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Central Bank Digital Currencies – Lessons from China

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This paper critically reviews the lessons learnt from the testing of China's digital currency, the e-CNY. Using a theory-based case study, it looks at the e-CNY testing through the lens of the academic literature on Central Bank Digital Currencies (CBDCs). The controlled field experiments by the Peoples Bank of China tested the technology, consumer usage and transaction robustness of the e-CNY. The results of this testing are collated, and the paper compares the transactions per second with other digital money offerings. It also investigates the results in the context of privacy and monetary policy. It is observed that several lessons can be learnt. These are that (1) CBDC testing needs to be phased and incorporate techniques, approaches, tools, and frameworks; (2) retail CBDCs compete with private forms of digital money for share of wallet; (3) the hybrid co-development model allows for a robust CBDC offering; and (4) privacy concerns and digital literacy impact user uptake. It is concluded that there is a role for retail CBDCs and that those central banks that are exploring the possibility should develop a testing regime.

Keywords: e-CNY, RMB, digital yuan, CBDC, central bank digital currencies, PBOC

1. INTRODUCTION

China has been testing its digital Yuan (e-CNY) Central Bank Digital Currency (CBDC) in response to the increased use of privately issued cryptocurrencies. At the same time there is a growing focus on CBDCs in developed countries. The Peoples Bank of China (PBOC) claims several successes from which these jurisdictions and academics can learn. This paper documents the testing of the e-CNY using publicly verifiable sources. As a theory-based case study, it looks critically at the process and the lessons learnt in the context of the scholarly research on CBDCs. This approach differs from traditional empirical testing in as much as the contextual conditions are not specified and/or controlled. Instead, the case study is selected because it is of scholarly interest [32].

The essence of a single case study approach is in identifying the new issues that arise [16]. In this respect, the e-CNY is worthy of investigation because it is a novel form of official legal tender in China, and is a substitute for cash in circulation. In other words, it is a retail CBDC. Its roll out is of relevance to other jurisdictions considering the issuance of CBDCs. As part of the M0 money supply, the e-CNY coexists with physical Yuan (CNY), also referred to the Renmimbi (RMB). As at 10th October 2022, the public have entered into a total volume 100 billion yuan (US$13.9 billion) of transactions using it.

The development and implementation of the e-CNY can be viewed as a strategic move by China to establish an alternative to the US dollar-dominated global financial system. This move can potentially endow China with greater monetary autonomy and help China reduce its reliance on the US dollar for international trade and transactions. It

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therefore fits the criteria for a relevant case study.

The e-CNY is defined as follows:

Definition 1.1 (The Digital Yuan: e-CNY)**.** A digital version of fiat Chinese currency issued by the PBOC. It is operated by second tier authorized banks and payment service providers. It is an account-based hybrid payment instrument. It is value-based and enjoys legal tender status (adapted from PBOC (2021) working document).[1]

By way of background, the PBOC issued a warning about cryptocurrencies (that are not legal tender in China) in September 2021.[2] Coincident with this, in 2020, the Payment and Clearing Association of China produced results of a survey that showed that 74 percent of the country used mobile devices to make payments on a daily basis.[3] These digital payments are distinct from crpytocurrencies. The dominant providers are WeChat Pay and Alipay. They are both digital wallet services that are built on top of their respective messaging platforms, WeChat and AliExpress. They allow users to store money in a virtual account, which can then be used to make payments for goods and services, transfer money to other users, and pay bills. Both services are integrated with bank accounts and credit cards, so users can easily transfer money in and out of the digital wallet.

There are two key concerns relating to retail CBDCs. The first is that they undermine efficient credit allocation due to an increase in central bank balance sheets at the expense of banks. If retail customers shift their deposits from commercial banks to CBDCs, it could potentially reduce the funds available for banks to lend. This could hinder their ability to efficiently allocate credit. The second is that they could also potentially undermine financial stability as it becomes easier to transfer thereby facilitating bank runs. Kumhof and [24] investigate these and find that it is neither possible to avoid a reduction in bank funding, nor a contraction in private sector liquidity and credit provision. These issues are explored further in section five. The case study builds on the existing insights gained into testing of CBDCs. For example, [26] provide some lessons learnt from CBDC pilots in the Caribbean, Europe and Latin America. They suggest that pilot programs are critical to the operations and execution of a CBDC. They also suggest that the CPMIIOSCO Principles for Financial Market Infrastructures (on Payment and Systems (2012)) are a useful guide to operations, governance, and management of a CBDC.

Their paper contributes to the debate on whether central banks should sponsor retail or wholesale CBDCs. Athanassiou [1] highlight the approach to the latter, where central banks have been testing the operational use of Distributed Ledger Technology (DLT) in real-time gross settlement of large-value domestic and cross border payments. This contrasts with the retail approach taken by the PBOC [21]. This is best explained by detailing the technical specification which is done in section three.

