks can no longer tap into these funds for lending.

In this sense, there will be partial disintermediation. It will have the same impact as citizens holding physical cash, i.e., they are no longer part of commercial banks' deposit base. However, fears of extreme financial disintermediation and higher cost of funds for borrowers are unfounded. These risks can be mitigated in a few ways, including 1) caps on CBDC deposits; 2) CBDC deposits to be non-interest bearing; or 3) tiered remuneration, i.e., a certain level of interest paid below a certain threshold or tier and an unattractive or zero rate for the next tier (Bindseil, 2019).

Figure 19
Retail CBDC, physical cash, electronic payment instruments



Cash is a direct claim on the central bank, while deposit accounts are claims on the commercial bank. Commercial banks back some of these claims by holding reserves at the central bank and have equity, but the value backing is never full. A CBDC that is unaffected by financial crisis must be a cash-like direct claim on the central bank.

Note: From (Auer & Böhme, 2021, p. 6)

4.3.2 Two-tier system

Figure 20 illustrates the two-tier system. This resembles the existing setup and is expected to be maintained under the new CBDC system. The advantage is that central banks will not be overburdened with interactions with the general public. This will not be the best use of their resources. Simultaneously, financial institutions retain their “intermediary” role in the economy. By providing CBDC, central banks can promote innovation and competition in the payments space for the various players to deliver the best CBDC solutions to the public.

Two-tier, hybrid model

There are two versions of a two-tier system. The first is the hybrid model where the central bank, commercial banks, and PSPs keep a detailed record of all transactions. The ledger kept by the central bank can act as a backup of the technical infrastructure, enhancing resilience. In other words, it allows the central bank to restart or reboot the payments system if needed, e.g., due to any PSP failures.

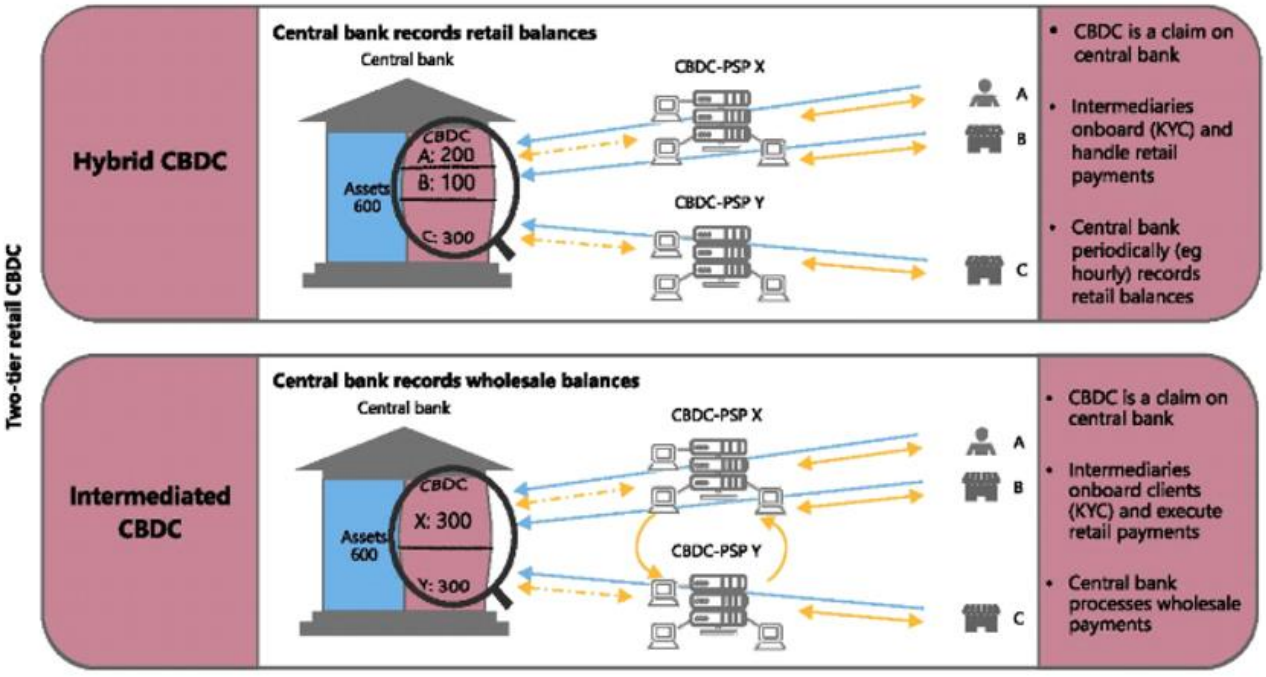
There are two concerns or disadvantages of this model. First, it will require greater computing power and energy use. It will also compromise efficiency and the real-time gross settlement (RTGS) requirement for retail CBDC. This is because the central bank’s records must be updated regularly. It may not require instantaneous updates but at least regularly, e.g., hourly. Second, it will raise privacy and data protection concerns because the central bank will have granular transaction data on citizens. Greater details on a centralised database will raise concerns over potential security breaches and data hacking. These are valid concerns. The first concern can be addressed by adopting the intermediated model and the second by appropriate design choices.

Two-tier, intermediated model

A second version of the two-tier system is the intermediated model. This requires less computing power and will help to facilitate RTGS efficiently. This is because the central bank only keeps a wholesale ledger rather than a detailed record of all retail transactions. The central bank will not require real-time updates. It could be done on a daily or weekly basis. This may entail closer supervision and oversight of commercial banks and the PSPs. The central bank would need to ensure that the wholesale holdings reported by the commercial banks and PSPs match the total of all retail transactions.

The assessment is that a two-tier, intermediated model is the most likely to be adopted by central banks. This is because of the RTGS requirement and the desire for efficiency. It will be more efficient regarding speed, energy use, and manpower needs. It will be the least disruptive compared to the current system. Concerns over privacy and data protection can be addressed by regulation, design choices, e.g., tiered anonymity, and technology, e.g., cryptographic techniques.

Figure 20
Two-tier system: hybrid and intermediated CBDC



Note: From (Auer & Böhme, 2021, p. 10)

4.4 Private solutions are superior

Sceptics argue that CBDC is superfluous and that private solutions can be more efficient (Cecchetti & Schoenholtz, 2021). They note that the public and private sectors are already working to provide a cheaper, faster, and more reliable system that aims for greater retail participation in the payments space. Examples include the TARGET (Trans-European Automated Real-time Gross Settlement Express Transfer) instant payment settlement (TIPS) system in the Euro area. It boasts a processing time of 10 seconds at the cost of EUR0.002 per transaction. In the UK, there is Faster Payments. Canada is testing Real-Time Rail (RTR). In the US, the Federal Reserve said the FedNow Service, which will allow businesses and individuals to send and receive payments instantly, will be launched in July 2023 (Cecchetti & Schoenholtz, 2021; Federal Reserve, 2023).

In the US, interbank transaction fees are still notoriously higher than in the Eurozone. This is partly due to Eurozone regulation which caps exchange fees. As such, low-hanging fruit to reduce fees for consumers in the US could come via caps on fees. However, it could encounter strong resistance from lobby groups. The proponents of CBDC highlight that this is likely to be a complex and laborious process. Further, it will not get around the problem of network effects, i.e., the threat posed by fintech and large tech companies that may dominate the payments space. This is a valid point that should not be underestimated.

4.5 Regulation will suffice

Sceptics of CBDC highlight that inefficiencies and high costs in the payments space should be tackled first and foremost by less disruptive options. These include well-designed and appropriate regulations. They argue it should be independent of whether the inefficiencies stem from market power abuse, monopolistic and anti-competitive pricing, or financial stability concerns (Cecchetti & Schoenholtz, 2021). If the threat is from crypto assets, an outright ban is proposed. The Managing Director of IMF, Kristalina Georgieva, said in a G20

meeting in February 2023 that banning private cryptocurrencies should be an option (Reuters, 2023). This was also echoed by recommendations from the IMF Executive Board on effective policies for crypto assets (IMF, 2023b). At the same time, however, they acknowledged that such strong regulatory actions could stifle innovation. The IMF Executive Board stated that it remains open-minded that the underlying technologies in crypto assets can be harnessed to support public policy objectives (IMF, 2023b).

Apart from outright bans, other regulatory measures that could fend off threats from crypto assets include punitive taxes or non-regulatory approvals, such as in Meta's Diem project (Cecchetti & Schoenholtz, 2021).

It is a valid point that regulation has a role to play. It will provide the necessary oversight of the payments system to ensure sufficient competition and efficient operations. At the same time, it should allow a conducive environment to harness the latest technology and foster innovation. They are important tools for policymakers to deploy. However, the one significant pushback is designing the appropriate and the right degree of regulation. Given the mercurial nature of technology, it is already an arduous and demanding task for regulators to keep up-to-date with the changes, let alone design the appropriate regulations. Despite their best efforts to be flexible, they could easily fall behind in this endeavour. If regulations are too lenient, they risk threatening financial stability. If they are too rigid, they may stifle innovation and hence, efficiency gains for society.

The fact is that transactions are increasingly digital. Central banks inevitably have to find ways to ensure central bank money remains relevant and pivotal in the payments system. This will cement credibility and confidence in central bank money. It will reinforce the implicit "convertibility promise" of commercial bank money to central bank money (Bindseil, 2022). Otherwise, public confidence in both central bank and commercial bank money can easily dissipate, threatening financial and social stability.

Regulation can help to prevent the abuse of market power or monopolistic pricing. However, it is unlikely to be sufficient to tackle the rapidly evolving payments space due to innovation and technology (Bindseil, 2022). It will be more sustainable and beneficial if central banks provide an alternative to private digital payment options. CBDC is such an alternative. A digital central bank money can offer the much-needed anchor for digital payments.

4.6 Central banks lack expertise

Another argument against CBDC is that central banks lack the expertise and comparative advantage to be competitive in the highly sophisticated and competitive digital payments arena. They could merely duplicate efforts from the private sector, which would be a wasteful use of resources and net welfare loss for society (Bindseil, 2022).

Bofinger and Haas (2021) argue that there is no solid and obvious case for CBDC from an allocative efficiency viewpoint. The value prepositions for CBDC are insufficient for it to go head-to-head with private commercial bank deposits and private retail payment systems like Visa, Mastercard, and PayPal. They note that the benefits of CBDC as a risk-free asset with no counter-party risk are overstated. This is because financial institutions and PSPs are already closely regulated and supervised. Hence, the risks of defaults are minimal.

There are a few counterpoints to these arguments. First, the primary intention of CBDC is not for the central bank to displace the private payment providers or the functions of financial intermediaries. As noted, the two-tier financial system is expected to be maintained. This implies CBDC will co-exist with commercial bank money, commercial banks, and the PSPs. Second, the free market does not always allocate resources efficiently. For example, certain segments of the population could be marginalised or under-serviced. This could include rural or remote areas deemed unprofitable by private enterprises. A CBDC will help ensure this population segment is not left behind in digital payments. Third, tight regulation, oversight,

and anti-competition laws will not necessarily guarantee an efficient payments system to lower costs or improve service quality.

Fourth, a few powerful providers could still dominate the payments system even with close supervision and oversight. This could result in inefficiencies and negative network effects, leading to higher costs for merchants and consumers (Bindseil, 2022). The existence of an alternative, e.g., CBDC, will lower the entry barrier for promising new entrants and foster competition. And fifth, it is not necessarily the case that central banks lack the expertise or flexibility to manage complex systems. The ECB demonstrates this. For example, the Eurosystem comprises the ECB and the 19 national central banks in the Eurozone, the countries that have adopted the Euro as the official currency. The Eurosystem is competent in running the complex T2S and 24/7 instantaneous settlement infrastructure such as TIPS.

4.7 CBDC could be inflationary

The argument is that CBDC could provide an accessible and efficient channel for governments to disseminate stimulus funds. This will be positive during crises, e.g., the COVID-19 pandemic, but it also raised concerns of abuse and fiscal profligacy. It may make it more expedient for governments to spend and lead to an increase in the money supply, which can be inflationary. On the other hand, some argue that CBDC could provide timely and additional information to central banks, at the aggregate level, e.g. CBDC spending in certain industries and up-to-date monitoring of price trends. This could mean more informed decision-making by central banks, e.g. pre-emptive actions to contain inflation before it gets going (Shinn et al., 2023). However, the jury is still out for both views. Strict fiscal and budget constraints will be the best protection over fiscal abuse and allay fears of over-spending by governments. At the same time, strict privacy measures must be in place before utilising the data for policy purposes, even at the aggregate level. A summary of the pros and cons of CBDC is in Table 5.

Table 5
Summary of the pros and cons of CBDC

	Arguments for CBDC - pros	Arguments against CBDC - cons
1.	Monetary sovereignty and financial stability – maintain the relevance of central bank money. Preserve seigniorage for the government. Prevent network effects, and market dominance by a few players.	Compromise privacy and data protection – authorities will have granular data on citizens. Centralisation of data with the government rather than different private entities carries cybersecurity risks.
2.	Safeguard the payments system – create a more level playing field for new entrants, fend off privately issued crypto assets as a medium of exchange.	Surveillance – concerns it could be used as a digital panopticon given increased data collection, data on spending patterns, and locations of citizens.
3.	Interoperability – encourage greater cooperation between payment providers, and reduce cross-border fees for trade settlements and remittances.	Cyber threats – centralisation of data increases cyber vulnerability. Greater surface attack area for hackers, single-point vulnerabilities.
4.	Financial inclusion – improved financial services and access to modern banking services for the 1.4bn unbanked.	Financial disintermediation – a reduced role for commercial banks that may compromise credit creation. This could lead to lower credit growth, higher cost of credit, and lower potential GDP growth in the long run.
5.	Promote innovation – programmability of payments, use of smart contracts to improve efficiency, and reduce costs. This is not the same as programmable money, which ECB and BOE have explicitly ruled out.	Private solutions are superior – CBDC are superfluous, unnecessary, and inefficient compared to the private sector. Private solutions will be less risky, will not entail the huge costs and risks of CBDC. The public sector is not good at innovation, should focus on regulation.
5.	Improve the efficacy of fiscal policy – efficient distribution channel for fiscal stimulus funds, improve efficiency, reduce leakages. More timely spending to influence aggregate demand.	Regulation will suffice – focus on regulation to reduce high interchange fees, improve efficiency. These are low-hanging fruits without risks.
6.	Central bank connection – given declining physical cash use in some countries, important for central banks to maintain a link with the public. Important for central bank money to anchor the financial system. CBDC offers safety, finality, liquidity, and integrity.	Central banks lack expertise and have no comparative advantage to tackle the highly sophisticated and competitive digital payments space.
7.	Savings on printing costs – will be more environmentally friendly.	Inflationary – CBDC may make it more expedient for central banks to print money and governments to spend. This may be inflationary in the long run.

