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## Article

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# Examining the role of blockchain and public-private partnerships in design and deployment of blockchain-enabled CBDC

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## ABSTRACT

The purpose of this study is to examine how blockchain technology with public-private partnerships (PPPs) can mitigate the challenges in design and deployment of Central Bank Digital Currencies (CBDCs). The study employs a quantitative approach, incorporating data from stakeholders through a questionnaire survey and an analysis of existing CBDC literature. The Kruskal-Wallis test is used to analyse survey data, collected from stakeholders, from financial institutions, technological businesses, and academia. The findings highlight the significance of embracing blockchain technology to improve CBDC security, scalability, and operational efficiency. Blockchain's solid framework and cybersecurity characteristics are critical for ensuring the integrity and trustworthiness of digital currency. Furthermore, the paper emphasizes the need of PPPs in driving innovation, building regulatory frameworks, and encouraging public education. These collaborations are critical for overcoming both technological and regulatory hurdles in CBDC deployment. The results highlight the need for balanced collaboration between the public and private sectors to successfully handle these difficulties, while employing blockchain technology to overcome execution constraints. In order to overcome impediments and guarantee the long-term survival and success of CBDCs, stakeholders must collaborate fairly and with openness. This study gives decision-makers and stakeholders insights into the opportunities and collaboration strategies for blockchain-enabled CBDCs.

## 1. Introduction

The emergence of cryptocurrencies and blockchain technology has prompted governments and central banks to explore the implementation of CBDCs (Sandner et al., 2020). CBDCs are defined as “digital form of central bank money that is different from balances in traditional reserve or settlement accounts” (Bank for International Settlements, 2020). CBDCs are being actively developed, with 94 % of central banks globally examining their potential to optimize payment systems (Iorio et al., 2024). Countries such as China, Russia, and members of the Eurozone are leading the charge through pilot programs leveraging blockchain technology, tailoring implementations to national goals and requirements. Notably, permissioned or hybrid Distributed Ledger Technology (DLT) frameworks are favored for their ability to combine transparency and security with centralized oversight (S. Guo et al., 2024). DLT frameworks often incorporate blockchain as their underlying architecture, enabling the integration of decentralized data structures with controlled access and governance mechanisms (Bellaj et al., 2024).

Blockchain technology offers distinct advantages for CBDC development in the Indian context by enhancing secure, transparent, and efficient KYC processes (Dumbre et al., 2024). Its ability to provide programmable payments, automate financial operations via smart contracts, and reduce costs aligns with the broader goals of enhancing financial inclusion and supporting digital transformation (Bechtel et al., 2022). Furthermore, blockchain's inherent features such as immutability, secure data sharing, and fraud resistance (B. Rawat et al., 2021) are critical for addressing the challenges of a diverse and expansive economy like India. Efforts to develop retail CBDCs with offline functionality are underway, utilizing proximity-based and non-proximity solutions to support secure transactions in underserved and remote areas (Chu et al., 2022; Nikam, 2024). This feature is particularly relevant for regions with limited internet connectivity, ensuring inclusivity and resilience in financial systems. While CBDCs hold significant promise in improving financial systems, challenges such as security, privacy, interoperability, and the risk of disintermediating commercial banks remain (Gross & Schiller, 2021). Furthermore, the global adoption of CBDCs raises concerns about regulatory complexities and

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infrastructure upgrades (Semeko, 2022).

Despite the progress in CBDC development, only limited research has focused on the specific challenges of CBDC implementation and how blockchain can address these issues (Mehra et al., 2024). Additionally, the role of PPPs in fostering successful CBDC deployment remains underexplored. This research stands as the first of its kind to explore the role of PPPs in CBDC implementation within the Indian context. This research seeks to address these gaps by examining the key challenges in CBDC implementation and exploring how blockchain technology, in collaboration with PPPs, can overcome these obstacles. Specifically, this study aims to answer the following research questions:

RQ1: What are the key challenges in the implementation of CBDCs, particularly regarding security, privacy, interoperability, and user adoption?

RQ2: How can blockchain technology address these challenges and contribute to the successful deployment of CBDCs?

RQ3: What role can public-private partnerships play in overcoming the hurdles in CBDC implementation?

The answers to these research questions are crucial for policymakers, financial institutions, and other stakeholders involved in CBDC projects. By identifying and addressing these challenges, stakeholders can ensure a smoother integration of CBDCs into the global financial ecosystem, enhancing their effectiveness and fostering broader adoption. This research aims to provide a comprehensive understanding of how blockchain technology and public-private partnerships can play a pivotal role in overcoming the challenges associated with CBDC implementation. It offers actionable insights to improve the design and deployment of blockchain-enabled CBDCs, ultimately supporting their successful integration into the financial system.

## 2. Review of literature

The dawn of blockchain technology has brought about a significant transformation across various sectors, especially in finance (Borhani et al., 2021). With its decentralized, transparent, and secure nature, blockchain underpins the development of Digital Currencies (Manda et al., 2024). Central banks globally, including the RBI, are investigating CBDCs to modernize payment systems, enhance financial inclusion, and improve transaction efficiency (Auer et al., 2021). Blockchain integration promises heightened security, real-time settlement, and improved transaction traceability (Centobelli et al., 2021). However, successful deployment of blockchain-enabled CBDCs requires overcoming several technological, regulatory, and market challenges (Nikam, 2024).

### 2.1. Technological advancements and challenges

Blockchain technology offers significant advantages, such as immutability, transparency, and security (Baygin et al., 2019), which are crucial for effective CBDC implementation (Sethaput & Innet, 2023). These features ensure transaction security and verification, reducing risks of fraud and cyber-attacks. Blockchain's programmability facilitates smart contracts, automating financial processes to enhance operational efficiency (Yoon & Pishdad-Bozorgi, 2022). Despite these benefits, challenges persist. Scalability is a major concern, as blockchain networks must handle high transaction volumes efficiently (Cambou et al., 2020). Ensuring interoperability with existing financial systems is essential for seamless integration and broad adoption of CBDCs (Yoshinaga et al., 2024). Addressing these challenges demands ongoing research and development to improve scalability, interoperability, and efficiency of blockchain networks (M. Shah, 2024).