2. METHOD

As explained, this is a theory-based case study. It is written within the context of scholarly research on CBDCs. As a methodological approach, this differs from traditional empirical testing in that it does not specify or control for surrounding conditions. Instead,

[1] The various terms relating to the Peoples Bank of China's (PBOC) central bank digital currency (CBDC) include inter-changeably the e-CNY, CNY, and RMB, all part of the M0 money supply.
[2] http://www.pbc.gov.cn/goutongjiaoliu/113456/113469/4348521/index.html
[3] http://www.xinhuanet.com/fortune/2021-01/14/c1126980065.htm

it allows for an in-depth analysis of the e-CNY's development, implementation, and outcomes, enabling a holistic understanding of the lessons learned.

To gather data for this study, a comprehensive review of existing scholarly literature on CBDCs was conducted. This literature review served as a theoretical framework to guide the analysis of the e-CNY testing process. Additionally, publicly available sources such as official reports, white papers, and statements from the PBOC were reviewed and utilized as primary sources of information. This was to ensure transparency and the credibility of the data collection process.

The analysis of the compiled information focused on the technology, consumer usage, and transaction robustness. The collected data is synthesized, allowing for a comparison of the e-CNY's performance in terms of transactions per second with other digital money offerings. In Sections 4 and 5, the findings are contextualized within the domains of privacy and monetary policy to gain a comprehensive understanding of their implications.

The limitations of this case study approach should be acknowledged. As a single example, the findings may not be directly comparable to other CBDC initiatives. At the same time, the reliance on publicly available sources may introduce potential biases or gaps in the data. Nonetheless, efforts have been made to ensure validity of the sources used and the insights stand-alone from the data.

Overall, the utilization of a theory-based case study approach offers a valuable methodological framework for critically examining the introduction of the e-CNY. The method allows for a nuanced exploration of the relationships and complexities surrounding China's digital currency initiative, contributing to the scholarly discourse on CBDCs, and providing insights for future research and policy-making in this domain [9].

3. TECHNICAL SPECIFICATIONS

This section details the technical specifications of the PBOC's CBDC, the e-CNY (as distinct from CBDCs issued by other central banks). The e-CNY is technology neutral in its distribution, although some of the PBOC partners may choose to utilize distributed ledger technology (DLT). As a cash substitute, the e-CNY has a face value that can vary and its transfer is made by digital data strings. Unlike in Europe and the United States, in the authors opinion, China does not have a well-developed debit and credit card system.[4] Its digital payment backbone is built on proprietorial systems owned by Alibaba (AliPay) and Tencent (WeChat Pay). These use QR codes that connect with digital wallets. When making a payment, the user displays a QR code on their phone, which the merchant scans to confirm the transaction. The money is then transferred from the user's virtual account to the merchant's account.

The QR code approach is conducive to a retail CBDC. This is because, in order to have successfully transaction, a buyer must acquire a means of payment and have it accepted at the point of sale. There then must be an exchange of (digital) money with the seller. The seller, in turn, must be able to use it as a payment method in other transactions. Using the current Chinese retail QR infrastructure, the e-CNY is built on a hybrid technical framework. It employs distributed infrastructure, utilizing the aforementioned digital wallets and QR codes. The framework is defined as follows,

[4] https://www.brookings.edu/research/chinas-payments-u-turn-government-over-technology/

Definition 3.1 (Hybrid technical framework)**.** The e-CNY utilizes a hybrid technical framework. It is built on a Tier 1 centralized architecture that combines with the distributed architecture of its Tier 2 banks. This supports both a steady state and an agile state which allows for co-development of functionality.

A beta version of the e-CNY was made available at the start of 2022. This was designed to be used in combination with iOS and Android on Chinese app stores. The app allows consumers to transfer money from a bank account to a downloaded digital wallet on their mobile device. This gives the user a choice of commonly used social payment platforms, including Alipay and WeChat Pay. The hybrid technical framework also makes use of the PBOCs banking co-developers distributed infrastructure. This is defined as follows:

Definition 3.2 (Distributed infrastructure)**.** The distributed infrastructure of the Tier 2 banks facilitates decentralized payments through DLT protocols that allow for simultaneous access, validation and record keeping. In order to do this the Tier 2 banks utilize their computer network and multiple nodes or locations, typically over the Internet.

As a retail offering, the e-CNY is account-based. This means it is able to verify the identity of the account holder [19]. This contrasts with a token- based wholesale CBDC, which relies on the ability of the paying institution to verify the validity of a transaction. In the latter, a token is resided on a blockchain and is a digital asset that represents a certain value. The distinction is important to understand the difference tests of CBDCs globally. A wholesale CBDC is based on a permissioned DLT and is issued and controlled by the central bank. It is used to settle large-value transactions between banks, but not intended to replace cash or other retail payment systems. On the other hand, a retail CBDC is intended for use by the general public, for everyday transactions and payments. A retail CBDC is available to individuals and businesses, just like cash or other forms of electronic money. It is used for small-value transactions.

