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The Digital Yuan vs. the Digital Euro: Diverging Paths in Central Bank Digital Currency Developments

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Abstract. *The emergence of Central Bank Digital Currencies (CBDCs) reflects the evolving role of central banks in digital finance. Among the most advanced initiatives, China's digital yuan (e-CNY) and the European Central Bank's Digital Euro represent contrasting approaches to CBDC design, regulation, and monetary policy. While the e-CNY prioritizes state control, financial sovereignty, and cross-border expansion, the proposed Digital Euro emphasizes privacy, financial stability, and regulatory compliance. This paper critically examines these two initiatives across four key dimensions: technological infrastructure, legal and regulatory frameworks, economic and monetary implications, and security/privacy/ethical considerations. Using a comparative qualitative approach, the paper synthesizes insights from central bank reports, policy research, and academic literature, assessing the trade-offs and challenges each CBDC faces. Findings show that the e-CNY can enhance monetary policy efficiency and adoption yet raises concerns over financial surveillance and capital control risks. The Digital Euro, by contrast, aims to preserve banking sector stability and user privacy, while facing hurdles in regulatory fragmentation and adoption scalability. The paper contributes to the current CBDC discourse by offering a structured comparison, highlighting policy lessons for central banks navigating digital currency implementation, while underscoring the need for harmonized global regulatory standards, balanced trade-offs between privacy and oversight, and the strategic role CBDCs can have for more efficient monetary policy, financial stability and inclusion.*

Keywords: Central Bank Digital Currencies, Central Banks, Digital Yuan, e-CNY, Digital Euro, Monetary Policy, Financial Stability.

Introduction

The rapid evolution of digital technologies promises to transform the global financial landscape profoundly, compelling central banks worldwide to reconsider the structure, issuance, and regulation of money. One significant development arising from this transformation is represented by CBDCs. Defined as a digital form of a nation's sovereign currency directly issued and regulated by a central bank, CBDCs combine the convenience and efficiency of digital transactions with the stability and trust associated with traditional fiat currencies (BIS, 2021; IMF, 2022). According to the Bank for International Settlements (BIS) 2023 survey, approximately 94% of global central banks are currently engaged in CBDC research, experimentation, or pilot programs, highlighting the critical importance central banks attribute to digital currency initiatives (Di Iorio, Kosse & Mattei, 2024). This shift toward digital currency issuance by central banks emerges from several critical factors driving monetary authorities worldwide: first, the global decline in cash transactions and a concurrent rise in digital payments necessitate digital alternatives that maintain central bank authority over monetary systems; second, the rapid adoption and expansion of fintech, cryptocurrencies and stablecoins present competitive challenges that potentially threaten monetary sovereignty, requiring central banks to innovate and provide equally efficient yet more secure digital payment solutions; and finally, CBDCs offer potential improvements in areas such as

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monetary policy transmission and financial inclusion, allowing traditionally underserved populations greater access to secure and cost-effective financial services (Carstens, 2023).

Among the most advanced initiatives in this endeavor are China's Digital Yuan (e-CNY) and Europe's Digital Euro, both of which illustrate distinct approaches to CBDC development and implementation. While China has taken a proactive and aggressive stance, rapidly rolling out large-scale pilots and integrating its CBDC into existing financial ecosystems, Europe has proceeded with caution and deliberation, emphasizing stakeholder consultation and financial stability considerations before committing to full-scale deployment.

As such, this paper looks at some of the progress of China's e-CNY, contrasting these developments with the European Central Bank's (ECB) Digital Euro. The primary aim of this paper is to provide a comparative analysis of the Digital Yuan and the proposed Digital Euro, exploring some key questions such as - what have been the main drivers and features behind China's rollout of the e-CNY and what challenges has it encountered, as well as how does the ECB's approach to the Digital Euro differ and what are its key concerns. By juxtaposing these two approaches to CBDC design and development, this paper seeks to extract some key insights from China's pilot experience and evaluate how they may inform Europe's ongoing efforts in CBDC development.

To address these questions, the study is structured around four critical dimensions that influence the design and adoption of CBDCs: (i) technological and operational considerations, (ii) legal and regulatory challenges, (iii) economic and monetary implications, and (iv) security and ethical concerns. This multi-dimensional approach enables a structured assessment of both the e-CNY and the Digital Euro, highlighting key areas of divergence and potential convergence.

The paper employs a qualitative comparative analysis, synthesizing insights from a range of authoritative sources, including international institutions, central banks, reports from the People's Bank of China (PBoC), the ECB, BIS, the International Monetary Fund (IMF), and independent policy research institutes such as the Atlantic Council. It also integrates findings from recent academic literature and industry reports to ensure a comprehensive understanding of both projects, as well as primary documentation such as ECB working papers on Digital Euro design and China's official white papers on e-CNY development which serve as the foundation for this analysis. By offering a systematic comparison of China and Europe's approaches to CBDC implementation, this study aims to contribute to policy discussions on digital currency development and adoption, with insights which can ultimately be relevant for European and international policymakers currently navigating the complex landscape of digital currency innovation.

Definitions and critical dimensions for analysis

CBDCs are digital representations of fiat currency, issued and regulated by a central bank, serving as legal tender within a given jurisdiction. Unlike digital assets such as cryptocurrencies, which are typically decentralized and subject to market volatility, or stablecoins which are usually emitted by a private entity, CBDCs are backed by the central monetary authority, ensuring stability and trust (BIS, 2021). According to the IMF (2022), CBDCs represent "a new form of central bank money distinct from commercial bank reserves, designed to function as a medium of exchange, unit of account, and store of value", in line with traditional monetary theory holding that sovereign currencies should serve these three primary functions (Friedman, 1971). As economies shift toward digital financial ecosystems, central banks are exploring CBDCs as a means of preserving the role of sovereign currency, facilitating and enhancing its efficiency in terms of its traditional functions, while also seeking to address existent and emerging challenges (Carstens, 2023).