### 2.2. Legal and regulatory frameworks

The regulatory landscape for blockchain and CBDCs is evolving, with central banks and regulatory bodies striving to establish clear guidelines and standards (Nikam, 2024). Legal and regulatory frameworks are

critical for ensuring CBDC security, stability, and trustworthiness (Yoshinaga et al., 2024). Blockchain's immutable and transparent nature aids in creating enforceable legal frameworks, enhancing regulatory compliance and reducing fraud risk (Auer et al., 2021). However, developing comprehensive regulatory frameworks for CBDCs is complex, involving data privacy, cybersecurity, and anti-money laundering (AML) regulations (Soana & de Arruda, 2024). The dynamic nature of blockchain technology further complicates regulatory efforts, requiring continuous adaptation and updates to policies (World Economic Forum, 2021). Public-private partnerships (PPPs) can play a key role by fostering collaboration between regulatory bodies and private sector entities to develop robust and adaptable regulatory frameworks.

### 2.3. Market dynamics and public-private partnerships

The introduction of CBDCs significantly impacts market dynamics, including competition, innovation, and financial stability (Dionysopoulos et al., 2024). PPPs have emerged as a strategic approach to address the challenges in public service. By leveraging the strengths of both sectors, PPPs can support the development, implementation, and scaling of CBDCs (Yakubova, 2023). PPPs can drive innovation by combining the technological expertise and agility of the private sector with the regulatory oversight and stability provided by the public sector (IMF, 2021). This collaborative approach can lead to more secure, efficient, and user-friendly CBDC solutions. Additionally, PPPs can address infrastructural challenges (M. A. Shah & Ghayas, 2022), such as developing scalable blockchain networks and integrating CBDCs with existing financial systems.

Various partnership models have been proposed for CBDC implementation, including synthetic CBDCs (SCBDCs) and two-tiered CBDCs. SCBDCs involve central banks and private sector entities, where the private sector issues digital currencies backed by central bank reserves (Ojo & Delaney, 2021). This approach harnesses private sector innovation while maintaining regulatory stability through the backing of central banks. By carefully considering these advantages and challenges, policymakers and financial institutions can effectively navigate the complexities of CBDC adoption and integration, ensuring a balance between innovation and stability in the evolving digital finance landscape (Ahiabenu, 2023).

### 2.4. Evidence and technological foundations of CBDCs

The evolution of CBDCs is closely tied to the diverse landscape of DLTs. While blockchain technology is prominent in this space, several alternative approaches are also being explored (Tan & Salo, 2023). Among the technologies highlighted on [cbdctracker.org](https://www.cbdctracker.org), blockchain-based solutions such as 'Hyperledger Fabric, Hyperledger Besu, R3 Corda, Quorum, XRP Ledger, Stellar, Hyperledger Iroha 2, and Ethereum' offer features tailored to CBDC requirements, including enhanced security, privacy, scalability, and cross-border interoperability (CBDC, Tracker). For example, India's e-Rupee utilizes a centralized blockchain-based system, operating within a hybrid model. Similarly, the Bahamas' Sand Dollar leverages a centralized blockchain structure with a two-tier model, while Sweden's E-Krona operates on a centralized, two-tier architecture. In China, the DCEP (Digital Currency Electronic Payment) system is also built on a centralized, permissioned blockchain framework, utilizing a two-tier architecture (Haque & Shoaib, 2023). These varying approaches underscore each country's adaptation to meet unique financial and regulatory requirements within their CBDC ecosystems (S. Guo et al., 2024). As CBDC research and development progress, selecting the appropriate DLT technology will be crucial in shaping the future of digital currencies around the world. (H. Wang, 2024).

The emergence of empirical evidence on blockchain-enabled CBDCs offers valuable insights into the practical realities of their deployment. China's digital yuan pilot projects, for instance, have demonstrated the

potential of CBDCs to enhance payment efficiency and financial inclusion, while also revealing challenges in user adoption and technological scalability (Cunha et al., 2021). Public-private partnerships, such as the collaboration between the European Central Bank and private sector entities for the digital euro, illustrate the potential of PPPs to drive innovation and address infrastructural challenges (Rumiantsev et al., 2024). These projects underscore the importance of stakeholder collaboration, regulatory clarity, and technological innovation for successful CBDC deployment.

### 2.5. Potential risks and concerns of CBDCs

CBDCs come with a number of potential risks and concerns that need to be carefully considered. CBDCs could destabilize the financial system by reducing bank deposits and impacting lending capacity if citizens prefer them over traditional banking services (Boar & Wehrli, 2021; Gross & Schiller, 2021). In India, where banks play a critical role in funding infrastructure and development projects (Ray, 2015), this shift could disrupt credit availability, especially during economic downturns. Rapid withdrawals from banks to CBDCs during times of uncertainty could amplify financial instability (Y. Wang et al., 2022). Additionally, while CBDCs are often promoted as tools for financial inclusion, there is concern that individuals without digital access could face exclusion, especially in regions with limited technological infrastructure (Bank for International Settlements, 2020).