In contrast to the limited testing of retail CBDCs, there are several large-scale tests of wholesale CBDCs. The Bank of International Settlements (BIS), for example, has conducted four successful experiments focused on wholesale CBDC and their use in cross border payments [4]. The Bank of Canada (BOC) has been conducting research and experimentation on CBDCs since 2016. In 2020, they ran a pilot program with a small number of participants to test the feasibility of a wholesale CBDC system. The European Central Bank (ECB) has also been conducting research on CBDCs, and in 2020 they announced the launch of a pilot program called "Target Instant Payment Settlement (TIPS)". The Bank of England (BOE) only started exploring CBDCs in early 2020. The BoE started its pilot program in collaboration with several financial institutions and has put out to tender the development of code.

Other notable wholesale CBDC projects include, the Monetary Authority of Singapore (MAS), which has been working on a project called "Project Ubin" since 2016, and the Swiss National Bank (SNB) has been running a pilot project called "Project Helvetia". The testing of Project Helvetia showed that wholesale CBDCs were faster and cheaper than traditional digital methods (BOC, 2022).

The Federal Reserve of United States (Fed) has also started exploring the potential use of CBDC, but they are in the early stages of study and research and have not yet announced a pilot program. Other distributed wholesale examples include Project Atom in Australia. That uses a permissioned blockchain run on the Ethereum network. The Saudi Central Bank and Central Bank of the United Arab Emirates (UAE) use IBM's Hyperledger as their platform.

A description of the various wholesale CBDC tests can be found in [25]. In that review, the authors question the performance, scalability, and cross-chain interoperability of some of these wholesale blockchain CBDCs.

3.1 The Design of the e-CNY

The initial design of the e-CNY was proposed by Yao [35] and subsequently enhanced in Yao [36]. The essential elements of the e-CNY are as follows:

- Account-based,
- Value-based,
- No-interest accrual,
- Low cost,
- Settlement upon payment,
- Anonymity (managed anonymity),
- Safety,
- Smart contract programmability.

This configuration gives e-CNY all the properties and functions of cash, a medium to establish account, a transaction token and a store of value. The PBOC has made e-CNY legal tender and the state is the only issuer. That said, it distributes the eCNY through approved operators. Despite this de-facto outsourcing of innovation on the digital distribution, the Digital Currency Research Laboratory (that is leading the PBOC side of the development) has over 40 patents protecting its intellectual property.[5]

In his speech at the Budapest Eurasia Forum in October 2020, former Governor of the People's Bank of China (PBOC), Xiaochuan Zhou, discussed the concept of China's two-tier design for its digital yuan. According to Zhou, the design consists of a first tier, comprising the central bank, whose primary responsibility is to supervise and maintain the stability of the digital yuan's value, and to establish reliable settlement and clearing infrastructure for the retail payment system and the broader economy, as well as for financial markets. The second tier, comprising authorized commercial banks and non-bank operators such as telecom operators and third-party payment platforms, are responsible for bearing the liquidity risk of financial markets, complying with anti-business and consumer users' money laundering regulations, and protecting the privacy of their customers. This two-tier approach is presented in Fig. 1. As a two-tier system, the e-CNY uses a centralized system in the relationship between PBOC and the commercial banks (1st tier) and Distributed Ledger Technology in the relationship between commercial banks and customers (2nd tier).

[5] https://www.coindesk.com/markets/2018/06/26/pboc-filings-reveal-big-picture-for-planned-digital-currency/

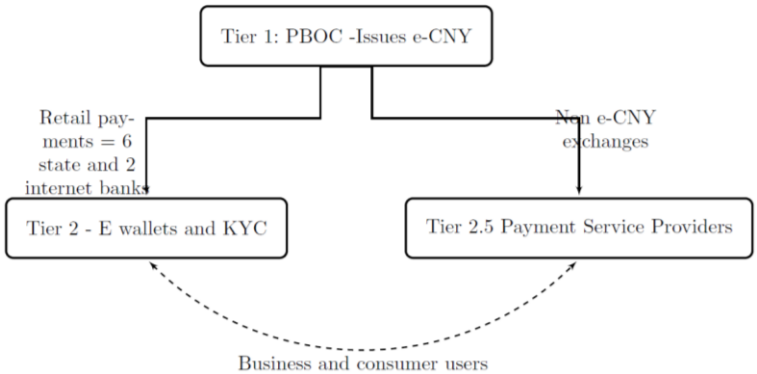

Fig. 1. This figure shows the structure of the e-CNY (Digital yuan) as a centralized digital currency. In order to download an e-CNY account/digital wallet a consumer or retailer has to download the application from a tier 2 institution. Tier 2 institutions are made up of the six largest state-owned banks and two digital banks. Tier 2.5 institutions that are just payment service providers allow interaction with other payment infrastructure companies.

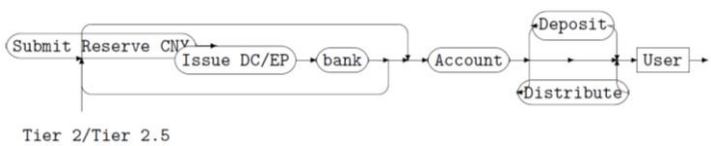

Fig. 2. This figure shows the process for the submission of reserves with the PBOC from the Tier 2 banking institutions and the subsequent issue of digital currency (DC) and electronic payment (EP). The PBOC maintains a basis points method for the submitted reserves, applying a variety of different spreads depending on the deposit maturities.