A key rationale for CBDC issuance is the increasing dematerialization of money and the rapid decline in the use of physical cash. With the expansion of digital payment platforms and private-sector financial innovations, the dominance of non-bank financial intermediaries in payment systems has raised concerns about monetary sovereignty and financial stability (Auer, Cornelli & Frost, 2022). CBDCs provide central banks with a public-sector alternative to private digital payments, ensuring that central bank money remains widely accessible and continues to serve as a reliable anchor for the financial system (BIS, 2023). From a financial inclusion perspective, CBDCs can enhance access to secure and cost-effective financial services, particularly in regions where traditional banking infrastructure is weak (World Bank, 2023). Furthermore, by offering a risk-free digital payment instrument, CBDCs reduce dependency on commercial bank deposits, allowing individuals and businesses to hold digital currency directly with the central bank and thereby lowering barriers to participation in the financial sector (IMF, 2023). This is particularly relevant in the context of China's e-CNY, which has been positioned as a tool to promote greater financial accessibility and reduce reliance on dominant private payment providers such as Alipay and WeChat Pay (Broby, 2024). Another critical advantage of CBDCs is their potential to enhance monetary policy transmission mechanisms - unlike physical cash which does not bear interest, CBDCs can be programmable, allowing central banks to implement more targeted policy interventions such as tiered interest rates or automated stimulus disbursements (BIS, 2023). Additionally, CBDCs provide real-time visibility into money flows and spending patterns, enabling policymakers to fine-tune liquidity management and mitigate systemic risks (Auer & Bohme, 2022). Finally, CBDCs offer a means of reducing transaction costs and improving payment system efficiency - through leveraging modern digital infrastructures, central banks can enable instant settlement, eliminating intermediaries and reducing frictions in domestic and cross-border payments (ECB, 2023).

Building upon this definition and rationales behind CBDCs, it is necessary to examine the critical dimensions that shape the design and practical implementation of CBDCs, as these dimensions influence the efficiency and functionality of CBDCs and determine their broader implications.

Technological and operational considerations

Distributed vs. Centralized Systems. The choice between Distributed Ledger Technology (DLT) and centralized digital currency systems remains one of the most pivotal design decisions in CBDC implementation. DLT, associated with blockchain technology, offers decentralized transaction verification, enhanced security, and transparency (BIS, 2023). However, scalability challenges, energy consumption concerns, and the complexity of integrating DLT into existing financial infrastructures pose significant problems (Auer et al., 2022). On the other hand, centralized systems, being managed directly by central banks, can provide greater control over monetary policy and transactional oversight but may introduce single points of failure and cybersecurity risks (World Bank, 2023). Thus, the optimal approach may lie in hybrid models that balance the strengths of both architectures while mitigating inherent limitations.

Interoperability and integration with existing payment infrastructures. For CBDCs to function effectively, seamless interoperability and integration with existing financial systems and payment infrastructure is essential, including integration with domestic Real-Time Gross Settlement systems, retail payment networks, and international financial infrastructure (IMF, 2023).

Offline payments and accessibility. CBDC adoption must account for accessibility challenges, particularly in regions with limited internet connectivity or financial infrastructure. Offline payment functionality is a crucial feature for ensuring financial inclusivity, allowing

transactions to occur even in the absence of continuous internet access (Carstens, 2023). Several pilot programs (including the e-CNY) have tested offline capabilities through near-field communication technology and hardware-secured wallets (BIS, 2022). However, ensuring security, preventing double-spending, and verifying transactions in an offline environment require solutions that balance efficiency and convenience with risk mitigation (IMF, 2023).

Legal and regulatory considerations

Cross-jurisdictional legal status. The legal status and recognition of CBDCs varies significantly across jurisdictions, posing challenges for regulatory compliance and cross-border usage. While some nations have issued legal frameworks recognizing CBDCs as official legal tender, others remain in exploratory phases with unclear regulatory pathways (Atlantic Council, 2023). The absence of harmonized global standards may impede CBDC interoperability and create inefficiencies in international transactions (Financial Stability Board, 2023).

Regulatory harmonization and compliance (AML/CFT). Central banks must design CBDCs to align with existing AML/CFT frameworks while ensuring that digital transactions maintain necessary transparency without undermining user privacy (IMF, 2023). The Financial Action Task Force (FATF) has emphasized the need for robust compliance mechanisms, including digital identity verification and transaction monitoring systems, to mitigate financial crime risks (FATF, 2022).

Data protection and privacy frameworks. Privacy considerations in CBDC design present a critical policy trade-off between user confidentiality and regulatory oversight. While central banks must ensure compliance with data protection laws, excessive surveillance can undermine public trust and eventually adoption (ECB, 2023). More innovative models such as zero-knowledge proof and cryptographic technologies offer potential solutions for balancing transparency with user privacy (Auer & Böhme, 2022).

Economic and monetary implications

Monetary policy and transmission mechanisms. The issuance of CBDCs has significant implications for monetary policy and the monetary policy transmission mechanisms. By offering a digital alternative to cash and commercial bank deposits, CBDCs can influence interest rate dynamics, money supply control, and liquidity management (BIS, 2023). The design of CBDCs - particularly whether they bear interest - could impact their attractiveness relative to traditional banking instruments (Brunnermeier & Landau, 2022). Furthermore, studies suggest that CBDCs can enhance monetary policy effectiveness by providing central banks with direct transmission channels for interest rate adjustments (IMF, 2023).