Privacy is a major problem since CBDCs may enable governments to track individual transactions in real time, posing moral questions about monitoring and possible abuse for social control (Kaur, 2024). In India as data protection regulations are still evolving, this risk is particularly noticeable (Singh & Singh, 2022). Implementing privacy-preserving technologies, such as zero-knowledge proofs, and establishing clear legal frameworks to restrict data access and use by authorities can help address these concerns. This capability of CBDCs to compromise financial privacy highlights the need for strong privacy protections to prevent potential overreach (Wang, 2024). Furthermore, cybersecurity threats pose a substantial risk; being digital in nature, CBDCs are vulnerable to cyberattacks that could lead to data breaches, financial loss, and disruptions in financial services, thereby undermining public trust (Davidson et al., 2018; Frost et al., 2019). Another area of concern is the programmability of CBDCs, which allows central banks to control certain functions, such as imposing negative interest rates or setting spending limits. While these features could support monetary policy, they may also restrict financial freedoms and be misused for economic or political purposes (Fahad & Bulut, 2024). Financial censorship risks are also associated with CBDCs, as governments might block transactions or freeze accounts, potentially limiting individual autonomy in financial matters (Auer et al., 2020). CBDCs introduce complex regulatory and operational challenges. The global competition among nations to implement CBDCs could lead to currency competition and shifts in economic influence, potentially causing international tensions (International Monetary Fund, 2021). The inclusive and collaborative approach to CBDC development, aligned with international standards, will be key to avoid such conflicts in India

### 3. Challenges in CBDC Implementation

The implementation of CBDCs presents a complex array of challenges that must be meticulously addressed to ensure their successful integration into existing financial systems (Svoboda, 2024). Key among these challenges is the potential reduction in credit availability, as CBDCs could divert funds away from traditional banking deposits, thus affecting the lending capacities of commercial banks (Y. S. Kim & Kwon, 2023). Additionally, the control over the money supply emerges as a significant concern, as the direct issuance and management of CBDCs by central banks could complicate existing monetary policies and possibly lead to financial instability. Digital illiteracy, particularly in less

urbanized regions, poses a formidable barrier, necessitating comprehensive educational initiatives and infrastructure enhancements to ensure equitable access and usability (Choudhary & Bansal, 2022).

The issues of scalability and cybersecurity also stand out, as any CBDC system must be robust enough to handle large volumes of transactions securely across a populous nation like India. Moreover, achieving broad public acceptance requires building trust through privacy, security assurances, and a user-friendly design. Finally, regulatory uncertainty and the need for flexible, adaptable frameworks highlight the ongoing need for clear guidelines and the ability to evolve with technological and regulatory shifts (Sampaio & Centeno, 2022; H. Wang, 2023). These challenges listed above and present in (Table 1) emphasize the complexity of CBDCs and the critical need for thoughtful, inclusive planning and implementation strategies.

The Table 1 presents a comprehensive overview of the major challenges in the implementation of CBDCs. Each entry highlights a specific issue, provides a brief description of the challenge, and cites relevant sources, offering a well-rounded understanding of the potential obstacles and considerations for policymakers and financial institutions as they navigate the complexities of introducing a CBDC.

### 4. Blockchain's role in Addressing CBDCs Challenges and Enhancing Utility

Blockchain technology in the context of CBDCs is pivotal due to its potential to address several inherent challenges associated with these digital currencies. Blockchain's decentralized nature offers robust security features that can safeguard against fraud and cyber-attacks, which are critical concerns for the integrity and trustworthiness of CBDCs. Table 2 provide a detailed examination of how these features helps to overcome specific obstacles, which in turn could significantly impact both monetary policy implementation and everyday financial transactions for users.

Blockchain technology offers robust solutions to a range of challenges across different domains. One critical area where blockchain excels is in technology and cybersecurity. By leveraging a decentralized and immutable ledger system, blockchain enhances security by thwarting fraud and addressing cybersecurity concerns effectively (Ramos & Ellul, 2024). Moreover, blockchain ensures stringent user protection through encrypted data storage, thereby safeguarding privacy and bolstering trust among users (Yang et al., 2021). In the realm of regulatory uncertainty, blockchain's inherent transparency and traceability play a pivotal role. These features enable the establishment of clear regulatory frameworks and ensure compliance in transactions, addressing concerns around regulatory ambiguity (Alora et al., 2024). Furthermore, blockchain technology can promote digital literacy by integrating user-friendly interfaces and educational tools into its applications, thereby enhancing understanding and adoption among users (Asmawi et al., 2024). Operationally, blockchain mitigates risks through its distributed and resilient architecture. This characteristic ensures high availability and reliability of transactions, reducing operational disruptions significantly (Dos Reis et al., 2023). Scalability, a perennial concern for blockchain, is addressed through innovative techniques like sharding and layer-2 protocols, which expand the network's capacity to process large volumes of transactions efficiently (Fernandez, 2023). In fostering public acceptance, blockchain's transparency and security features are pivotal. These attributes build trust among users and stakeholders, while smart contracts automate processes, thereby enhancing user experience and reliability (Alora et al., 2024). Blockchain also complements traditional banking by offering new services such as cross-border payments and decentralized finance options, thereby expanding the capabilities of traditional financial systems (Y. Guo & Liang, 2016; Zhang, 2020).

Moreover, blockchain supports the continuity of credit availability through decentralized finance (DeFi), ensuring that consumers and businesses have access to alternative credit options (Manda et al., 2024).