Note: From (Auer et al., 2020; Bindseil, 2022; Bindseil et al., 2021; Demirgüç-Kunt et al., 2022)

Chapter 5: The challenges

History has repeatedly shown that introducing a new form of money comes with risks and resistance. There are five key challenges for CBDC adoption. They include incorporating the appropriate technology, amendments to the legal framework, ensuring the design features are consistent with the policy objectives and legal requirements, managing the operational risks, and fostering broad public acceptance.

5.1 Appropriate technology and cybersecurity

A fundamental question is whether CBDC adoption requires a complete overhaul of the current architecture. Could it augment and build on the existing system instead? On the financial architecture, retaining the current two-tier fractional banking system is the most plausible setup. On the technology architecture, distributed ledger technology (DLT) has been mooted as a possible alternative to the centralised ledgers that central banks currently utilise.

We can rule out the deployment of a permissionless or public DLT where all nodes can act as validators. This is due to the sensitivity of personal data involved. It will violate compliance requirements on privacy and data protection. The Bank of Canada explicitly stated that a public DLT is unsuitable for CBDC (Minwalla, 2020). A permissioned or private DLT, where only specific nodes are permitted as validators, is also unlikely to be feasible, given the speed and scalability issues. The need to update all the nodes regularly and in a timely manner will be cumbersome, compromising efficiency and the speed of transactions. As such, the existing centralised ledger system is likely to be retained.

A major challenge for CBDC adoption is to ensure it is cyber resilient to guard against cyber attacks, fraud, and hacks. If this is not well managed, everything else will fail, e.g., privacy, data protection. Central banks need to ensure that necessary cybersecurity measures are in place to prevent systemic risks to the system. PBOC has stated that cyberattacks will be

substantial when the e-CNY is deployed (PBOC, 2021; Soderberg et al., 2022). It singled out cybersecurity as a key concern that has hindered a full nationwide rollout. Other central banks echo this. For example, in 2019, Federal Reserve Chair Jerome Powell listed cyber risks as a top threat to financial stability (Australian Financial Review, 2019). A House of Lords report on the proposed digital pound stated that CBDCs could be targets of cyberattacks and pose a vulnerable single point of failure for the payment system (Economic Affairs Committee, 2022).

5.2 Amending the legal framework

A strong legal framework has always been and will remain the bedrock of public trust in central bank money. It is essential for the success of CBDC. The public must be confident that their transaction data and privacy are adequately protected. It must strike the right balance between data protection/privacy and compliance. This compromise will differ for each jurisdiction, depending on each society's preferences and cultural norms. It reinforces the notion that there will not be a universal CBDC. Instead, the CBDC design will be tailor-made and unique for each jurisdiction. Nevertheless, for CBDC to be interoperable cross-border, there must be agreed standards and governance to facilitate interoperability.

New laws must be enacted to cater for the new CBDC system. The challenge will be to devise new laws on the run in the fast-changing payments environment. The regulators must also be astute and on top of things to strike the right balance. Regulation must be vigorous and extensive to safeguard the system from malfeasance and nefarious activities. It must continue to satisfy strict KYC/AML/CFT, but at the same time, it cannot be too onerous that it stifles innovation. A clear mechanism must also be devised to resolve disputes and loss-sharing. Anti-trust and anti-competition laws will need to be constantly updated to stay relevant and prevent monopolistic pricing.

For the public sector, it will require an all-of-government effort. Coordination between government departments will be essential. This is to establish consistent standards,

governance, and regulations across departments. There must be a mechanism for regulations to be reviewed regularly and to stay abreast of the changes in the payments space.

To get the public's buy-in, governments may also need to enact specific laws to allay public concerns over using CBDC. For example, in February 2023, US Majority Whip, Tom Emmer, introduced the *"CBDC Anti-Surveillance State Act"* (Emmer, 2023). The US Federal Reserve and the Federal Government do not have the authority to issue CBDC directly to individuals without Congressional approval. The bill emphasizes the need to protect citizens' civil liberties, privacy of financial data, and prevent government overreach, including surveillance.

New laws to be introduced

Given the growing influence of large tech firms in the digital age, new laws are constantly being introduced and updated. This ensures the regulatory backdrop is kept in sync with the technological changes to safeguard consumers, e.g., fend-off anti-trust, anti-competition, and monopolistic practices.

For example, the European Commission has been proactive in safeguarding markets in the digital sector. Its approach is shifting from ex-post, anti-trust intervention and fines to a more pro-active ex-ante approach to regulation. In December 2020, the European Commission proposed two new acts: the Digital Markets Act (DMA) and the Digital Services Act (DSA). The European Parliament approved both acts on 5 July 2022 (Madiega, 2022).

The DMA aims to ensure high competition, a level playing field for all players, and prevent abuse of market power from large tech firms (Ahnert et al., 2022). It hopes to limit data control and collection by large digital platforms known as gatekeepers.

The DSA aims to ensure transparent advertising and guard against disinformation and illegal content. Once adopted, they will alter how large tech companies are allowed to operate in the European Union (EU). It can set the precedence and benchmark for similar regulations across the world. The new rules on data protection, privacy, and transparency will inevitably

spill over to CBDC and dictate activities pertaining to data collection, storage, and usage for all parties involved, including the central bank and commercial banks.

In March 2023, the European Parliament approved a bill to proceed with talks with the EU member states on the final form of the new European Digital Identity (eID) framework. It aims to provide a safe and secure cross-border authentication with the e-Identity system on the internet without a password for citizens and businesses (European Commission, 2023; European Parliament, 2023). It includes utilising zero-knowledge proof technology to protect privacy in digital wallets for EU citizens. These legislations will help to set privacy and data protection standards in a new CBDC system.

5.3 Concurrent consideration of design and legal aspects

Another major challenge for central banks and government agencies involved is to consider the design and the legal aspects concurrently. The objectives of the different departments will not always be in sync with each other, and it will involve trade-offs. For example, technology is available today for a CBDC design to be 100% anonymous, just like cash. The transaction history, the amount, and the location can all be encrypted. This ticks the boxes for those that desire anonymity and privacy. However, it will not pass the compliance requirements, i.e., KYC/AML/CFT rules. They require a certain level of transparency to ensure the legitimacy of transactions. It is an example where a particular CBDC design may tick the technology box but not the compliance box.

At the end of the day, it is imperative that different departments working on CBDC, technology, legal, compliance etc., constantly communicate the broad goals and limitations. They must not operate in silos. Before embarking on the design, the technology camp must ascertain what is feasible and permissible. At the same time, the legal/compliance camp needs to provide the necessary guidelines to ensure that the technology efforts are not wasted on designs that are not plausible. An all-of-government approach is required.

5.4 Management of operational risks

Implementing CBDC will pose a significant practical challenge that should not be underestimated. With new technology, one cannot be 100% confident that everything will run smoothly despite the best efforts to cover all the bases and address the potential weak points. Pilot runs to stress test the system before implementation is important to ascertain the system's robustness. At the same time, protocols must also be in place to shore up the system’s resilience. This includes having viable contingency plans for extreme events. This could entail constant backups of databases, but this will incur costs and compromise efficiency. Running the new CBDC system will also imply additional costs for commercial banks. The government is expected to foot the bulk of the bill to set up the infrastructure, e.g., on the technology, legal etc. This can be paid for with the seigniorage income or tax revenue. For commercial banks, there will need to be mechanisms to compensate them for their role in the management and distribution of CBDC.

5.5 Fostering public acceptance

Wide public support and approval will be imperative for the success of CBDC. Consumers and merchants will ultimately be the final users. It will not take off unless they are convinced of the benefits, such as convenience, safety, and cost savings. They must be assured that adequate privacy and data protection measures are in place. Educating the public on the benefits and risks of CBDC will be crucial to get all the stakeholders on board.

The government will have to take the lead with public education and promotion. Once users are entrenched on a particular platform, it is challenging to alter behaviours and habits. This is illustrated by the low adoption rate of the e-CNY thus far, more than three years after the first pilot run. PBOC has begun to record the e-CNY as part of cash in circulation: as of December 2022, it stood at CNY13.61 billion or just 0.13% of outstanding M0 (Cao & Qu, 2023). Another example is the Ecuador central bank, the first to launch a retail payment system in 2015. The project was abandoned in 2018 because of poor adoption, poor design,

and a lack of marketing and education. This contributed to the lack of public trust in the new system. It was eventually terminated after three years (White, 2018, 2021).

Chapter 6: The necessary conditions

A successful retail CBDC adoption requires fundamental conditions that must be in place. There are at least 12 essential requirements, but they are not exhaustive. They can be classified under four categories, including:

1) Physical infrastructure – it will continue to utilise the existing commercial bank networks;

2) IT infrastructure – it involves a centralised ledger system, adequate cybersecurity, means to promote innovation, e.g., programmable payments, and the ability for CBDC to function even without an internet connection, i.e., functional offline;

3) Legal infrastructure – to support CBDC's status as legal tender. The framework must be applicable for the digital age, with adequate measures to satisfy privacy, data protection, and compliance requirements; and

4) Financial infrastructure – maintenance of the two-tier system to minimise disruptions to the banking sector.

They are discussed in detail in the following sections.

6.1 Two-tier system maintained

As noted in Section 4.3, a two-tier system will be imperative for a retail CBDC. This will minimise disruptions and mitigate financial disintermediation. A two-tier, intermediated model would facilitate RTGS and ensure the maximum efficiency of the new system. This sets the foundation for all the other conditions discussed below. If the financial system is severely impaired and financial stability is at risk, CBDC is effectively dead on arrival. There will not be any appetite to consider the potential benefits and goals that CBDC adoption hopes to achieve.

6.2 Centralised system and Real-Time Gross Settlement (RTGS)

The payments system currently operates on a centralised ledger system where the central bank is the central authority that all the transacting parties trust. This is opposed to a distributed ledger system which does not require a third party. A system's transaction speed is denoted by the number of transactions per second (TPS)[2]. This indicates the network's scalability and capacity to process transactions in real-time. Scalability – i.e., the ability to accommodate new users – is important for mass adoption, such as in the payments arena and retail CBDC.

Laboure (2021) highlighted the slow speed of transactions of distributed ledger technology (DLT) based systems such as Bitcoin and Ethereum. Bitcoin's TPS is estimated at 7 and Ethereum's at 20, Table 6. When Ethereum migrated to the Proof-of-Stake (PoS) concept in September 2022 (Ackermann, 2022), transaction speeds were projected to increase to 20,000 to 100,000 TPS. However, reaching maximum capacity may take a few years (Barchat, 2022).

In contrast, PayPal's TPS is estimated at 193, Mastercard's at 45,000, and Visa's at 65,000. China's e-CNY is at 300,000.

Table 6

Estimated transaction speed of different platforms and physical cash

Medium	Transactions per second		
Cash	Unlimited	PayPal	193
China CBDC	300000	BitcoinCash	65
Facebook Libra	80000	Litecoin	56
Visa	65000	Dash	48
Mastercard	45000	Ethereum	20
Ripple	1700	Bitcoin	7

Note: From Deutsche Bank, Visa, Mastercard, various websites, (Laboure, 2021)

Shabsigh et al. (2020) conclude that it is unclear whether DLT will gain broad traction as a basis for a large-value payment system. Regarding speed, efficiency, and scalability, the centralised ledger system is still superior to the current DLT technology. The technology would need to handle millions of small-size transactions daily.

DLT technology will undoubtedly continue to develop over time (Ali & Narula, 2019; Auer & Böhme, 2021). However, centralised systems are also expected to continue to advance.

Scalability is an essential consideration for a retail CBDC. Alibaba reported that it could handle 544,000 orders per second on Single's Day in 2019. This increased further to a new record high in 2020 at 583,000 orders per second (Alibaba, 2020; Zhang, 2019). The conclusion is that for a retail CBDC, the need for scalability, efficiency, and to facilitate RTGS, a centralised system is preferred to DLT.

Table 7 notes the high energy consumption for DLT systems. For Visa and Mastercard, it is just 0.00649 KWh per transaction. Physical cash (Euro) is at 0.08 KWh per printed banknote, but this rises to a staggering 118 KWh per transaction for Bitcoin. From an energy efficiency viewpoint, it is another nail in the coffin that Bitcoin will not be a suitable and sustainable medium of exchange in the payments system.

Table 7

Estimated energy consumption of different platforms and physical cash

Medium	KWh per transaction
Ripple	0.00001133
Visa (USD)	0.00649
Mastercard (USD)	0.00649
Facebook Libra	0.00649
Cash (Euro)	0.08 KWh per printed banknote
Dash	1.517
Litecoin	18.522
BitcoinCash	18.957
Ethereum	20.294
Bitcoin	118

Note: From Deutsche Bank, Visa, Mastercard, various websites, (Laboure, 2021)

The new CBDC system must handle the millions of daily retail payments as efficiently as the current system. It must be reliable and uninterrupted around the clock, 24/7/365 (SWIFT, 2014). The transition to the new system must be seamless such that users would not notice any material difference. Transaction settlements must be instantaneous or close to it, on any day and at any time, whether in a crowded city centre or remote, rural areas.

As such, it is essential to continue with the centralised ledger system to facilitate RTGS, which is already in operation in many countries. This inter-bank fund transfer system processes transactions continuously and in real-time.

RTGS contrasts with Deferred Net Settlement systems (DNS) where banks aggregate transactions before sending them to a central clearing house for settlement. These are not continuous throughout the day; they only happen periodically or at the end of the day. DNS involves delays, often desirable for large transfers in the millions and billions of dollars. The time lag acts as an additional layer of security to guard against fraud and unauthorised transfers. Redundancies in the system boost reliability and security. The time lag acts as a "cooling off" period for verifications on both ends, for the sender and receiver, before it is finalised.