Fig. 2 presents the structure of the e-CNY. The e-CNY is run on the principle of anonymity for smaller values and traceability for higher values. The PBOC claims the administering system gathers less transaction information than other payment systems due to a security and privacy firewall. It has designated staff who are able to access information based on a tiered authorization that requires official directed requests. The robustness of such protocols was not the subject of testing. As a two-tier system, it is the authorized institutions who develop and share apps in collaboration with the PBOC. As such, the anonymity also relies on the robustness of the co-developed applications.

The Tier 2.5 level of the e-CNY is made up of Payment Service Providers (like AliPay and WeChat Pay). In this way, the CBDC is designed to co-exist with other forms of digital payment. Tier 2 institutions have benefited from the testing environment. In April 2021, Tencent publicly disclosed its phased progress in design, research and development.[6] It launched its Tencent Digital e-CNY Wallet. This allows a WeChat Pay user to scan a retailer collection code through WeChat Pay and make a payment on a pop-up interface. This demonstrates the benefits from co-development.

In summary, the way that the e-CNY design differs from wholesale offerings is that the latter allows the central bank the ability to conduct monetary policy and are typically built using blockchain technology. In this respect, the large values common Tier 2/Tier 2.5 in the transmission network are not anonymous.

[6] https://www.mpaypass.com.cn/news/202204/13115356.html

4. RESULTS

The PBOC conducted a series of trials, the timeline of which is detailed in Fig. 3. The results presented are drawn from public sources. In effect, the controlled field experiments by the PBOC used digital technology as a control variable, consumer usage as an independent variable and transaction robustness as a dependent variable on several issues raised by scholars.

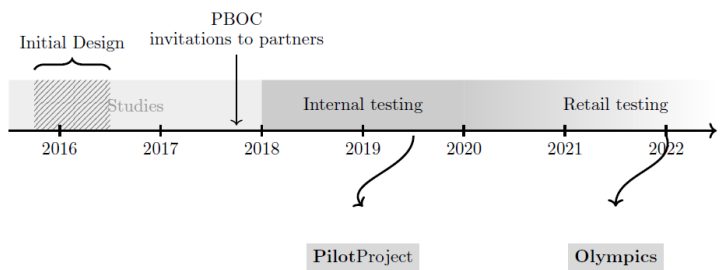

Fig. 3. This figure shows the timeline of the e-CNY testing. In 2016, the PBOC set up the Digital Currency Institute. At the end of 2017, the State Council approved the testing of the e-CNY. As at June 30th 2021, more than 20.8 million individual wallets and in excess of 3.5 million business wallets had been downloaded.

The testing was rolled out by provinces, with the major cities being targeted. The test areas added and cumulative downloads of the application are shown in Table 1.

Table 1. The testing provinces and cities added and the cumulative number of digital wallet applications downloaded.

Date	Testing provinces/cities added	Downloads
Apr-20	Shenzhen, Suzhou, Chengdu, Xiong'an	100,000
Apr-21	Shanghai, Hainan, Changsha, Xi'an, Qingdao, Dalian	100,000(e)
Dec-20	Shenzhen (Futian)	100,000
Mar-21	Tianjin, Chongqing, Guangzhou, Fuzhou, Xiamen, Zhejiang	100,000(e)
Jun-21	Shanghai	350,000
Jun-21	All participating regions	21,000,000
Oct-21	All participating regions	140,000,000
Jan-22	Beijing, Zhangjiakou (Olympics) and rest of China	261,000,000

The testing in Beijing and Zhangjiakou were done during the Winter Olympics, resulting in increased international scrutiny on the nature of the e-CNY. (e) = estimate based on RMB amount transacted of 20m.
Source: Compiled from China Daily and newspaper reports.

The standard measure of performance in payments is Transaction Per Second (TPS). The TPS rate of a digital payment system is important because it determines how many transactions can be processed in a given period of time, which in turn affects the overall speed and efficiency of the system. A high TPS rate means that more transactions can be processed in a shorter period of time, which can lead to faster confirmation times and lower

transaction fees for cryptocurrencies (which is not a concern for CBDCs). On the other hand, a low TPS rate can result in slower confirmation times and a higher likelihood of network congestion and delays. Currently, the TPS rate of Bitcoin is relatively low. This is because the Bitcoin network is based on a proof-of-work consensus mechanism, which is inherently slow and resource-intensive. Other digital currencies or blockchain projects that use different consensus mechanism such as EOS, Ripple and Stellar can handle a higher TPS rate. It is worth mentioning that some digital payments, like those of Visa uses a centralized network and does not rely on a consensus mechanism to validate transactions.