**Table 1**  
Challenges in implementation of CBDCs.

S.No	Challenges in CBDCs	Description	Source
1	Concerns about reduction in credit availability for consumers and businesses.	CBDCs might reduce bank deposits, impacting lending capacities and potentially causing credit availability issues.	(Y. S. Kim & Kwon, 2023; Souissi & Nabi, 2023).
2	Control Over Money Supply	CBDC could complicate the central bank's ability to manage the money supply, potentially leading to financial instability	(D & Kar, 2022)
3	Digital Illiteracy	India's digital literacy rates are low, particularly in rural areas, necessitating education and infrastructure development.	(Choudhary & Bansal, 2022; Dutta & Mathur, 2014)
4	Ensuring flexibility and adaptability in the face of emerging challenges	Designing the CBDC system to adapt to technological and regulatory changes, ensuring future resilience.	(Alora et al., 2024)
5	Fostering broad public acceptance of CBDC	Building public trust and acceptance through user-friendly design, reliability, and addressing privacy and security concerns.	(Juskaite et al., 2019)
6	Impact on Traditional Banking	Concerns about how CBDCs might disrupt or displace existing banking structures and functions.	(D & Kar, 2022)
7	Implementing strict measures and protocols to protect users' concerns such as security, privacy, and data protection	Addressing privacy and data protection is crucial given the high rate of cyber-attacks in India and the need for public trust.	(Darbha & Arora, 2020; Lee et al., 2021)
8	Incorporating appropriate technology and Addressing cybersecurity	Ensuring the CBDC infrastructure is secure and can handle large volumes of transactions, while protecting against cyber threats.	(Hansen & Delak, 2022)
9	Managing operational risks associated with implementing CBDC	Ensuring the smooth operation of the CBDC system and addressing potential technical issues during deployment and stress testing.	(Allen et al., 2020)
10	Regulatory Uncertainty	Developing clear legal frameworks to govern the issuance and use of CBDCs, reducing uncertainty for businesses and consumers.	(Sampaio & Centeno, 2022; H. Wang, 2023)
11	Scalability Issues	The CBDC system must be scalable to handle vast population and high transaction volumes.	(Homoliak et al., 2023; Tsai et al., 2018)

The adaptability of blockchain technology to evolving financial technologies and requirements ensures its long-term viability, making it a resilient solution for future challenges (Tapscott et al., 2019). Finally, blockchain's programmable nature allows for precise control and monitoring of the money supply through smart contracts, enhancing transparency and governance in monetary systems (Auer & Boehme, 2020). In short, blockchain technology not only addresses current challenges across various sectors but also offers transformative solutions that pave the way for a more secure, transparent, and efficient digital

**Table 2**  
Blockchain Solution in Addressing CBDC Challenges.

S.No	Challenges	Blockchain Solution	Source
1	Incorporating appropriate technology and cybersecurity measures	Blockchain offers a decentralized and immutable ledger system that enhances security by preventing fraud and address cybersecurity concerns.	(Ramos & Ellul, 2024)
2	Implementing strict measures and protocols to protect users' concerns such as security, privacy, and data protection	Blockchain ensures data privacy and protection through and encrypted data storage, enhancing user trust.	(Yang et al., 2021)
3	Regulatory Uncertainty	Blockchain provides transparent and traceable transactions, which can aid in establishing regulatory frameworks and ensuring compliance.	(Alora et al., 2024)
4	Digital Illiteracy	Blockchain can be integrated into user-friendly applications that promote digital literacy through simplified interfaces and educational tools.	(Asmawi et al., 2024)
5	Managing operational risks associated with implementing CBDC	Blockchain's robust and distributed nature ensures high availability and reliability, reducing the risk of operational disruptions.	(Dos Reis et al., 2023; McLaughlin, 2024)
6	Scalability Issues	Blockchain can support scalable solutions by using techniques such as sharding and layer-2 protocols, which enhance the network's capacity to process large volumes of transactions.	(Fernandez, 2023)
7	Fostering broad public acceptance of CBDC	Blockchain's transparency and security features can help build public trust. Additionally, smart contracts can automate processes, enhancing user experience and reliability.	(Alora et al., 2024)
8	Impact on Traditional Banking	Blockchain can provide complementary services like cross-border payments, enhancing traditional banking capabilities.	(Y. Guo & Liang, 2016; Zhang, 2020)
9	Concerns about reduction in credit availability for consumers and businesses	Decentralized finance (DeFi) on blockchain can offer new credit options, ensuring continued credit availability	(Manda et al., 2024)
10	Ensuring flexibility and adaptability in the face of emerging challenges	Blockchain is highly adaptable, able to evolve with new financial technologies and requirements, ensuring long-term viability.	(Tapscott et al., 2019)
11	Control Over Money Supply	Blockchain's programmable nature allows precise control and monitoring of the money supply through smart contracts.	(Auer & Boehme, 2020)

future. By addressing challenges like interoperability, data privacy concerns, and security risks, blockchain can enhance the overall effectiveness and resilience of CBDCs, offering a robust framework for secure and efficient digital currency transactions.

## 5. Research gap and objectives

Despite the growing body of literature on blockchain and CBDCs, several gaps remain. There is a need for a more detailed understanding of how PPPs can enhance blockchain-enabled CBDC deployment. Methodologically, there is a lack of mixed-method studies combining quantitative and qualitative data to provide a comprehensive understanding of stakeholder perspectives and real-world applicability. Empirically, more evidence is needed from pilot projects and real-world implementations to derive best practices. Existing research lacks a robust framework for analysing the impact of different partnership models on innovation and market dynamics (IMF, 2021). Moreover, the existing literature on CBDCs highlights benefits and macroeconomic impacts but lacks a comprehensive analysis of sector-specific challenges, especially in emerging economies like India. Critical gaps remain in understanding public sector regulatory hurdles, private sector contributions through fintech and blockchain, and the integration of academic insights into practical solutions.

This study, the first of its kind in India, focuses on the role of PPPs in CBDC implementation and explores blockchain-enabled solutions. By identifying and ranking key challenges and examining the role of PPPs in addressing them, this research provides actionable insights for advancing CBDCs. The study seeks to offer strategic guidelines for policymakers and financial institutions to create a secure, efficient, and user-friendly digital currency ecosystem.