6.3 Cybersecurity

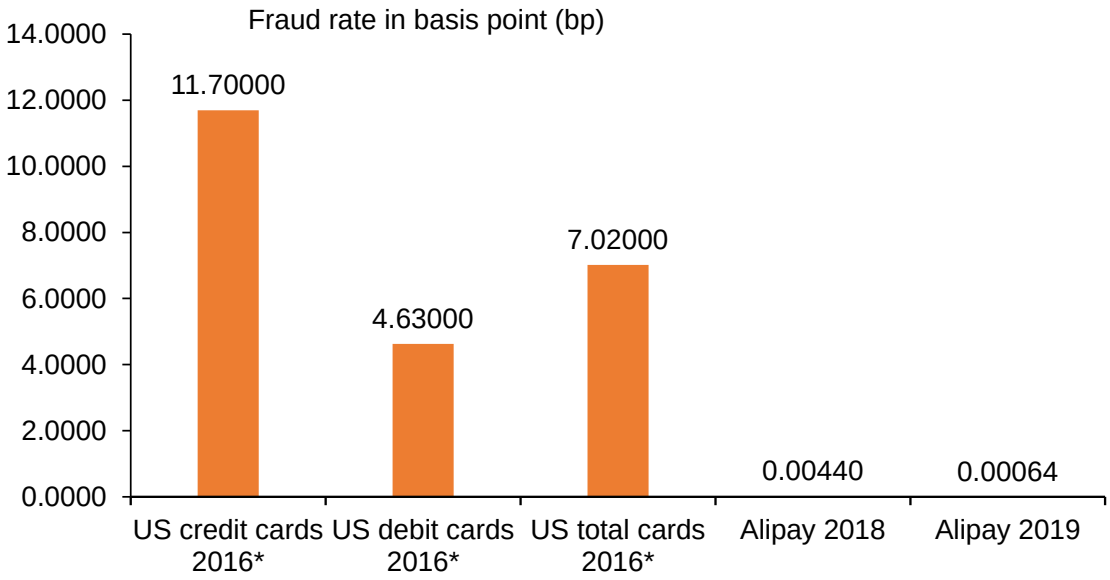
Ensuring a cyber-resilient CBDC system is paramount to successful adoption. If trust in central bank money breaks down for whatever reason (e.g., security breaches or thefts), it threatens the stability of the payments and financial system. While CBDC adoption exposes the financial system to new cybersecurity risks (Fanti & Kostiainen, 2022), this should not deter policymakers from pursuing CBDC. It is still possible to develop a safe and secure CBDC system using the current technology (Fanti & Kostiainen, 2022).

China's two major payment providers, Alipay and WeChat Pay, show that it is possible to keep fraud rates low. According to Alipay's self-disclosure, its fraud rate was just 0.0044 basis points in 2018 (1 basis point or bp equals 0.01%). It dipped further in 2019 to

0.00064bp, Figure 21 (Alipay, 2021). For every USD10 million in payments, the fraud-induced loss was less than USD0.64 – much better than the fraud rate for bank cards in both China and the US. In China, it was 0.87bp in 2019; in the US, it was 11.7bp in 2016 (CBN Editor, 2020; Prasad, 2021; Turrin, 2021; US Federal Reserve, 2018), Figure 22. Alipay attributed the 2019 fraud rate drop to the rollout of Alibaba's AI-powered risk engine, AlphaRisk (Businesswire, 2020).

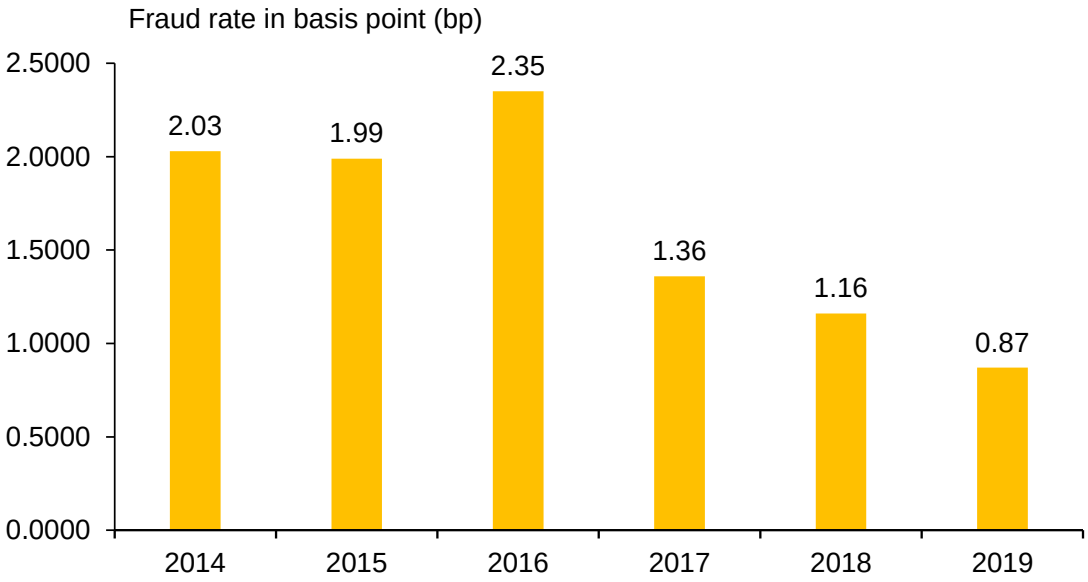
Alipay and WeChat Pay's experiences in cybersecurity and fraud detection are invaluable for China's e-CNY development. It has given PBOC a head start on CBDC cyber-resilience compared to the rest of the world. Given the unpredictable nature of technology and the speed of change, it is impractical to cover all weaknesses despite the best efforts. We will never know all the vulnerable points until the system commences. As such, the system must be agile, resilient, and able to respond to adverse shocks.

Figure 21
Alipay's low fraud rate compared to bank cards in China and US



Note: From *https://www.federalreserve.gov/publications/2018-payment-systems-fraud.htm; Table 10; https://cshall.alipay.com/lab/help_detail.htm?help_id=201602076097; https://3g.163.com/dy/article/E74E0E9H0519QIKK.html

Figure 22
The card fraud rate in China has been declining



Note: From https://www.chinabankingnews.com/2020/09/24/chinese-bank-cards-rise-8-9-yoy-in-2019-to-8-53-billion/; https://www.sohu.com/a/321431599_659885

Underscoring the importance of cybersecurity, the BIS Innovation Hub (BISIH) recently launched Project Tourbillon to tackle the three core features of CBDC. These are cyber resilience, scalability, and privacy (BIS Innovation Hub, 2022d). It also highlights that any CBDC design will involve trade-offs between these three areas. For example, greater cyber resilience to guard against attacks may entail additional cryptography layers, which will slow payment speed.

Another subtle point is that the CBDC system must also be robust to guard against hacking from quantum computers in the future. The White House issued a memorandum calling for increased focus on quantum-resistant cryptography to mitigate the risks of hacking from more powerful quantum computers of the future (White House, 2022b).

6.4 Tiered or managed anonymity

The public must be assured that their transactions will not be transparent to the central bank or other regulators. The desire for anonymity does not necessarily imply an association with illicit or nefarious activities (Bech & Garratt, 2017).

Regulators will need to strike the right balance between transparency and privacy. There must be a certain level of transparency to ensure that transactions are legitimate and satisfy KYC/AML/CFT requirements. Failure to do so will mean a backward step in law enforcement and a threat to financial system integrity. On the other hand, users will desire CBDC to retain a certain degree of anonymity, as per physical cash.

A compromise can be a tiered or managed anonymity approach as pursued by PBOC. PBOC stated that the e-CNY would follow the principle of "anonymity for small value and traceable for high value" (PBOC, 2021). Users can opt for different anonymity levels, which require different degrees of personal information and spending limits, as shown in Table 8.

Table 8
e-CNY - different anonymity, disclosure, and spending limits

Anonymity level	Requirement	Single payment	Cumm daily limit	Balance limit
Highest	Mobile number	CNY2k (S$400)	CNY5k (S$1k)	CNY10k (S$2k)
Standard	ID, linked to acc	CNY50k (S$10k)	CNY100k (S$20k)	CNY50k (S$100k)

Note: Different degrees of disclosures for various spending limits on e-CNY. From https://forkast.news/headlines/china-reveals-e-cny-wallet-specifications/

For example, the highest level of anonymity only requires a mobile phone number, but single payments are restricted to CNY2k (USD290). The cumulative daily spending limit is capped at CNY5k (USD730), and the balance is capped at CNY10k (USD1.5k).

The new CBDC system may have to introduce this flexibility on payment anonymity to get the public's buy-in. This will make CBDC more palatable for users and allay fears over unnecessary government surveillance, particularly for small amounts.

It can also be flexible because if the authorities suspect illicit transactions, the CBDC design could enable them to lift the anonymity veil to scrutinise transactions more closely. There could be a high legal barrier as a check and balance, with authorisation sought from several agencies before investigators can proceed. This is to prevent abuse and allay the public's fears of unchecked and relentless power from the state. Ultimately, the aim is to balance anonymity or privacy with compliance requirements to safeguard the financial system's integrity.

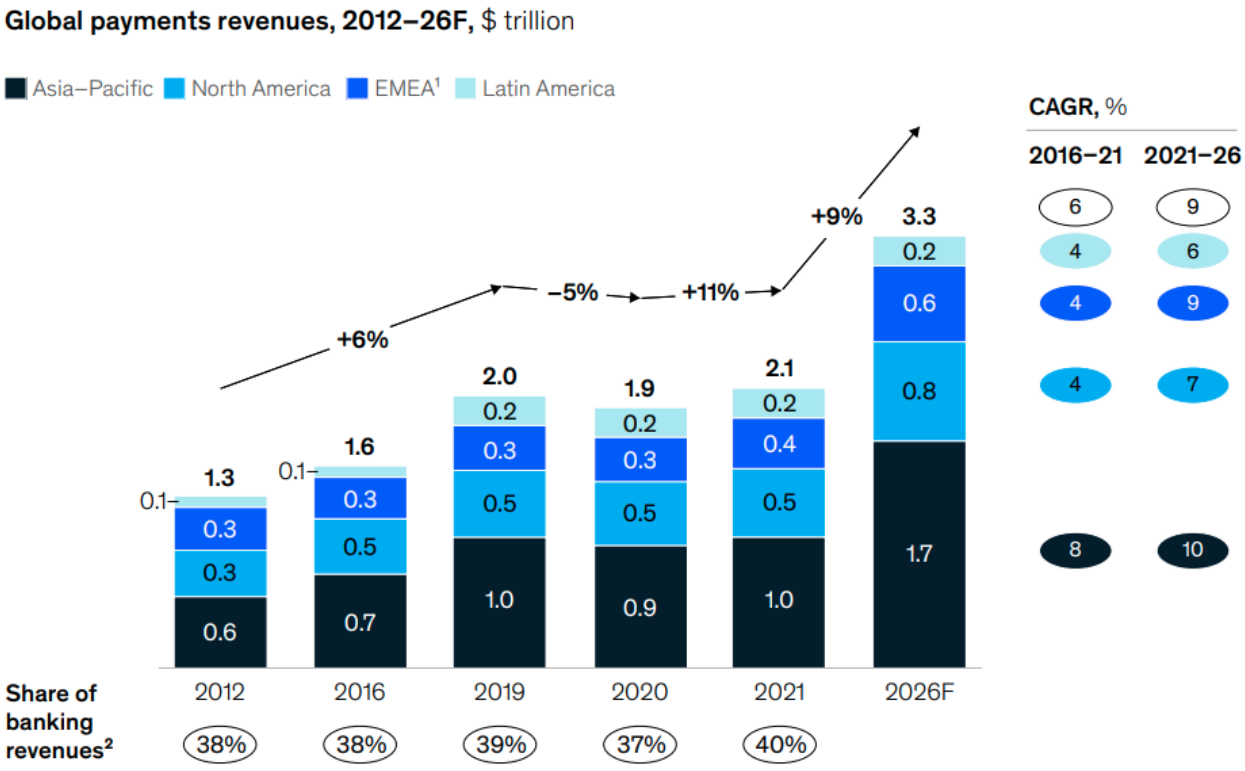
6.5 Convenient, hassle-free, and cost savings

The new CBDC system must be convenient, hassle-free, easy to use, and cost-effective. It must demonstrate that it can deliver cost savings to merchants and consumers. It must be low-cost for all, implying users do not need the latest, most expensive smartphones. Increased competition in the payments space should deter network effects, market concentration, and anti-competitive pricing. Since CBDC is the equivalent of physical cash, no fees should be attached to its use.

In societies with high dependency on physical cash as a mode of settlement for point-of-sale transactions, CBDC introduction can lower the costs of commerce. Cash usage entails costs due to storage, transportation, and manpower. This is particularly pertinent for developing economies with less sophisticated financial sectors.

McKinsey & Company (2022) reported that global payment revenue increased by 11% in 2021 to USD2.1 trillion, Figure 23. It fell by 5% in 2020 due to the pandemic, but between 2014 to 2019, it grew on average by 7%. McKinsey projects it will return to the long-term trend growth rate of 6-7% in the coming years, with global revenue to hit USD3.3 trillion by 2026. This will be driven by global growth and the continued digitalisation trend in payments (McKinsey & Company, 2022).

Figure 23
Global payments revenues rebounded 11% post-Covid in 2021



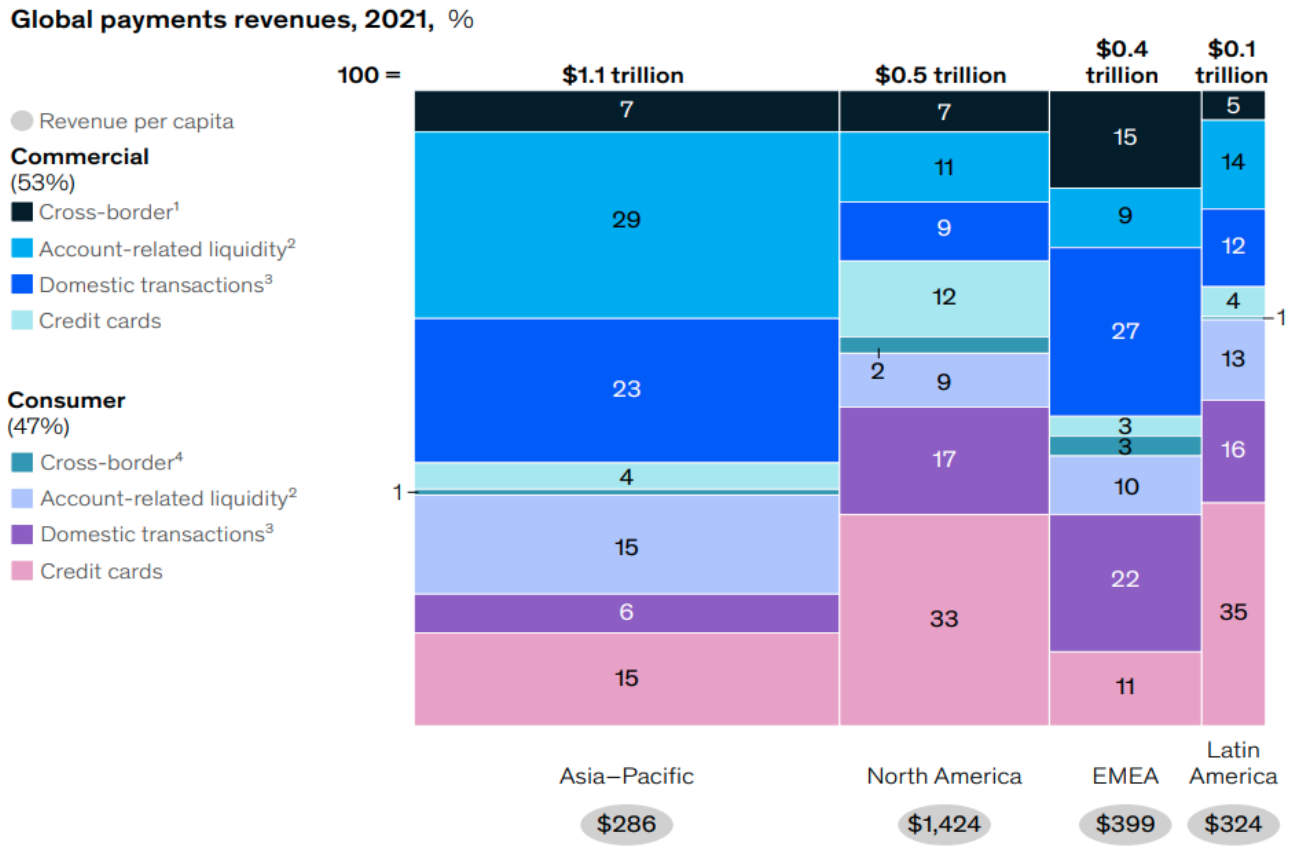
[1]Europe, Middle East, and Africa.
[2]Total banking revenues excludes Capital Markets and Investment Banking (CMIB) revenues. Given the current macroeconomic volatility, payments share in banking revenues for 2026 are not forecast.
Source: McKinsey Global Payments Map

Note: From McKinsey & Company, "The 2022 McKinsey Global Payments Report, October 2022, p.5"

CBDC introduction can potentially reduce interchange fees or revenue paid for credit card usage as it will provide an alternative in the digital payment space. Interchange fees are the costs merchants incur for utilising card services. It offers convenience for users but comes at a cost for merchants, which is eventually passed on to consumers. For example, credit card fees accounted for 15% of the total payment revenue for Asia-Pacific consumer transactions in 2021 (USD165 billion). In EMEA (Europe, Middle East, and Africa), it was just under 11% (USD44 billion); in North America, it was 33% (USD165 billion); and in Latin America, it was 35% (USD35 billion) of the total payment revenue, the bottom panel of Figure 24.