Financial stability and commercial banking implications. The introduction of CBDCs could alter the traditional role of commercial banks, leading to potential disintermediation if depositors shift funds from bank deposits toward risk-free central bank liabilities (World Bank, 2023). To mitigate this risk, many central banks are exploring deposit limits or tiered remuneration structures to balance CBDC adoption with banking sector stability (Auer et al., 2022). The impact on financial intermediation must be carefully managed to ensure that CBDCs complement rather than disrupt existing financial systems (BIS, 2023).

Financial inclusion. CBDCs also hold significant promise in promoting financial inclusion, particularly in developing economies with unbanked populations (Carstens, 2023). By providing a publicly accessible, low-cost digital payment system, CBDCs can reduce barriers and facilitate greater economic participation (World Bank, 2023). However, effective implementation requires

addressing technological and financial literacy gaps and ensuring robust infrastructure in underserved regions (IMF, 2023).

Security and ethical concerns

Cybersecurity and resilience. As CBDCs become integral to financial systems, ensuring their resilience against cyber threats is paramount, with potential risks including data breaches, hacking, and DDoS attacks (BIS, 2022). Thus, central banks must invest in robust cybersecurity measures such as quantum-resistant encryption and multi-layered authentication protocols, to safeguard CBDC ecosystems (IMF, 2023).

Ethical concerns. Ethical concerns surrounding CBDCs extend to issues of financial surveillance, government overreach and individual autonomy. While CBDCs can enhance financial transparency, excessive state control can erode public trust (Carstens, 2023). Policymakers must ensure that CBDC frameworks incorporate democratic governance principles to uphold financial freedom while maintaining regulatory integrity (IMF, 2023).

China's Digital Yuan: analysis on four dimensions

China's e-CNY represents one of the most advanced and ambitious CBDC pilot projects globally. As designed by the PBoC, the e-CNY aims to enhance financial inclusion, increase the efficiency of the payment system, and provide a state-backed alternative to private digital payment providers (Fullerton & Morgan, 2022). The digital yuan is part of China's broader strategy to modernize its monetary system and potentially challenge dominance in international trade (Caudevilla & Kim, 2022).

Technological and operational considerations

In terms of its technological and operational considerations, the e-CNY is designed as a retail CBDC, intended to complement physical cash and coexist with traditional electronic payments. Unlike many CBDC projects that explore decentralized architectures, the digital yuan follows a two-tier operational model where the PBoC issues the currency and authorized financial institutions distribute it to end users (BIS, 2023). The technological architecture of the digital yuan showcases a hybrid model that combines elements of centralization with some DLT features. The PBoC maintains a centralized ledger that ensures oversight, stability, and regulatory control; however, certain aspects of DLT are incorporated to enhance security, transparency, and efficiency in transactions (Fullerton & Morgan, 2022). This hybrid approach allows for a controlled yet adaptive infrastructure that differs from fully decentralized blockchain-based digital currencies. One of the defining characteristics of the digital yuan is its interoperability with China's existing digital payment ecosystem. The e-CNY has been designed to seamlessly integrate with major private payment networks such as Alipay and WeChat Pay, which dominate retail transactions in China. This level of integration ensures that users can access and utilize the digital yuan through familiar platforms without facing significant technological barriers (Caudevilla & Kim, 2022). By embedding the digital yuan within the well-established digital payment infrastructure, the PBoC seeks to encourage widespread adoption while maintaining monetary sovereignty. Another notable innovation is the e-CNY's ability to facilitate offline transactions. Through the implementation of near-field communication technology, the digital yuan can be used in areas with limited or no internet connectivity, providing an essential feature for ensuring financial inclusion. This offline functionality allows users to conduct peer-to-peer transactions securely without requiring real-time access to banking networks, which is particularly relevant in emergencies or rural areas with underdeveloped financial infrastructure. Additionally, the e-CNY is designed to support

programmability, an advanced feature that allows for the automation of financial transactions through the use of smart contracts. This capability enables conditional payments, policy-based monetary transfers, and embedded compliance mechanisms that could enhance the effectiveness of fiscal and monetary policy measures (Fullerton & Morgan, 2022). The ability to encode rules within the digital currency itself allows for innovative applications such as targeted government subsidies, automated tax collection, and more efficient disbursement of welfare payments.

Despite these technological advancements, challenges remain regarding the scalability and energy efficiency of the digital yuan's infrastructure. The reliance on a centralized system introduces potential points of failure, making the network susceptible to cyberattacks and operational disruptions. Furthermore, the energy consumption required to maintain such a large-scale digital financial system raises concerns about sustainability and long-term feasibility. Addressing these issues will be critical in ensuring the robustness and resilience of the digital yuan as it moves toward broader implementation.

Legal and regulatory considerations

From a legal and regulatory standpoint, the digital yuan is recognized as legal tender within China, requiring all merchants to accept it. However, cross-border usage remains contentious due to monetary sovereignty concerns, capital controls, and geopolitical implications (BIS, 2023). China has actively pursued cross-border CBDC trials under the mBridge Project, a collaboration with BIS, Hong Kong, Thailand, and the UAE, aiming to enhance multi-CBDC interoperability (BIS, 2023). Nevertheless, concerns persist that e-CNY could be leveraged to bypass international sanctions, raising scrutiny from Western economies (Fullerton & Morgan, 2022). The lack of uniformity in global CBDC standards creates loopholes and inefficiencies in cross-border transactions, requiring increased international regulatory coordination (Financial Stability Board, 2023).