## 6. Research methodology

This study examines the perspectives of public, private, and academic players regarding the challenges in CBDCs, with a particular focus on the role of blockchain technology and public-private partnerships in overcoming these challenges. A comprehensive questionnaire survey was administered from March to August 2024. The collected data underwent statistical analysis to identify potential disparities in the perceived rankings of challenges across various stakeholder groups. The invited participants were selected through a purposive sampling technique to ensure complete perspective on CBDC initiatives. This diverse group includes public sector representatives (centrally selected banks for CBDCs), private sector experts (financial institutions and technology companies for practical and technical viewpoints), and academics for research-based analysis. Public-sector or centrally selected banks participating in the CBDC initiative are institutions actively engaged in pilot projects or policy discussions. In total, the CBDC pilot phase involves 15 banks, including public institutions such as the State Bank of India, Bank of Baroda, Union Bank of India, Punjab National Bank, Canara Bank, and Indian Bank, alongside private institutions such as ICICI Bank, Yes Bank, IDFC First Bank, HDFC Bank, Kotak Mahindra Bank, Axis Bank, IndusInd Bank, Federal Bank, and Karnataka Bank. Private-sector participants were also from fintech companies, financial institutions, and blockchain firms with demonstrated expertise in digital payment systems and blockchain infrastructure, ensuring a strong technological and practical foundation for the initiative. Additionally, academics were included based on their research and publications on digital currencies, blockchain technology, and financial inclusion, contributing theoretical and analytical depth to the initiative. This mix ensures an inclusive understanding (Sandner et al. (2020)) of CBDC challenges, as public sector participants provide regulatory insights, private sector participants offer practical implementation knowledge, and academics contribute theoretical perspectives.

A complete set of 300 questionnaires were circulated to achieve a large sample size that is proportionate and representative of all

stakeholders. A total of 192 response had been collected, reflecting a 64 % rate of response. The study employed a standardized questionnaire utilizing a 7-point Likert scale to measure the perceived challenges associated with the implementation of CBDCs and to identify potential areas of collaboration within PPPs. The questionnaire was disseminated both physically and online via email, clearly outlining the study's objectives and requesting participation.

The collected data was analysed using descriptive statistics like mean, standard deviation, and ranking. Inferential statistical tests like Kruskal-Wallis test, was employed to identify significant differences in the rankings of collaboration criteria among the public, private, and academic sectors. The Kruskal-Wallis test, a non-parametric method, was chosen due to its suitability for ordinal data.

## 7. Results

A total of 300 questionnaires were distributed to ensure a comprehensive and proportionate representation of all stakeholders. The survey received 192 valid questionnaires, the biggest representation came from private sector, with 82 respondents (Table 3) accounting for 43 % of the total. The academia followed closely behind with 67 participants (34 %), while the public sector accounted for the remaining 22 % of respondents.

This distribution presents a balanced picture, integrating opinions from academics, businesses, and government organisations. This balanced representation improves the generalisability of the findings and allows for a fuller understanding of stakeholder attitudes towards effective collaboration in CBDC projects. In terms of professional experience, 38 % of respondents have over 15 years of experience, while 25 % have 11–15 years, 22 % have 6–10 years, and 16 % have below 6 years. This distribution ensures that perspectives from both seasoned experts and emerging professionals contribute to the study, enriching the analysis of stakeholder insights on CBDCs and collaborative initiatives.

### 7.1. Ranking of challenges in CBDC implementation

To evaluate the various challenges involved with the adoption of CBDCs, a detailed survey was performed among relevant stakeholders. Respondents rated the challenges on a seven-point Likert scale, with 1 indicating low impact and 7 indicating significant. The following (Table 4) ranks these challenges according to the average scores provided by respondents. This analytical approach assures that the rankings represent a broad consensus on each challenge's urgency and relevance, as viewed by the respondents.

The survey results offer a comprehensive view of the challenges associated with implementing CBDCs, as perceived by respondents. Topping the list is the imperative to "incorporate appropriate technology and address cybersecurity concerns", reflecting the paramount importance of robust technological infrastructure in ensuring the security and reliability of digital currency systems. Following closely behind is the challenge of security, privacy, and data protection, highlighting the critical need to safeguard sensitive information and foster user trust in CBDC platforms. Regulatory uncertainty emerges as another

**Table 3**  
Demographic Profile of Respondents.

Category	No. of respondents	Percentage
Public	43	22 %
Private	82	43 %
Academia	67	34 %
<i>Experience No. of respondents Percentage</i>		
Below 6 years	30	16 %
6–10 years	42	22 %
11–15 years	48	25 %
Above 15	72	38 %

**Table 4**  
Ranking of challenges in CBDC implementation.

S. No	Challenges	Mean	Stdev	Rank
1	Incorporating appropriate technology and Addressing cybersecurity	6.77	0.834	1
2	Security, Privacy, and Data Protection	6.28	0.997	2
3	Regulatory Uncertainty	5.75	0.851	3
4	Fostering broad public acceptance of CBDC	5.48	1.031	4
5	Digital Illiteracy	5.02	0.998	5
6	Impact on Traditional Banking	4.69	1.034	6
7	Concerns about reduction in credit availability for consumers and businesses	4.37	1.023	7
8	Scalability Issues	4.05	1.074	8
9	Control Over Money Supply	3.75	1.126	9
10	Flexibility and Adaptability	3.71	1.023	10
11	Managing operational risks associated with implementing CBDC	3.57	1.084	11

significant hurdle, emphasizing the need for clear legal frameworks to govern CBDC issuance and usage, providing clarity for all stakeholders. Fostering broad public acceptance of CBDCs is also a prominent concern, highlighting the importance of addressing user concerns and ensuring user-friendly design. Digital illiteracy presents a challenge, particularly in less urbanized areas, emphasizing the need for educational initiatives to ensure equitable access and understanding. Concerns about the impact on traditional banking structures, as well as potential reductions in credit availability, further underscore the complexities of CBDC integration. Scalability issues and the challenge of central bank control over the money supply round out the top concerns, highlighting the importance of designing flexible, adaptable systems capable of handling large transaction volumes efficiently. This ranking is guided by the potential impact of each challenge on systemic stability, user adoption, and long-term viability of CBDCs within a country's broader economic and social fabric. Each challenge requires a strategic approach to address effectively, ensuring that the rollout of a CBDC is beneficial and minimally disruptive.