For commercial transactions, credit card fees accounted for 4% of the total payment revenue in Asia-Pacific (USD44 billion), 12% in North America (USD48 billion), 3% in EMEA (USD15 billion), and 4% in Latin America (USD4 billion), the top panel of Figure 24.

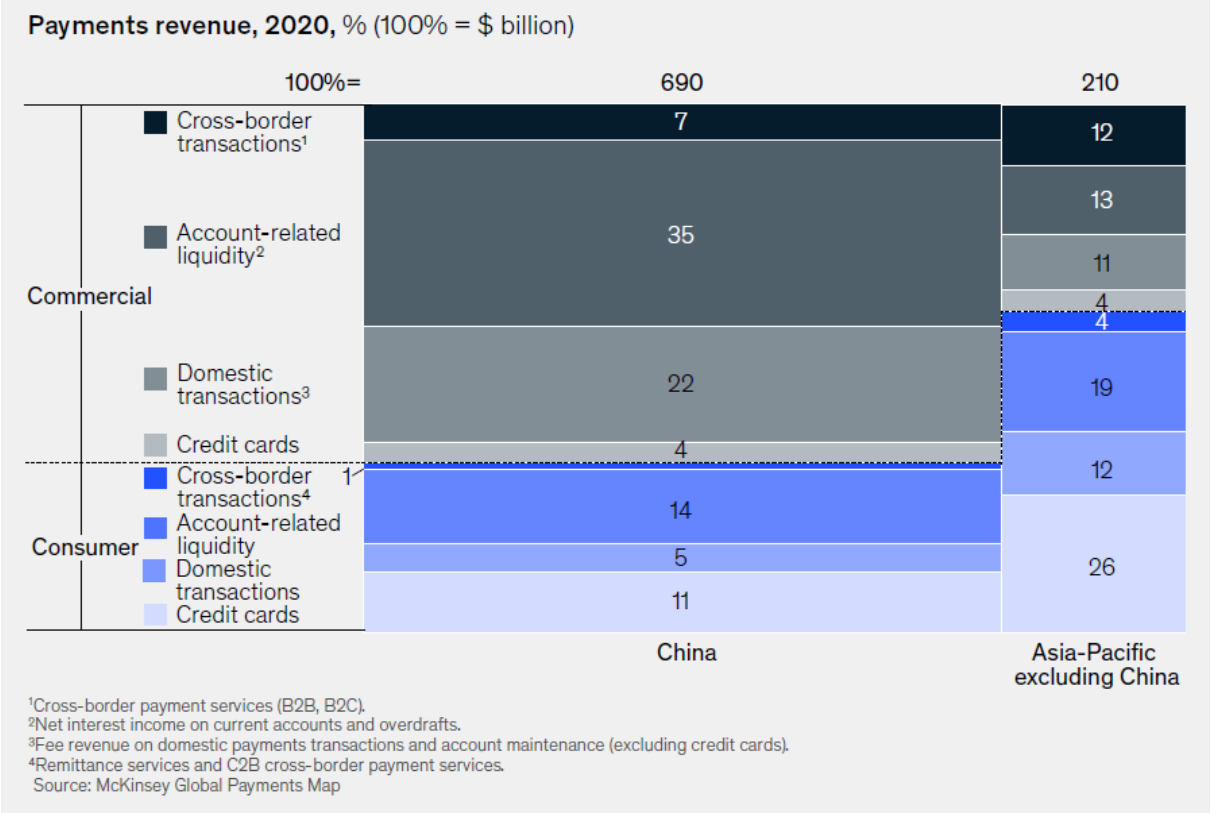
Figure 24
Global payments revenue pool – Asia-Pacific led the way



Note: From McKinsey & Company, "The 2022 McKinsey Global Payments Report, October 2022, p.6"

In Asia-Pacific, the data suggest greater scope for cost savings in consumer transactions than in the commercial sector. For example, credit card fees for consumer transactions accounted for 11% of payment revenue (USD76 billion) in China and 26% (USD55 billion) for the rest of Asia-Pacific. Commercial transactions, meanwhile, only had 4% in credit card fees, Figure 25.

Figure 25
Payments revenue dynamics – China and rest of Asia-Pacific



Note: From McKinsey & Company, "The 2021 McKinsey Global Payments Report, October 2021, p.12"

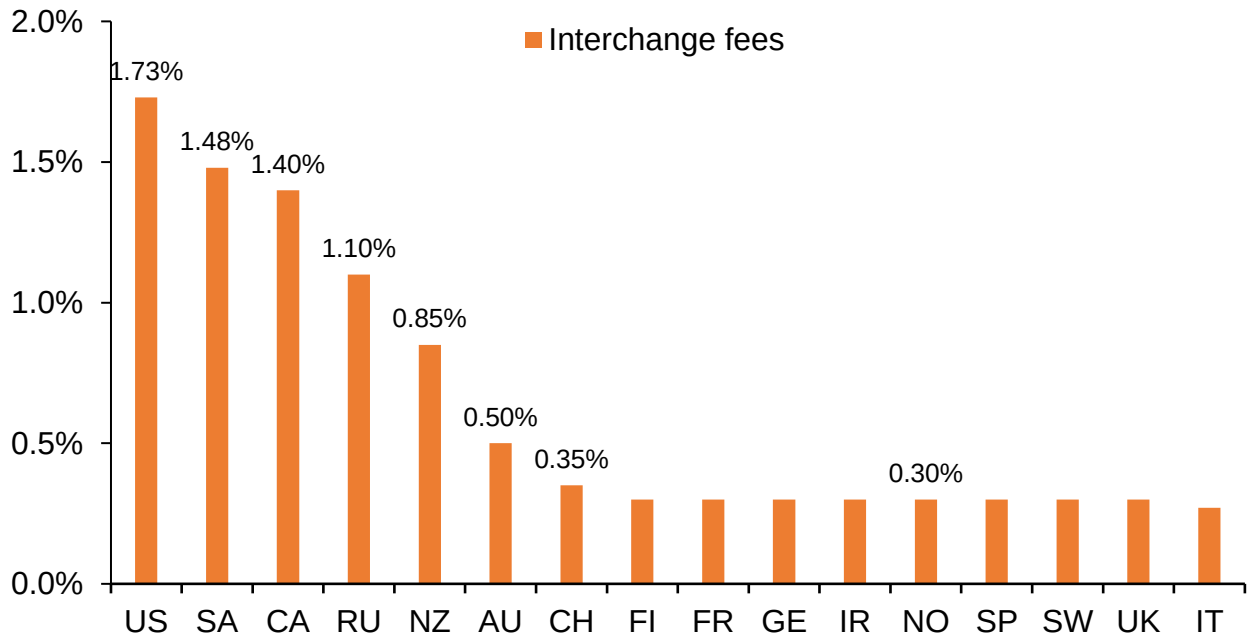
Interchange fees are difficult to ascertain as they vary by region and target segments, e.g., consumers vs. business, and the terms and conditions differ. Radage (2022) provides estimates of the interchange fees, Figure 26. The data are mainly for Europe and North America. Nevertheless, they illustrate much higher interchange fees in the US and Canada compared to Europe and China.

The low fees in Europe are due to the caps on card-based payment transaction fees introduced in December 2015 (European Commission, 2016). In China, the proliferation of Alipay and WeChat Pay in everyday payments helped to keep fees low.

As such, for China, lowering interchange fees may not be the primary driver for the e-CNY. A key motivation is for the state to re-establish monetary sovereignty and control over the payments system from the two dominant tech companies. Besides China, CBDC's ability to

introduce competition in the payments space and eventually drive down interchange fees will be important catalysts for widespread adoption.

Figure 26
Interchange fees by country



Note: From Clearly Payments, (Radage, 2022). SA (South Africa), CA (Canada), RU (Russia), NZ (New Zealand), AU (Australia), CH (China), FI (Finland), FR (France), GE (Germany), IR (Ireland), NO (Norway), SP (Spain), SW (Sweden), UK (United Kingdom), IT (Italy).

6.6 Non-interest bearing

Just like physical cash, CBDC should be non-interest bearing to discourage inflows into CBDC deposits. It will reinforce CBDC's primary role as a medium of exchange rather than as a store of value. At the same time, it will dismiss apprehensions of negative interest rates on CBDC deposits. Most central banks consider negative interest rates impractical, as they are unpopular and will deter CBDC adoption. It would also be inconsistent with the notion that CBDC is a digital version of M0.

Central banks' continued provision of physical cash will also make negative interest rates on CBDC impractical. Citizens can merely withdraw their savings and hold cash. This was the case in Germany after ECB cut rates into negative territory in 2014. Germany's largest

safe manufacturer, Burg-Waechter KG, said the sale of home safes jumped 25% in the first half of 2016 compared to the same period for the previous year. A family-owned safe retailer in Hamburg, Hamburger Stahltresor GmbH, reported that sales have expanded by 25% since 2014. (Dauer, 2016).

Some advocate flexible rates on CBDC deposits, both positive and negative. The rationale is that it corrects the anomaly of physical cash being zero-interest bearing despite fluctuations in inflation and interest rates. Second, flexible interest rates on CBDC can enhance the efficacy of monetary policy (Bordo & Levin, 2017; Dyson & Hodgson, 2016; Lariccia, 2018). However, this is more of a theoretical discussion than a policy tool that central banks are seriously considering.

6.7 Cap on CBDC deposits

A cap on CBDC deposits will deter excessive inflows into CBDC, mitigate financial disintermediation, and reinforce CBDC's role as a medium of exchange. CBDC should not be viewed as an alternate store of value, i.e., another risk-free digital asset class. There are various prepositions, such as an outright cap, tiered remuneration, and a progressive fee structure that sets higher fees for larger deposits, as espoused by Bindseil et al. (2021) and Brunnermeier and Landau (2022).

A simple outright cap on CBDC deposits appears to be the easiest to implement to begin with. The cap can be flexible and more sophisticated methods could be explored in the future. Caps on CBDC deposits will also help to prevent digital bank runs, particularly in times of financial stress, such as the recent episode of the collapse of Silicon Valley Bank and Signature Bank in the US. With physical banknotes, bank runs are restrained to a certain extent by the physical act of withdrawing cash. There are also limitations to holding physical cash, e.g., storage capacity, costs, and security risks. Without caps on CBDC deposits, digital bank runs could occur rapidly, particularly in modern digital banking. Moving cash

from one bank to another could just involve a few clicks. This could increase market volatility (Sanchez-Roger & Puyol-Antón, 2021). As such, a cap on CBDC deposits is essential.

BOE has proposed a limit between GBP10,000 to 20,000 per individual. It is deemed high enough to encourage adoption but not too high that it leads to financial disintermediation (Bank of England, 2023a, 2023b). BOE also stated that a limit of GBP10,000 will be sufficient for 75% of UK income earners to hold their salary. With a limit of GBP20,000, this figure rises to 95% of earners.

6.8 Complement cash, not replacement

The new CBDC system must cater to all segments of society and not just the tech-savvy (H. Wang, 2022). This includes the young, elderly, and physically challenged. Physical cash is the most inclusive mode of payment because of its convenience and ease of use. As such, central banks must – and have said they will – continue to provide this option. This is an important point that central banks need to emphasise to halt damaging rumours and fearmongering.

Another reason why central banks should continue to provide physical cash is because it provides a tangible and credible backup plan if anything goes wrong with CBDC. This is particularly germane for developing economies with relatively high cash use and less developed financial infrastructure.

Furthermore, it will enhance the system's operational resilience and robustness, such as against natural disasters, power cuts, or any low-probability yet high-impact events, e.g., terrorist attacks (Pichler et al., 2020). A clear and pertinent case was the devastating floods in Zhengzhou, in Henan Province, China, in July 2021 (Areddy, 2021). Electricity and internet coverage were down for several days, disabling Alipay and WeChat Pay apps. Shops reverted to "physical cash only" transactions. The reduced use of physical cash over the years also meant that it was not readily available. This forced some to resort to barter. The bottom line is that it provides redundancy to the payments system and aids resilience.

6.9 Function offline

Following the previous point, the CBDC system must be able to function offline and not be dependent on Wifi, internet connections, or to the electricity grid. This enhances the system's resilience and robustness, aiding in the financial inclusion objective. In other words, those in remote areas (without Wifi or internet access) can still use CBDC. A robust online-offline system for CBDC is imperative for the smooth functioning of the payments system. Kiff (2022) emphasizes this point and notes that a non-dependence on the internet could make or break CBDC adoption for many central banks and countries. Offline payment technology has existed for some time, and several companies have launched new versions of Avant and Mondex, the stored-value payment platforms. Other companies, including Giesecke+Devrient (Giesecke+Devrient, 2023) and WhisperCash (WhisperCash, 2023), can already provide offline CBDC capabilities.

6.10 Programmable payments

Smart contracts open up interesting possibilities for industry players. They incentivize commercial banks and PSPs to innovate and develop creative solutions and products for users. For businesses, programmable payments could enable a more efficient way to settle payments once goods have been delivered and received. This will cut out intermediaries, resulting in greater efficiency and lower costs.