China has implemented strict AML and CFT measures for e-CNY transactions. Unlike cryptocurrencies, which offer pseudonymity, the digital yuan follows a "controlled anonymity" model, where small-value transactions retain privacy, but large-value transfers are fully traceable by authorities (Caudevilla & Kim, 2022) By integrating robust compliance mechanisms, including transaction monitoring, real-time reporting and automated fraud detection systems, the e-CNY aims to enhance financial integrity, but concerns over state surveillance remain prevalent (IMF, 2023).

Thus, a critical policy trade-off in CBDC design is the balance between user privacy and regulatory oversight. The e-CNY's centralized ledger system enables authorities to track transactions, raising concerns over financial surveillance and data protection (BIS, 2023). While China has emphasized that data is encrypted, however critics argue that broad government access and back-doors could undermine trust in the system (Fullerton & Morgan, 2022). Emerging privacy-enhancing cryptographic techniques, such as zero-knowledge proofs and multi-party computation could provide solutions to balancing transparency with user confidentiality (Auer & Böhme, 2022). However, China's regulatory approach prioritizes financial security over transactional anonymity, distinguishing it from more privacy-focused CBDC models under consideration in Europe and the US (ECB, 2023). Furthermore, privacy concerns extend to cross-border usage and foreign users - the digital yuan has been tested internationally through the mCBDC Bridge project, raising fears that China could track foreign financial activities or facilitate surveillance beyond its borders (Caudevilla & Kim, 2022). The introduction of programmable money features, which could potentially restrict or condition spending behavior further underscores ethical concerns around financial autonomy (BIS, 2023). Despite assurances that personal financial data will be protected, questions remain about how much transactional anonymity citizens and businesses will retain. Unlike decentralized CBDC models,

China's approach prioritizes financial oversight and state control, making it a powerful tool for monetary governance but a contentious development from a privacy standpoint. As the digital yuan continues to expand, balancing financial security with individual privacy rights will be crucial in shaping its domestic and global acceptance.

Economic and monetary implications

The issuance of the e-CNY can have profound implications for monetary policy transmission. By offering a central bank-controlled digital alternative to cash and commercial bank deposits, the e-CNY enables the PBoC to exercise greater control over money supply and liquidity. One of the key advantages of the e-CNY is its ability to provide real-time transactional data, enhancing the PBoC's capacity to monitor economic activity and fine-tune monetary policy interventions (Fullerton & Morgan, 2022). A crucial consideration is whether the e-CNY could facilitate negative interest rate policies. Since digital currency holdings could be subjected to tiered interest rates or expiration mechanisms, the PBoC may gain a new tool to stimulate spending during economic downturns. However, this would require careful policy calibration to avoid unintended shifts in savings behavior (IMF, 2023; Brunnermeier & Landau, 2022).

Another central concern regarding the e-CNY is its potential to induce commercial bank disintermediation. If depositors shift funds from bank deposits to risk-free e-CNY wallets, banks may face liquidity constraints, reducing their ability to provide credit to businesses and consumers (World Bank, 2023). The PBoC has acknowledged this risk and proposed holding limits on e-CNY wallets to prevent excessive outflows from traditional bank deposits (Caudevilla & Kim, 2022). Additionally, a tiered remuneration structure is considered in order to deter mass migration away from commercial banks while ensuring the digital yuan remains a viable payment instrument (Auer et al., 2022). Another implication for financial stability is the potential change in the cost of funding for banks. If banks lose retail deposits, they may be forced to increase reliance on wholesale funding, leading to higher borrowing costs and reduced credit availability (BIS, 2023). To counteract these risks, the PBoC must carefully design e-CNY policies that integrate seamlessly with China's existing banking system (IMF, 2023).

One of the long-term strategic objectives of the e-CNY is to reduce China's reliance on the US dollar in international trade. The digital yuan has been promoted as a potential settlement currency for Belt and Road Initiative projects and regional trade agreements, including the Regional Comprehensive Economic Partnership (Caudevilla & Kim, 2022). If widely adopted, the e-CNY could enhance China's role in global trade, gradually challenging the dominance of the US dollar in cross-border transactions. While adoption remains limited, successful integration into regional payment infrastructures could increase the international appeal of the digital yuan, especially among countries seeking alternative payment systems to the dollar-based SWIFT (Fullerton & Morgan, 2022). However, the e-CNY's international expansion faces geopolitical resistance, particularly from Western economies concerned about China's ability to bypass international sanctions and control cross-border financial flows.

Lastly, the digital yuan has the potential to enhance financial inclusion, particularly in rural and underserved regions of China. By providing a state-backed, low-cost digital payment alternative, the e-CNY can extend financial services to populations lacking traditional banking access (World Bank, 2023). Additionally, the PBoC has emphasized offline payment capabilities, ensuring that individuals without stable internet access can still use the digital yuan for transactions (Carstens, 2023). However, widespread adoption depends on digital literacy and infrastructure development. While urban areas have readily integrated digital payments, rural populations may

require targeted education initiatives and improved access to mobile banking services (IMF, 2023). Furthermore, ensuring strong cybersecurity measures and data protection will be critical to maintaining public trust in digital financial services.