## 7.2. Public private partnership in CBDC

Public-private partnerships (PPPs) are pivotal in improving public service delivery by leveraging the complementary strengths of the public and private sectors (Shah et al., 2023). Research emphasizes the importance of various factors for PPP success, including economic considerations, relationship management, project oversight, and the entrepreneurial orientation of public agencies (Lopez, 2021). The adoption of PPPs in South Korea and Singapore is shaped by distinct elements such as fiscal pressure and political motivations, reflecting each country's unique approach to infrastructure development (S. Kim & Choi, 2023). Moreover, PPPs bring advantages such as cost savings, enhanced service quality, and shared risk, which collectively promote economic growth and financial stability in fields like healthcare (Kachula et al., 2023). A deep understanding of these factors and fostering effective public-private collaboration are crucial for the successful implementation of PPPs across various public service sectors.

Public-private partnerships are essential in the implementation of CBDCs, as they harness the combined strengths of both sectors (Adrian, 2022). These partnerships can boost efficiency and drive innovation in public service delivery, including sectors like healthcare and smart city initiatives, while also mitigating risks and addressing funding gaps (Quan et al., 2023). By partnering with the private sector, CBDCs can leverage market expertise and resources, leading to the creation of more secure and user-friendly digital currency systems (Adrian, 2022). Additionally, public-private partnerships have demonstrated their ability to cultivate sustainable economic and social environments, promoting urban prosperity through innovative governance models. As a result, integrating public-private partnerships in CBDC implementation can

enhance service delivery, foster innovation, and effectively address challenges. Table 5 illustrates notable differences in how each stakeholder group public, corporate, and academic prioritizes various topics for effective CBDC collaboration.

The table presents the varying priorities of the public, private, and academic sectors in the collaboration on CBDCs. The public sector places the highest emphasis on developing and establishing legal and regulatory frameworks, with a mean score of 6.23 and a rank of 1, demonstrating its focus on creating a solid legal foundation for CBDCs. This is followed by defining security standards and protocols (Mean = 6.01, Rank = 2) and monitoring implementation for compliance with regulations (Mean = 5.98, Rank = 3), reflecting a commitment to ensuring that CBDCs are both secure and legally compliant.

In contrast, the private sector prioritizes the design and development of technical infrastructure (Mean = 6.27, Rank = 1) and innovation and research to enhance CBDC functionality (Mean = 6.09, Rank = 2). This focus on practical and technical aspects underscores the private sector's role in the operational and technological success of CBDCs. Additionally, integrating CBDCs with existing financial services (Mean = 5.82, Rank = 3) is also a top priority, highlighting the sector's concern with ensuring compatibility and functionality within current systems.

The academic sector, ranks innovation and research to enhance CBDC functionality as its top priority (Mean = 6.28, Rank = 1), emphasizing its commitment to advancing technological and theoretical knowledge. This is closely followed by developing legal and regulatory frameworks (Mean = 5.78, Rank = 2) and defining security standards and protocols (Mean = 5.78, Rank = 3), indicating a balanced approach between foundational elements and cutting-edge advancements.

These differences in priorities suggest that successful CBDC implementation will require effective collaboration among the three sectors. The public sector's focus on legal and regulatory issues, the private sector's emphasis on technical development and integration, and the academic sector's dedication to innovation must be aligned to create secure, efficient, and innovative CBDC systems.

The chi-square analysis as reported in above Table 6, on various collaboration areas between public and private sector in CBDC implementation reveals differing levels of consensus among the public, private, and academic sectors. For most areas such as "Developing and establishing legal and regulatory frameworks", "Defining security standards, facilitating coordination among government entities", "Monitoring compliance, conducting public education, designing technical infrastructure", "Innovating and researching CBDC functionality, leading pilot testing", "integrating CBDCs with existing financial services, and implementing feedback mechanisms" the chi-square values indicate no significant differences in how these sectors prioritize these activities. The significance levels for these areas range from 0.494 to 0.784, suggesting a general agreement across sectors.

However, the analysis identifies one notable exception: managing the operational aspects of CBDC distribution. With a chi-square value of 8.194 and a significance level of 0.017, this area shows significant differences in prioritization among the sectors. This indicates that the importance placed on operational management differs markedly across the public, private, and academic sectors, highlighting a key area of divergence in the collaborative efforts for CBDC implementation. It is clear that there is broad consensus on most aspects of CBDC collaboration, managing distribution emerges as a critical area requiring focused attention and alignment among all stakeholders.

## 8. Discussion

This study contributes to the expanding research on blockchain's role in CBDCs implementation, particularly when CBDCs are increasingly piloted and studied by countries representing over 95 % of global GDP. Blockchain technology is central to the design of many projects Upadhyay (2024) because it enables secure, transparent transactions, with notable applications in countries like China and the Bahamas for

**Table 5**  
Public-private partnership areas of collaboration in CBDC.

Area of Collaboration	Public			Private			Academic		
	Mean	St. Dev	Rank	Mean	St. Dev	Rank	Mean	St. Dev	Rank
Develop and establish legal and regulatory frameworks.	6.23	0.83	1	5.09	0.54	9	5.78	0.73	2
Define security standards and protocols.	6.01	0.82	2	5.36	0.67	7	5.78	0.88	3
Monitor implementation for compliance with regulations.	5.98	0.48	3	5.18	0.87	8	5.56	0.92	6
Conduct public education and awareness campaigns.	5.92	0.86	4	5.09	0.7	11	5.72	0.89	5
Integrate CBDC with existing financial services.	5.77	0.44	5	5.82	0.4	3	5.5	0.62	7
Facilitate coordination among government entities.	5.77	0.78	6	5.09	0.7	10	5.72	1.02	4
Design and develop the technical infrastructure.	5.69	1.04	7	6.27	0.65	1	5.33	0.69	8
Lead pilot testing efforts.	5.46	0.58	8	5.55	0.69	4	5.33	0.91	9
Innovate and conduct research to enhance CBDC functionality.	5.31	0.85	9	6.09	0.94	2	6.28	0.75	1
Manage the operational aspects of CBDC distribution.	5.31	0.85	10	5.36	0.67	6	5.28	0.83	10
Implement feedback mechanisms and improve services.	5.08	0.86	11	5.45	0.82	5	5.17	0.79	11