6.11 Account-based rather than token-based

Whether to adopt a token or account-based system touches on the ownership structure or accessibility of CBDC. The most plausible model is an account-based one, as it satisfies KYC/AML/CFT requirements. Three factors differentiate the two systems: the authentication or identification requirements, the underlying data structure, and the methodology used to transfer funds.

For token-based CBDC, ownership is demonstrated by having access to a private key-pass or digital signature. This can be achieved with the help of a Public Key Cryptography Infrastructure (PKI). Knowledge of the key-pass is essentially “I know and therefore I own” (Bossu et al., 2020). It preserves a high degree of anonymity but may not satisfy all the compliance requirements. Accessibility will be broader but more complex compared to an account-based system. If the key-pass is lost, it will be equivalent to losing physical currency; the user will no longer have access to the CBDC funds.

For an account-based CBDC, ownership is tied to a digital identity, similar to the details one would need to provide to open a bank account. The identity of the account holder grants the person access to the funds. This can be referred to as “I am and therefore I own” (Bossu et al., 2020). There is greater transparency than in a token-based system, and it will satisfy KYC/AML/CFT requirements.

In a token-based system, the user must verify the object's validity or token being used to transfer funds. In an account-based system, the onus is on verifying the identity of the user. This is done via a password and OTP (one-time password) for added security. The ledger is updated once the transfer is done. It resembles the current system where funds can be transferred from one bank account to another.

As noted earlier, the CBDC funds are not parked at the central bank but with the commercial banks in e-wallets or digital wallets. These e-wallets can be an app, a website address, or a hard wallet, e.g., a card. The CBDC funds can be transferred from one account to another or from wallet to wallet.

Concerning privacy, a tiered anonymity method can be applied. For example, amounts below a certain threshold can be 100% anonymous, while larger transactions require greater disclosures. The threshold can be flexible, e.g., one can apply for one-off large lump-sum payments, e.g., purchases of white goods and furniture. An intermediated architecture and

cryptographic techniques can prevent the central bank from having access to granular transaction details.

Account-based models will also be more economical and energy-efficient compared to token-based. Token-based models require two records: one to track the token and another to track the ownership of the token. This means more work for commercial banks, implying additional costs and reduced efficiency. It will also entail higher energy use.

6.12 Other conditions

The requirements outlined above address the question of what is needed or necessary for CBDC adoption. However, they would not guarantee success by themselves. There are other important considerations, and they touch on the social factors. They have not received much coverage to date. A non-exhaustive list includes the following:

1) Social acceptance and public support – The first question is how to encourage demand for the new CBDC system. What social issues must policymakers address to encourage widespread usage and adoption? Would it work if forced upon citizens? A hard-line approach that infringes on the liberties of citizens is unlikely to be effective. Instead of the stick, a carrot approach might be more palatable. For example, Alipay and WeChat Pay provided small incentives in the early years to encourage adoption. The central bank will have to take the lead to convince the public and provide enough incentives for them to adopt a new method of digital payments.

Citizens must also be convinced that sufficient safeguards are in place to protect their data and privacy. Will society be comfortable with the potential of the central bank having access to more data on citizens, even if it is on an aggregate level? This will differ for each society, and each will have to arrive at a suitable compromise. It will depend on culture and societal norms. For example, in China, the success of the online payment platforms Alipay and

WeChat Pay suggests that citizens comfortably accede private transaction data to the two big tech companies in exchange for greater convenience and cost savings.

2) Different legal settings – The legal environments will differ from country to country. A policy deemed acceptable in one jurisdiction may not be tolerated in another. The proposed changes to the legal environment must be balanced with safeguards for users. For instance, one potentially contentious point in protecting user privacy is the treatment of "location". For any given transaction record, the location of the transaction is implicitly recorded, along with the amount, item, and time. Up to now, most probably do not put much emphasis on location; it is not a priority to protect it. Many are happy to use navigation apps such as Google Maps and Waze. However, with digital payments using CBDC, the treatment of "location data" could be more sensitive as it can link transaction details with identity and location. We could encounter a situation where the location information was innocuous on previous navigation apps but will now be considered private and confidential.

3) Political will – The government will play an important role in guiding and fostering CBDC adoption. It will have to fork out the initial investment costs, set the necessary governance and rules of engagement, and create the legal environment for CBDC to operate.

4) Public education – The government must work with the private sector to promote the benefits of CBDC. Otherwise, adoption will be lacklustre. For example, three years after the pilot program, China's e-CNY comprises only 0.1% of the total private digital payments (CNY100 billion or USD14.5 billion) (Muir, 2023). It highlights the difficulties in getting citizens to change habits once they are familiar with a particular system. It is probably more acute in China's case, given the ubiquitous nature of Alipay and WeChat Pay, but other countries are likely to encounter similar hurdles (Cao & Qu, 2023).

Chapter 7: Central bank setups

The Atlantic Council reported that as of December 2022, 11 out of the 114 countries it tracks have officially launched CBDC, or 10%. They are mainly smaller countries, including Nigeria, Jamaica, Bahamas, and the eight Eastern Caribbean countries (Anguilla, Saint Kitts and Nevis, Antigua and Barbuda, Montserrat, Dominica, Saint Lucia, Saint Vincent and the Grenadines, and Grenada). They comprise only 0.5% of the global nominal GDP as of 2022 (IMF, 2022).

China began pilot runs on the e-CNY in early 2020 and is the only major country to do so to date. China's economy was 18% of the global nominal GDP in 2022. Table 9 summarises the key setups of these countries, including the CBDC type, architecture, one-tier or two-tiers, underlying technology, user access, and the main motivations.

Table 9
Summary of setups of central banks who have launched/pilot CBDC

Country	Use case	Architecture	One-tier or two-tier	Underlying technology	Access: account vs token	Technology partnerships	Motivation
China	Retail	Intermediated	Two-tier	Centralized	Account	N/A	Diversify digital payment options, promote competition in digital payments, safeguard the payments system, cross-border payments.
Nigeria	Retail	Intermediated	Two-tier	DLT	Account	Bitt Inc	Financial inclusion, from 64% to 95%
Bahamas	Retail	Intermediated	Two-tier	Centralized/DLT	Both	NZIA Limited	Financial inclusion, enhance AML/CFT
Jamaica	Retail	Intermediated	Two-tier	Centralized	Account	eCurrency Mint	Reduce cost of cash usage, handling, storage
Eastern Caribbean	Retail	Intermediated	Two-tier	DLT	Both	Bitt Inc	Financial inclusion, enhance AML/CFT

Note: Author compilation of central banks who have launched CBDC or in a pilot stage, namely PBOC. From (Atlantic Council, 2022; Bank of Jamaica, 2020; Central Bank of Nigeria, 2023; Central Bank of the Bahamas, 2023; Eastern Caribbean Central Bank, 2021; PBOC, 2021).

General observations

There are a few common traits among the CBDC that have been launched: they are all retail CBDC with an intermediated architecture, an account-based model, and they adopt a two-tier system. The underlying technology is generally centralised, though the Bahamas also incorporates DLT. The Eastern Caribbean CBDC, known as DCash, was designed and developed by the international fintech company, Bitt Inc. It runs on the blockchain, possibly due to the absence of a central body for the eight countries. Bitt Inc also operates Nigeria's CBDC, the e-Naira.

In Nigeria, cash was the dominant mode of payment for point-of-sale transactions in 2021, amounting to 63% of total payments. This was followed by digital/mobile wallet at 13%, debit card at 8%, and credit card at only 4%. Given limited digital transactions, a CBDC based on DLT may suffice for now. It will be interesting to see how this develops as digital payments pick up.

So far, adoption has been disappointing. For example, since the launch of the e-Naira in October 2021, less than 0.5% of Nigerian citizens have used it (IMF, 2023a). This mirrors the experience of the e-CNY as well. It underscores the importance of active promotion and possibly incentives in the early stages to encourage adoption.

Given that China's e-CNY is the most significant in terms of size and impact, the rest of this chapter will focus on China's experience. The following questions are addressed:

i) What are the objectives of the e-CNY?

PBOC has stated three broad objectives:

1) To diversify the forms of cash provided by the central bank to the public, satisfy public demand for digital modes of payment, and support financial inclusion;
2) Promote competition and safety of retail payment services; and

3) Explore ways to improve cross-border transactions by lowering transfer costs and improving efficiency (PBOC, 2021).

ii) How will the e-CNY function?

The mechanism of the e-CNY is built around the concept of “one coin, two databases, three centres” (一币，两库，三中心) (Ba, 2020; Duffie, 2022). “One coin” refers to the e-CNY as a unit of account. It is a direct liability of PBOC, just like physical CNY notes and coins. “Two databases” refer to i) the issuance database - PBOC’s ledger that tracks all outstanding e-CNY; and ii) the transaction database - ledgers of the commercial banks in the two-tier system. The public interfaces with commercial banks, not the central bank. “Three centres” consist of i) the registration centre, which records all e-CNY ownership and transactions; ii) the authentication centre, which verifies transaction requests via either a) a public key infrastructure (PKI) for financial institutions and high-end users; or b) identity-based cryptography (IBC) for retail transactions; and iii) the big-data centre, which analyses data to detect illegal activities. e-CNY will be transferred between e-wallets via quick response (QR) codes which Alipay and WeChat Pay currently deploy.

iii) What is the e-CNY design and architecture?

PBOC is the sole issuer of e-CNY, and distribution is via authorised operators: the seven commercial and the two online banks. These are ICBC, Agricultural Bank of China, Bank of China, China Construction Bank, Bank of Communications, Postal Savings Bank of China, China Merchant’s Bank, MyBank (Alipay), and WeBank (WeChat Pay). As such, it is a retail CBDC and adopts a two-tier system.

It combines the hybrid and intermediated CBDC architecture illustrated in Figure 20. It resembles a hybrid architecture in that the commercial banks and other PSPs will update PBOC on a “regular” basis to ensure that the central bank has a copy of all retail CBDC

holdings and transactions. Importantly, this is not on an instantaneous basis. The advantage is that PBOC will keep a copy of all holdings as a backup. An intermediated architecture implies PBOC will only keep a wholesale ledger of all transactions, not granular details on citizens in real-time.

iv) Will Alipay and WeChat Pay still play a role?

Yes. Mu Changchun, the Director of the Digital Currency Research Institute at PBOC, said in March 2021 that the e-CNY project is not intended to replace Alipay or WeChat Pay (Hall, 2021). Instead, Mr Mu stated it would act as a "back-up" and provide "redundancy for the retail payment system". It will co-exist with Alipay, WeChat Pay, and physical cash. The two payment providers will remain an essential and integral part of the digital payments system. The intention is that e-CNY will be the currency but Alipay and WeChat Pay will be the "digital wallet" or "e-wallet". They will be part of the distribution channel along with the commercial banks.

Under the new system, e-CNY will be exchanged directly rather than via bank balances, which is the current arrangement when using Alipay or WeChat Pay. Under the current system, the funds seen on smartphone apps are account balances in a bank account somewhere. If e-CNY is used, it will be a long string of characters, hashes, and numbers representing digital CNY on the smartphone itself. Inside the Alipay and WeChat Pay e-wallet, users will have the additional option to include e-CNY along with links to bank balances. The e-CNY deposits in these e-wallets will be non-interest bearing.

v) What are the implications for international trade settlements?

There is potential for more China-related trade to be settled in e-CNY. However, this is unlikely to be the case worldwide anytime soon, given international political resistance and scepticism over China's intentions and motives for the e-CNY.

The settlement of China-related trade in e-CNY will be determined to a large extent by the potential cost savings. The larger the savings, the better the chances of adoption. In 2021, China was the world's largest exporter accounting for 15% of global merchandise exports, followed by the US at 8%. China was the second largest importer, accounting for 11% of global merchandise imports. The US was the world's largest importer with 13% market share (IMF, 2022).

In 2021, PBOC said the amount of cross-border merchandise trade settled in CNY rose 21% from a year earlier to CNY5.77 trillion. It accounted for 14.7% of total trade in 2021 and has risen to 16.6% in the first half of 2022 (X. Wang & Zhang, 2023). The trajectory is on the uptrend, partly driven by geopolitical tensions. Other countries are also looking to hedge and diversify from the USD as a means of trade settlement. As more of China's merchandise trade is settled in CNY, this should also increase demand for e-CNY.

vi) What role will the e-CNY play in China's digital logistics network (DLN)?

It could provide a seamless and cost-efficient means to settle trade with China over time. This could have significant implications. China's digital retail payments sector is already well-served with Alipay and WeChat Pay. It begs the question: what does the e-CNY bring to the table? In addition to the points outlined above, the added advantage is that the e-CNY can fit into the broader ecosystem of China's ongoing digitalisation effort. From this perspective, the e-CNY is more than just a digital currency. It is the digital ticket into China's smart blockchain and AI-enabled digital logistics network (DLN).

It can help exporters and importers place orders, track progress, and pay or receive funds seamlessly and cost-effectively. For example, buyers can place orders online, pay for them with the e-CNY, and track the whole process from containing loading to customs clearance. Whether the e-CNY can catalyse a new trade settlement system remains to be seen. There is potential to do so, beginning with China-related trade (Turrin, 2021).

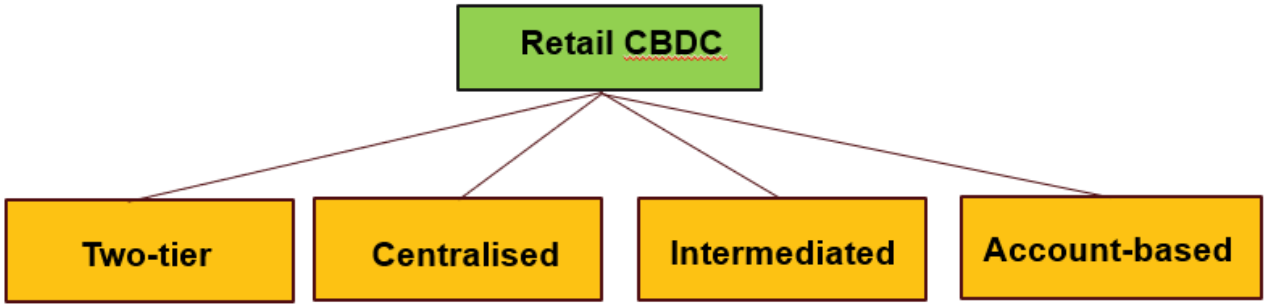
Chapter 8: Assessment of the arguments and future research

My assessment based on my research is that a retail CBDC that serves a large population will require at least four foundations. This is summarised in Figure 27. They include:

1) Maintenance of the two-tier fractional banking system;
2) Operation on a centralised ledger system to facilitate RTGS;
3) An intermediated architecture to facilitate RTGS and efficiency; and
4) An account-based model to satisfy compliance requirements.

For smaller countries, such as those already launched, including Nigeria, Bahamas, and the Eastern Caribbean, a DLT-based system could suffice for now, as scalability may not be an issue. We need to monitor whether this will still be the case if demand and digital transactions pick up. The current DLT-based technology may not suffice for larger economies or regions with more sophisticated financial systems, such as China, Europe, or the UK.