Security and ethical concerns

The security implications of the digital yuan are a central point of debate, particularly given its state-controlled digital infrastructure. While the PBoC has implemented multi-layered cryptographic security measures, concerns persist regarding its susceptibility to cyberattacks, system failures, and unauthorized data access (Fullerton & Morgan, 2022). The digital yuan relies on a two-tier system, where commercial banks and authorized payment institutions distribute the currency while the PBoC maintains ultimate oversight (Caudevilla & Kim, 2022). This structure, while offering resilience against single-point failures, raises concerns about centralized control over financial transactions. More specifically, China has adopted a tiered privacy model, where low-value transactions allow for some degree of anonymity, whereas high-value transactions are fully traceable, particularly for AML/CFT compliance (BIS, 2023). While this enhances financial security, it has also sparked concerns about mass surveillance, data collection, and potential misuse of financial information by the state (Caudevilla & Kim, 2022). Unlike decentralized digital assets, such as cryptocurrencies, the digital yuan operates within a closed, government-regulated ecosystem, allowing the PBoC to monitor, block, or reverse transactions (Fullerton & Morgan, 2022).

EU's Digital Euro: analysis on four dimensions

Technological and operational considerations

The ECB has embarked on an ambitious initiative to develop a Digital Euro - a retail CBDC designed to complement physical cash while addressing the evolving payment needs in the euro area (ECB, 2023). The ECB formally moved into the preparation phase of the project in October 2023 following a two-year investigative study project (ECB, 2023). The Digital Euro is envisioned to ensure that central bank money remain a stable monetary anchor in an increasingly digital economy, reinforcing financial stability, enhancing payment system efficiency and promoting monetary sovereignty (EBF, 2023). However, its successful deployment hinges on resolving key challenges in technology, regulation, economic impact, and privacy concerns.

In terms of technological considerations, the ECB is exploring both primary technological architectures - a centralized infrastructure, and a DLT-based system. Each approach presents distinct advantages and challenges concerning scalability, efficiency, resilience, and interoperability with existing financial infrastructure. In a centralized architecture, the ECB would directly manage the issuance and processing of transactions through its infrastructure. This model aligns with the traditional structure of central bank money management, ensuring high levels of oversight, security and efficiency in transaction settlement (ECB, 2023). A centralized approach benefits from well-established governance and operational frameworks, mitigating systemic risks such as transaction failures and security vulnerabilities. However, one major drawback of a fully centralized system is its scalability limitations in high-volume retail payments. The Digital Euro would need to accommodate millions of concurrent transactions while maintaining low latency and cost efficiency. Given that digital payments in the euro area already exceed 50 billion transactions annually (ECB, 2023), a fully centralized system would require extensive computing power and real-time processing capabilities, which could strain existing infrastructure (Brühl, 2023). Another concern is single-point failure risk. Unlike cash, which operates independently of infrastructure

availability, a centralized digital euro would depend on ECB servers. System downtime or cyberattacks on central infrastructure could disrupt monetary transactions at a large scale (Westermeier, 2024). To mitigate this risk, the ECB has proposed offline functionality, allowing limited-value transactions without immediate network connectivity, but the technical implementation of such a system remains under discussion (ECB Working Paper No. 2980, 2023).

The alternative, DLT-based approach, would leverage blockchain-inspired mechanisms, enhancing security, transparency, and resilience. DLT enables a decentralized validation system, reducing single-point vulnerabilities and enhancing resistance to cyber threats (ECB, 2023; BIS, 2023). In theory, DLT could also facilitate programmability, enabling features such as smart contracts for automated payment execution based on predefined conditions (Brühl, 2023). However, significant hurdles exist in implementing a fully decentralized Digital Euro at scale. First, blockchain-based transactions tend to be slower and more computationally intensive than traditional centralized payment systems, making large-scale retail adoption challenging (EBF, 2023). Furthermore, DLT-based systems like blockchain often involve consensus mechanisms such as proof-of-work or proof-of-stake, which may not align with the ECB's policy objectives for efficiency and sustainability (BIS, 2023). A key concern in a decentralized model is the governance structure - while decentralization improves security, it also requires mechanisms to enforce monetary policy decisions and ensure compliance with regulatory standards, such as AML/CFT and financial supervision. The ECB would need to retain control over monetary issuance and transaction oversight, which could be too complex in a DLT setting (ECB Occasional Paper No. 360, 2023).

Recognizing the limitations of both centralized and fully decentralized models, the ECB is evaluating hybrid architectures that integrate elements of both approaches. A hybrid system could utilize a tiered architecture, where the ECB manages the core ledger while allowing intermediaries such as commercial banks and payment service providers to handle transaction processing (ECB, 2023). This model aligns with the ECB's goal of maintaining financial stability while leveraging technological advancements (Effects of a Digital Euro on Financial Stability, 2023). Additionally, privacy considerations remain a central challenge. Unlike cash transactions, a digital euro inherently generates transaction data, raising concerns about government surveillance and financial privacy (Westermeier, 2024). To address this, the ECB has proposed privacy-enhancing technologies such as zero-knowledge proofs and cryptography which would enable transaction verification without revealing underlying user data (ECB Working Paper No. 2980, 2023). The balance between privacy protection and compliance with AML/CFT remains a delicate policy issue (European Commission, 2023).

A critical feature under consideration for the Digital Euro is its offline functionality, ensuring payment accessibility in regions with limited internet connectivity. The ECB has proposed an offline-capable Digital Euro, allowing users to conduct transactions without immediate network access similar to cash (ECB, 2023). This feature is particularly relevant for rural areas, underserved communities, and crisis scenarios where digital infrastructure may be unreliable (European Banking Federation, 2023). Implementing secure offline payments requires advanced hardware-based security measures, such as trusted execution environments or secure elements in mobile devices and smart cards, to prevent double-spending and fraud (ECB Working Paper No. 2980, 2023). While enhancing financial inclusion, offline transactions must also balance privacy concerns with regulatory requirements (Westermeier, 2024).