**Table 6**  
Statistical difference on rankings different areas for successful collaboration.

S. No.	Area of Collaboration	Chi-Square	df	Asymp. Sig.
1	Develop and establish legal and regulatory frameworks.	1.41	2	0.494
2	Define security standards and protocols.	0.613	2	0.736
3	Facilitate coordination among government entities.	2.417	2	0.299
4	Monitor implementation for compliance with regulations.	0.536	2	0.765
5	Conduct public education and awareness campaigns.	0.725	2	0.696
6	Design and develop the technical infrastructure.	3.126	2	0.209
7	Innovate and conduct research to enhance CBDC functionality.	0.674	2	0.714
8	Lead pilot testing efforts.	0.486	2	0.784
9	Integrate CBDC with existing financial services.	1.077	2	0.584
10	Manage the operational aspects of CBDC distribution.	8.194	2	0.017
11	Implement feedback mechanisms and improve services.	0.967	2	0.617

retail CBDCs and cross-border purposes (Haque & Shoaib, 2023). The decentralized ledger and permissioned DLT structures in CBDCs address critical issues like data security and privacy, making blockchain an essential component for secure and compliant CBDC infrastructures (Kaur, 2024).

PPPs further demonstrate blockchain’s utility, as seen in cross-border CBDC projects like the mBridge collaboration among the central banks of Hong Kong, Thailand, and the UAE (Bank for International Settlements, 2024). Such partnerships are essential for developing robust interbank settlement systems, illustrating blockchain’s ability to foster collaborative CBDC frameworks that span both technical and jurisdictional boundaries (Arnone, 2024). This strategic use of blockchain underscores its potential not only for operational efficiency but also for enhancing trust and interoperability across CBDC ecosystems.

**8.1. Theoretical contribution**

This study contributes to the expanding theoretical landscape of CBDCs by proposing a comprehensive, stakeholder-centered approach to address key implementation challenges in CBDCs. As digital currencies and blockchain technology gain traction Hanafizadeh and Ali-pour (2024), central banks increasingly explore the potential of permissioned DLT to underpin CBDC infrastructure (S. Guo et al., 2024). By integrating insights from diverse stakeholders, this research extends the theoretical framework for PPPs in digital finance, emphasizing the alignment of regulatory, technological, and societal priorities for successful CBDC adoption.

While CBDCs may or may not rely on DLT, those that do often leverage either permissioned or permissionless DLT, depending on use cases. Wholesale CBDCs frequently employ permissioned DLT systems to ensure security and regulatory compliance, whereas retail CBDCs may adopt non-DLT systems, permissioned DLT, or hybrid models (H. Wang, 2024). This theoretical flexibility underscores the adaptability of blockchain and other digital ledger systems for various CBDC applications. This study also underscores blockchain’s decentralized ledger as a theoretical solution to enhance transparency, traceability, and security in CBDC ecosystems. The findings offer a theoretical model for CBDC implementation using blockchain, applicable to diverse digital asset contexts, advancing our understanding of secure, transparent digital finance ecosystems.

**8.2. Managerial and policy implications**

For policymakers and financial managers, this study offers practical insights into CBDC implementation, particularly through effective public-private partnerships. Blockchain and DLT enable secure, traceable transactions within CBDCs, yet the choice of permissioned or hybrid systems impacts scalability, accessibility, and regulatory compliance. Findings indicate that the public sector prioritizes regulatory frameworks and security standards, suggesting that policymakers should focus on building legal structures that address security, privacy, and data protection. For example, creating clear legal guidelines around data sovereignty and cross-border data flow could help establish a secure and compliant framework for blockchain adoption in CBDCs. These frameworks would not only facilitate blockchain integration but also encourage public trust and confidence in the digital currency ecosystem.

From a managerial perspective the private sector’s focus on technological infrastructure and innovation highlights the need for financial institutions to develop blockchain solutions that are compatible with existing financial systems. Financial managers should prioritize investments in blockchain infrastructure that ensures seamless integration with traditional banking systems and offers scalability. Moreover, they should invest in advanced cybersecurity measures to safeguard against emerging threats. For instance, adopting multi-layered security protocols, such as encryption and tokenization, could mitigate operational risks and protect sensitive financial data. Financial institutions should also engage in regular cybersecurity audits and collaborate with technology providers to stay ahead of potential vulnerabilities.

These findings advocate for greater investment in technological readiness and cybersecurity measures to mitigate operational risks and enhance user experience. These practical implications highlight the importance of a balanced and coordinated PPP framework where the public, private, and academic sectors can collaborate. By aligning their strengths, the partnership between them can meet the technological, regulatory, and educational demands of CBDC implementation. Policy-makers can establish regulatory foundations, while the private sector can drive technological innovation and academic institutions can

contribute research and education on blockchain applications. Together, they can create a secure, functional, and widely accepted digital currency ecosystem. Leveraging blockchain’s security and traceability in CBDC architecture, coupled with robust PPPs, will enable stakeholders to navigate the complexities of CBDC implementation, ensuring the benefits of digital currencies are maximized while minimizing associated risks.

8.3. Limitations and future research

This research, focused on the Indian context, may have limitations in its generalizability to regions with varying regulatory frameworks and technological advancements. Expanding the sample to include international stakeholders would facilitate a more comprehensive understanding of regional disparities and broader applicability. While the survey methodology provides valuable quantitative insights, incorporating qualitative interviews could offer a deeper understanding of the nuanced perspectives on the rapidly evolving digital currency and blockchain landscape.