Figure 27
Four foundations for a retail CBDC



Note: A summary of what is needed for a retail CBDC. Author compilation.

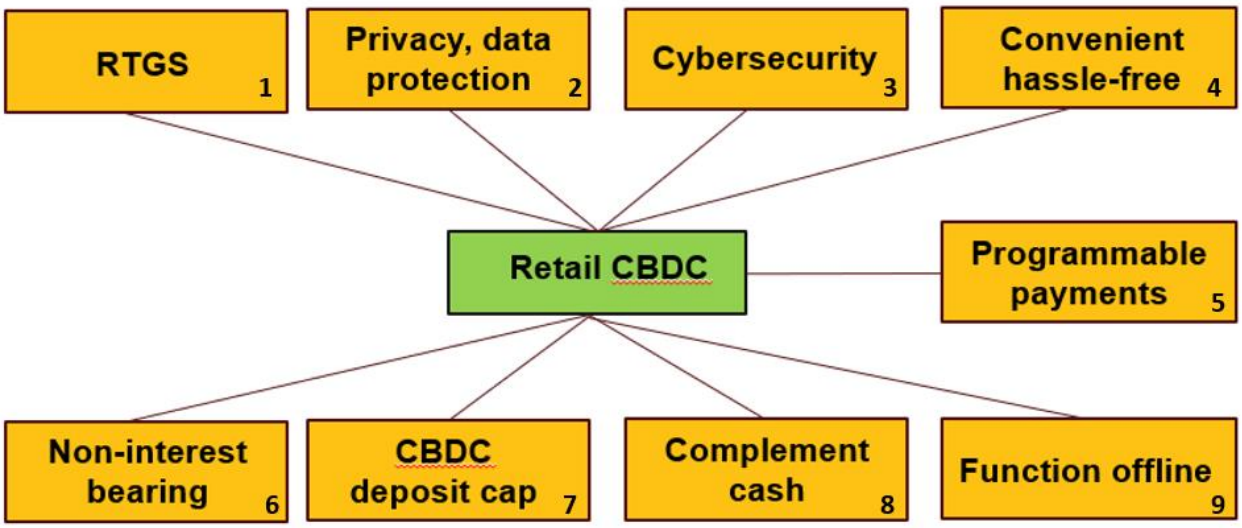
On top of these four foundations, there are other essential requirements that must be in place to increase the chances of a successful adoption. These are summarised in Figure 28. The list is as follows, though it may not be exhaustive.

1) Facilitation of RTGS. A centralised system coupled with an intermediated architecture is the most feasible option based on the current technology;
2) Sufficient privacy and data protection measures. This will entail having the appropriate laws and regulations and utlising the technology on offer. This is a significant barrier to adoption which is constantly at the top of user concerns from numerous surveys. For example, a survey of European consumers revealed that they rank privacy as a top priority (Kantar Public, 2022). The survey also showed that European consumers prefer a CBDC to a private digital currency, i.e., crypto assets. It also showed they prefer the digital payments system to be overseen by the central bank or commercial banks instead of private big tech companies (Kantar Public, 2022);
3) Strong cybersecurity protection. A recent MIT Digital Currency Initiative (DCI) and Maiden survey showed that US consumers ranked security as their top concern regarding CBDC. This is followed by convenience or ease of use and privacy (Gjefle et al., 2021; Noll, 2023);
4) It must be convenient and easy to use. It must be hassle-free such that all segments of society can use it, including children, the elderly, etc;
5) It must promote innovation. This could entail programmable payments and the use of smart contracts;
6) Non-interest bearing. This is to mitigate financial disintermediation risks. It will also reinforce CBDC's primary objective as a medium of exchange, not as an alternate digital store of value. It will share the same feature as physical cash, which is also non-interest bearing;
7) Cap on CBDC deposits. This is also to mitigate financial disintermediation risks. It will also deter detrimental digital bank runs. This risk should not be underestimated, particularly in an era of increasing digitalisation and higher interest rates compared

to the past decade. Digitalisation in banking implies that a large amount of funds can be moved around much faster than in the past. For example, in the Senate Banking hearing on the collapse of Silicon Valley Bank (SVB), Federal Reserve Board Vice Chair for Supervision Michael S. Barr testified that USD42 billion of deposits was withdrawn on 9 March. Another USD100 billion was scheduled to leave the next day. This implied USD142 billion in just two days or 81% of SVB's USD175 billion in deposits at the end of 2022 (Son, 2023);

8) Complement to cash. CBDC should co-exist and not replace cash. This will enhance the system's robustness and resilience to adverse shocks; and
9) Functionable offline. This will reinforce the system's robustness, resilience, and inclusiveness. It should be able to function regardless of geographical location and internet connection.

Figure 28
Required conditions for a retail CBDC



Note: A summary of the required conditions for a retail CBDC. Author compilation.

A cap on CBDC deposits seemingly suggests it would limit cross-border payments, making it infeasible and impractical. However, we should remember that a retail CBDC is designed for small denominations and real-time transactions. For large amounts involved in cross-border payments, it is undesirable for it to be settled instantaneously or conducted in real-time. This is the case for SWIFT transfers which require confirmations from both the sender and the receiver.

For large cross-border payments, it is desirable to build in some redundancy and delays. This will act as an added security feature that can reinforce the system's resilience. It will also help to detect fraud, permit time to conduct KYC/AML/CFT checks etc. This is why large wholesale transactions are not settled in real-time. It is based on the same principle.

Future research

How to creatively compensate the banks

Further research will need to be conducted on how policymakers can creatively compensate commercial banks for their continued and vital role in the new CBDC system. This must go beyond just issuing them banking licenses and a franchise value. Some suggestions include i) lowering the reserve requirements for banks. At the same time, regulators may need to step up bank supervision and monitoring to ensure they remain well-capitalised and financially strong. This is particularly true in a more volatile interest rate and inflation environment, as seen by the two bank failures in the US in March 2023. It will be particularly pertinent for the global systemically important banks (GSIB), and ii) providing support for value-added services related to CBDC accounts, e.g., through grants or subsidies.

The authorities may also have to be open to bank mergers and consolidations in some countries. This is because some commercial banks that operate the two-tier CBDC intermediated model could face increased cost pressures. As such, they may lose their competitive edge, leading to a higher probability of mergers or acquisitions by more efficient

banks. Increased competition from non-traditional players in the payments space, such as fintech firms, could also be another driving factor. The bottom line is that commercial banks must be compensated for the essential role they will continue to play and the opportunity cost of funds moving from bank to CBDC deposits.

Cross-border payments and interoperability among foreign CBDCs

The use of CBDC to facilitate cross-border flows is one major area that is just at the early stage of research. There is tremendous potential to lower the cost of cross-border payments. At the same time, there are enormous challenges. These include setting common standards, governance, the legal framework, and ensuring the different CBDCs are interoperable.

For a country like Singapore, one pushback against CBDC is that it already has a well-functioning digital domestic payments system. This is true, but it is confined to the domestic payments space. If we want to consider cross-border flows for efficiency and cost savings, CBDC would have the advantage. It will benefit corporates that are involved in international fund transfers. It will also lower the cost of remittances for the thousands of foreign workers in Singapore who remit money home regularly, e.g., to the Philippines, India, and Bangladesh.

Another counter-argument is that Singapore has already established bilateral real-time retail payment systems with Thailand, Malaysia, and India without CBDC. For example, the linkage of Singapore's PayNow with Thailand's PromptPay (MAS, 2021a), Malaysia's DuitNow (MAS, 2021b), and India's Unified Payments Interface (UPI) (MAS, 2023). However, these are bilateral arrangements. Setting up bilateral arrangements with different countries worldwide is time-consuming, cumbersome, and inefficient. It can be done more efficiently via a CBDC arrangement.

The BIS Innovation Hub (BISIH) already has a number of cross-border CBDC projects. They include i) Multi-CBDC or mBridge – involving the central banks of China, Hong Kong,

Thailand, and the United Arab Emirates (UAE). This aims to facilitate real-time, peer-to-peer, cross-border payments, and foreign exchange transactions using CBDC (BIS Innovation Hub, 2022c); ii) Project Dunbar – involving the central banks of Australia, Malaysia, Singapore, and South Africa (BIS Innovation Hub, 2022a). Financial institutions can use CBDC issued by the participating central banks to transfer funds directly with each other on the shared platform (MAS, 2022); and iii) Project Icebreaker – involving the central banks of Israel, Norway, and Sweden. It is exploring ways for the central banks to interlink their domestic retail CBDC and use it for international payments (BIS Innovation Hub, 2022b).

Chapter 9: Conclusion

CBDC is a new, exciting, and burgeoning area of research. It is the talk of the town and creeping into the general public's lexicon. However, it is a complicated and complex topic that brings together multiple evolving disciplines. They include political economics, financial economics, the payments system, law, and technology. There are two versions of CBDC, a wholesale and a retail CBDC. A wholesale CBDC applies to a small number of interbank players, while a retail CBDC is for the general public. This thesis focuses on retail CBDC.

A retail CBDC is the digital version of physical notes and coins or M0. It is essentially about upgrading sovereign central bank money to ensure it stays relevant in the modern digital era. It will preserve central bank sovereignty, foster financial stability, counter private network effects, and safeguard and promote lower fees in the payments system through increased competition. It can facilitate interoperability among foreign CBDCs. This could lead to substantial savings for cross-border payments and remittances.

The proliferation of crypto assets raised the prospect that privately issued crypto assets, which may have no connections to sovereign fiat currencies, could be used for payments in an economy. This caused central banks to up the ante on their research into CBDC.

Over the centuries, the shape and form of money have constantly evolved, dictated by technology. It is no different today. It has evolved from cowrie shells, paper money, credit cards, to a digital form by way of deposits in commercial banks. There has always existed a complex tango between the form of money and technology. The enduring trait of money is not the physical attributes but the function it plays. Regardless of the form, money must fulfil three functions: a store of value, a medium of exchange, and a unit of account.

Rapid technological advancements have enabled central banks to discuss the possibility of CBDC. We live in an exciting era that occurs once in a century or so. We could witness the birth of a new form of money through a retail CBDC. For the first time in history, the general public can hold a “digital asset” that is a direct liability of the central bank.

However, there are monumental challenges to CBDC adoption. They include the need for 1) appropriate technology to ensure strong cybersecurity; 2) a sound legal framework; 3) policymakers need to consider the design and legal aspects concurrently; 4) manage the operational risks; and 5) foster widespread public support. It is an evolving and demanding project that is subject to changes.

There are necessary conditions that must be in place for the successful adoption of a retail CBDC. The four foundational conditions include 1) maintain the two-tier fractional banking system; 2) operate on a centralised system to facilitate efficiency and RTGS; 3) adopt an intermediated architecture; and 4) follow an account-based rather than a token-based model to aid efficiency and satisfy compliance requirements.

On top of these, other basic requirements need to be in place to increase the chances of a successful adoption. They include 1) a system that aids real-time gross settlement (RTGS); 2) adequate legal measures to protect privacy and data; 3) strong cybersecurity protection; 4) convenient and easy to use; 5) promotes financial innovation; 6) non-interest bearing; 7) cap on CBDC deposits. This is to mitigate the risks of financial disintermediation. It will cement CBDC’s primary function as a medium of exchange, not as a store of value; 8) complement physical cash and not replace it altogether; and 9) able to operate offline and not depend on internet connections.

These conditions address what is needed for CBDC adoption but will not guarantee success. There are other factors that need to be considered, these pertain to social and cultural factors. The government must proactively promote CBDC to aid widespread adoption. They

must convince the public that strict measures and protocols will be implemented to protect users' key concerns, including security, privacy, data protection, and ease of use.

Beyond upgrading and fostering competition in the domestic payments space, the big opportunity for CBDC lies in reducing cross-border fees. Governments are in the best position to drive and set the standards for interoperability among different CBDCs. This will be consistent with the G20 Leaders' Declaration in Bali in November 2022 to explore how CBDC can facilitate and lower the cost of cross-border payments. The ultimate long-term goal is to achieve interoperability among foreign CBDCs.

Central banks will attempt to cover all the bases and prepare as comprehensively as possible. However, technical and teething problems will only surface once they stress test the system. They need to remain flexible and adaptable. The underlying message is to "get going" if they plan to launch in the next 10-15 years. Cybersecurity is a paramount and ongoing challenge that will influence public confidence and social acceptance.

Given the increasing political rivalry between the US and China, CBDC may also take on a political angle. It would be worthwhile to isolate the virtues of CBDC from politics and assess them objectively.

Endnotes

[1] https://www.hkma.gov.hk/eng/key-functions/money/hong-kong-currency/notes/#:~:text=The%20Government%2C%20through%20the%20HKMA,issue%20banknotes%20in%20Hong%20Kong.

The Government, through the HKMA, has given authorisation to three commercial banks, namely The Hongkong and Shanghai Banking Corporation Limited (HSBC), the Bank of China (Hong Kong) Limited, and the Standard Chartered Bank (Hong Kong) Limited, to issue banknotes in Hong Kong.

[2] TPS is calculated by the formula, TPS = number of transactions per block / block time in seconds.

The number of transactions per block is the block size in bytes divided by the average transaction size in bytes.
Block size is the amount of transaction data one block can store, transaction size varies between 226 bytes and 500 bytes.
Block time is the average time needed to confirm a transaction on a network (Ledger Academy, 2022).

References

Aad, E., Young, S., Kinzinger, A., & Lohiya, N. (2020). *Mastercard White Paper: Cashing Out Economic Growth through Payment Digitlisation.pdf*.

Ackermann, R. (2022, September 15). *The Merge is here: Ethereum has switched to proof of stake*. MIT Technology Review. https://www.technologyreview.com/2022/09/15/1059520/the-merge-is-here-ethereum-has-switched-to-proof-of-stake/

Ahnert, T., Assenmacher, K., Hoffmann, P., Leonello, A., Monnet, C., & Porcellacchia, D. (2022). *The economics of central bank digital currency*. *2713*, 52.

Alfonso, V., Kamin, S., & Zampolli, F. (2022). *BIS Working Papers No 989 Central bank digital currencies (CBDCs) in Latin America and the Caribbean*.

Ali, R., & Narula, N. (2019). *Redesigning digital money: What can we learn from a decade of cryptocurrencies?* 13.