The ECB approach to integrating the Digital Euro into existing payment frameworks exemplifies a model that prioritizes compatibility and ease of adoption (ECB, 2023). Nevertheless,

achieving interoperability across multiple jurisdictions remains a challenge, particularly in regions with disparate regulatory frameworks and technological standards (Boar & Wehrli, 2021). For successful adoption, the Digital Euro must be interoperable with existing financial infrastructure, including SEPA, commercial bank networks and private digital wallets. A failure to integrate with private sector systems could hinder adoption and result in fragmented payment ecosystems (EBF, 2023). Additionally, the ECB is considering the role of the Digital Euro in cross-border transactions, particularly in alignment with initiatives such as Project mBridge (BIS, 2023). If implemented successfully, the Digital Euro could reduce reliance on foreign payment systems (e.g., Visa, Mastercard) and strengthen the EU's monetary sovereignty in global finance (Report on a Digital Euro, 2023).

Legal and regulatory considerations

The introduction of a Digital Euro raises significant legal challenges, particularly regarding its status as legal tender across the Eurozone and its interoperability with international financial regulations. The EC (2023) has proposed that the Digital Euro should have the same legal standing as physical cash, obligating merchants to accept it as a means of payment. However, legal harmonization remains complex, as national jurisdictions within the Eurozone retain some autonomy over payment policies and consumer protection laws (ECB, 2023). Ensuring cross-border compatibility with non-EU regulatory frameworks, such as the US Bank Secrecy Act and BIS's Project mBridge for cross-border CBDCs, further complicates its deployment (BIS, 2023). A lack of harmonized regulatory frameworks could create fragmentation risks, limiting the Digital Euro's adoption inside and outside the EU.

A major issue concerns the liability structure of intermediaries, particularly regarding fraud, consumer rights, and dispute resolution mechanisms. If the Digital Euro follows an intermediated model, where commercial banks and payment services providers manage user accounts, regulatory questions arise regarding the distribution of liability between the ECB and private institutions (European Banking Federation, 2023). Additionally, defining smart contract enforceability within a Digital Euro framework remains an unresolved legal challenge (Brühl, 2023).

As a state-backed digital currency, the Digital Euro must align with the EU's AML/CFT Directive and international frameworks set by the FATF, the primary concern being preventing illicit activities while ensuring the seamless usability of the Digital Euro for legitimate transactions (ECB, 2023). Traditional cash transactions offer anonymity, but the Digital Euro will require identity verification and transaction monitoring, raising questions about privacy vs. compliance (Westermeier, 2024). To balance these concerns, the ECB has proposed tiered identity verification mechanisms: small, low-risk transactions may allow pseudo-anonymity, whereas higher-value transactions would require strict "Know-Your-Customer" compliance (ECB Working Paper No. 2980, 2023). Additionally, integrating AI-driven screening into Digital Euro transactions could enhance fraud detection, but this raises concerns about algorithmic bias and data protection (EC, 2023). Another significant challenge is ensuring AML compliance for offline transactions, where real-time monitoring is not possible. While the ECB has suggested pre-set spending limits for offline Digital Euro wallets, concerns persist about untraceable peer-to-peer transactions facilitating financial crimes (ECB, 2023).

In terms of privacy, the envisioned Digital Euro needs to strike a balance between user privacy and regulatory oversight. Under EU law, financial transactions are subject to the GDPR, which mandates strict limitations on personal data collection and processing (EC, 2023). A fully traceable Digital Euro could erode financial privacy, leading to potential concerns over government

surveillance of transactions (Westermeier, 2024). The ECB has outlined several privacy-enhancing technologies to mitigate these risks: zero-knowledge proofs, allowing transactions to be verified without revealing personal data; decentralized identity management, where users retain control over their identity credentials; or programmable privacy settings, whereby users could choose between different levels of privacy based on transaction size and risk category (ECB, 2023). While AML/CFT regulations require compliance with financial surveillance laws, excessive government access could undermine trust in the Digital Euro. Thus, clear legal firewalls must be established to prevent unauthorized state monitoring (EBF, 2023).

Economic and monetary implications

The introduction of a Digital Euro has profound implications for monetary policy and its transmission mechanisms. The Digital Euro would serve as a new monetary instrument, influencing money supply, interest rates, and the velocity of money circulation (ECB, 2023). A key consideration is whether the Digital Euro would function as a substitute or complement to existing forms of central bank money. If widely adopted, it could alter the monetary base composition, affecting the money multiplier effect and the efficiency of central bank interventions (Bindseil et al., 2023). One of the primary transmission channels affected would be interest rate policy. Unlike commercial bank deposits, the Digital Euro could be non-interest bearing or subject to tiered remuneration to prevent large-scale shifts from bank deposits to central bank money (ECB Occasional Paper No. 360, 2023). A remunerated Digital Euro, however, could function as an effective monetary policy tool, allowing central banks to directly influence short-term interest rates and enhance the transmission of policy changes to financial markets (Brühl, 2023). Moreover, in times of economic distress, the Digital Euro could facilitate more direct monetary stimulus. Central banks could implement helicopter-money policies by crediting digital wallets, bypassing traditional banking intermediation (BIS, 2023). However, such direct interventions raise concerns about political independence and potential fiscal dominance, necessitating clear operational frameworks to prevent excessive government interference in monetary policy.