Average payment transaction sizes are around 380 bytes. The speed of transactions on distributed ledgers is therefore a major concern for scalability, particularly where a consensus protocol is used. The Bitcoin blockchain, for example, can only generate approximately 7 transactions per second. The e-CNY is not consensus-based protocol and therefore is able to deliver much higher TPS.

The results of the initial testing are shown in Table 1. The estimated e-CNY 200,000 TPS is based on the 10,000 reported test results. That is still below AliPay which is currently handling 500,000 TPS but is significantly above Visa which is on 1,700 TPS (which is based on its official claim of over 150 million payment transactions per day). The results are significantly better than the Ripple Private Ledger which is currently being tested by the Bank of France (BOF) as a platform for a Euro based CBDC.

Table 2. Transactions per second (2022) efficiency and performance indicator.

Platform	2022 TPS	Future TPS	Observation
e-CNY	10,000	200,000	Promising test results.
AliPay	500,000	500,000+	Fully operational.
Ethereum 2.0	20	100,000+	Proof-of-stake upgrade.
Ripple Private ledger	1,500	Unknown	Testing for digital Euro.
Visa	1,700	1,700+	Aims to improve peak levels.
Hamilton (Boston Fed)	170,000	1,700,000	Exploratory research at MIT.

Sources: Centre for Strategic and International Studies and public statements, Alipay, Ethereum, Ripple, Visa and the Federal Reserve Bank of Boston (Boston Fed) and the Massachusetts Institute of Technology's Digital Currency Initiative (MIT).

The PBOC does not release usage breakdown. That said, Morning Consult, a private provider of high-frequency and survey data, undertook a survey of 1,000 Chinese consumers between May 2-7, 2022.[7] The results, with an unweighted margin of error of +/–3 percentage indicated that 186 of the respondents has downloaded the e-CNY app. 72% of this sub-sample used the e-CNY to shop online, whilst 67% used it to travel on public transport. These two uses were incentivised by discounts to encourage usage. Some 30% of respondents said they were very favourable towards the e-CNY after using it. This is less than the 48% response for AlipPay and 49% for WeChatPay. Interestingly, thirteen percent of the entire sample did not reside in a pilot city, highlighting the large population capture of the trails. Only 15% of those who did not have the app said they preferred cash, whilst 17% preferred AliPay or WeChatPay.

By way of a limitation to the e-CNY case study approach, issues that arose as a result of testing were not made public. That said, the PBOC deputy governor Fan Yifei was re-

[7] https://morningconsult.com/2022/06/13/e-CNY-adoption-in-china-is-coming/

ported to have made the observation in the middle of 2021. While e-CNY test runs showed potential, he said "some problems still need to be solved."[8] In this respect, he identified some weakness in regulatory rules, acceptance environments, and point of sale payment systems.

5. DISCUSSION

The e-CNY testing has demonstrated that it it possible to deploy a CBDC in a retail setting. The usage has, however, been initially lower than anticipated.[9] Despite this, the phased process model approach to the testing reflects the systemic importance of money issuance. Fig. 4 shows how these tests incorporated techniques, approaches, tools, and frameworks. This suggests that the systematic approach is one that other central banks should emulate.

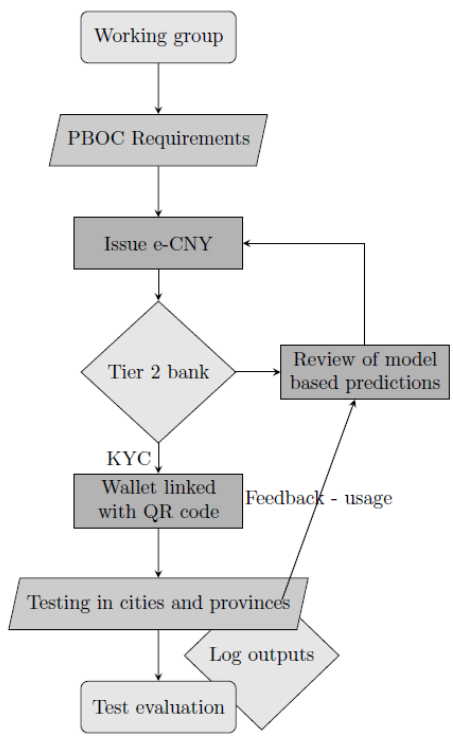

Fig. 4. This figure presents a general process of model-based testing. The testing starts with CBDC design. Using the PBOC working group test criteria, test execution follows in several cities and provinces in which the System Under Test is tested by increasing the number of downloaded applications and encouraging usage by "red packages" (freebies) and discounts. The results of testing are then valuated and modifications/upgrades made.

Whilst there has been testing of wholesale CBDCs in several jurisdictions, retail testing is still nascent. The Chinese tests show that this is an omission, as testing has allowed for further development and refinement of the e-CNY offering.