Alibaba. (2020, November 12). *Alibaba Cloud Supported 583,000 Orders/Second for 2020 Double 11—The Highest Traffic Peak in the World!* Alibaba Cloud Community. https://www.alibabacloud.com/blog/alibaba-cloud-supported-583000-orderssecond-for-2020-double-11---the-highest-traffic-peak-in-the-world_596884

Alipay. (2021, January). *Information Disclosure Announcement of Non-bank Payment Institutions on Customer Complaints and Handling Situation (2020)—Service Hall—Alipay*. https://cshall.alipay.com/lab/help_detail.htm?help_id=201602076097

Areddy, J. T. (2021, October 19). China Flooding Exposed Risks in Beijing's Plan to Launch Digital Currency. *Wall Street Journal*. https://www.wsj.com/articles/china-flooding-exposed-risks-in-beijings-plan-to-launch-digital-currency-11634654928

Atlantic Council. (2022, November). *Central Bank Digital Currency Tracker*. Atlantic Council. https://www.atlanticcouncil.org/cbdctracker/

Auer, R., & Böhme, R. (2021). *Central bank digital currency: The quest for minimally invasive technology*. 20.

Auer, R., Cornelli, G., & Frost, J. (2020). Rise of the Central Bank Digital Currencies: Drivers, Approaches and Technologies. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.3724070

Australian Financial Review. (2019, March 11). *Fed chairman Jerome Powell just revealed what he fears most*. Australian Financial Review. https://www.afr.com/world/fed-chairman-jerome-powell-just-revealed-what-he-fears-most-20190311-h1c84z

Ba, S. (2020, December 22). *The Development Status and Trend of Global Digital Currency-Che Guevara: Let's Face the Reality and Be Loyal to Our Ideals-Caixin.com*. https://bashusong.blog.caixin.com/archives/239505

Bank of England. (2020a). *Discussion Paper—Central Bank Digital Currency: Opportunities, challenges and design*. 57.

Bank of England. (2020b, July 24). *What is money?* What Is Money? https://www.bankofengland.co.uk/knowledgebank/what-is-money

Bank of England. (2023a). *The digital pound: A new form of money for households and businesses? Consultation Paper*.

Bank of England. (2023b). *The digital pound: Technology Working Paper*.

Bank of Jamaica. (2020, March 31). *A Primer on BOJ's Central Bank Digital Currency » Bank of Jamaica*. Bank of Jamaica. https://boj.org.jm/a-primer-on-bojs-central-bank-digital-currency/

Barchat, C. (2022, October 31). *The Ethereum Merge (ETH 2.0) explained*. MoonPay. https://www.moonpay.com/blog/ethereum-merge-eth-2

Bech, M., & Garratt, R. (2017). Central bank cryptocurrencies. *BIS Quarterly Review, September 2017*, 16.

Bindseil, U. (2019). Controlling CBDC through tiered remuneration. *SUERF, The European Money and Finance Forum, SUERF Paper Note, Issue No 95*, *95*, 11.

Bindseil, U. (2022). *The case for and against CBDC – five years later* (SSRN Scholarly Paper ID 4038828; p. 14). Social Science Research Network. https://papers.ssrn.com/abstract=4038828

Bindseil, U., Panetta, F., & Terol, I. (2021). Central Bank Digital Currency: Functional Scope, Pricing and Controls. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.3975939

BIS. (2016). *A glossary of terms used in payments and settlement systems*.

BIS Annual Economic Report 2021. (2021). *BIS Annual Economic Report 2021*. 118.

BIS Innovation Hub. (2022a). *Project Dunbar—International settlements using multi-CBDCs*. 63.

BIS Innovation Hub. (2022b). *Project Icebreaker: Central banks of Israel, Norway and Sweden team up with the BIS to explore retail CBDC for international payments*. https://www.bis.org/about/bisih/topics/cbdc/icebreaker.htm

BIS Innovation Hub. (2022c). *Connecting economies through CBDC*.

BIS Innovation Hub. (2022d). *Project Tourbillon explores cyber resiliency, scalability and privacy in a prototype CBDC*. https://www.bis.org/about/bisih/topics/cbdc/tourbillon.htm

Bloomberg News. (2021, March 25). China Digital Yuan Will Co-Exist With Alipay, WeChat, PBOC Says. *Bloomberg.Com*. https://www.bloomberg.com/news/articles/2021-03-25/china-digital-yuan-will-co-exist-with-alipay-wechat-pboc-says

Bofinger, P., & Haas, T. (2021, February 1). Central bank digital currencies risk becoming a gigantic flop. *VoxEU.Org*. https://voxeu.org/article/central-bank-digital-currencies-risk-becoming-gigantic-flop

Bordo, M., & Levin, A. (2017, September 23). Central bank digital currency and the future of monetary policy. *VoxEU.Org*. https://voxeu.org/article/benefits-central-bank-digital-currency

Bossu, W., Itatani, M., Margulis, C., Rossi, A. D. P., Weenink, H., & Yoshinaga, A. (2020). Legal Aspects of Central Bank Digital Currency: Central Bank and Monetary Law Considerations. *IMF Working Papers*, *20*(254). https://doi.org/10.5089/9781513561622.001

Browne, R. (2022, May 13). *Regulators are getting nervous about stablecoins after Terra's stunning collapse*. CNBC. https://www.cnbc.com/2022/05/13/regulators-anxious-about-stablecoins-like-tether-after-ust-collapse.html

Brunnermeier, M. K., & Landau, J.-P. (2022). *The digital euro: Policy implications and perspectives*. 53.

Businesswire. (2020, May 14). *Alipay Unveils Enhanced AI-Powered Risk Engine AlphaRisk to Safeguard Businesses Amid Accelerating Digitization | Business Wire*.

https://www.businesswire.com/news/home/20200514005941/en/Alipay-Unveils-Enhanced-AI-Powered-Risk-Engine-AlphaRisk

Callaghan, R. (2021, December 19). *92 Percent of Global Money is Already Digital (Find out who owns 99 percent of It)*. Lifestyle Medicine with Rory Callaghan. https://www.rorycallaghan.com/92-percent-of-global-money-is-already-digital-find-out-who-owns-99-percent-of-it-2/

Cao, A., & Qu, T. (2023, March 4). *China's e-CNY blues: Major test bed shows sluggish adoption*. South China Morning Post. https://www.scmp.com/tech/policy/article/3212245/chinas-ambitious-e-cny-plan-faces-one-giant-hurdle-winning-over-1-billion-consumers-home

Carstens, A. (2021). *Money is one of humanity's greatest inventions. It enables you to specialise in one profession instead of having to do everything by yourself or go through all the fuss of bartering goods. It brings the best out of every individual, according to individual capabilities. Money is, so to speak, the oil that makes the machinery work.* 72.

CBDC Project Overview. (2023). *CBDC Project Overview*. MIT Media Lab. https://www.media.mit.edu/projects/central-banks-and-digital-currency/overview/

CBN Editor. (2020, September 24). *Chinese Bank Cards Increase 8.9% YoY in 2019 to 8.53 Billion—China Banking News*. https://www.chinabankingnews.com/2020/09/24/chinese-bank-cards-rise-8-9-yoy-in-2019-to-8-53-billion/

Cecchetti, S., & Schoenholtz, K. (2021, July 8). Central bank digital currency: The battle for the soul of the financial system. *VoxEU.Org*. https://voxeu.org/article/central-bank-digital-currency-battle-soul-financial-system

Central Bank of Nigeria. (2023, March). *ENaira*. https://www.cbn.gov.ng/currency/enaira.asp

Central Bank of the Bahamas. (2023, March). *Digital Bahamian Dollar Sand Dollar*. https://www.sanddollar.bs

Chainalysis. (2021, February). *Chainalysis-Crypto Crime Report 2021.pdf*. https://go.chainalysis.com/rs/503-FAP-074/images/Chainalysis-Crypto-Crime-2021.pdf

Chainalysis. (2022, February). *The Crypto Crime Report 2022.pdf*. https://go.chainalysis.com/rs/503-FAP-074/images/Crypto-Crime-Report-2022.pdf

Champ, B. (2007). Private Money in our Past, Present, and Future. *Economic Commentary*, *1/1/2007*. https://www.clevelandfed.org/publications/economic-commentary/2007/ec-20070101-private-money-in-our-past-present-and-future

Cheng, J. (2020, April 20). China Rolls Out Pilot Test of Digital Currency. *Wall Street Journal*. https://www.wsj.com/articles/china-rolls-out-pilot-test-of-digital-currency-11587385339

Coeur, B., Cunliffe, J., Bank of International Settlements, European Central Bank, Sveriges Riksbank, Bank of England, Bank of Canada, Bank of Japan, Board of Governors Federal Reserve System, & Swiss National Bank. (2020). *Central bank digital currencies: Foundational principles and core features report no. 1 in a series of collaborations from a group of central banks*. https://www.bis.org/publ/othp33.pdf

Coin Market Cap. (2023, March). *Top Stablecoin Tokens by Market Capitalization*. CoinMarketCap. https://coinmarketcap.com/view/stablecoin/

Dauer, U. (2016, August 30). *German savers lose faith in banks*. MarketWatch. https://www.marketwatch.com/story/german-savers-lose-faith-in-banks-2016-08-30

Demirgüç-Kunt, A., Klapper, L., Singer, D., & Ansar, S. (2022). *The Global Findex Database 2021: Financial Inclusion, Digital Payments, and Resilience in the Age of COVID-19*. The World Bank. https://doi.org/10.1596/978-1-4648-1897-4

Duffie, D. (2022). *THE US, CHINA, AND THE WORLD AT A CROSSROADS*. 11.

Dyson, B., & Hodgson, G. (2016). *Why Central Banks Should Start Issuing Electronic Money*. 44.

Eastern Caribbean Central Bank. (2021, March 31). *Bitt Partners with ECCB to Develop World's First Central Bank Digital Currency in a Currency Union | Eastern Caribbean Central Bank*. https://www.eccb-centralbank.org/news/view/bitt-partners-with-eccb-to-develop-worldas-first-central-bank-digital-currency-in-a-currency-union

ECB. (2022, November 9). *Programmable payments in digital euro*. https://www.ecb.europa.eu/paym/digital_euro/investigation/governance/shared/files/ecb.degov221109_item42programmablepayments.en.pdf?ba49ce86e55322e6df02e690e46ceca8

ECB. (2023). *The digital euro: Our money wherever, whenever we need it*. https://www.ecb.europa.eu/press/key/date/2023/html/ecb.sp230123~2f8271ed76.en.html

Economic Affairs Committee. (2022, January 17). *House of Lords—Central bank digital currencies: A solution in search of a problem? - Economic Affairs Committee*. https://publications.parliament.uk/pa/ld5802/ldselect/ldeconaf/131/13104.htm#_idTextAnchor017

Edelman Global Report. (2023). *2023 Edelman Trust Barometer Global Report.pdf*. https://www.edelman.com/sites/g/files/aatuss191/files/2023-03/2023%20Edelman%20Trust%20Barometer%20Global%20Report%20FINAL.pdf

Emmer, T. (2023, February 23). *Emmer Leads Effort to Squash Financial Surveillance State Initiatives*. Congressman Tom Emmer. https://emmer.house.gov/2023/2/emmer-leads-effort-to-squash-financial-surveillance-state-initiatives

European Commission. (2016, June 9). *Antitrust: Regulation on Interchange Fees* [Text]. European Commission - European Commission. https://ec.europa.eu/commission/presscorner/detail/fr/MEMO_16_2162

European Commission. (2023, March). *European Digital Identity*. https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/europe-fit-digital-age/european-digital-identity_en

European Data Protection Supervisor. (2019, August 5). *Libra network joint statement_en.pdf*. https://edps.europa.eu/sites/edp/files/publication/19-08-05_libra-network-joint-statement_en.pdf

European Parliament. (2023, March 16). *Parliament ready to negotiate with Council for an EU-wide digital wallet | News | European Parliament*. https://www.europarl.europa.eu/news/en/press-room/20230315IPR77508/parliament-ready-to-negotiate-with-council-for-an-eu-wide-digital-wallet

Fanti, G., & Kostiainen, K. (2022, June). *Missing Key: The Challenge of Cybersecurity and Central Bank Digital Currency*. https://media-exp2.licdn.com/dms/document/C561FAQGxhYOfM1HRRg/feedshare-document-pdf-analyzed/0/1655381658269?e=1656547200&v=beta&t=5aKBpPYqhTd-C8IHXOcF8UVT8RslmcnfNVrI6WemYTw

FDIC. (2023, March 12). *FDIC Creates a Deposit Insurance National Bank of Santa Clara to Protect Insured Depositors of Silicon Valley Bank, Santa Clara, California*. https://www.fdic.gov/news/press-releases/2023/pr23016.html

Federal Reserve. (2020, March 9). *The Fed—How long is the lifespan of U.S. paper money?* Board of Governors of the Federal Reserve System. https://www.federalreserve.gov/faqs/how-long-is-the-life-span-of-us-paper-money.htm

Federal Reserve. (2021, December 7). *2022 Currency Budget*. https://www.federalreserve.gov/foia/files/2022currency.pdf

Federal Reserve. (2022, May 6). *The Fed—How much does it cost to produce currency and coin?* Board of Governors of the Federal Reserve System. https://www.federalreserve.gov/faqs/currency_12771.htm

Federal Reserve. (2023, March 15). *Federal Reserve announces July launch for the FedNow Service*. Board of Governors of the Federal Reserve System. https://www.federalreserve.gov/newsevents/pressreleases/other20230315a.htm

FIS Worldpay. (2022, March). *Global e-commerce Market Projected to Grow 55 Percent by 2025, FIS Study Finds—Press Releases | FIS*. FIS Global. https://www.fisglobal.com/en-sg/about-us/media-room/press-release/2022/global-e-commerce-market-projected-to-grow-55-percent-by-2025-fis-study-finds

G20 Leaders. (2022, November 16). *G20 Bali Leaders' Declaration*. G20 Bali Leaders' Declaration. https://www.whitehouse.gov/briefing-room/statements-releases/2022/11/16/g20-bali-leaders-declaration/

Giesecke+Devrient. (2023). *CBDC: Digital cash for everyone, anywhere, anytime*. https://www.gi-de.com/en/payment/central-bank-digital-currencies

Gjefle, E., Herring, Z., Kubli, C., O'Rear, B., & Rakusen, G. (2021). *The Future of Our Money_Centering Users in the Design of Digital Currency*. https://www.maidenlabs.org/_files/ugd/93b65a_242f6839b55a4a80a752b986b39a62e3.pdf

Gnan, E., & Masciandaro, D. (2018). *Do We Need Central BAnk Digital Currency? Economics, Technology and Institutions*. https://www.suerf.org/docx/s_cf0d02ec99e61a64137b8a2c3b03e030_7025_suerf.pdf

Goodfriend, M. (2016). *The Case for Unencumbering Interest Rate Policy at the Zero Bound*. 34.

Greenspan, A. (2008, September 9). *The Age of Turbulence by Alan Greenspan: 9780143114161 | PenguinRandomHouse.com: Books*. PenguinRandomhouse.Com. https://www.penguinrandomhouse.com/books/300162/the-age-of-turbulence-by-alan-greenspan/

Haldane, A. (2015). *How low can you go?* 2.