One of the most debated aspects of the Digital Euro is its potential impact on financial stability and the traditional banking sector. Studies indicate that a large-scale shift of deposits from commercial banks to the ECB could reduce banks' lending capacity, leading to higher borrowing costs (Brühl, 2023). The ECB has proposed holding limits (e.g., €3,000 per individual) to mitigate the risk of excessive deposit outflows (ECB, 2023). The introduction of the Digital Euro could significantly enhance the ECB's ability to implement monetary policy by providing real-time insights into money circulation and payment behaviors (ECB Occasional Paper No. 360, 2023). Unlike cash, the Digital Euro could feature programmable money functions, allowing for policy tools such as negative interest rates on idle balances to influence spending behaviors (ECB, 2023). This shift could lead to higher lending costs, as banks would need to compensate for the loss of cheap retail deposits by increasing reliance on market funding (Effects of a Digital Euro on Financial Stability, 2023). Consequently, credit allocation could be constrained, affecting economic growth and increasing financial sector vulnerabilities (ECB Working Paper No. 2980, 2023). To mitigate risks, the ECB has proposed holding limits, non-interest-bearing structures, and a "reverse waterfall" mechanism that automatically transfers excess balances to commercial bank accounts (ECB, 2023). Additionally, a tiered access structure - where financial institutions can hold Digital Euro reserves but individuals face caps - has been suggested to balance stability and financial sector resilience (BIS, 2023).

The Digital Euro also holds significant potential for enhancing financial inclusion, particularly for unbanked and underbanked populations across in underserved regions of the Eurozone. By providing a state-backed and cost-free digital payment option, the Digital Euro could bridge existing financial gaps, offering secure access to money without requiring traditional bank accounts by providing citizens with a free, universally accessible digital payment option, reducing reliance on private-sector payment providers (EC, 2023). The ECB has also emphasized the importance of offline functionality, which would allow users in rural and underserved areas to transact without continuous internet connectivity (Westermeier, 2024). Moreover, integrating the Digital Euro with existing public infrastructure, such as post offices and municipal service centers, could facilitate broader adoption among populations without digital banking access (Brühl, 2023). However, financial inclusion efforts must also address the digital divide, particularly among elderly individuals and those with limited technological literacy. Ensuring a user-friendly interface, multiple access channels (smartphones, prepaid cards, and physical terminals), and regulatory protections against digital fraud will be crucial to maximizing the Digital Euro's inclusivity.

Security and ethical concerns

Given the ongoing discussions on the design of the Digital Euro, whether centralized or incorporating decentralized elements, it is expected to be a high-value target for cyberattacks, including hacking, fraud, and large-scale data breaches. The ECB has recognized this risk and has proposed multi-layered security protocols to enhance resilience against potential attacks (ECB, 2023). These measures include end-to-end encryption, real-time fraud detection, and secure digital identity verification mechanisms.

One concern in terms of cybersecurity is the threat potentially posed by quantum computing in the near future. While conventional cryptographic methods are currently effective, quantum computers could eventually break these encryption standards, exposing Digital Euro transactions to potential security breaches (BIS, 2023). To address this, the ECB has proposed research into quantum-resistant cryptographic techniques, such as lattice-based encryption and post-quantum cryptography frameworks, ensuring long-term security of the system (ECB, 2023). Furthermore, real-time transaction monitoring and AI-powered fraud detection are expected to play a critical role in identifying suspicious activities. The ECB is likely to implement machine learning algorithms that can detect anomalous transaction patterns, preventing money laundering, identity theft and digital fraud.

Another contentious debates surrounding the Digital Euro concerns the balance between user privacy and regulatory transparency. Unlike physical cash, which allows for anonymous transactions, the Digital Euro will generate digital records of every transaction, raising concerns over government surveillance and financial privacy erosion (Westermeier, 2024). To mitigate these concerns, the ECB has proposed the integration of privacy-enhancing technologies to ensure selective anonymity. These could include zero-knowledge proofs or secure multi-party computation, allowing transaction verification without exposing personal user data (ECB, 2023). The ECB is also considering tiered privacy mechanisms, where low-value transactions may remain anonymous, while high-value transfers would require stronger identity verification. Another key privacy concern is government overreach and potential misuse of transaction data. While authorities require access to digital payment data for crime prevention, excessive data collection could lead to unwarranted financial surveillance. The European Data Protection Board has emphasized that Digital Euro transaction records must be stored with strict access controls and clear legal oversight to prevent potential misuse (EC, 2023). To comply with AML/CFT, the Digital Euro must integrate robust identity verification and compliance measures. The ECB has

suggested the adoption of digital identity frameworks, such as self-sovereign identity solutions, which provide users with control over their own digital identity credentials while still enabling regulatory compliance (ECB, 2023). The ECB must carefully design a system that allows law enforcement access in cases of criminal activity, while still protecting user confidentiality in lawful transactions (Westermeier, 2024). A potential compromise may involve pseudonymous accounts, where identities are concealed except in legally justified cases.

Given the globalized nature of financial systems, ensuring secure cross-border interoperability is another challenge for the Digital Euro. International transactions will need to comply with multiple regulatory regimes, including the FATF standards on cross-border payments. Moreover, integration with other CBDCs (e.g., the mBridge project) will require interoperable security protocols and anti-fraud mechanisms (BIS, 2023). To address these challenges, the ECB is exploring blockchain-based authentication methods that allow for secure, tamper-proof cross-border transactions. Additionally, developing a universal legal framework in collaboration with the European Commission and BIS will be necessary to ensure harmonized compliance with international cybersecurity standards.