[8] https://ambcrypto.com/chinas-e-cny-test-runs-show-progress-but-some-problems-still-need-to-be-solved/
[9] https://finance.caixin.com/2022-12-28/101982996.html

The debate on the role of CBDCs has evolved from one of technical capacity to structural reform of the monetary system. In this respect, the testing of the retail eCNY offers valuable insights and supports testing done on wholesale CBDCs in other jurisdictions [21]. Together the evidence provides promising evidence that cash retail and wholesale CBDCs can co-exist, even in competition with other electronic money. The evidence does not, however, extend to private crypto-currencies as these are banned in China. That said, one of the lessons learnt from the testing is that CBDCs do compete for share of wallet and that has important uptake implications for any retail offering. The testing was designed to identify how different groups of consumers reacted. In the Xi'an pilot test, for example, a 100 yuan distribution of e-CNY was made to around 10,000 covid medical staff and volunteer representatives. Initially, the e-CNY were gifted in the form of "red envelopes". These are traditionally ornate red paper envelopes given with a gift of money inserted. In this trial, they were distributed in the form of digital red wallets. The testing evolved and pilot offered discounts of more than 10 million yuan to promote usage. This use of incentives shows that uptake of digital currency is not guaranteed, even if it is made legal tender as was the case with the e-CNY.

The decision to include smart contract programmability into the e-CNY was a bold one because of concerns about potential vulnerabilities. That said, the first application using this functionality was only completed in January 2023.[10] As such, it is too early to tell if this delivers utility to the offering.

In summary the e-CNY testing contributed to two wider debates. One debate is focused on token-based or account-based CNBCs. The testing of the e-CNY shows that there is a role for account-based offerings. The main difference between account and token-based offerings is the nature of the verification required. Token offerings rely on the payee to provide verification that any funds are available. This suggests account-based accounts have an advantage, however the disadvantage is that they need to be managed. The other debate as to whether a CBDC should be interest bearing or not, the e-CNY shows adoption is possible without interest, although the free distributions and discounts offered could be viewed as incentives.

5.1 Monetary Policy

Any CBDC is a central bank liability and as such the testing of the e-CNY is a monetary event. The e-CNY is nominally a CNY/RMB, the dual names for the official currency and unit of account common in China. It therefore serves as a medium of exchange and when fully introduced a store of value. There is however a distinction between the wholesale and the retail market. Current deposits by banking institutions held by the PBOC are deposit claims which are used in the wholesale market for settling high value transactions.[11] Physical RMB and e-CNY, in contrast, incorporate a monetary value and are circulated in the retail market as a means of payment for retail transactions. These are classified as M0 in the money supply.

According to Trading Economics, in June 2022, the PBOC had more than 9,600 billion RMB in outstanding M0 Money Supply. This is the most liquid measure of the money supply including coins, notes and e-CNY in circulation.[12] The total transaction volume of

[10] https://cointelegraph-com.cdn.ampproject.org/c/s/cointelegraph.com/news/china-s-digital-yuan-gets-smart-contract-functionality-alongside-new-use-cases/amp

[11] PBOC is also working with the Bank of International Settlements on a project called mBridge which aims to develop a wholesale CBDC.

[12] https://tradingeconomics.com/china/money-supply-m0

e-CNY, by contrast, was only 83 billion, as of May 31 2022. As such, there should be no measurable impact of e-CNY issuance on monetary policy.

In terms of financial stability, it was noted by [23] that the e-CNY also has a benefit, reducing the risk of corporate default by AliPay or WeChat Pay (both of which have become systemically important in Chinese payments). These platforms charge a vendor fee. In contrast, the e-CNY does not charge a fee. In terms of monetary impact, Barrdear and Kumhof [3] calibrated a DSGE model and found that GDP could be raised perpetually by around 3% if CBDC issuance was around 30% of GDP. This could occur as a result of a reduction in real interest rates and monetary transaction costs. Yang and Zhou [33] also investigated the impact of the e-CNY on monetary policy. They conclude it will speed up the velocity of circulation, increase the multiplier effect and suggest it might improve the transmission effect of existing monetary policy tools. With these findings, it is not surprising that the database on CBDCs is moving to one of structural reform of the monetary system [29]. This debate centers on the nature of CBDCs as a cash only or an interest baring instrument, much the same as the retail versus wholesale division [12].

The scholarly concern about monetary stability is greater when the CBDC accounts are held at the central bank. As these would be risk-free and backed by the central bank, they would be perceived as more attractive than deposits at a bank. In times of concern about the banking system retail deposits could be switched much easier than in the past [6]. As [14] demonstrates, if cash and CBDC are costless, then cash is redundant. In other words, any benefit from using cash can be achieved using just the CBDC. Li and Huang [25] report that the PBOC is keen to avoid this and the disintermediation of commercial bank accounts into e-CNY wallets. It is not clear if there was any evident of this during the testing phase, although this is unlikely given absence of critical mass. The PBOC (2021) also posit the claim that during times of a currency or debt crisis, domestic funds will be withdrawn from e-CNY as well as banks, which no doubt will be subject of future research should the e-CNY become mainstream.