Hall, I. (2021, March 26). Digital yuan is 'back-up' to private payment platforms, says PBoC. *Global Government Fintech*. https://www.globalgovernmentfintech.com/digital-yuan-is-back-up-to-private-payment-platforms-says-pboc/

H.M. Queen Maxima of the Netherlands, & Carstens, A. (2022, April 18). *CBDCs for the People*. Project Syndicate. https://www.project-syndicate.org/commentary/cbdc-design-for-financial-inclusion-by-agustin-carstens-and-queen-maxima-of-the-netherlands-2022-04

IMF. (2022, October). *World Economic Outlook (October 2022)—China Real GDP growth*. https://www.imf.org/external/datamapper/NGDP_RPCH@WEO

IMF. (2023a, February 16). *Nigeria: 2022 Article IV Consultation-Press Release; Staff Report; and Statement by the Executive Director for Nigeria*. IMF. https://www.imf.org/en/Publications/CR/Issues/2023/02/16/Nigeria-2022-Article-IV-Consultation-Press-Release-Staff-Report-and-Statement-by-the-529842

IMF. (2023b, February 23). *IMF Executive Board Discusses Elements of Effective Policies for Crypto Assets*. IMF. https://www.imf.org/en/News/Articles/2023/02/23/pr2351-imf-executive-board-discusses-elements-of-effective-policies-for-crypto-assets

International Monetary Institute. (2022, January 23). *International Monetary Review, January 2022, Vol. 9 No. 1 | IMI*. http://www.imi.ruc.edu.cn/en/PUBLICATIONS/InternationalMonetaryReview/9b8581c6965e474d9c6af6cf80388a83.htm

Kampmann, U. (2012, October 25). The history of Chinese coinage 3 – China invents paper money. *CoinsWeekly*. https://coinsweekly.com/the-history-of-chinese-coinage-3-china-invents-paper-money/

Kantar Public. (2022). *Study on New Digital Payment Methods*. https://www.ecb.europa.eu/paym/digital_euro/investigation/profuse/shared/files/dedocs/ecb.dedocs220330_report.en.pdf

Khan, A., & Malaika, M. (2021). *IMF Working Paper: Central Bank Risk Management, Fintech, and Cybersecurity.pdf*.

Kiff, J. (2022, September). *Taking Digital Currencies Offline*. IMF. https://www.imf.org/en/Publications/fandd/issues/2022/09/kiff-taking-digital-currencies-offline

Kiff, J., Alwazir, J., Davidovic, S., Farias, A., Khan, A., Khiaonarong, T., Malaika, M., Monroe, H. K., Sugimoto, N., Tourpe, H., & Zhou, P. (2020, June 26). *A Survey of Research on Retail Central Bank Digital Currency*. IMF. https://www.imf.org/en/Publications/WP/Issues/2020/06/26/A-Survey-of-Research-on-Retail-Central-Bank-Digital-Currency-49517

Kosse, A., Mattei, I., & Bank of International Settlements. (2022). *Gaining momentum—Results of the 2021 BIS survey on central bank digital currencies*. https://www.bis.org/publ/bppdf/bispap125.pdf

Laboure, M. (2021). *The Future of Payments: Series 2. Part 2. When digital currencies become mainstream*. 23.

Lariccia, F. (2018). *Central Bank Digital Currency: A Macro-Financial Perspective*. https://doi.org/10.13140/RG.2.2.14624.43525

Ledger Academy. (2022, December 16). *Transactions Per Second (TPS)*. Ledger. https://www.ledger.com/academy/glossary/transactions-per-second-tps

Lee, A. (2021, March 26). *China's digital yuan will 'provide backup' if Alipay, WeChat Pay hit problems*. South China Morning Post. https://www.scmp.com/economy/china-economy/article/3127136/china-digital-currency-provide-backup-alipay-tencents-wechat

Madiega, T. (2022). Digital markets act. *European Parliamentary Research Service*, 12.

MAS. (2021a, April 29). *Singapore and Thailand Launch World's First Linkage of Real-time Payment Systems*. https://www.mas.gov.sg/news/media-releases/2021/singapore-and-thailand-launch-worlds-first-linkage-of-real-time-payment-systems

MAS. (2021b, September 27). *Singapore's PayNow and Malaysia's DuitNow to Link in 2022*. https://www.mas.gov.sg/news/media-releases/2021/singapore-paynow-and-malaysia-duitnow-to-link-in-2022

MAS. (2022, March 24). *Project Dunbar*. https://www.mas.gov.sg/publications/monographs-or-information-paper/2022/project-dunbar

MAS. (2023, February 21). *Launch of Real-time Payments between Singapore and India*. https://www.mas.gov.sg/news/media-releases/2023/launch-of-real-time-payments-between-singapore-and-india

Massi, M., Sullivan, G., Strauß, M., & Khan, M. (2019, May 28). *How Cashless Payments Help Economies Grow*. BCG Global. https://www.bcg.com/publications/2019/cashless-payments-help-economies-grow

McCook, H. (2014, July 5). *Under the Microscope: The Real Costs of a Dollar*. https://www.coindesk.com/markets/2014/07/05/under-the-microscope-the-real-costs-of-a-dollar/

McKinsey & Company. (2020). *How COVID-19 has pushed companies over the technology tipping point—And transformed business forever*. 9.

McKinsey & Company. (2022, October). *The 2022 Mckinsey Global Payments Report*. https://www.mckinsey.com/~/media/mckinsey/industries/financial%20services/our%20insights/the%202022%20mckinsey%20global%20payments%20report/the-2022-mckinsey-global-payments-report.pdf

Meir, N. (2021, July 22). Atlantic Council releases new state-of-the-art Central Bank Digital Currency Tracker. *Atlantic Council*. https://www.atlanticcouncil.org/news/press-releases/atlantic-council-releases-new-state-of-the-art-central-bank-digital-currency-tracker/

Minwalla, C. (2020, June 24). *Security of a CBDC* (No. 2020–11). Bank of Canada. https://doi.org/10.34989/san-2020-11

Muir, M. (2023, March 13). Central banks' digital currency plans face public backlash. *Financial Times*.

Noll, F. (2023). *What Consumer Surveys Say about the Design of a U.S. CBDC for Retail Payments*.

PBOC. (2021, July). *Progress of Research & Development of e-CNY in China*. http://www.pbc.gov.cn/en/3688110/3688172/4157443/4293696/2021071614584691871.pdf

Pichler, P., Summer, M., & Weber, B. (2020). *Does digitalization require Central Bank Digital Currencies for the general public? In: Monetary Policy and the Economy 4/2019*.

Prasad, E. S. (2021). *The Future of Money: How the Digital Revolution Is Transforming Currencies and Finance*. Harvard University Press.

PYMNTS. (2022, March 13). *Ethereum 2.0 Will Not Be Any Faster, Vitalik Buterin Said. But It Will Still Scale Massively*. https://www.pymnts.com/blockchain/2022/ethereum-2-0-will-not-be-any-faster-vitalik-buterin-said-but-it-will-still-scale-massively/

Quarles, R. (2021). *Parachute pants and central bank money*. 6.

Radage, K. (2022, October 25). Clearly Payments—Interchange fees by country. *Credit Card Processing and Merchant Account*. https://www.clearlypayments.com/blog/interchange-fees-by-country/

Redmond, P. (2021, December 2). *The History of Paper Money—Clear Junction*. https://clearjunction.com/blog/the-history-of-paper-money/

Reuters. (2023, February 25). *Banning cryptocurrencies should be an option for financial stability*. South China Morning Post. https://www.scmp.com/tech/policy/article/3211527/banning-cryptocurrencies-should-be-option-ensure-financial-stability-imf-says-discussing-debt

Richey, E. (2017, October 26). *Cashless Cities: Realizing the Benefits of Digital Payments*. PaymentsJournal. https://www.paymentsjournal.com/cashless-cities-realizing-benefits-digital-payments/

Robertson, J. (2012). *Future Money: Breakdown or Breakthrough?* Green Books.

Sanchez-Roger, M., & Puyol-Antón, E. (2021). Digital bank runs: A deep neural network approach. *Sustainability (Switzerland)*, *13*(3), 1–18. https://doi.org/10.3390/su13031513

Schweizerische Eidgenossenschaft, The Federal Council. (2019). *Central bank digital currency—Federal Council report in response to the Postulate 18.3159, Wermuth, of 14.06.2018*. 40.

Seeh, F. (2021, February 23). *How new entrants are redefining cross-border payments*. https://www.ey.com/en_sg/banking-capital-markets/how-new-entrants-are-redefining-cross-border-payments

Sewall, S., & Luo, M. (2022). *The Geopolitics of Digital Currency*. 26.

Shabsigh, G., Khiaonarong, T., & Leinonen, H. (2020). Distributed Ledger Technology Experiments in Payments and Settlements. *FinTech Notes*, *20*(01). https://doi.org/10.5089/9781513536330.063

Shah, D., Arora, R., Du, H., Darbha, S., Miedema, J., & Minwalla, C. (2020, February 25). *Technology Approach for a CBDC* (No. 2020–6). Bank of Canada. https://doi.org/10.34989/san-2020-6

Shinn, J., Chantry, S., & Bahamon, D. (2023, February 21). CBDCs can help central banks tame inflation. *OMFIF*. https://www.omfif.org/2023/02/cbdcs-can-help-central-banks-tame-inflation/

Sigalos, M. (2022, January 6). *Crypto scammers took a record $14 billion in 2021*. CNBC. https://www.cnbc.com/2022/01/06/crypto-scammers-took-a-record-14-billion-in-2021-chainalysis.html

Sigalos, M., & Browne, R. (2022, October 13). *Tether, world's biggest stablecoin, cuts its commercial paper holdings to zero*. CNBC. https://www.cnbc.com/2022/10/13/tether-worlds-biggest-stablecoin-cuts-commercial-paper-to-zero.html

Soderberg, G., Bechara, M., Bossu, W., Che, N., Kiff, J., Lukonga, I., Mancini-Griffoli, T., Sun, T., & Yoshinaga, A. (2022). *Behind the Scenes of Central Bank Digital Currency: Emerging Trends, Insights, and Policy Lessons*. 35.

Son, H. (2023, March 28). *SVB customers tried to withdraw nearly all the bank's deposits over two days, Fed's Barr testifies*. CNBC. https://www.cnbc.com/2023/03/28/svb-customers-tried-to-pull-nearly-all-deposits-in-two-days-barr-says.html

Statista. (2023a). *Statista: Germany CIC to GDP 2010-2021*. Statista. https://www.statista.com/statistics/1096226/cic-to-gdp-ratio-in-germany/

Statista. (2023b). *Statista: US CIC to GDP 2001-2021*. Statista. https://www.statista.com/statistics/1337708/cic-to-gdp-ratio-in-usa/

Sveriges Riksbank. (2017). *The Riksbank's e-krona project*. 8.

Sveriges Riksbank. (2022). *First banknotes in Europe*. https://www.riksbank.se/en-gb/about-the-riksbank/history/historical-timeline/1600-1699/first-banknotes-in-europe/

SWIFT. (2014). *Reducing risk and increasing resilience in RTGS payment systems.pdf*.

Treasury Inspector General for Tax Administration. (2021). Implementation of Economic Impact Payments. *Implementation of Economic Impact Payments*, 37.

Turrin, R. (2021). *Cashless: China's Digital Currency Revolution*. Authority Publishing. https://books.google.com.sg/books?id=YO1bzgEACAAJ

US Federal Reserve. (2018, October 18). *Changes in U.S. Payments Fraud from 2012 to 2016: Evidence from the Federal Reserve Payments Study*. Board of Governors of the Federal Reserve System. https://www.federalreserve.gov/publications/2018-payment-systems-fraud.htm

Waller, C. J. (2021). *Christopher J Waller: CBDC - A Solution in Search of a Problem?* https://www.bis.org/review/r210806a.htm

Wang, H. (2022). *How to Understand China's Approach to Central Bank Digital Currency?*

Wang, X., & Zhang, Z. (2023, January 30). *What's in store for yuan internationalization in 2023?* Nikkei Asia. https://asia.nikkei.com/Spotlight/Caixin/What-s-in-store-for-yuan-internationalization-in-2023

WhisperCash. (2023). *WhisperCash—Offline Central Bank Digital Currency*. https://www.whispercash.com/

White House. (2022a, March 9). *Executive Order 14067—Ensuring Responsible Development of Digital Assets | The American Presidency Project*. https://www.presidency.ucsb.edu/documents/executive-order-14067-ensuring-responsible-development-digital-assets

White House. (2022b, May 4). *National Security Memorandum on Promoting United States Leadership in Quantum Computing While Mitigating Risks to Vulnerable Cryptographic Systems*. The White House. https://www.whitehouse.gov/briefing-room/statements-releases/2022/05/04/national-security-memorandum-on-promoting-united-states-leadership-in-quantum-computing-while-mitigating-risks-to-vulnerable-cryptographic-systems/

White House. (2022c, September). *Policy Objectives For a U.S. Central Bank Digital Currency System*. https://www.whitehouse.gov/wp-content/uploads/2022/09/09-2022-Policy-Objectives-US-CBDC-System.pdf

White House. (2022d, September). *Technical Design Choices For a US Cenral Bank Digital Currency System*. https://www.whitehouse.gov/wp-content/uploads/2022/09/09-2022-Technical-Design-Choices-US-CBDC-System.pdf

White House. (2022e, September). *Technical Evaluation For a US Central Bank Digitial Currency System*. https://www.whitehouse.gov/wp-content/uploads/2022/09/09-2022-Technical-Evaluation-US-CBDC-System.pdf

White, L. H. (2018, April 2). *The World's First Central Bank Electronic Money Has Come – And Gone: Ecuador, 2014-2018 | Cato at Liberty Blog*. https://www.cato.org/blog/worlds-first-central-bank-electronic-money-has-come-gone-ecuador-2014-2018

White, L. H. (2021, May). *Should the State or the Market Provide Digital Currency?* | *Cato Institute*. https://www.cato.org/cato-journal/spring/summer-2021/should-state-or-market-provide-digital-currency

Wong, J. C. (2019, March 18). The Cambridge Analytica scandal changed the world – but it didn't change Facebook. *The Guardian*. https://www.theguardian.com/technology/2019/mar/17/the-cambridge-analytica-scandal-changed-the-world-but-it-didnt-change-facebook

World Bank. (2022, September). *Remittance Prices Worldwide—Making Markets More Transparent*. https://remittanceprices.worldbank.org/

World Bank. (2023). *Annual global real GDP growth (annual %)* |. https://data.worldbank.org/indicator/NY.GDP.MKTP.KD.ZG

World Bank, & KNOMAD. (2022). *Remittances Brave Global Headwinds*.

Zhang, J. (2019, November 20). *Here's how Alibaba powered billions of transactions on Singles' Day*. South China Morning Post. https://www.scmp.com/tech/e-commerce/article/3038539/how-alibaba-powered-billions-transactions-singles-day-zero-downtime