Conclusion

The e-CNY and the Digital Euro represent critical steps toward the future of central bank digital money, and their ultimate success will depend on how effectively they address the four critical dimensions explored in this paper - technological infrastructure, legal and regulatory frameworks, economic and monetary implications, and security considerations—along with their respective sub-dimensions. While sharing a common objective - to modernize national payment systems and enhance monetary policy efficiency and financial inclusion, their designs reflect different policy priorities, governance models, and economic aspirations. China's e-CNY prioritizes state control, financial sovereignty, and global expansion, integrating seamlessly with its existing digital payment ecosystem while positioning itself as a potential instrument for renminbi internationalization. However, it raises significant concerns regarding financial surveillance, privacy limitations, and its geopolitical implications. Conversely, the Digital Euro follows a more cautious, privacy-centric approach, seeking to balance financial innovation with regulatory oversight and banking sector stability. While this approach ensures compliance with EU data protection laws and AML/CFT frameworks, it introduces challenges related to fragmented legal harmonization, limited programmability, and potential adoption barriers.

The findings underscore some key trade-offs. From a technological perspective, this means a balance between centralized control and distributed ledger integration, interoperability with existing payment systems, and the development of offline payment functionalities to ensure accessibility. In terms of legal and regulatory challenges –a balance between cross-jurisdictional recognition, AML/CFT compliance, and robust data protection frameworks will shape the usability and trust in each system. On the economic and monetary front, success will be influenced by a balanced focus on monetary policy transmission mechanisms and bank disintermediation. Lastly, in security, privacy, and ethical considerations, resilience against cyber threats, the implementation of privacy-preserving technologies, and ethical concerns around state surveillance and financial autonomy will determine broader adoption and acceptance.

The contrasting models of China's state-driven, controlled framework and the EU's privacy-focused, stability-driven approach towards CBDC provide critical insights into the trade-offs between innovation, financial sovereignty, and user trust in digital currency systems, as long-term viability will depend on these structural elements.

DIMENSIONS		E-CNY	DIGITAL EURO
Technological and operational considerations	**Distributed ledger technology vs. centralized systems**	Predominantly centralized system with selective DLT elements for security and transparency. The PBoC maintains ultimate control.	Exploring a hybrid model combining centralization with decentralized components, ensuring control while enabling private intermediaries to facilitate transactions.
	Interoperability and integration with existing payment infrastructures	Fully integrated with domestic payment platforms (Alipay, WeChat Pay). Expanding into cross-border trade through mBridge trials.	Designed for interoperability within the Eurozone's financial networks, aiming for compatibility with SEPA instant payments and commercial bank infrastructure.
	Offline Payments and Accessibility	Supports offline transactions using Near-Field Communication and dedicated hardware wallets to ensure financial inclusion in rural areas.	Offline transactions are a design goal, but specific implementation details remain under development. Potential reliance on secure mobile wallets or physical payment cards.
Legal and regulatory considerations	**Cross-jurisdictional legal status of CBDCs**	Recognized as legal tender within China, requiring all merchants to accept e-CNY. International legal clarity remains limited.	Legal tender across the Eurozone, with potential expansion to non-EU countries through bilateral agreements.
	AML/CFT	Follows a "controlled anonymity" model: small transactions remain private, while large-value transfers are fully traceable. Compliance with strict AML/CFT measures.	Fully adheres to EU AML/CFT directives, integrating Know Your Customer (KYC) requirements and transaction monitoring. Privacy-preserving technologies under development.
	Data Protection and Privacy Frameworks	Operates under China's data security regulations, enabling extensive state oversight. Government access to transaction data is a key concern. Government retains broad visibility over transactions. Concerns over state surveillance and potential for financial repression.	Governed by GDPR, ensuring strong data protection for users. Exploring Zero-Knowledge Proofs (ZKPs) and other privacy-enhancing technologies (PETs). Stronger emphasis on privacy protections. ECB exploring decentralized identity management and PETs to balance privacy with regulatory oversight.
Economic and monetary implications	**Impact on monetary policy and transmission mechanisms**	Provides real-time economic data to the PBoC, enhancing monetary policy responsiveness. Could support negative interest rate implementation.	ECB cautious about direct monetary policy effects. Designed to complement existing monetary tools without destabilizing the banking system.
	Financial stability and commercial banking implications	Potential for disintermediation, as depositors may shift funds from commercial banks to e-CNY wallets. Holding limits and tiered remuneration strategies proposed to mitigate risks.	Similar concerns regarding bank disintermediation. Holding caps (e.g., €3,000 per individual) and indirect issuance via commercial banks aim to minimize systemic risks.
	Financial inclusion potential	Aims to provide unbanked populations, particularly in rural areas, with a state-backed digital payment option. Offline functionality is key to accessibility.	Focused on enhancing financial inclusion within the Eurozone. Challenges remain regarding digital literacy and accessibility in underbanked communities.
Security and ethical concerns	**Cybersecurity threats and resilience strategies**	Multi-layered encryption, AI-driven fraud detection, and cybersecurity protections implemented by the PBoC. Potential vulnerability to state-backed cyber threats.	ECB investing in quantum-resistant cryptographic security and AI-driven fraud detection. Compliance with EU cybersecurity directives.
	Ethical considerations	Programmability enables policy-driven spending restrictions, raising concerns over government control of financial behavior.	Designed to ensure autonomy of users. ECB explicitly avoids programmability to maintain trust and ensure full convertibility with cash and deposits.

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