Based on a survey of 192 stakeholders, this study offers a snapshot of current challenges related to CBDCs. However, given the dynamic nature of CBDC technology and regulatory frameworks, a longitudinal study would provide a more in-depth understanding of evolving stakeholder perspectives over time. A comparative analysis across different geographical contexts would provide further understanding of how cultural, regulatory, and technological factors influence CBDC challenges and adoption. Future studies should also explore how integrating CBDCs with other digital financial technologies, such as decentralized finance (DeFi) and artificial intelligence (AI), could enhance the security, efficiency, and inclusivity of digital currency systems.

9. Conclusion

The paper provides a detailed investigation regarding the challenges associated with the CBDC implementation and illustrates how blockchain technology can be used to efficiently address these concerns. Blockchain’s decentralized ledger architecture provides a strong solution by improving security, preserving privacy through encrypted data storage, and easing regulatory compliance through discernible and

traceable transactions (Javaid et al., 2022). The Kruskal-Wallis test revealed a substantial variation in how stakeholders ranked the management of operational aspects of CBDC distribution, emphasizing the importance of sector-specific policies and more coordination. While most areas of collaboration, such as regulatory frameworks and public education, were unanimous, divergent priorities in operational management indicate possible areas for additional debate and refinement. Overall, the findings emphasize the need of using blockchain technology and cultivating successful public-private partnerships to overcome the various issues of CBDC implementation. By coordinating sector-specific goals and capitalising on blockchain’s benefits, stakeholders may improve the security, functionality, and acceptance of CBDCs, paving the road for their effective integration into the global financial system.

Thus, the effective deployment of CBDCs depends on tackling major challenges using technical solutions such as blockchain and cultivating strong public-private collaborations. By merging all stakeholders’ knowledge and resources, safe, efficient, and user-friendly digital money systems may be developed, benefiting the larger economic and social structure. Communication that is transparent and a balanced approach to collaboration are critical for tackling problems and sustaining CBDCs’ long-term existence and success.

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**Mushtaq Ahmad Shah:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Project administration, Methodology, Formal analysis, Data curation, Conceptualization. **Navneet Raj:** Writing – review & editing, Formal analysis.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. QUESTIONNAIRE

Dear Participant,  
Greetings

We are conducting a survey to evaluate the challenges and collaborative areas for successfully implementing Central Bank Digital Currencies (CBDCs). The purpose is to assess the challenges in CBDCs, with a particular focus on the role of blockchain technology and public-private partnerships in overcoming these challenges. This research aims to gain insights into key factors that will contribute to the effective rollout and adoption of CBDCs.

As one of the few selected participants in this survey, your responses are invaluable to us, and we greatly appreciate your time and inputs.

Be assured that all information that you provide will be strictly confidential and will be used for academic purpose only. We guarantee complete anonymity. We are simply interested in your opinions; there are no right or wrong answers.

Thank you for taking time off from your busy schedule to participate in this research project.

Section A: About the Respondent

1). Your Name: \_\_\_\_\_

11). Type of Organisation:

- a) Public company
- b) Private company
- c) Research & Academic

111). How many years of work or research experience do you have?

- a) Below 6 years
- b) 6-10 years
- c) 11-15 years
- d) Above 15

**Section B.**

1. Please rate the following items based on the challenges you perceive in Central Bank Digital Currencies (CBDCs). (1 = Strongly Insignificant, 2 = Insignificant, 3 = Slightly Insignificant, 4 = Neutral, 5 = Slightly Significant, 6 = Significant, 7 = Strongly Significant) by putting a tick (✓) at appropriate place.

1. Concerns about reduction in credit availability for consumers and businesses.	1	2	3	4	5	6	7
2. Control Over Money Supply	1	2	3	4	5	6	7
3. Digital Illiteracy	1	2	3	4	5	6	7
4. Ensuring flexibility and adaptability in the face of emerging challenges	1	2	3	4	5	6	7
5. Fostering broad public acceptance of CBDC	1	2	3	4	5	6	7
6. Impact on Traditional Banking	1	2	3	4	5	6	7
7. Implementing strict measures and protocols to protect users' concerns such as security, privacy, and data protection	1	2	3	4	5	6	7
8. Incorporating appropriate technology and Addressing cybersecurity	1	2	3	4	5	6	7
9. Managing operational risks associated with implementing CBDC	1	2	3	4	5	6	7
10. Regulatory Uncertainty	1	2	3	4	5	6	7
11. Scalability Issues	1	2	3	4	5	6	7

2. Evaluate the listed items which you consider to be the significant areas of Public-Private Partnership (PPP) collaboration in CBDC implementation.

(1 = Strongly Insignificant, 2 = Insignificant, 3 = Slightly Insignificant, 4 = Neutral, 5 = Slightly Significant, 6 = Significant, 7 = Strongly Significant)

1. Conduct public education and awareness campaigns.	1	2	3	4	5	6	7
2. Define security standards and protocols.	1	2	3	4	5	6	7
3. Design and develop the technical infrastructure.	1	2	3	4	5	6	7
4. Develop and establish legal and regulatory frameworks.	1	2	3	4	5	6	7
5. Facilitate coordination among government entities.	1	2	3	4	5	6	7
6. Implement feedback mechanisms and improve services.	1	2	3	4	5	6	7
7. Innovate and conduct research to enhance CBDC functionality.	1	2	3	4	5	6	7
8. Integrate CBDC with existing financial services.	1	2	3	4	5	6	7
9. Lead pilot testing efforts.	1	2	3	4	5	6	7
10. Manage the operational aspects of CBDC distribution.	1	2	3	4	5	6	7
11. Monitor implementation for compliance with regulations.	1	2	3	4	5	6	7

**Data availability**

Data will be made available on request.

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