Kumhof and Noone [24] suggests that the way to manage a CBDC conservatively is to link it to an adjustable interest rate and to make the CBDC and central bank reserves distinct, that is not convertible into each other. Kim and Kwon [22] made a theoretical contribution using a monetary general equilibrium model to illustrate how an interest baring CBDC decreases the supply of commercial bank credit, raises the nominal interest rate and lowers reserve-deposit ratios at commercial banks. Berentsen and Schar [5] proposed a system that allows for monetary policy to be effective in such an environment. The e-CNY avoids these issues by not bearing interest. Another approach would be to control the total amount of balances allowable.

5.2 Regulation

This case study also highlights the role of regulation in a successful roll out of a retail CBDC. The testing of the e-CNY did not extend to legal structure and clarity on the rights and obligations of those involved in transaction disputes. As such, liability issues that may arise in the future due to fraud, counterfeiting, loss or theft.

The regulation of the e-CNY falls primarily under the *Law of the Peoples Bank of China* (the law) which was revised to cover both physical and digital forms. The testing phase of the e-CNY led the PBOC to conclude that it required tailor made regulations

(PBOC (2021)). The areas focused on:

- The dissemination of information related to e-CNY, such as its features, usage guidelines, and potential risks. This ensures that the public has access to accurate and comprehensive information.
- The adoption and acceptance of e-CNY among the public and businesses. This focuses on strategies and initiatives to educate and persuade stakeholders about the benefits and advantages of using e-CNY as a digital payment method.
- The guidelines for maintaining comprehensive and reliable records of e-CNY transactions. This helps to ensure transparency, traceability, and accountability in the digital currency ecosystem.
- The requirements for stakeholders to report relevant data and information to the appropriate authorities. This includes transactional data, user information, and other statistics that help in monitoring and regulating the e-CNY system effectively.
- The measures to safeguard the stability, integrity, and security of the digital currency ecosystem, such as risk management frameworks and contingency plans. The measures to protect from fraud, unauthorized transactions, and other risks. These are still in their infancy. In future, they will have to provide for provisions for payment guarantees, redeemability of e-CNY, dispute resolution mechanisms, and mechanisms to address issues related to consumer rights and privacy.

The introduction of CBDCs will require central banks to engage in new areas of oversight, like network or telecommunication systems. Since it would be necessary to guarantee that monetary stability could remain in the event of technical failures. The central banks would have to provide or underwrite resilience. China is aware of these issues. The PBOC claims the e-CNY can used to reduce corruption citing the example of provincial funds being sent to a town. They suggest the digital trail, if paid in e-CNY, would prevent corruption (PBOC (2021)). Whether it proves successful or not in this respect will no doubt be the subject of future research.

5.3 Privacy

Finally, privacy is an important societal topic in China, as elsewhere. As such, the concerns were investigated as well. It was found that in October 2019, China introduced the *National Cryptography Law* that ensured that the e-CNY would have minimum encryption standards. As a result, contrary to some perceptions, China's has an established data protection framework, albeit as Jingchun (2005) explains, shaped by local norms.

The United States has no national-level data protection position. In China, they have a Personal Information Protection Law 2021 which is similar in its provisions to Global Data Protection Regulations (GDPR) in Europe. That said, checks and balances are still required, although these require a trade-off between efficiency and the proof algorithms. An approach favoured by Shamir [31] and Itakura and Nakamura [17] is to use a consensus approach to sensitive data where several of bodies agree to disclosure. In part, e-CNY governance has such checks and balances built into it. At the tier 1 level, meta data is available to PBOC. Chaum and Heyst [10] suggest using group signatures that only reveal when a group member transacted. Some of the e-CNY tier 2 banking applications use zero-

knowledge proofs which can check that an account balance is sufficient for a transaction without revealing the underlying balance [7]. Other approach-es not adopted by e-CNY include homomorphic encryption, Multi-party computation and differential privacy [30, 34, 15].

The privacy concerns potentially impact the roll from a CBDC. Davoodalhosseini [14] argues that a CBDC is costly for retail users because they lose some anonymity. Fig. 5, based on his theoretical work, shows that the impact of this is a lower take up on the e-CNY. This theoretical contribution turned out to be evidence during the testing of the e-CNY. This would suggest that retail CBDCs will likely not replace cash and or other mediums of exchange in the near future.

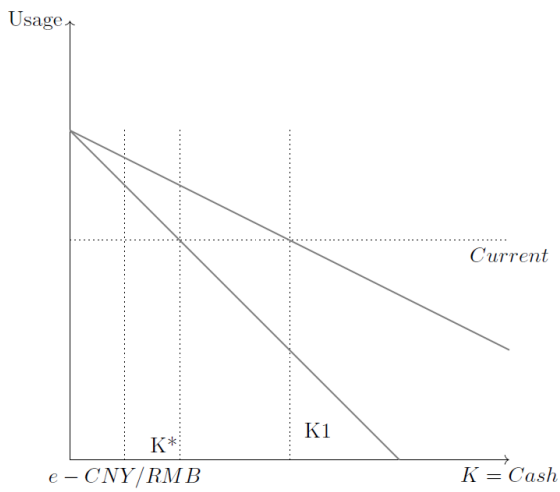

Fig. 5. This figure presents the PBOC's planning problem, namely to maximize welfare of the e-CNY. According to [14] proposition from which it is adapted, the e-CNY will be used retail when K is small, and cash is used when K is large. The e-CNY would be universally accepted if cheaper than RMB cash to implement. The reality is that the cost of the technology will result in an e-CNY mix at point K1. The perceived loss of privacy will however result in a lower uptake at point K*.

The e-CNY addresses the issue of access through the use of wallets. As it is is simultaneously an account-based, quasi-account-based and value-based instrument. This essentially means the claims to the value are stored with a reference to the wallet holder identity, just as in a bank account. Auer and Bohme [2] point out that such an approach requires a strong linkage to identity.

In China, privacy is a controversial subject. Second-generation identity cards have a non-contact IC chip card that includes employment and education history, religion and ethnicity, the individual police, medical and insurance records, as well as controversially their personal reproductive history [20]. The privacy of the e-CNY transaction history is therefore a concern. Privacy is also clearly an area for future scholarly research. Allied to privacy in CBDCs, there has been some work on privacy in digital payments. Chen *et al.* [11] conducted a survey of Alipay customers to examine how digital payment data privacy preferences in China. They found that there was a paradox whereby consumers did have privacy concerns but there was no relationship between these and the number of data-

sharing authorizations they made. Mu Changchun, Director of the PBC's Digital Currency Research Institute (DCI), emphasized the concept of "controllable anonymity" for the digital yuan in his speech at the China Development Forum 2021 Economic Summit. Darbha and Arora [13] observe that a CBDC has to comply with "know your customer" and "anti money laundering" regulations. This impacts the level of privacy as it requires the storage of personal data and classifications. With the e-CNY, this is done at the Tier 2 level by the partner institutions. It is also a key metric in the technical specifications.

To partially address these concerns, in the testing phase, the e-CNY used a tiered approach to privacy, mirroring some aspects of small cash transactions. Those wallets with small balances (1 10,000 e-CNY) and those that have transaction limits (2,000 e-CNY per transaction and 5,000 e-CNY per day) remained anonymous. Requests for larger transaction limits required the user identification and the user had to undergo know your customer due diligence.

6. CONCLUSION

This theory-based case study presented the testing of the e-CNY by the PBOC. It used the academic literature on CBDCs to shed light on the issues being investigated. The most salient of these is the different treatment required for retail as opposed to wholesale CBDCs. Retail CBDCs have unique regulatory and privacy issues. Despite these, the testing of the e-CNY showed that widespread adoption was possible and that the instrument could co-exist with cash and other digital offerings. The testing of the e-CNY also demonstrated that several key aspects need to be tested simultaneously. These include,

- Technical feasibility testing of the infrastructure and systems that will be used to support the CBDC, such as blockchain technology or DLTs.
- Security and resilience testing of the CBDC systems, to ensure they can protect against hacking, fraud, and other malicious activities.
- Scalability testing of the ability of the CBDC systems to handle a large volume of transactions and users.
- Interoperability testing of how well the CBDC systems will integrate with other existing financial systems and technologies.
- User acceptance testing of how well the CBDC systems are accepted and used by the general public and other stakeholders.
- Legal and regulatory testing of the compliance of the CBDC with relevant laws and regulations.
- Monetary policy testing of the impact of CBDC on monetary policy and its ability to achieve the central bank's objectives.
- Economic testing of the impact of CBDC and the potential benefits and drawbacks of CBDC in comparison to other forms of money.

The case study demonstrates that the Chinese government provided an accommodating legal framework in which to introduce the e-CNY, making it legal tender and introducing a cryptography law and revising the *Law of the Peoples Bank of China*. The research shows that addressing record-keeping, reporting and state-wide persuasion through incen-

tives are considerations for other jurisdictions. Privacy was found to be a concern, despite the checks and balances that were built into the system and the national data protection regulations.

Technically, the account-based e-CNY proved robust. It handled 142 million transactions and 261,000,000 digital wallet downloads as at October 2021, an estimated 1 in 5 of the eligible population in the testing area. The graduated testing showed robust scale up, which is encouraging. The co-development proved innovative, with tier two institutions benefiting from the testing phase.

That said, as a case study, there are several areas that could be empirically explored in future studies. For example, understanding factors that influence individuals' willingness to adopt and use CBDCs, such as trust, convenience, privacy concerns, and perceived benefits. Research could also focus on enhancing the user experience of retail CBDCs. This includes exploring user interfaces, accessibility, ease of use, and features that encourage user engagement. From a technical perspective, empirical researchers could explore interoperability, technical challenges, and potential integration with the existing financial ecosystem.

In summary the testing of the e-CNY by the PBOC demonstrated that the feasibility of retail CBDCs in a large economy. As a retail offering, the e-CNY proved fit for purpose. This case study illustrates that such testing is essential for the evolution of the technology and privacy protocols. In the light of these results, it is recommended that central banks in other jurisdictions extend the depth and scope of their retail CBDC proofs of concept and prototypes.

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